2024
ERAD

12th European conference on RADar in meteorology and hydrology (ERAD 2024)

Book of Abstracts

9-13 September 2024

Città Universitaria Sapienza
University of Rome, Rome, Italy

Since 2000, the biennial ERAD (European conference on RADar in meteorology and hydrology) conference is an awaited occasion, within the radar community, to connect academia, industry, and weather services, in an international and dynamic environment, fostering collaboration among scientists, engineers, and operational stakeholders. This journey keeps going thanks to the dedicated effort and collaboration of the international weather radar community.

The Institute of Atmospheric Sciences and Climate of Italian National Research Council (CNR-ISAC) and the Sapienza University of Rome had the honour to host the 12th edition in Rome, Italy.

Each ERAD conference, while sharing common goals, offers something unique that reflects the characteristics of its host venue and organizers. In Rome, we had the privilege of holding the conference on the vibrant main campus of Italy's largest university, Sapienza University of Rome, which provided ERAD 2024 with access to the monumental Aula Magna auditorium and the fascinating Museum of Classical Art.

Continuing the tradition of ERAD conferences, students and early-stage researchers had the opportunity to attend the event and trainings, present their studies, and most importantly, network within a diverse community that fosters knowledge in the areas of scientific and technological research related to radar in meteorology and other environmental applications. Some of them received support for their participation, and poster competitions and oral presentations were organized to stimulate quality research.

Finally, ERAD 2024 also provided a valuable platform for scientists and weather services to interact with manufacturers to stay informed about the latest product offerings related to weather radar.

As many other conferences, after the experience of COVID 19 pandemic, ERAD 2024 offered the flexibility of attendance, allowing participants to be physically present at the Sapienza venue or to join remotely.

At the conference, seven keynotes were presented, including one by the winner of the Gutta Aurea award, dedicated to the late Prof. Frank S. Marzano. A total of 154 oral presentations and 217 poster presentations were delivered in sessions organized according to the following topics:

– Clouds and precipitation physics

– Operational aspects

– Weather radar and climate

– Weather Radar technologies

– Radar hydrometeorological applications

– Radar and society

– Space borne clouds and precipitation radar

We are pleased to present the collection of all the abstracts presented at the 12th edition of the European Conference on Radar in Meteorology and Hydrology.

Enjoy the reading!

The Organizing Committee of ERAD 2024

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Gutta Aurea award

The "Gutta Aurea" (golden drop, in latin) award has the ambition of preserving the human and scientific memory of our late colleague Frank Marzano, who passed away prematurely and unexpectedly in 2022 at the age of 59. The Gutta Aurea award is supported by the association Prof. Frank Silvio Marzano – "Per Aspera Ad Astra" (https://www.fsmadastra.org) and CETEMPS (https://cetemps.aquila.infn.it). The award intends to recognize outstanding international contributions in remote sensing applied to atmospheric science, meteorology, and telecommunications.

The 2024 "Gutta Aurea" award went to Alessandro Battaglia, who was invited to present a "lectio magistralis".

SPACEBORNE DOPPLER RADARS: FROM EARTHCARE TO WIVERN (A PERSONAL WINDING ODYSSEY)

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Doppler radar observations from fast-moving space-borne platforms are very challenging. After more than 20 years of studies and technology development on 29 May 2024, at 00:20 CEST the first atmospheric Doppler radar was successfully launched into space on board the EarthCARE satellite. The mission is now in the commissioning phase and the first radar data look very promising. The long period of waiting between the approval of the mission and its launch has not only allowed a better understanding of the Doppler signal and the development of correction algorithms for Doppler velocities, but has also stimulated the definition and refinement of innovative concepts for spaceborne radars. In this talk I will revisit these last twenty years with some anecdotal stories and some key papers of my personal growth path in the study of this exciting new field.

In particular, the WIVERN (WInd VElocity Radar Nephoscope, www.wivern.polito.it) concept (Illingworth et al., 2018), currently in Phase A as part of the ESA Earth Explorer 11 programme, is discussed by highlighting its novelty and how its new capabilities have been facilitated by EarthCARE Doppler radar studies. WIVERN promises to complement the Aeolus Doppler wind lidar, which measures mainly clear-air winds, by providing the first global observations of the vertical profiles of winds in cloudy areas. The mission will also strengthen the cloud and precipitation observation capability of the Global Observing System by providing unprecedented revisit time of cloud and precipitation vertical profiles.

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Keynotes

ID: 228
Keynote speaker: Michelson Daniel | Environment and Climate Change Canada |

WMO GUIDE TO OPERATIONAL WEATHER RADAR BEST PRACTICES – FIRST EDITION

D. Michelson[1], M. Curtis[2], T. Kane[2], H. Yamauchi[3], T. Einfalt[4], M. Hagen[5], M. Istok[6], R. Lorandel[7], D. Rinderknecht[6], B. Rohrdantz[8], P. Rossi[9], A. von Lerber[10] [1]Environment and Climate Change Canada,

[2]Bureau of Meteorology, [3]Japan Meteorological Agency, [4]hydro & meteo GmbH, [5]German Aerospace Center,

[6]National Oceanographic and Atmospheric Administration,

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[8]German Weather Service,

[9]World Meteorological Organization,

[10]Finnish Meteorological Institute,

The Joint Expert Team on Operational Weather Radar (JET-OWR) of the World Meteorological Organization (WMO) has prepared seven of eight volumes of its Operational Guide to Weather Radar Best Practices (BPG). The scope addresses the end-to-end of a complete weather radar system starting with the planning and sustainable resourcing of a national weather radar program, and ending with a radar-based quantitative precipitation estimate (QPE). Included in this scope are the representation (formatting) of sweep and volume data in polar (spherical) coordinates (FM301-CfRadial2, see separate presentation), and methods of data exchange. The respective BPG parts are guides to weather radar

I. Network Program Design
II. Technology
III. Procurement
IV. Siting, Configuration and Scan Strategies
V. Calibration, Monitoring and Maintenance
VI. Data Processing
VII. Data Representation and International Exchange
VIII. Operational Weather Radar Glossary of Terminology

The BPG identifies typical challenges associated with each of these topics, and offers solutions for each, including essential literature references. Target audiences are managers (decision-makers) of weather radar networks and practitioners like engineers and software developers, of WMO’s Members that are National Meteorological and Hydrological Services and supporting organizations, both those embarking on the establishment of a national weather radar network and those that already have.

In early 2024, Volumes I, II, III, and VII were officially published. Volumes IV, V and VI have been submitted to the third session of WMO’s Infrastructure Commission in April 2024. Volume VIII is still at the thought stage, and could either contribute to or complement the AMS Glossary of Meteorology, recognizing that the WMO has recently taken the initiative to create a standard vocabulary that may also serve this purpose.

The BPG is expected to complement existing material such as the chapter on weather radar in the WMO Guide on Instruments and Methods of Observation (GIMO, WMO Publication No. 8, Volume III, Chapter 7), the International Standards Organization's "Meteorology — Weather radar — Part 1: System performance and operation" (ISO 19926-1:2019), and WMO Integrated Global Observing System (WIGOS) Manual and Guide (WMO Publications No. 1160 and 1165, respectively).

ID: 262
Keynote speaker: Chandrasekar V. | Colorado State University |

RAINFALL PROCESSES AND ESTIMATION IN COMPLEX TERRAIN: APPLICATION TO THE SAN FRANCISCO BAY AREA

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[2]*Arpa Piemonte,*

[3]*NOAA,*

The Advanced Quantitative Precipitation Information (AQPI) project is a regional initiative which involves upgraded weather radar data utilization for more precise precipitation estimation and short-term nowcasting in the San Francisco Bay Area. The rugged topography of the San Francisco Bay Area poses significant challenges in monitoring and predicting extreme rainfall and subsequent flooding events. The national weather monitoring provided by the NEXRAD radar network, is very good for a large scale picture. However due to deployment locations, often lacks the accuracy needed to get localized information sufficiently. This arises because precipitation frequently originates or intensifies in atmospheric layers too low for the NEXRAD network to effectively monitor, due to orographic lifting and warm rain collision- coalescence processes. The incorporation of four X-band and one C- band radars through the AQPI project significantly enhanced monitoring capabilities over the Bay Area. However, it also presents scientific challenges in effectively integrating this array of observations gathered by radars operating at different wavelengths and facing varying levels of obstruction from complex mountainous terrain.

An updated version of the Dual-Polarization Radar Operational Processing System (DROPS) is used in this work to provide rainfall estimates for the various wavelengths involved (S, C, X) and integrate them into a composite rainfall map over the Bay Area. The updated DROPS algorithm implements additional precipitation estimators, which will be evaluated for case studies alongside the standard blended algorithm of DROPS 2.0

ID: 172
Keynote speaker: Trömel Silke | Institute for Geosciences, Department of Meteorology, University of Bonn, Germany |

POLARIMETRIC RADAR OBSERVATIONS MEET ATMOSPHERIC MODELLING (PROM) - A RESEARCH INITIATIVE IN GERMANY

S. Trömel[1,2], and the PROM team[1]

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[2]Laboratory for Clouds and Precipitation Exploration, Geoverbund ABC/J, Bonn, Germany,

Funded by the German Research Foundation, the research initiative PROM exploits polarimetric precipitation radars in synergy with measurements from cloud radars, and other instrumentation available at the German Meteorological Service (DWD), supersites and research institutions towards the fusion of radar polarimetry and atmoshperic modelling to improve our understanding of moist processes and current microphysical parameterisations. This presentation introduces a selection of results from PROM achieved so far.

Projects Operation Hydrometeors and PARA applied a dual-strategy for model evaluation including 1) the comparison of measured polarimetric variables with their simulated counterparts via the developed polarimetric forward operator EMVORADO, and 2) the comparison of simulated state variables with their radar-derived counterparts using microphysical retrievals. The identified model issues are tackled (e.g. freezing process, excessive riming, ice/snow partitioning) and some improvements are already implemented in a pre-operational ICON version. PRISTINE is now using more realistic hydrometeor morphologies and the DDA scattering approach to further improve EMVORADO.

Combined multi-frequency and polarimetric cloud radar observations obtained within the IMPRINT project provide a statistical analysis of signatures of ice particle growth and subsequent aggregation close to the dendritic growth layer (DGL). Experiments with a Lagrangian super-particle model with habit prediction and a polarimetric forward operator help to better understand the potential role of secondary ice processes for the radar signatures observed in the DGL.

Project PICNICC developed an artificial neural network retrieval to detect riming from cloud radar Doppler spectra. PICCNIC also provided the framework for the development of the Vertical Distribution of Particle Shape (VDPS) retrieval for cloud hydrometeor shape and orientation. The VDPS technique is based on range-height-indicator (RHI) scans of slanted LDR and co-cross correlation coefficient to derive profiles of polarizability ratio and the degree of orientation.

A technique similar to the VDPS retrieval was developed within the project SPOCC, with the focus set on the utilization of RHIs of Doppler spectra of ZDR and horizontal-vertical correlation coefficient. Based on the Doppler spectra of these two quantities up to 5 species of hydrometeors can be identified by means of polarizability ratio and degree of orientation.

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ID: 218
Keynote speaker: Frommknecht Bjoern | European Space Agency (ESA) |

EARTHCARE - THE CLOUD AEROSOL AND RADIATION EXPLORER'S MISSION STATUS AND OPERATIONAL PHASE MANAGEMENT

B. Frommknecht[1], T. Fehr[1], D. Bernaerts[1], P. Deghaye[1], M. Eisinger[1], T. Hummel[1], K. Takuji[2], R. Koopman[1], N. Tomomi[2], S. Rusli[1], T. Tanaka[2], T. Eiichi[2], V. Tzallas[1], J. von Bismarck[1], K. Wallace[1], C. Caspar[1]

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The influence of clouds on incoming solar and reflected thermal radiation remains the largest contribution to the overall uncertainty in climate feedbacks due to the diverse cloud formation processes and their complex interaction with solar and thermal radiation. Furthermore, climate models still show deficiencies in correctly representing aerosol-cloud interactions (ACI) and precipitation patterns limiting the overall confidence in climate predictions.

Global observations of vertical cloud ice and liquid water profiles with simultaneous and collocated solar and thermal flux observation will provide crucial data to address these uncertainties. Furthermore, collocated global observation of vertical aerosol profiles and types are required to address their direct effects and indirect ACI effects.

In response to these needs, the European Space Agency (ESA), in cooperation with the Japan Aerospace Exploration Agency (JAXA), will launch the Earth Cloud Aerosol and Radiation Explorer, EarthCARE, on a SpaceX Falcon-9 rocket in May 2024 from Vandenberg, California, USA.

The two active instruments embarked on the satellite, a cloud-aerosol lidar (ATLID) and a cloud Doppler radar (CPR), together with the passive multispectral imager (MSI) and broad- band radiometer (BBR), will provide synergistically derived vertical profiles of cloud ice and liquid water, aerosol type, precipitation, as well as heating rates, solar and thermal top-of- atmosphere radiances with the objective to reconstruct top-of-the-atmosphere short- and longwave fluxes at an accuracy of 10 Wm^{-2} on a 10 km ´ 10 km scene.

EarthCARE data products have been developed by ESA and JAXA in a coordinated approach ensuring continuous information exchange between European and Japanese algorithm teams. Both agencies will ensure the free and open dissemination of EarthCARE data to the science community, with the intention to disseminate instrument Level 1b data six months, single-instrument Level 2a data nine months, and synergistic Level 2b data 18 months after launch.

The presentation will provide an overview of the current mission status and operational phase management by giving an overview of the currently on-going and planned mission commissioning activities and provide an outlook on the operations phase management and setup.

ID: 314

Keynote speaker: Okamoto Hajime | Research Institute for Applied Mechanics, Kyushu University |

CLOUD PHYSICAL PROPERTIES AND VERTICAL VELOCITY EXPECTED FROM EARTHCARE MISSION

H. Okamoto[1], K. Sato[2], A. Sheik[1], T. Nishizawa[3], H. Horie[4], H. Iwai[4], M. Ueno[1], M. Satoh[5], W. Roh[5], T. Nakajima[6]

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Cloud feedbacks remain to be the largest source of uncertainties in Coupled Model Intercomparison Projects, across CMIP3 to CMIP6. Climate model averaged rainfall biases for El Nino events have been reported in IPCC reports across AR3, AR5 and AR6. These may be attributed to the insufficient parameterization of convections, low-level water clouds and ice cloud processes. To solve these issues, we need global observing system that measures cloud, aerosol, their radiative properties and vertical velocity to better understand cloud and precipitation formation and their relation to radiation.

JAXA-ESA joint mission EarthCARE will be launched in 2024. EarthCARE will carry the first space-borne 94GHz cloud profiling radar (CPR) with Doppler function, 355nm-high-spectral resolution lidar (ATLID), multi-spectral imager (MSI) and Broad Band Radiometer (BBR). We developed JAXA level 2 algorithms. The L2 cloud products include cloud mask (occurrence), cloud particle type, cloud particle category, cloud microphysics, Doppler velocity in clouds, terminal velocity of cloud particles and vertical air motion in clouds. The L2 algorithms correspond to the extended version to those for CloudSat, CALIPSO and MODIS and the latter has been distributed as JAXA EarthCARE A-train products.

The vertical velocity with cloud microphysics retrieved from EarthCARE is expected to provide global picture of ice particle flux, liquid and solid ice precipitation flux and upward air motion in convections. Doppler velocity would be effective to discriminate phase (liquid or ice) of precipitation. It is also noted that the Doppler velocity is, in general, not the same as terminal velocity nor air-motion but the sum of the reflectivity weighted terminal velocity and vertical air motion. Therefore, simultaneous retrieval of terminal velocity/air motion and cloud microphysics are needed for the proper interpretation.

Synergetic ground-based observation system has been constructed as super site in NICT Koganei, Tokyo to validate the EarthCARE products. The ground-based system consists of 94GHz high-sensitivity-cloud radar (HG-SPIDER) and electric scanning cloud radar (ES-SPIDER), 355nm-Multiple-Field-of-view Multiple Scattering Polarization Lidar, 355nm-high spectral resolution lidar, 355nm-direct-detection Doppler lidar, coherent Doppler lidar (Iwai et al., 2013) and wind profiler. The observation system will be used to evaluate L2 algorithms and products.

ID: 297

Keynote speaker: Hidde Leijnse | Royal Netherlands Meteorological Institute (KNMI)|

REFLECTIONS ON ATTENUATION: WHERE ARE WE 70 YEARS AFTER HITSCHFELD-BORDAN?

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It is 70 years ago since Hitschfeld and Bordan published their paper on rain-induced attenuation of radar signals and a correction method for it. Their elegant mathematical formulation of the problem in terms of an ordinary differential equation that can be analytically solved has spurred most of the research on attenuation correction during the past seven decades. Today, their work is as relevant as ever, not in the least because of the widespread use of radars operating at attenuating wavelengths (C-band, X-band, K-band). For example, most of the European weather radar network operates at C-band, X-band radar networks are used for urban applications and as gap fillers, and the GPM core satellite has a dual-wavelength Ku/Ka- band radar on board.

Hitschfeld and Bordan noted that their method can become unstable and inaccurate in case of large attenuation combined with calibration errors. Several researchers have dealt with this issue by adding an additional unknown but constant error factor that may include calibration offsets, wet radome attenuation, as well as multiplicative biases in the relation between specific attenuation and radar reflectivity. This additional factor can be solved if an independent estimate of total path-integrated attenuation is available (i.e., an additional equation is added to the system).

Here, we investigate different methods of constraining this system of equations. We use differential phase, stable clutter targets, radar intercomparisons, and rain gauges to estimate the total path-integrated attenuation. We combine this with calibration monitoring variables to unravel the contributions of wet radome attenuation, calibration offsets, multiplicative biases in k-Z relations, and rain-induced attenuation. We present analyses for several rainfall events observed by the two C-band weather radars operated by KNMI in The Netherlands. Knowledge of the spatial and temporal scales on which these contributions vary is essential for this analysis. New insights about these components will contribute to estimating the uncertainties related to them, as well as designing and refining correction methods.

Clouds and precipitation physics

ID: 1, Poster presentation

DEPENDENCE OF RADAR/LIDAR DERIVED CLOUD PROPERTIES ON ENVIRONMENTAL CONDITIONS OVER THE NORTH ATLANTIC AND SOUTHERN OCEAN

G. McFarquhar[1]*, Z. Xia*[1]

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The accurate representation of Cold Air Outbreaks (CAOs) and affiliated mixed-phase boundary layer (BL) clouds in models is challenging. How BL cloud properties evolve during CAOs and their dependence on meteorological conditions as well as location is not well understood but is important for the simulation of Earth's energy budgets. Here the properties of polar BL clouds over the North Atlantic (NA) and Southern Ocean (SO) are compared using remote sensing retrievals from the Measurements of Aerosol Radiation and CloUds over the SO (MARCUS) and Cold-air Outbreaks in the Marine BL Experiment (COMBLE) conducted over the NA. Retrieved microphysical properties such as cloud number concentration Nd, cloud effective radius Re and water/ice content were retrieved using varying retrieval methodologies based on different remote sensors to create an ensemble of solutions to quantify uncertainties. MARCUS observations show a stronger BL inversion than COMBLE, with a higher mean EIS (estimated inversion strength)/LTS (lower tropospheric stability) of -0.03K/13.10K compared to COMBLE's -3.2 K/9.3 K. 39.3% of CAOs observed during COMBLE were intense with M> 5 K, while MARCUS only had 1.2% observations with M > 5 K. 94.3%/66.9% of clouds sampled in CAOs during COMBLE/MARCUS had cloud top heights < 4 km. The mean BL cloud top heights increased by over 400 m and the BL deepened by over 500 m as M increased in both regions. MARCUS observed a 13.2% moister BL structure than COMBLE when M >7.5 K due to stronger BL inversion trapping more moisture within the BL. Under the same LTS, EIS, and M conditions, clouds sampled during MARCUS were on average 11.7% drier, and 45.9% more turbulent than COMBLE. During CAOs, 54.2% of single-layer BL clouds sampled during MARCUS had liquid-dominated bases compared to 39.5% during COMBLE. Additional dependence of derived microphysical properties on environmental conditions will be presented. Most importantly, BL clouds properties differ depending on whether they were acquired over the NA or SO, even when accounting for the dependence on environmental conditions.

ID: 2, Oral presentation

GEOGRAPHICAL FINGERPRINTS ON SNOW GROWTH PROCESSES: A SURVEY FROM TROPICS 2 TO ANTARCTICA USING TRIPLE-FREQUENCY RADAR OBSERVATIONS

H. Li[1], Q. Li[2], S. Kneifel[3], L. v. Terzi[3], Z. Ruan[1], L. Liu[1], Y. Zhang[2], C. Zhang[4], X. Sun[2]

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[2]*National University of Defense Technology,*

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Half of the global precipitation events originate from snow, however, our understanding on the physics of ice microphysics is still poor. In the past decade, both simulation and observational studies have leveraged vertically-pointing triple-frequency radars to advance process-level understanding of snow microphysics. The springing up of triple-frequency campaigns throughout the world opens an unique opportunity to identify the prevailing snow growth processes, and the unprecedented observations facilitate an assessment of snow growth characteristics over various geographies.

From July to September 2022, we successfully carried out Multi-frequency radar Experiment for TRopical Ice Clouds (METRICs), the first Multi-frequency radar campaign in tropics, in southern China. In this study, we aim to identify the climatology of snow microphysics over tropics, mid-latitudes, high-latitudes and Antarctica using radar observations of stratiform precipitation from METRICs, TRIPEx-pol, BAECC and AWARE. Our results suggest that majority of snow observed over low- to mid-latitude sites originates from homogeneous nucleation while heterogeneous nucleation dominates snow formation over high latitudes. The snow observed over southern China is characterized by the most prominent riming growth, and the observed triple-frequency signatures are generally inline with the simulations asuming an exponential distribution and a rime mass fraction of around 0.5. In contrast, limited riming growth was found over west Europe where snow aggregation is rather active. The weakest snow growth signatures were found over west Antarctic where the snow characteristical size is the largest at a given radar reflectivity factor, potentially owing to the scarcity of ice nucleating particles. This study for the first time reveals that the geographic dependence of major snow growth processes, and demonstrates the promise of using triple-frequency setups for improved understanding of snow microphysical climatology from a global perspective.

ID: 3, Poster presentation

USING VISSS AND CLOUD RADAR OBSERVATIONS TO CHARACTERIZE SECONDARY ICE PRODUCTION EVENTS

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Secondary ice production (SIP) can significantly alter cloud microphysics, while the conditions favorable for SIP is yet well defined. At the temperature range of -8 ~ -3℃, newly generated ice particles via SIP are preferably grown into columns. Hence, the observed microphysics of ice columns at surface, if observed, are inherently linked to the in-cloud processes taking place above. In this study, observations collected with the Video In Situ Snowfall Sensor (VISSS) from multiple field sites were used for identifying and characterizing ice columns. The fall velocity, canting angle distribution and aspect ratio of ice columns as well as column aggregates were manually identified and parameterized as a function of maximum dimension. These characteristics were then used for identifying ice columns in VISSS observations of snowfall with a mixture of ice types. Combined VISSS and cloud radar observations suggest that the amplification of ice column number concentration attributing to secondary ice process is favorable in shallow stratus clouds. We present a case study showing how the ice column generation in the lower clouds is modulated by hydrometeors falling from above. We also found that the presence of ice lollies is associated with locally increased liquid water path.

ID: 4, Poster presentation

ZDR BACKWARDS ARC: RADAR EVIDENCE OF MULTI-DIRECTIONAL SIZE SORTING IN THE STORM PRODUCING 201.9 MM HOURLY RAINFALL ON 20 JULY 2021 IN ZHENGZHOU, CHINA

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We present radar polarimetric characterizations of the storm producing 201.9 mm hourly rainfall on 20 July 2021 in Zhengzhou, China. We employed the separation signatures of enhanced polarimetric observations to investigate hydrometeor size sorting processes and unraveled multi-directional size sorting (MSS) in action during the most intensive rainfall period. The MSS occurred as a low-level differential reflectivity ZDR backwards arc signature encompassing the rainfall center. The coupled polarimetric signatures allowed us to quantify the size sorting directions in the storm, and we found that the increase of size sorting directions is associated with rainfall intensification. Our model simulations further suggest that the presence of arc-shaped updrafts is conducive to MSS. This work sheds novel insights into the kinematics-driven microphysics in extreme rainfall storms and warrants the potential of coupled polarimetric signatures in warning catastrophic extreme rainfall events.

ID: 6, Poster presentation

IMPACT OF OROGRAPHY AND WIND DYNAMICS ON PRECIPITATION DISTRIBUTION DURING CYCLONIC EVENT: A CASE STUDY OF CYCLONE BATSIRAI IN LA REUNION ISLAND

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The specific geographical features of Réunion Island, its tropical climate, and rugged terrain make the island prone to world-record precipitation events. The complex terrain of the Island significantly alters the circulation of air masses and influences precipitation patterns. The objective of this study is to examine the effect of orography and wind direction on the spatio-temporal distribution of precipitation, identifying areas at risk of heavy precipitation during the passage of the intense cyclone Batsirai on February 2 and 3, 2022.

To study precipitation dynamics, X-band radar data collected as part of the ESPOIRS project were utilized. These data provide a highly detailed distribution of precipitation near the ground. Additionally, a high-resolution simulation (500m) was conducted using the Meso-NH model to complement these data and obtain meteorological parameters. Thus, a radar operator was implemented to simulate unattenuated reflectivity and precipitation near the ground.

Comparison between surface wind observations and the model indicates that the model reasonably reproduces observed wind conditions, with a low bias in direction (20°) and speed (10m/s). However, comparison of radar observations with the radar operator simulation shows an overestimation of rainfall possibly due to the microphysics used in the model or the operator reflectivity conversion law, which are not suitable for tropical environments.

The findings reveal that during Cyclone Batsirai, three phases were identified based on wind direction: southeast wind, east wind, and northeast wind. During the first two phases, a localized intensification of precipitation was observed along the Langevin valley at low altitude, due to the convergence of moist air into the valley and its ascent along the mountain slopes. This localized intensification was not accurately reproduced by the model, underscoring the importance of high-resolution radar observations. During the final phase of the cyclone, with a northeast wind, precipitation becomes more widespread due to air divergence.

This study will make it possible to monitor the area at risk of heavy rainfall as a function of the cyclone's position, and to evaluate the Meso-NH model and the radar operator with a view to future improvements.

ID: 7, Poster presentation

Best Poster Presentation Award presented to Ioanna Tsikoudi

T-MATRIX SIMULATIONS OF SPECTRAL POLARIMETRIC VARIABLES FROM A CLOUD-RADAR

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Cloud radar observations and spectral polarimetry are crucial for understanding cloud microphysics. This work focuses on generating simulations of a 94 GHz cloud radar observations in rain, pointing at 45 degrees and comparing with real observations. The spectral differential reflectivity (sZ_{DR}) and spectral differential phase ($s\delta_{hv}$) are the variables of interest. They are produced with the T-matrix method, by computing the electromagnetic scattering properties and simulating the radar response (Mishchenko et al., 2000, Leinonen et al., 2014).

The study describes the simulation tool that explores diverse conditions, allowing for the modification of rain rate, white and spectral noise, and turbulence parameters. The effect of atmospheric turbulence introduces an increased spread of velocities within the radar volume and contributes to the blurring of the spectral features, such as smearing out the distinct features (Mie scattering notches) in the Doppler spectrum. Incorporating the impact of turbulence in the simulations for spectral polarimetric variables is a complex task and the attempt is discussed in this study. Challenges and limitations are also demonstrated.

Finally, the simulations are compared with the observations of a 94 GHz ground-based Cloud radar pointing at 45 degrees and reveal a good correlation, demonstrating the efficacy of the simulation process in reproducing spectral polarimetric variables.

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ID: 8, Oral presentation

COMPARING HYDROMETEOR CLASSIFICATION RETRIEVED FROM DUAL-POLARIZATION C-BAND DOPPLER WEATHER RADARS TO DUAL-POLARIZATION DOPPLER PROFILER OBSERVATIONS

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Although dual-polarization Doppler weather radars have improved the accuracy of precipitation estimates over the past decades, retrieving hydrometeor types from these weather radars remains challenging. In this study hydrometeor types are identified by using the wradlib hydrometeor classification scheme on C-band weather radar observations in the Netherlands. Four case studies occurring between 2021 and 2023 were selected. A dual-frequency, dual- polarization Doppler profiler, operating at Ka-band and W-band at an elevation angle of 45 degrees, is employed to verify the results. Doppler spectra of polarimetric variables (such as spectral reflectivity and spectral differential reflectivity) from this profiler are used to verify the outcomes of the hydrometeor classification scheme applied to the C-band radar. The following steps are taken for this purpose. First, the probability of occurrence of each hydrometeor type is calculated using the wradlib scheme. Additionally, measured C-band reflectivities are used to compute mixing ratios of four different hydrometeor classes (rain, snow, hail/graupel, and wet snow). Second, we derive parameters of particle size distributions (PSD) from these mixing ratios, using relations that are also employed in the Harmonie Numerical Weather Prediction (NWP) model. The PSDs are combined with scattering properties from the open-access ARTS Microwave Single Scattering Properties Database to form Doppler spectra of polarimetric variables. This last step requires the hydrometeor terminal fall speeds, which are computed from the particle diameter, again using relations employed in the Harmonie NWP model. The resulting spectra can be compared to the spectra actually measured by the profiling radar. Differences between constructed and observed spectra are not necessarily caused by incorrect classifications resulting from the wradlib algorithm. Although the ARTS database has been extensively tested and widely used, applying this dataset inevitably introduces uncertainties. Furthermore, although HARMONIE's PSD parametrizations and fall-speeds were employed, numerous alternatives exist, which could yield different results. Lastly, the observations retrieved from the profiler were retrieved at an elevation angle of 45 degrees, a compromise to make use of both the Doppler and dual-polarization measurements. Nonetheless, this study provides insights into the effectiveness of dual-polarization C-band weather radars in classifying hydrometeor types.

ID: 11, Poster presentation

PREDICTING RIMING FROM DOPPLER CLOUD RADAR OBSERVATIONS USING ARTIFICIAL NEURAL NETWORK

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Riming, the process of supercooled liquid water accretion on ice particles in mixed-phase clouds, is crucial for precipitation formation. Traditional methods relying on mean Doppler velocity (MDV) measurements face challenges in convective and orographically influenced clouds. We propose a novel approach utilizing artificial neural networks (ANNs) to predict riming using ground-based cloud radar data.

Training data from winter 2014 in Finland include Ka- and W-band radar alongside in situ snowfall observations, enabling retrieval of rime mass fraction (FR_PIP). ANNs are trained separately on Ka-band and W-band radar data to predict the rime fraction FR_ANN. Two configurations are considered: ANN 1 incorporating radar reflectivity factor (Ze), MDV, spectrum edge width (SEW), and skewness, and ANN 2 using Ze, SEW, and skewness only.

Both ANN configurations effectively predict strong riming (FR_ANN > 0.7) and low values (FR_ANN ≤ 0.4) for unrimed snow. Results show comparable performance between ANN 1 and 2, indicating the feasibility of riming prediction without MDV. Remarkably, predictions align well with in situ observations in convective clouds, suggesting applicability even in complex atmospheric conditions. Application to orographic cases yields high FR_ANN values consistent with ground observations of solid graupel particles. This study demonstrates the potential of ANNs in extracting complex relationships from radar data, offering insights into riming processes and enhancing precipitation forecasting in mixed- phase clouds.

ID: 12, Poster presentation

PEAKO AND PEAKTREE: TOOLS FOR DETECTING AND INTERPRETING PEAKS IN CLOUD RADAR DOPPLER SPECTRA – CAPABILITIES AND LIMITATIONS

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Cloud radar Doppler spectra are of particular interest for investigating cloud microphysical processes, such PEAKO is a supervised machine learning tool that can be trained to obtain the optimal parameters for peak We demonstrate the toolkit's capabilities and limitations through two case studies and simulations of cloud Both algorithms are openly available on GitHub.

EXPERIENCE WITH CLOUD ELECTRIFICATION ADDED TO THE ICON MODEL

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We implemented a cloud electrification submodel into the ICON NWP model. The implementation has been done for two moment cloud microphysics and consists in modelling of charges of six hydrometeors and of positive and negative ions. The charge separation is based on Takahashi's data. We will present our results of simulations of idealized convective storms and first experiments simulating real events. To validate the model performance we will use measurements of lightning and data from a cloud profiler and a X-band radar located at Milesovka observatory.

ID: 23, Oral presentation

POSITIVE AND NEGATIVE SCATTERING DIFFERENTIAL PHASE: OBSERVATIONS AND UTILIZATION IN MICROPHYSICAL RETRIEVALS.

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Differential phase upon scattering (DPS) is assumed to be always positive in clouds and precipitation in areas free from in-cloud electric fields. Mainly horizontal orientations of hydrometeors may result in positive DPS. Radar data with negative DPS values from horizontally oriented particles are demonstrated and explained. It is shown that the same cloud regions observed with closely located radars can exhibit DPS of opposite signs.

Microphysical retrievals using positive and negative DPS are discussed. Two situations are considered in detail: microphysics of the melting layer and hail sizing. Particles in the melting layer are Rayleigh scatterers at S band and are characterized by their sizes, ice/water content, axis ratios, number concentration, and flutter intensity. These parameters are obtained using measured reflectivity, ZDR, DPS, and KDP. Situations with negative DPS are considered for WSR-88D radars.

The nature of negative DPS from Rayleigh and non-Rayleigh hydrometeors is discussed. Negative DPS in hail is demonstrated. A new effect of coupled DPS resonances of opposite signs is considered. Resonance particles’ sizes for the power/ZDR do not coincide with the DPS resonance sizes. Relations between positive or negative DPS and the hail size are discussed.

ID: 27, Poster presentation

ANALYSIS OF STRATIFORM PRECIPITATION SYSTEMS BY MP-PAWR

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MP-PAWR (Multi-parameter phased array weather radar) is an X-band dual-polarization radar that has been in operation at Saitama University (about 30 km north of Tokyo) since 2018. The MP-PAWR is characterized by its ability to observe 3D data within a radius of 60 km and an altitude of 15 km in 30 seconds without gap. This makes MP-PAWR suitable for observing rapidly changing convective precipitation. Since MP-PAWR operates multiple (114) elevation angles and continuous zenith observation, is has advantages to observe stratiform precipitation. The analysis using MP-PAWR can cover the three-dimensional structure of the precipitation system, precipitation particle type classification, wind field analysis using the multi-elevation VAD, EVAD, VVP methods, and zenith observations every 30s. In addition, with a single-polarization phased array radar (PAWR) owned by Japan Radio Company, a dual Doppler analysis can be performed using simultaneous MP-PAWR and PAWR observations. In this study these analysis methods are applied for precipitation system associated with Typhoon Jongdari on 28 July 2018 for more than one day. In this case, stratiform precipitation was dominated when the typhoon was relatively far from the radar. This stratiform precipitation divided into two phases, and the echo top was higher during the latter phase of stratiform precipitation than the earlier phase. It was confirmed by the updrafts from the dual Doppler and VAD analyses. This difference is reflected in the ZDR values. This difference can be explained by the changes in the low-level stability. Other cases will be analyzed with the same method.

ID: 39, Poster presentation

IMPACT OF ASSIMILATING DIFFERENT TEMPERATURE VARIABLES ON MICROPHYSICAL PROCESSES IN CONVECTIVE AND STRATIFORM PRECIPITATION: A CASE STUDY OF FRONTAL SYSTEM IN TAHOPE IOP

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This study investigates the influence of assimilating different temperature variables on microphysical processes during convective and stratiform precipitation area. Through Observing System Simulation Experiments (OSSEs), we examine the assimilation of temperature and water vapor data using the Weather Research and Forecasting (WRF) model with the Goddard Global Cloud Ensemble (GCE) scheme and the WRF-LETKF Radar Assimilation System (WLRAS). By selecting a frontal case of the TAHOPE (Taiwan-Area Heavy rain Observation and Prediction Experiment) IOP #3, radar data from the RCWF and NCAR-SPOL are assimilated. Results reveal distinct impacts of temperature assimilation on various microphysical variables. Furthermore, examining changes in microphysical variables during assimilation reveals discrepancies in total cloud and precipitation quantities, with snow exhibiting significant overestimation and cloud amounts consistently underestimated. Comparison between assimilating different temperature profiles unveils significant differences in snow and rainwater variations, particularly attributed to the dynamics of the vertical motion. These findings underscore the importance of considering temperature variables in assimilation schemes for accurate representation of microphysical processes and subsequent precipitation forecasts.

ID: 46, Poster presentation

STORM CHARACTERISTICS BASED ON 5 YEARS OF MEASUREMENTS OF DOPPLER POLARIMETRIC VERTICAL CLOUD PROFILER

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We present our analysis of 5 years of measurements (2018-2022) of a vertically pointing radar MIRA 35c situated at the Milešovka meteorological observatory in the Czech Republic. In the analysis, we examine cloud structure of severe convective storms and compare differences in measured data for cases when lightning discharges were observed very close to the radar position, and for cases when lightning discharges were observed in greater distance from the radar position. The MIRA 35c radar is a Doppler polarimetric radar working at 35 GHz (Ka-band) with a vertical resolution of 28.9 m and a time resolution of 2 s approximately. For the analysis, we considered radar data which radar reflectivity was at least 10 dBZ at 5 km or higher above the radar to ensure that there was a cloud above the radar. We divided the radar data into "near" data (a lightning discharge was registered up to 1 km from the radar position) and "far" data (a lightning discharge was registered from 7.5 to 10 km from the radar position) by EUCLID (EUropean Cooperation for LIghtning Detection). We will show several of the following compared quantities: (i) power in co-channel (pow), (ii) power in cross-channel (pow-cx), (iii) phase in co-channel (pha), (iv) phase in cross-channel (pha-cx), (v) equivalent radar reflectivity (Ze), (vi) Linear Depolarization Ratio (LDR), (vii) co-polar correlation coefficient (RHO), (viii) Doppler radial velocity, (ix) Doppler spectrum width (W), and (x) Differential phase (Phi). Our results show that the characteristics of the compared radar quantities are clearly distinct for "near" dataset from "far" dataset. Furthermore, there is a clear evolution close to the time of discharges of the observed radar quantities in the "near" dataset, which is not visible in the "far" dataset.

ID: 47, Oral presentation

Best Oral Presentation Award presented to Jorma Rahu

GROUND-BASED PRECIPITATION RADAR SIGNATURES OF ANTHROPOGENIC SNOWFALL EVENTS DOWNWIND OF INDUSTRIAL AIR POLLUTION HOT SPOTS

J. Rahu[1,2], T. Voormansik[1,2], D. Michelson[3], E. Hung[3], N. Donaldson[3], H. Keernik[1], H. Trofimov[1], P. Post[1], V. Toll[1]

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Anthropogenic aerosols emitted from industrial hot spots could glaciate supercooled liquid cloud droplets. We present observational evidence for the glaciation events downwind various industries. The evidence comes from spaceborne satellite instruments and ground-based precipitation radars. Glaciation events result in daily snowfall accumulations of up to 15 mm. The glaciation of supercooled liquid clouds due to emissions from industrial hot spots shows that anthropogenic aerosols can effectively act as ice-nucleating particles, highlighting the need for further research on the potential effect on Earth's climate.

ID: 51, Poster presentation

FIRST APPLICATIONS OF THE VIRGA-SNIFFER – A NEW TOOL TO IDENTIFY PRECIPITATION EVAPORATION USING GROUND-BASED REMOTE-SENSING OBSERVATIONS

H. Kalesse-Los[1], J. Witthuhn[1,2], A. Kötsche[1], J. Röttenbacher[1], A. Foth[1], T. Vogl[1]

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Precipitation that fully evaporates before reaching the ground is called virga. Combined long-term ground-based remote-sensing observations with vertically pointing cloud radar and ceilometer are well-suited to identify these precipitation evaporation fall streaks. Here we show the first application of a new open-source tool, the Virga-Sniffer (Kalesse-Los et al., 2023) which was developed within the frame of RV Meteor observations during the ElUcidating the RolE of Cloud–Circulation Coupling in ClimAte (EUREC4A, Stevens et al., 2021) field experiment in Jan–Feb 2020 in the Tropical Western Atlantic. The Virga-Sniffer Python package is highly modular and configurable and can be applied to multilayer cloud situations. In the simplest approach, it detects virga from time-height fields of cloud radar reflectivity and time series of ceilometer cloud base height. Optional parameters like lifting condensation level, a surface rain flag, and time–height fields of cloud radar mean Doppler velocity can be added to refine virga event identification.

The Virga Sniffer was applied to RV Meteor observations during EUREC4A and statistical results as well as an evaporation case study are presented. About 42 % of all detected clouds with bases below the trade inversion (i.e. warm clouds) were found to produce precipitation that fully evaporates before reaching the ground. A proportion of 56% of the detected warm- cloud virga originated from trade wind cumuli. These results substantiate the importance of complete low-level precipitation evaporation in the downstream winter trades. The Virga- Sniffer performance was assessed by comparing its results to the Cloudnet target classification (Illingworth et al., 2007). A total of 86 % of pixels identified as virga correspond to Cloudnet target classifications of precipitation.

For the case study, W-band radar Doppler spectra data from a rain fall streak, identified as virga by the Virga-Sniffer, was used to calculate evaporative cooling rates. Sensitivity studies were performed to investigate the influence of vertical wind and relative humidity uncertainties on cooling rate retrievals. Future applications of the Virga-Sniffer include studies on distinguishing moist processes based on water vapor isotopic observations, contrasting precipitation evaporation climatologies in the dry and wet season in the trade cloud regime and characterizing snow sublimation in the polar regions.

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ID: 54, Oral presentation

GENERATING A MULTI-DOPPLER RADAR 3D WIND COMPOSITE FOR THE WESCON-WOEST CAMPAIGN IN SOUTHERN ENGLAND

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Predicting convective storm intensity and evolution are a primary challenge in numerical weather prediction. A move to sub-km model grid scales, which can resolve individual updrafts, highlights the deficiency of suitable observations to evaluate convective storms in NWP. The WesCON/WOEST campaign, which focused on the "Wessex" region (South West England) during Summer 2023, included aircraft, extra radiosondes, UASs, wind profilers as well as a dense network of Doppler radars - intended to examine the dynamics of convection. With three Dopplerised dual-polarization enabled radars, and the potential to include the operational network radars, we present 3D winds derived from two X-band Doppler radars and one Met Office operated C-Band radar from the WOEST campaign. The radars operated with two alternating strategies: one covering a range of elevations up to 17 degrees for deriving winds in cloud and one covering shallower angles for detailed boundary-layer wind retrievals. We present the steps taken to generate 3D wind fields for the WesCON/WOEST campaign, paying particular attention to the unfolding of Doppler radar data. The vertical winds derived from the 3D composite will be compared against vertical wind estimates from other platforms from the WesCon- WOEST campaign. A model evaluation strategy will be presented, illustrating how the 3D wind composite fits in the multi-platform multi-variable evaluation of km-scale and sub-km scale NWP.

ID: 56, Poster presentation

RADAR AND LIGHTNING CHARACTERISTICS OF TORNADIC STORMS IN CATALONIA

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Tornadoes are frequently observed in Catalonia (NE Iberian Peninsula). The density of events in this region is around 1.65 tornadoes year^{-1} 10^{-4} km^{-2} according to recent studies (Rodríguez et al., 2021), being one of the most affected areas in southern Europe, and reaches its maximum

south of Barcelona. During the last years several works based on synoptic patterns and mesoscale pre-convective environments prone to tornadogenesis and on tornado climatology in the area of study have been published (e.g. Rodríguez & Bech, 2021; Rodríguez & Lemus-Canovas, 2023).

Herein, we analysed radar and lightning characteristics of tornadic storms registered in Catalonia between 2010 and 2023. We used the mosaic image (CAPPI 1 km) from the C-band radar network from the Metorological Service of Catalonia (SMC; Altube et al., 2015), which is the most basic radar tool for weather surveillance, to assess the storm morphology following the Gallus et al. (2008) classification. Moreover, we studied lightning activity for each event using data from the lightning detection network of the SMC. We have also analysed seasonal-variations on convection characteristics from tornadic storms.

The analysis was performed separately for tornadoes formed inland and those formed offshore (i.e. waterspouts), which can be associated with fair weather conditions. We take into account data from a 30-minute temporal-window around the tornado-formation time.

The results presented here could be useful for weather forecasting and surveillance tasks by identifying convective storms capable of forming tornadoes.

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ID: 61, Oral presentation

DECODING CLOUD MICROPHYSICS: A STUDY USING THE INNOVATIVE PROCESS-ORIENTED VERTICAL PROFILE (POVP) TECHNIQUE WITH WSR-88D RADAR OBSERVATIONS

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Precipitation systems, including flash-flood-generating supercells, are key components of Earth's atmospheric systems. Profound understanding of the microphysical structure of precipitation within these systems is pivotal for refining weather forecasting, quantitative precipitation estimation (QPE), and deciphering cloud microphysical processes. However, the real-world morphologies of severe storms, particularly high-precipitation storm cells or tornadic supercells, are seldom confined to the shapes like a vertical column defined as Column Vertical Profile method. Many storm cells are tilted by shear instead of vertical oriented. Moreover, the shape and size of the downdraft and updraft are not vertically uniform across different radar elevation scans. To address these challenges, this study proposes a novel Process-Oriented Vertical Profile (POVP) technique, which generates vertical profiles of dual polarimetric radar variables within a vertically tilted column, taking into account only a selected percentile of radar variable within a broader contour at each radar scan. This technique is designed to capture updraft/downdraft (precipitation shaft) within storms with spatial continuity. For demonstration purposes, this study employed contours defined by the 50th percentile reflectivity. The examples shown in this study include the 2013 El Reno Tornado case, a fast-moving supercell near Dallas, TX, and the record-breaking flash flood case near Fort Lauderdale, FL. The novel POVP technique successfully captured the microphysics characteristics within the convective supercells. In addition, using POVP guided R(Z) relationship shows significant improvement on radar QPE compared with the traditional Z-R relationships. Lastly, Hydrometeor Classification Algorithm is applied to POVP within the core of convection and show new insights of convective microphysics.

ID: 67, Poster presentation

MICROPHYSICAL STRUCTURES IN THE MELTING LAYER BASED ON IN-CLOUD AND GROUND-BASED PRECIPITATION PARTICLE IMAGING OBSERVATIONS

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A new balloon-borne particle imaging radiosonde "Rainscope" has been developed (Suzuki et al. 2023). Rainscope has made it possible to acquire images that clearly recognize the outlines and irregularities of ice particles, as well as their state of aggregation and melting. In addition, Rainscope is designed to measure the fall velocity of a particle in the cloud by the equipped two infrared sensors measuring the passing time.

We launched a Rainscope on 20 February 2022, into a stratiform cloud associated with a developing low system at Mito, Japan (36.3N, 140.4E). In addition to raindrops below the 0 degrees Celsius level, Rainscope observed various forms of solid precipitation particles near and above the freezing level, such as almost melted ice particles, partially melted snowflakes, hexagonal graupel and snowflakes. Although not numerous, small snowflakes with a fall velocity of about 1 m/s were also observed. The fall velocity of the almost melted particles was distributed in the middle of the fall velocity of graupel and raindrops shown by the previous study.

Clear particle image acquisition by Rainscope contributes significantly to the understanding of the internal structure of the melting layer, such as knowledge of the vertical distribution of melting (soaking) degree as well as fall velocity related to density. However, Rainscope with an ascent rate of 5 m/s passes through the melting layer in a few minutes, making it impossible to obtain sufficient data samples. Therefore, we improved it to a ground-based instrument and deployed it in winter field experiments. When the temperature is near 0 degrees Celsius in winter, it is possible to observe sleet, which consists with snow/melting particles and raindrops. On 24 December 2022, temperatures were 1-2 degrees Celsius and sleet with melting graupel and melting snowflakes were observed in Shiozawa, Japan (37.0N, 138.9E). Particle images were classified according to their shape and surface condition as completely melted, partially and mostly melted, and non-melted particles. Particle-size and fall velocity distribution showed that the falling velocity increased and the particle size decreased as melting progressed. In the melting-graupel case, it was shown that dry and wet graupel could potentially be classified by pixel values in the particle images obtained from Rainscope.

ID: 68, Poster presentation

PROPOSAL FOR A NEW PRECIPITATION PARTICLE OBSERVATION METHOD USING THE RAINSCOPE AND THE UAV

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Precipitation particles have been observed over the sky using sonde and weather radar in japan. However, the problem of the sonde is that it’s difficult to observe at the fixed point. The problem of weather radar is that it cannot directly capture precipitation particles. To solve these problems, we think that a new method of observation of precipitation particles is needed. So, we examined the feasibility of precipitation particle observation using the UAV equipped with observation instrument. Specifically, the Rainscope, which can simultaneously observe particle images and particle fall velocity[1], is mounted an all-weather UAV, which can fly even in bad weather. In this study, we conducted indoor experiments using an all-weather UAV equipped with the Rainscope, and to aim at determining the raindrop particle size distribution and fall velocity distribution at rest and in flight. Using an all-weather UAV equipped with the Rainscope, ground measurements were conducted with the UAV stationary on the ground, and aerial measurements were conducted with the UAV flying at 1 m above the ground. The observation pattern was varied from a set rainfall rate of 10 mm/h to 100 mm/h in 10 mm/h increments, and ground and aerial measurements were made for 3 minutes each. The sum of the ground measurement results and the sum of aerial measurement results were compared to confirm the distribution of raindrop particle size and fall velocity. The raindrop particle size distribution was superimposed with the modified gamma distribution[2]. The parameter $\mu<0$ for the modified gamma distribution results in a monotonically decreasing distribution, $\mu=0$ results in a linear distribution, and $\mu\geq0$ results in a distribution dominated by a particle size that is not the smallest particle size. The result of the raindrop particle raindrop size distribution showed that both were $\mu\geq0$, so that a particular particle size that was not the smallest dominated the distribution, and the distribution shapes were similar for ground and air measurements. And, the results of the fall velocity distribution showed that both distribution shapes were similar. But, the number of subjects in the aerial measurements was smaller than ground measurements, and the calculated rate of fall velocity was different. This is thought to be due to the fact that the fall velocity could not be calculated in part due to the effects of propeller rotation and the drone's rocking motion.

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ID: 71, Poster presentation

MICROPHYSICAL RETRIEVALS IN MIXED-PHASE CLOUDS WITH LOW LWP USING CLOUD RADAR

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Mixed-phase clouds, which have a significant impact on the global climate, are complex systems where liquid water and various types of ice particles coexist at temperatures below the freezing point. A key process in mixed-phase clouds is riming which alters microphysical and scattering properties of ice particles. Cloud radar is a powerful instrument for observing and understanding the processes that occur within mixed-phase clouds. Observations from multi-frequency radars and simulation results were combined in recent research to retrieve microphysical properties of ice particles in snowfall and ice clouds. This study presents an attempt to retrieve all common microphysical properties of ice particles, such as maximum dimension, density, aspect ratio and number concentration in slight rime condition using Doppler spectra at 35 and 94 GHz. Two mixed-phase cloud events with low liquid water path are studied for such purpose. Spectral dual-wavelength ratio is introduced to retrieve maximum dimension of particles. An iteration process is developed to retrieve aspect ratio and density of ice particles from observation of spectral differential reflectivity at 35 GHz. The number concentration of particles is retrieved from spectral reflectivity at 35 GHz. With all the retrieved microphysical properties, ice water content and particle size distribution can be further derived. The ice water content is compared with results from an empirical model. The retrieved properties obtained from using three distinct mass-size relations are compared. Also, the profiles retrieved from bulk and spectral quantities are compared. The retrieval process can provide microphysical properties of ice particles that are consistent with each other. It is found that the retrieved ice water content is generally smaller than that from empirical model. Besides, the mass-size relation has significant impact on all retrieved microphysical properties except maximum dimension. The resulting profiles from bulk retrieval are smoother, while spectral retrieval can provide values in regions where the former cannot. The possible error from different sources is discussed or estimated, including the effect on dual-wavelength ratio from the elevation angle of radar, the neglect of differential attenuation caused by liquid and the usage of soft spheroid model.

ID: 72, Oral presentation

IMPACT OF ASSIMILATING RADAR REFRACTIVITY WITH RADIAL WIND AND REFLECTIVITY IN THE CONTEXT OF ENSEMBLE KALMAN FILTER

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Surface moisture data is pivotal for predicting convective initiation and heavy rainfall. Radar-derived refractivity offers this crucial moisture in various weather conditions. In this study, we integrated radar-derived refractivity with radial wind and reflectivity data using the high-resolution Weather Research and Forecasting local ensemble transform Kalman filter data assimilation system. We selected two cases from the Southwest Monsoon Experiment 2008 and conducted two sets of experiments. The first set aimed to understand the impact of assimilating radar refractivity alongside reflectivity and radial wind in both cases. Results revealed that assimilating reflectivity and radial velocity adjusted near-surface humidity based on flow-dependent error correlation, albeit with some spatial inaccuracies leading to underestimated rainfall. Further assimilation of refractivity enhanced convergence and improved corrections in low-level moisture, temperature, and wind fields, resulting in better forecasts for both light and heavy rainfall up to 6 hours ahead. The second set of experiments focused on the second case to explore the benefits of increased refractivity assimilation frequency and identify optimal assimilation strategies. It was found that more frequent assimilation captured moisture variations effectively, enhancing wind convergence and improving short-term forecasts. Specifically, assimilating refractivity before the occurrence of precipitation optimized environmental moisture correction, accurately representing humidity, and strengthening wind convergence during precipitation events.

ID: 76, Poster presentation

PATTERNS IN POLARIMETRIC X-BAND RADAR DATA CHARACTERIZING SEVERE HAIL EVOLUTION

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Radar parameters for recognition of hail forming in storm are studied on the example of severe hail events in northern Bohemia. Both parameters using dual polarization and methods based on horizontal reflectivity are discussed.

During June 2022 and July 2023, two severe hailstorms occurred within the range of the X-band radar located on the Milešovka observatory. On 27 June 2022 storms formed during the afternoon over a spacious part of Czechia in the warm air ahead a cold front. Severe hail was recorded in many places including the foothills of the Ore Mountains and south of the Bohemian Central Highlands. Hailstones up to 5 cm in diameter were reported within the range of the Milešovka X-band radar. On 30 July 2023 supercell storm evolved near Louny town and moved along the Ohře river valley and further along the Elbe valley. Severe hail was reported from narrow area spreading from Roudnice nad Labem town eastward. Hailstones up to 4.5 cm in diameter were reported from the edge of the radar range, however the storm evolution proceeded within the radar range.

Dual-polarized Doppler weather radar FURUNO is located at the top of the Milešovka observatory tower. It allows a detailed description of the storm structure with parameters indicative of conditions suitable for the development of severe hail. The evolution of the field of horizontal reflectivity, differential reflectivity column, hydrometeor classification (HCLASS), vertically integrated liquid and other quantities are investigated. As the ground truth the ESWD reports are used. Since increased lightning activity is related to the development of severe thunderstorms with hail, it will also be investigated. Potential hailstorms occurring in the summer 2024 within the radar range will also be included in the study.

ID: 77, Poster presentation

DISCRIMINATING BETWEEN "DRIZZLE OR RAIN" AND SEA SALT AEROSOLS IN CLOUDNET FOR MEASUREMENTS OVER THE BARBADOS CLOUD OBSERVATORY

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The highly sensitive Ka-band cloud radar of the Barbados Cloud Observatory (BCO, Stevens et al., 2016) frequently reveals radar reflectivities below -50 dBZ (haze echoes) within updrafts and below cloud base of shallow cumulus clouds. Haze echoes over the BCO are signals from hygroscopically grown sea salt aerosols (Klingebiel et al., 2019). Synergistic retrievals like Cloudnet provide the potential to identify the thermodynamic phase of hydrometeors by applying state-of-the-art routines on a complex combination of ground-based remote sensing instruments (Illingworth et al., 2007). Based solely on relying on radar reflectivities, haze echos are classified as precipitation ("Drizzle or rain") within the Cloudnet target classification scheme for the measurements over the BCO. We present a technique to discriminate between "Drizzle or rain" and sea salt aerosols in Cloudnet that will be applicable for marine Cloudnet sites. The method is based on deriving heuristic probability functions utilizing a combination of radar reflectivity factor, radar Doppler velocity, and ceilometer attenuated backscatter coefficient. The method is crucial for investigating the occurrence of precipitation and significantly improves the Cloudnet target classification scheme for the measurements over the BCO. The results are validated against the amount of precipitation detected by the Virga-sniffer tool developed by Kalesse-Los and Witthuhn et al. (2023) over a two year period and during the ElUcidating the RolE of Cloud– Circulation Coupling in ClimAte (EUREC4A; Stevens et al. (2021)) field experiment in Jan–Feb 2020 for the measurements in the vicinity of the BCO. Illingworth, A. et al.: Cloudnet: Continuous Evaluation of Cloud.

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ID: 83, Oral presentation

PEERING INTO THE HEART OF THUNDERSTORM CLOUDS: INSIGHTS FROM CLOUD RADAR AND SPECTRAL POLARIMETRY

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Lightning is a natural phenomenon that can be dangerous to humans. It is therefore challenging to study thunderstorm clouds using direct observations. In this study, cloud radar at 35 GHz is used to study the properties and dynamics of thunderstorm clouds. It is based on a case of thunderstorm on 2021-06-18 from 16:10 to 17:45 UTC near Cabauw, The Netherlands. Spectral polarimetric radar variables are used to investigate possible hydrometeors in the clouds and look for vertical alignment of ice crystals that is expected due to electric torque. The technique of Doppler spectra analysis is used to help understand the behaviors of different types of particles within a radar resolution volume. Due to challenges posed by Mie scattering, scattering simulations are carried out to aid the interpretation of spectral polarimetric variables. From the results, there is a high chance that supercooled liquid water and conical graupel are present in thunderstorm clouds. There is also a possibility of ice crystals arranged in chains at the cloud top. Ice crystals become vertically aligned a few seconds before lightning and return to their usual horizontal alignment afterwards. However, this phenomenon has been witnessed in only a few cases, specifically when the lightning strike is near the radar's line of sight or when the lightning is exceptionally strong. Doppler analyses show that updrafts are found near the core of the thunderstorm cloud, while downdrafts are observed at the edges. Strong turbulence is also observed as reflected by the large Doppler spectrum width.

ID: 84, Poster presentation

ENHANCED CALIBRATION AND COMPARISON METHODOLOGY FOR W-BAND CLOUD RADAR UTILIZING DISDROMETER RAIN DATA

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Calibrating meteorological radars remains a significant challenge in quantitative radar meteorology. While conventional methods are well-established for radars operating at centimeter wavelengths, the advent of millimeter-wave cloud radars at W-band frequencies introduces unique calibration hurdles due to differences in scattering and attenuation. This study investigates the intricacies of W-band cloud radars and evaluates viable calibration strategies to ensure precise measurements. Emphasis is placed on a calibration approach utilizing disdrometer rain data, anticipated for application in European W-band cloud radars contributing data to ACTRIS. Synchronous data from the radiometer and mobile weather station are used as sources of additional information that is necessary to implementing algorithms for comparison and fusion of radar and disdrometer data. Key aspects of the methodology are outlined, implemented within a research software tool, and demonstrated. This software tool has the potential for expansion to facilitate comparisons of additional Doppler moments and spectra using disdrometer and cloud radar data inputs. Illustrative examples are provided, showcasing the software's capabilities for comprehensive analysis of radar reflectivity, Doppler spectra, and other meteorological parameters, including their statistics, thereby enhancing the calibration process.

ID: 85, Oral presentation

ESTIMATING AGGREGATION EFFICIENCIES USING POLARIMETRIC RADARS

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This study develops and uses a simple methodology for retrieving layer-averaged snow aggregation efficiencies from vertical profiles of polarimetric radar signatures alone. To do this, we use a set of recently developed theory-based generalized power-law and exponential expressions by Dunnavan and Ryzhkov (2023) which predict the relative decrease (increase) in snow number concentration (mean volume diameter) downward from an initial height due to the steady- state balance of aggregation and vapor deposition with sedimentation. We then optimize the theoretical aggregation efficiency of these steady-state equations through a nonlinear least-squares fitting against similar observed polarimetric retrievals of number concentration and mean volume diameter. For 20 Range-Defined Quasi Vertical Profiles (RD-QVP) of aggregation polarimetric radar signatures in synoptic snowstorms, we estimated a median aggregation efficiency of 0.15 with a relatively narrow interquartile range that spanned from about 0.1 to just over 0.2. These values are consistent with both in-situ aircraft (Field and Heymsfield 2003) and laboratory measurements (Connolly et al. 2012; Hosler and Hallgren 1960). Estimated aggregation efficiency values are also insensitive to the optimized or chosen gamma distribution shape parameter. From these estimated aggregation efficiencies, we developed a simple temperature-dependent parameterization that can be used to dynamically determine aggregation efficiencies in numerical models. These expressions, parameterizations, and estimated aggregation efficiency values can be used to improve microphysical parameterization of the aggregation process in numerical weather prediction models and to better understand the aggregation process itself.

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ID: 88, Oral presentation

FRAGMENTATION OF GRAUPEL AND SNOWFLAKES DUE TO COLLISION

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We carried out laboratory experiments to explore the fragmentation of ice particles caused by collision. This mechanism is one of the most important secondary ice processes in the atmosphere and is hypothesized to be responsible for radar signatures observed in the dendritic growth zone in mixed-phase clouds. In our experiments, we investigated graupel-graupel and graupel-snowflake collisions. We deduced the fragment number and size distributions, as well as their dependency on collision kinetic energy. Based on our experimental data and a theoretical framework, we propose new coefficients to parameterize the number of fragments resulting from ice-ice collisions.

The ultimate goal of our project is to build a link between laboratory experiments, radar observations, and numerical modelling to gain a better understanding of ice multiplication due to collision.

ID: 93, Oral presentation

INVESTIGATION OF THE DUAL-POLARIZATION RADAR BRIGHT BAND SIGNATURES USING MELTING MODEL PROFILE IN NORTHERN TAIWAN

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A melting model profile (MMP) utilizing exclusively polarimetric radar measurements is developed and applied to four years of S-band dual-polarization radar data over northern Taiwan for investigating melting layer (ML) signatures, also known as a bright band (BB). The algorithm exploits the ML signatures from high elevation angles radar data ($> 6^{\circ}$) in cross-correlation coefficient (ρ_{hv}), differential reflectivity (Z_{dr}), and reflectivity (Z) to obtain ML features such as intensity (I), thickness (T), and peak height (H).

This algorithm determines the optimal H map from various elevation angles and azimuthal directions of radar data. Validation against radiosonde data indicates good agreement in estimated H values, with an averaged mean difference of 0.2 km. Furthermore, the inclusion of Z_{dr} in this algorithm led to a 27% increase in the ML detection rate, indicating the crucial role of Z_{dr} in MMP. Correlation analysis of ML features was carried out to investigate microphysical processes and properties within ML in detail. These features include the Z and Z_{dr} gradient above ML, mean values of Z and Z_{dr} below and above ML, I, T, and the BB peak values of Z, Z_{dr}, and ρ_{hv}. The features are investigated to understand the aggregation processes as particles approach ML and the melting process within the ML. The correlation analysis indicates that the retrieved ML features facilitate understanding the ML microphysical processes.

Keywords: melting layer; dual-polarized radar observations; melting model profile (MMP)

ID: 95, Poster presentation

CHARACTERIZATION OF MICROPHYSICAL AND DYNAMICAL PROCESSES FOR MESOSCALE CONVECTIVE SYSTEMS FROM DUAL-POLARIMETRIC RADAR NETWORKS

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Mesoscale convective systems (MCSs) cause severe weather phenomena such as heavy rain, strong winds, and hail, which can result in social and economic damage. To improve the forecasting accuracy of the MCS, it is necessary to improve the understanding of their developing mechanism. Previous studies have characterized large-scale environmental conditions using reanalysis and observational data. Considering the multiscale interaction at the development stage of MCSs, high-resolution observational data is needed to analyze the mesoscale mechanisms that trigger the formation and development of MCS. In this study, we investigate the microphysical and dynamical processes of MCSs through the composite analysis using radar polarimetric observations and wind fields derived from the wind synthesis system using Doppler Measurements (WISSDOM) scheme.

We divided MCSs into four types: convective cells (CC), mesoscale convective complex (MCC), and parallel/diagonal squall line (PSL/DSL), based on visual inspection by experts using radar and satellite images. The tracking information of MCSs is used to determine the reference location and time for composite analysis. The storm-relative features are analyzed by averaging observation data in the storm-relative domain by considering the movement features of MCSs. The composite of polarimetric observations provides insights into the evolution of the microphysical processes. The dynamic variables calculated from the wind fields reveal the triggering and maintaining mechanisms of MCS. In conclusion, we characterize the microphysical and dynamical processes of each MCS type through a composite analysis of the high-resolution observational data.

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ID: 108, Poster presentation

NON-PARAMETRIC RETRIEVAL OF DROP-SIZE DISTRIBUTION PROFILES BASED ON CLOUD RADAR SPECTRAL POLARIMETRY

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Polarimetric cloud radar has become an essential tool for state-of-the-art cloud and precipitation observations. These radars are capable of providing the same set of radar observables as conventional polarimetric meteorological radars. A big advantage though is that the observables from cloud radars are spectrally resolved, i.e. measured independently for particles coexisting in the same resolution volume but move with different, relative to the radar, velocities. Since velocity of particles is a proxy of their size, such spectral polarimetric observations are a base for advanced retrieval techniques. High signal-to-noise ratio leading to small uncertainties in polarimetric observations, and Doppler resolution in the order of few cm/ s result in high information content of cloud radar observations. In this study we present a non-parametric profiling of drop-size distributions. The used variational approach is based on existing techniques developed for dual-frequency spectral observations and spectral polarimetric observations from centimeter-wavelength radars. The developed retrieval is applied to measurements from a collaborative measurement campaign organized by the German Weather Service (DWD) and Radiometer Physics GmbH. The campaign took place at the DWD meteorological observatory in Hohenpeißenberg, Germany in 2021. The collected dataset allows us to evaluate the results of the developed retrieval using a variety of in situ and remote-sensing instruments.

OBSERVATIONAL STUDY OF TOPOGRAPHIC EFFECTS OF SNOW CLOUDS

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The western side of the central mountain range of Japan is known as one of the heaviest snowfall regions in the world. When strong northwesterly monsoons blow from Siberia to the Japanese islands, especially in case of a strong east-west pressure gradient, and the flow readily ascends the terrain, it is known to dump heavy snow on the upwind side of the spine mountains (e.g. Echigo Mountains). The topographic effects of snow clouds have been reported for enhancement due to orographic lifting a barrier effect by high mountains, but the effects of terrain less than 1 km in height between the Sea of Japan and the spine mountains have not been fully investigated. We focused on the topographic effects of snow clouds as they overtake mountains less than 1 km in height, using X-band polarimetric radars, K-band vertical pointing radars, and ground-based instruments.

We conducted ground observations at Tokamachi (37.131°N, 138.767°E) on the upwind side and Shiozawa (37.043°N, 138.851°E) on the downwind side across the Uonuma Hills (about 700 m altitude). Both sites are at similar altitudes, 195 m, and 191 m, respectively. The distance between the observation sites is about 14 km. We installed optical disdrometers (OTT Hydromet GmbH, Parsivel2), video disdrometers modified from a particle sonde (MEISEI ELECTRIC CO., LTD., Rainscope), and a K-band vertical pointing radars (METEK Meteorologische Messtechnik GmbH, Micro Rain Radar) at both sites. We also installed X- band polarimetric radars (FURUNO ELECTRIC CO., LTD., WR-2100) at locations farther from the Uonuma Hills than the ground observation sites of Tokamachi and Shiozawa, respectively.

On 22 December 2024, increases in snow depth of approximately 30 cm in 15 hours were observed at both ground observation sites due to snow clouds flowing from Tokamachi to Shiozawa. Ground temperatures ranged from -2 to 0 °C. The dominant type of snow particles on the ground was rimed aggregate at both sites until 18:00, and graupel was observed only at Tokamachi after 18:00. Also, the rimed aggregate before 18:00 showed a higher riming degree with larger circularity and fall speed of snow particles in Tokamachi than in Shiozawa. It was inferred from radar observations that the time variation and the difference between sites of snow particles were due to a change in the magnitude and extent of the effect of orographic lifting on the upwind side of the Uonuma Hills with increasing wind speed.

ID: 110, Oral presentation

CHARACTERIZING WINDS AND CLOUDS INSIDE TROPICAL CYCLONES WITH THE PROPOSED ESA EARTH EXPLORER 11 WIVERN MISSION

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The WIVERN (WInd VElocity Radar Nephoscope,www.wivern.polito.it, Illingworth et al., 2018) mission, currently under the Phase-A of the ESA Earth Explorer 11 program, promises to provide new insight in the cloud and dynamical structure of tropical cyclones (TC). More generally, the mission will strengthen the cloud and precipitation observation capability of the Global Observing System by providing unprecedented revisit time of cloud and precipitation vertical profiles. The objective of this work is to explore the potential of the WIVERN conically scanning Doppler 94 GHz radar for filling the wind observation gap inside tropical cyclones (TCs).

To this aim, realistic WIVERN notional observations of TCs are produced by combining CloudSat 94 GHz radar reflectivity observations with ECMWF co-located winds (Tridon et al., 2023). The statistical analysis of the results demonstrates that WIVERN could profile most of the TCs, particularly the glaciated part of the cloud above the freezing level and the precipitating stratiform regions. Because of its lower sensitivity, the WIVERN radar would provide 75% observations of clouds and 45% accurate horizontal winds in TCs in comparison to where CloudSat detects clouds. However, thanks to its rapid conical scanning, WIVERN would indeed provide ∼50 times more observations of clouds and 30 times more observations of horizontal winds in comparison to the number of clouds sampled by CloudSat. Therefore, the proposed observing system has the potential to complement the sparse observations made by reconnaissance flights and ground- based Doppler radars, thus providing additional data to be assimilated in numerical weather prediction models and hopefully further improving forecasts of tropical cyclone intensity and track.

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ID: 115, Poster presentation

CLOUDSAT AND A-TRAIN WARM RAIN CHARACTERIZATION

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Spaceborne radars have the ability to provide global observations of cloud and precipitation systems especially over the remote oceans where surface-based observations are not available (Battaglia et al., 2020). However, the detection of clouds and associated precipitation in the lowest km of the atmosphere remains a major challenge (Lamer et al., 2020). This affects our ability to monitor and characterise important microphysical processes, such as the onset and growth of warm rain. Warm rain is frequently observed over the tropical oceans and affects cloud lifetime and Cloud Radiative Effects (CRE). In order to account for the role of warm rain in the hydrological cycle and global radiation budget and to improve its representation in large-scale models, it is paramount to understand and quantify warm rain and the microphysical processes associated with it.

Despite its importance, the frequency of occurrence of warm rain and its dependency on macrophysics (LWP and mesoscale organization) and microphysical (aerosols) parameters remain not well represented in numerical models. In this study, multisensor observations from NASA's A-train constellation are used to study the warm rain process over the oceans. CloudSat's Cloud Profiling Radar (Tanelli et al., 2008) had excellent sensitivity (~-30 dBZ) combined with the smallest footprint (1.4 km), ideal for measurements of light precipitation and drizzle. Studies have shown that CloudSat-CPR identifies a number of warm precipitating clouds compared and that co-located brightness temperature (TB) and path integrated attenuation (PIA) are two potentially helpful measures to examine warm rain (Battaglia et al., 2020).

This study explores how PIA and T_B respond to rain-LWP and cloud-LWP of warm rain cells to understand how and when clouds develop to rain. Warm rain is categorised based on cloud types observed, such as stratocumulus and cumulus, and also according to surface unattenuated reflectivity to study the usefulness of T_B and PIA in understanding warm rain processes. Identifying and quantifying the microphysical processes underlying the conversion of clouds to rain will be advanced in this work. The study will be later used with the data from the upcoming ESA/JAXA Earth Cloud Aerosol Radiation Explorer (EarthCARE) mission.

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ID: 119, Poster presentation

COMPARISON OF VERTICALLY POINTING KA-BAND AND C-BAND RADAR OBSERVATIONS FOR THE CHARACTERIZATION OF RIMING EVENTS

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The 17 dual-polarization Doppler radars of the German C-band radar network, operated by the German Meteorological Service (DWD), perform vertically pointing 'birdbath' observations every 5 min as part of the operational scanning cycle. Since 2021, full Doppler spectra in both polarizations as well as the standard radar moments of these birdbath observations are stored. In this presentation, we demonstrate the potential use of these measurements for cloud analysis above the radar sites, focusing on the moments of reflectivity and mean Doppler velocity. We show examples of time-height cross-sections for different weather situations and compare them with simultaneous vertical measurements from Ka-band cloud radars that are located in the same region. Even though the C-Band and Ka-Band radars are separated by up to 70 km from each other, the agreement in the large-scale spatio-temporal structures that are visible in the radar data for the observed weather systems is remarkable. To assess the possibility of retrieving quantitative microphysical information from the C-band radar birdbath measurements, we apply to the C-band radar data a riming retrieval algorithm that was originally developed and has been extensively tested for Ka-band cloud radars. Riming describes the process by which supercooled liquid droplets freeze on ice crystals upon contact. The retrieval is based on a previously established relationship between the rime mass fraction of frozen hydrometeors and their fall velocity, which increases with growing rime mass. In particular, we analyze the effect of the coarser time resolution of the C-band radar observations (5 min, compared to 30 s for the cloud radar). Our Ka-band results indicate that riming events are characterized by a typical duration of 20 min and a vertical extent of 1 km, which can also be resolved by the C-band radar birdbath scan. Overall, the application of the riming retrieval algorithm to the C-band radar data requires only minor modifications, e.g., for filtering clutter or strong convection. Our results provide an example of how processing routines developed for vertically looking cloud radars may be transferred to operational weather radars whose measurement range extends to an elevation angle of 90° or close to it. A unique aspect of such operational weather radars is their even distribution over large regions and the very consistent data availability with standardized operating procedures across all sites.

ID: 120, Oral presentation

A NEW ALGORITHM FOR DISCRIMINATING AGGREGATION AND RIMING BASED ON POLARIMETRIC WEATHER RADARS

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The distinction between riming and aggregation is of high relevance for model microphysics and for data assimilation and can contribute to optimize warnings of potential aircraft icing hazards, due to the close link between riming and supercooled liquid water in the atmosphere. Even though radar-based discrimination between these two processes is still pending, we hypothesize that an according discrimination algorithm exploiting national polarimetric weather radar networks only is possible. In order to set up an algorithm based solely on polarimetric radar measurements, quasi-vertical profiles (QVPs) of reflectivity (Z_H), differential reflectivity (Z_{DR}) and estimated depolarization ratio (DR), the key variable for detecting riming, are utilized to learn about the information content of each individual polarimetric variable and their combinations for identifying riming. High-resolution Doppler spectra that are available from the vertical scans of the C-band radar network of the German Meterological Service since spring 2021 (to date the only operational network providing such data) serve as input and ground-truth for the development of the riming detection algorithm. First, we introduce the novel mean isolated spectra profile (MISP) technique, which provides clutter free and noise reduced spectra data in a height vs. time format. The MISPs of mean Doppler velocity are used to infer regions with particles falling faster than 1.5 m/s and accordingly associated with riming. This approach offers a unique opportunity to link hydrometeor fall velocities to polarimetric variables in an operational setting. Several machine learning methods have been tested to detect riming from the corresponding QVPs of polarimetric variables. The best performing algorithm is a fine-tuned gradient boosting model based on decision trees, the feasibility of which has been demonstrated in several case studies. Moreover, the extreme stratiform precipitation event observed on 14 July 2021 in western Germany in the Ahr valley was selected to validate the performance of the final retrieval independently. Considering balanced accuracy, the algorithm is able to correctly predict 74% of the observed riming features, allowing reliable detection of riming with the national radar network, which may offer promising perspectives for operational applications.

ID: 125, Poster presentation

RETRIEVAL OF SNOW WATER EQUIVALENT FROM THIES LASER DISDROMETER IN THE SOUTHERN ITALY APENNINES

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It is well known that an accurate assessment of the snow water equivalent (hereafter, SWE) is crucial for managing and preventing hydrometeorological risks, for the estimation of avalanche hazard as well as for many other fields (e.g. transportation, energy providers etc.) that are strongly conditioned by snow events.

In recent years, the laser disdrometer has gradually emerging as an appealing alternative to the traditional instruments for the assessment of solid precipitation, although there is still a limited knowledge about its performance and accuracy, especially in mountainous areas.

In this work, the performance of the Thies CLIMA laser optical disdrometer for SWE estimation are evaluated through a comparative study with the collocated measures of a standard heated tipping-bucket rain gauge, the FAK010AA sensor. The two devices, together with an automatic weather station, were deployed for a long-term field campaign in the Southern Italy Apennines at Montevergine Observatory (40.936569°N, 14.728316°E, 1280 m a.s.l.). The available dataset includes more than 20 snow events occurred between January 2020 and March 2024. After a careful data processing, which involved the adaptive filtering for disdrometer diameter-fall velocity spectra introduced in Capozzi et al. (2021), the 30-min accumulated SWE (in mm) from rain gauge and from disdrometer were compared in terms of several statistical scores.

As can be expected, the level of accordance between the two devices is strongly dependent on the snow density assumption used for SWE estimation from disdrometer. In this study, we used the assumption proposed by Zawadski et al. (2005), in which the snow density is a function of the riming fraction (f_{rim}) which usually varies from 1 (unrimed) to 5 (heavily rimed particles). The best results in terms of Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) were obtained with $f_{rim} = 1$, whereas the best scenario for BIAS and Error Percentage scores is $f_{rim} = 2$. A special focus is dedicated to some specific snow events, in which the optimal MAE and RMSE values were obtained assuming a higher degree of riming ($f_{rim} = 3$ and $f_{rim} = 4$). Furthermore, a discussion about the impact of the horizontal wind speed and about the relationship between f_{rim} and the maximum diameter of the hydrometeors is offered.

References

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ID: 133, Oral presentation

ON THE ESTIMATION OF CONVECTIVE UPDRAFT VELOCITIES USING GOES IR COOLING RATES AND MULTI-DOPPLER RADAR TECHNIQUES: LESSONS LEARNT FROM THE ESCAPE AND TRACER FIELD CAMPAIGNS

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Convective clouds play a critical role in the Earth's climate system, acting as sinks of total water in the atmospheric column through precipitation, thereby contributing to the atmospheric energy balance and water cycle. Early in the lifecycle, convective clouds experience rapid cloud top ascent that is manifested by a decrease in the IR brightness temperature (TB_{IR}). Under the assumption that the convective cloud top acts like a black body, the near convective top updraft velocity can be estimated from the IR cooling rate (DTB_{IR}/Dt) and a temperature profile. The methodology is subject to a few drawbacks: 1) coarse temporal resolution (5 minutes for the standard GOES sampling mode, 1 minute for the GOES mesoscale mode); 2) non uniform beam filling effects if the convective updraft does not fill the 2x2 km^2 IR pixel; and 3) limited to near cloud top estimates of the vertical air motion. Multi-Doppler radar analysis from the ESCAPE and TRACER campaigns provides estimates of convective updraft velocity at higher spatiotemporal resolution throughout the convective core column and can be used to evaluate the updraft velocity estimates from the IR cooling rate for limited samples.

Here, a database of near-cloud top convective updrafts during the early phase of their lifecycle is developed. The methodology is based on the fusion of GOES and NEXRAD observations. A number of selected case studies are analyzed from the unique dataset of the TRACER/ESCAPE field campaigns that took place in Houston TX during the summer of 2022. Using the MAAS algorithm (Lamer et al., 2023), cells are detected and tracked based on the NEXRAD 3D observations. The NEXRAD-based convective cloud top heights are used to adjust the GOES TB_{IR} for the parallax misplacement and the GOES and NEXRAD observations are co-registed. The derived (DTB_{IR}/Dt) are compared to the NEXRAD observations (e.g. the cloud top echo detected by the radar, the size of the high vertical integrated liquid (VIL) cluster or the maximum updraft velocity inside the cell derived from dual-Doppler techniques). A statistical analysis will be presented for the IR cooling rates and the multi-Doppler based estimates of convective vertical air motion. Preliminary results indicate that the IR cooling rates are good predictors of convective updraft strength at least during the early phase of the convective cloud lifecycle. The conditional sampling methodology can be emulated using radar and IR forward models thus, allowing to evaluate the representation of convective motions in cloud resolving modes.

ID: 135, Poster presentation

RADAR TESTS FOR THE AWACA CAMPAIGN

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The ERC Synergy funded project AWACA aims to understand the atmospheric branch of the water cycle over Antarctica. It will rely on innovative observations of the tropospheric meteorological conditions and the isotopic composition of water vapor and hydrometeors along a 1100 km transect between the Dumont d'Urville station at the coast and the Concordia station on the high inner Antarctic plateau. At DDU, a new solid state X-band (9.4 GHz) polarimetric scanning radar (StXPol) will be deployed alongside an RPG 94 GHz cloud radar and a Metek MRR-PRO 24 GHz rain radar. At four temporary stations along the transect, a Metek MIRA 35 GHz cloud radar will be deployed alongside an MRR-PRO and a BASTA 95 GHz cloud radar. In preparation for the deployment of the instruments along the transect, newly purchased radar systems are being tested in Switzerland and France.

StXPol was deployed in February 2024 in Eriswil, Canton Bern, Switzerland. The campaign was part of the CLOUDLAB project of ETH Zürich, which aims to investigate ice nucleation in winter stratus clouds. The radar was deployed alongside a scanning MIRA, a vertically-pointing MIRA and a scanning RPG 94 GHz cloud radar, allowing for multi-frequency observations of clouds and rain. Unfortunately, no snowfall was observed within the deployment period of our system.

In Paris, the four MIRA cloud radars which will be used in the AWACA campaign are being tested over two months. Each MIRA is fixed in the roof of a wooden shelter next to an MRR-PRO and a BASTA, in the same configuration as will be used in Antarctica. The four MIRA radars will be compared to each other and to the MRR-PRO and BASTA for sensitivity and inter-calibration. Different settings and configurations are being trialed to prepare for the unsupervised operation in Antarctica.

ID: 139, Poster presentation

EVALUATION OF TWO MICROPHYSICS SCHEMES IN THE AROME MODEL USING AN OBJECT-BASED APPROACH APPLIED ON DUAL-POLARISATION RADAR DATA.

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Great efforts have been dedicated to study thunderstorms as they can cause a lot of damages. Despite significant progress made with numerical weather prediction models, forecasting storms remains challenging. One way to improve forecasts is to strengthen the representation of clouds through the microphysics schemes implemented in the models. In the French convective scale model AROME (*Brousseau et al., 2016*), two microphysics are available: ICE3 (*Pinty and Jabouille, 1998*) is the operational one-moment scheme, that describe the content evolution of 5 hydrometeor categories and LIMA (*Vié, 2016*) is a partially two-moment scheme used for research. Dual-polarization radar observations are valuable for microphysics schemes evaluation (*Ryzhkov et al., 2020*) as they provide information about the size, shape and orientation of hydrometeors. Thunderstorms and in particular supercells, are associated with recurrent, distinctive polarimetric signatures (*Kumjian and Ryzhkov, 2008*). Z_{DR} columns, quasi-vertical columns of enhanced differential reflectivity extending above the freezing level, are of particular interest as they are a proxy of storm's updrafts (*Snyder et al., 2015*) and super- cooled water at high altitudes (*Kumjian et al., 2014*).

The main objective of this work is to assess the ability of AROME, coupled with ICE3 or LIMA microphysics schemes, to reproduce accurate storm structures and polarimetric signatures.

To do so, an automated detection of Z_{DR} columns is implemented following *Snyder et al. (2015)*, and `tobac` algorithm (Tracking and Object-Based Analysis of Clouds – *Heikenfeld et al., 2019*) is used to track storm objects. A number of convective days of 2022 with a variety of storm structures are studied with both a global and an object-based approach. Simulated polarimetric fields are obtained thanks to the *Augros et al. (2016)* radar forward operator applied to AROME forecasts. For both microphysics schemes precipitations are evaluated, as well as reflectivities inside the storm objects and characteristics of cells and events. Polarimetric variables are then examined and more precisely Z_{DR} columns objects.

Besides evaluating the model microphysics, this study aims to better understand the discrepancies between simulated and observed objects (thunderstorm cells, Z_{DR} columns, …), a necessary first step towards using these objects in an assimilation context to improve storm-scale analysis and forecast.

ID: 148, Poster presentation

UNRAVELLING THE MICROPHYSICAL CHARACTERISTICS OF EXTREME RAINFALL OVER TROPICAL STATIONS USING X-BAND DUAL-POLARIZATION RADAR OBSERVATION

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Extreme rainfall events causing severe damage to property and human life are increasing worldwide, and this rise is attributed to a variety of factors, from global warming to urbanization. The region on the lee side of the Western Ghats typically receives <1000 mm of annual rainfall and is considered a semi-arid region. Recently, several extreme precipitation events have been reported from southeast peninsular India. One such extreme rain event occurred in the study region on 07 October 2021, during which 114 mm of rainfall (nearly equal to the climatological monthly rainfall of October) occurred in just 2 hours. Characteristics of rainfall during this event, in terms of rain rate distribution and raindrop size distribution, are completely different from the rainfall events that typically occur (from climatology) in that month. A dual-polarization radar for observing precipitation at X-band (DROP-X) has been used to track the precipitating system that produced extreme rainfall and understand the microphysical processes during its evolution. It is found that the system is very shallow (rain height is less than 6 km) and is embedded in a large and deep convective cell, which is moving from northeast to southwest. The system initially originated north of Gadanki is intense, with the riming process dominating at higher heights, as evidenced by large horizontal reflectivity (ZH), small differential reflectivity (ZDR), and specific differential phase shift (K_{DP}) values above the melting layer. The production of secondary ice particles above the melting layer enhanced the concentration of ice particles, which was observed. The growth of ice particles above the melting layer and the melting of ice particles below the melting layer produced heavy rainfall at the surface. The system became shallow when it passed over Gadanki but produced copious rainfall in 2 hours. Low-level hydrometeor growth is predominantly seen during this period. However, when the system moved south of Gadanki, it intensified rapidly, with larger Z_H values reaching greater heights (>12 km). The DROP-X measurements have provided a unique opportunity to understand the microphysical processes occurring in such an extreme rainfall event.

ID: 150, Oral presentation

A POLARIMETRIC RADAR ANALYSIS OF PRE-MONSOON DEEP CONVECTIVE SYSTEMS AND A HAIL-PRODUCING EVENT OBSERVED IN THE MONSOON CORE ZONE

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The pre-monsoon season from March to May significantly contributes to rainfall and exhibits considerable spatial and temporal variations. However, during the pre-monsoon season, the occurrence of thunderstorm activity across central and other parts of India is more, primarily driven by intense and deep convection. These thunderstorms bring heavy rainfall, thunder, lightning, and hailstorms. In this study, we present a composite analysis of 13 deep convective cloud systems and a case study of a hail-producing storm during the pre-monsoon season of 2023 observed by C-band dual-polarization (CPOL) radar at the IITM's Atmospheric Research Testbed (ART) facility in Silkheda, 60 km north of Bhopal. This CPOL radar in the monsoon core zone offers high-resolution Doppler and polarimetric radar measurements, enabling a comprehensive examination of the dynamic evolution of the precipitating convective clouds.

The vertical growth and severity of the observed 13 cases of deep convective systems are assessed by measuring the 35- and 45-dBZ echo top heights (ETHs). The mean heights of the 35-dBZ and 45-dBZ ETHs are around 13 km and 11 km, respectively, indicating an intense and deep convection. The composite contoured-frequency-by-altitude diagrams (CFADs) show that there is a high frequency of smaller values of differential reflectivity (Z_{DR} ~0 dB) and specific differential phase (K_{DP}) above the melting layer. This indicates that intense convective updrafts dominate the pre-monsoon convective systems, causing hail/graupel particles to be rimmed above the melting layer. The wider distribution or higher values of Z_H, Z_{DR}, K_{DP}, and small correlation coefficient RhoHV (<0.95) near the surface indicate the presence of a rain- hail mixture.

Next, we provide a case study analysis of a storm that produced hail on April 30, 2023, with cloud tops reaching a height of 14 km. It has been observed that riming is dominant during the evolution of convection and produces very low values for Z_{DR} and K_{DP}. These features show that the graupel/hail is present above the melting layer between 6 to 10 km, but the high value of RhoHV (~1) at these altitudes suggests that the graupel/hail is dry. The wet hailstones and large raindrops signatures close to the surface are also observed and are characterized by higher values of Z_H (> 50 dBZ), enhanced Z_{DR} (~ 3-4 dB), and a depleted RhoHV (< 0.95). Additionally, a K_{DP} exceeding 1.8°/km near the surface indicates the process of hail melting/hail coated with water. The results highlight the importance of vertically-resolved polarimetric radar measurements for characterizing the structures of deep convective clouds and related microphysics in the monsoon core zone.

ID: 152, Oral presentation

ANALYSIS OF RADAR DOPPLER SPECTRA OBSERVED BY AN AIRBORNE CLOUD RADAR

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Radar Doppler spectra from vertically-pointing cloud radars have been successfully used to derive physical and microphysical properties of clouds and precipitation, such as air motion, particle fall speed, or cloud-drop and drizzle parameters. The majority of past studies have utilized spectral observations of stratiform clouds from ground-based radar systems, often augmented by observations from additional instrumentation, for example, radiometers or radars at different wavelengths. We use observations from the NSF NCAR HIAPER Cloud Radar (HCR) to investigate the applicability of spectral retrieval techniques to observations from a stand-alone single-wavelength airborne radar. HCR is a 94 GHz cloud radar which is deployed in an underwing pod on the NSF NCAR Gulfstream V aircraft. The observations used for our study were collected in different climatic regions, ranging from the tropics to the Southern Ocean, and encompass convective and stratiform clouds and precipitation in liquid and frozen states. We explore how the analysis of cloud radar Doppler spectra can provide additional information on up- and downdrafts, and share the challenges of deriving air motion and particle fall speed from observations from a fast-moving platform. We identify regions with bi-modal spectra, investigate how they relate to higher-order moments such as skew and kurtosis, and their implications for microphysical analysis.

PRECIPITATION INITIALIZATION IN THE WEATHER MODEL HARMONIE APPLYING A HYDROMETEOR CLASSIFICATION SCHEME

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Warnings for severe weather with the non-hydrostatic weather model Harmonie can be improved by moving the initial state of the model closer to reality. We have achieved this by correcting the 3-D fields of rain, snow and graupel after the 3-D variational data assimilation in the model, which does not include improving precipitation fields from observations.

The hydrometeor classification code from the open source library wradlib has been applied to the 3-D data from KNMI's two C-band dual polarization Doppler weather radars. This code has been optimized and extended at KNMI, to create 3-D fields of mixing ratios of rain, snow, sleet and graupel by combining the probabilities of occurrence of the hydrometeor types with measured radar reflectivities. These 3-D fields of mixing ratios are used in Harmonie to correct its 3-D precipitation fields.

The impact of the improved initializations on forecasts of convection, clouds, precipitation and wind gusts will be shown.

ID: 163, Oral presentation

THE MEAN DIAMETER UPDATE APPROACH FOR ENSEMBLE-BASED DUAL-POLARIMETRIC RADAR DATA ASSIMILATION

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According to the principle of dual-polarimetric parameters, the differential reflectivity (Z_{DR}) is highly related to the mean diameter of raindrops. The numerical model presents this feature by showing the one-to-one relationship and high correlation between simulated Z_{DR} and the mass-weighted mean diameter (D_m) of raindrops. The mean diameter update (MDU) approach is developed to update D_m explicitly, which consequently leverages the relationship between Z_{DR} and the D_m in the ensemble-based data assimilation. In the pseudo-observation experiment, it is proved that the MDU approach can generate more correction on the microphysical states by updating D_m explicitly. A series of experiments are conducted to evaluate the impacts on analyses and forecasts in the real case and the feasibility with different microphysics parameterization (MP) schemes. The results illustrate that the MDU approach can decrease Z_{DR} analysis errors more efficiently, which is consistent with the further reduction of D_m. The result is the same when different MP schemes are employed, indicating that the MDU approach is feasible with various MP schemes. With more accurate microphysical states in the analysis field, the performance of the quantitative precipitation forecast (QPF) can be further improved with the implementation of the MDU approach. In conclusion, the accuracy of analyses and forecast is enhanced by taking advantage of the characteristic of simulated Z_{DR} and D_m with the MDU approach.

ID: 168, Oral presentation

INVESTIGATING THE ORIGIN OF W-BAND RADAR KDP SIGNATURES INSIDE AND BELOW THE DENDRITIC GROWTH LAYER

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In snow, the specific differential phase (KDP) measured by dual polarimetric cloud radars is commonly understood as an indicator for the presence of high concentrations of small, nonspherical particles. Nevertheless, KDP is also dependent on other properties of hydrometeors like density, orientation, phase and size. Attributing the contribution of different hydrometeors to an integrated KDP value observed by a radar is challenging and mostly tackled by modelling approaches.

In the winter 2022-2023, we operated an innovative simultaneous-transmission-simultaneous-reception (STSR) scanning Doppler W-band cloud radar (LIMRAD94) together with a novel video in situ snowfall sensor (VISSS) in the Colorado Rocky Mountains. Our observations enhanced the extensive measurements of the Atmospheric Radiation Measurement (ARM) Surface Atmosphere Integrated Field Laboratory (SAIL) campaign where a Ka-band and a X-band radar were deployed. Particle information, like size, number, shape, and complexity were obtained from the VISSS.

The investigation of high-KDP fall streaks combined with in-situ data from the VISSS at times revealed anticorrelations between number concentration of small particles and high KDP values. By combining different radar frequencies and exploiting various data processing techniques, we try to untangle the contribution of small and large particles to the magnitude of KDP. Additionally, the influence of external drivers like strong turbulence layers and synoptic fronts on polarimetric radar variables is shown.

ID: 171, Poster presentation

POLARIMETRIC RADAR OBSERVATIONS OF A TORNADIC SUPERCELL IN JERSEY, CHANNEL ISLANDS, ON 1 – 2 NOVEMBER 2023

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At approximately midnight on 2 November 2023, a significant tornado affected parts of Jersey in the Channel Islands. With an intensity rating of IF3 / T6, this was the strongest tornado to have been recorded in the British Isles since 1954. The tornado occurred in a thunderstorm that developed close to the cold front of an intense extratropical cyclone, named "Storm Ciarán" by the Met Office, which produced widespread damaging winds over northern France and adjacent areas. The tornadic thunderstorm passed within a few kilometres of the Doppler, polarimetric, C-band radar located on Jersey. Radar observations of the storm will be explored here, making use of Doppler, polarimetric and conventional parameters. Evidence of a debris signature in the polarimetric fields and an associated debris ball in the reflectivity field will be presented. These data represent the first observations of a polarimetric tornado debris signature in the British Isles. The structure of the storm will be explored by construction of vertical sections using available plan-position-indicator scans, after correction for the storm movement in the time interval between scans.

ID: 174, Poster presentation

HUMIDITY PROFILES AND ARCTIC MIXED-PHASE CLOUDS AS SEEN BY AIRBORNE G- AND W-BAND RADARS (HAMAG)

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Arctic clouds pose a large challenge for weather and climate models. This is partly due to insufficient measurements in the remote Arctic and subsequent uncertainties in microphysical cloud parameterizations. Current state-of-the-art instrumentation such as cloud radars operating at W-band deliver valuable measurements of macro- and microphysical properties but lack sensitivity to small ice hydrometeors and water vapor in clouds.

The new G-band radar GRaWAC (G-band Radar Water vapor profiling and Arctic Clouds) is a frequency-modulated continuous wave radar with frequencies at 167.3 and 174.8 GHz at the wing of the 183 GHz water vapor absorption line. By making use of the differential absorption technique for the measurements at the two frequencies, it is possible to extract water vapor profiles in clouds. The high frequencies also make the observations of small hydrometeors in the non-Rayleigh regime possible.

The airborne campaign HAMAG took place in February 2024 in Kiruna, Sweden, over the Bothnian Bay and along the Atlantic Norwegian coast. The research plane Polar 6 of the Alfred-Wegener-Institute flew the airborne GRaWAC alongside a W-band radar and a microwave radiometer, with the frequent launching of dropsondes supporting the measurements. First results show that the radar's higher sensitivity leads to the improved detection of haze compared to the conventional W-band radar. We sampled open and closed convective cells along the Norwegian coast originating from a cold air outbreak. These cells and their precipitation are well visible in the radar measurements, enabling synergistic retrievals of microphysical properties by exploiting the suite of remote sensing data. The contribution will introduce the HAMAG campaign and show first insights into airborne measurements of the G-band radar GRaWAC.

ID: 178, Oral presentation

CONVERGING THE ICON 2-MOMENT MICROPHYSICS TO OBSERVATIONS: EVALUATION WITH POLARIMETRIC MICROPHYSICAL RETRIEVALS

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Polarimetric radar operators like EMVORADO (Efficient Modular VOlume scan RADar Operator) enable direct comparisons of model-based, synthetic polarimetric variables with actual radar observations. On the other hand, recent research achieved considerable improvements in the accuracy of polarimetric microphysical retrievals. This enables a dual strategy for a detailed model validation exploiting radar polarimetry: (1) in the polarimetric radar observation space comparing simulated and observed radar parameters (see contribution by Mendrok et al.) and (2) in retrieval space comparing modelled quantities with polarimetric microphysical retrievals. This contribution focuses on the latter, i.e., synergistic evidences obtained in retrieval space.

ICON-D2 with the Seifert-Beheng two-moment microphysical scheme shows, similar to other numerical weather models, a tendency to excessive riming and graupel production. As a consequence, oversized graupel also results in too large drop sizes below the melting layer. Using iterative model parameter adjustment and model evaluation, our goal is to bring the results from ICON and subsequent radar simulations by EMVORADO in better agreement to the radar observations. Multiple experiments with adapted microphysical parameters in ICON (e.g., sticking efficiencies, riming efficiencies, terminal velocities, parameters governing the ice/snow-graupel partitioning, shedding parameters) as well as assumptions within the radar operator EMVORADO (e.g. wet growth parametrization within the melting scheme) are investigated and evaluated.

To date, clear improvements with reduced graupel production and mean drop sizes more in line with the radar observations have already been achieved, but further adjustments are tested.

ID: 185, Poster presentation

AN INVESTIGATION ON MICROPHYSICAL CHARACTERISTICS OF HEAVY RAINFALL EVENTS OVER TAIWAN

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Heavy to extremely heavy rainfall events are the major source of flash floods, landslides and agricultural damage. An increase in heavy rainfall events, more particularly in between May to September months, over Taiwan necessitate for the detailed investigation. The present study is aimed to investigate the spatial and temporal variations in the heavy rainfall events over Taiwan. Long-term data sets from the ground-based rain gauges, disdrometers, airborne radars (TRMM/GPM DPR) are used to investigate the rainfall and microphysical attributes of heavy rainfall events. The results showed higher occurrence frequency of heavy rainfall events over central Taiwan than the rest of the island. The contour frequency by altitude diagram of rainfall and raindrop size distribution estimates from the GPM DPR data products revealed contrasts in the microphysical features of heavy rainfall events across Taiwan. Apart from this, Modern-Era Retrospective analysis for Research and Applications, Versions2 (MERRA-2), re-analysis. Moderate Resolution imaging spectroradiometer (MODIS) and re-analysis data sets are also used to explore the influence of aerosol-cloud interactions on heavy rainfall events over Taiwan.

ID: 186, Poster presentation

A STATISTICAL EVALUATION OF CONVECTIVE CLOUD SYSTEMS IN A NUMERICAL WEATHER PREDICTION MODEL WITH POLARIMETRIC RADAR OBSERVATIONS

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The representation of microphysical processes in clouds contributes significantly to the uncertainty of precipitation forecasts. Towards improving the prediction of convective precipitation, we developed a systematic framework to statistically evaluate cloud microphysical parameterizations in a numerical weather model using polarimetric radar observations from the German C-band radar network. Polarimetric radar observations are sensitive to cloud particle properties, such as particle shape, phase, or density, and are thus well suited for evaluating cloud microphysics. A particular focus of this study is on high-impact weather situations, such as hail or convective rain. Convective weather is particularly difficult to predict and the choice of microphysics scheme significantly impacts the prediction of important characteristics of convective systems. We systematically characterize the performance of 5 microphysics schemes in predicting convective systems over a 30-day data set.

The observational data for this study were collected using two polarimetric research radar systems in the area of Munich, southern Germany, operating at C- and Ka-band frequencies, and a complementary polarimetric C-band radar operated by the German Meteorological Service (DWD). The weather simulations were performed with a convection-permitting regional weather model setup of the Weather Research and Forecast (WRF) model and with 5 microphysics schemes of varying complexity (double-moment, spectral bin, particle property prediction (P3)). The simulation of polarimetric radar signals consistent with the simulated cloud properties was achieved by applying a polarimetric radar forward operator. Convective cell objects are identified and tracked in model and radar data alike using an automated cell tracking algorithm. This enables Lagrangian tracking of individual convective cells, which allows statistical evaluation of simulated convective cell properties over their life cycles.

The resulting data set of convective cell objects is statistically analyzed in several ways. 1) Macrophysical properties such as the frequency, intensity, and area of high-impact weather situations are compared. 2) The distribution into stratiform and convective precipitation is examined. 3) The ability of the model to reproduce polarimetric signatures is evaluated. 4) The results are related to the convective life cycle, and other convective cell characteristics, such as cell intensity, size or spatial distribution.

ID: 192, Poster presentation

LIGHTNING ACTIVITY OVER THE CZECHIA FROM THE PERSPECTIVE OF GROUND-BASED DETECTION NETWORKS

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We present analysis of lightning data of three lightning detection networks covering the Czech Republic during 2015-2021. Specifically, we investigate the data of the World Wide Lightning Location Network (WWLLN), the Blitzortung network and the European Cooperation for Lightning Detection (EUCLID) network. The work examines the spatial and temporal characteristics of lightning discharges, the relationship between lightning discharges and land cover from CORINE Land Cover data set, and the relationship of lightning discharges with weather types based on the Czech Hydrometeorological Institute (CHMI) data.

ID: 197, Poster presentation

DETERMINATION OF LOW-LEVEL TEMPERATURE PROFILES FROM MICROWAVE RADIOMETER OBSERVATIONS DURING RAIN

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The continuous development and improvement of weather and climate models poses a great challenge to atmospheric remote sensing. For the evaluation of the models, increasingly better-resolved measurements and retrieval methods are needed, e.g. regarding air temperature profiles. Conventional observational approaches mainly fail as they are limited to provide continuous observations of temperature profiles under all weather conditions and especially during rain.

A microwave radiometer (MWR) can provide temporally highly resolved profiles of temperature and humidity, as well as integrated water vapor and liquid water path (Westwater et al., 2005), however, state-of-the-art retrievals are generally only possible during non-raining conditions (Ware et al., 2004). During rain the atmosphere becomes opaque to microwave radiation and thus no reliable information can be retrieved from higher atmospheric layers. Additionally, the radome of the instrument might get wet and the received signal is dominated by the liquid water accumulated on the instrument.

Here we show that the rain impact can be reduced by using only off-zenith elevation scans, i.e., observations at lower elevation angles, because liquid water usually accumulates at the top of the MWR. Furthermore, the influence of rain can be reduced by using only the higher frequencies of the oxygen absorption complex which are almost saturated anyway and will thus not be influenced as strongly by liquid water.

A cross comparison with retrievals for certain angles and certain frequencies gives information about how accurate the rain retrieval is under different conditions, i.e., cloud free or during rain (Fig. 1). The retrieval performance is shown on simulations as well as on real measurements. The results show a good performance within the atmospheric boundary layer which is of high interest for precipitation studies. These promising results can help to directly observe the cooling due to precipitation evaporation and better quantify the according cooling rates within the atmospheric boundary layer.

NOVEL MEASUREMENTS OF G-BAND DOPPLER SPECTRA IN ICE CLOUDS AND PRECIPITATION

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Using the 200GHz “GRaCE” Doppler radar at the Chilbolton Observatory in the UK, unique measurements of G-band Doppler spectra in a precipitating ice cloud are presented, along with coincident measurements from S-, Ka-, and W- band radars. The cloud system comprised of a 4-km deep layer of ice hydrometeors, with embedded layers of supercooled liquid water (as observed from simultaneous lidar measurements). Large Ka-G dual frequency ratios of up to 15dB were observed, which we attribute to strong non-Rayleigh scattering at 200 GHz. The prevalence of non-Rayleigh effects throughout the cloud layer provides more information on particle sizes than using lower frequencies alone.

Examination of the measurements as Doppler spectra profiles provides more detailed insight. Bimodal Doppler spectra are observed throughout much of the measurement period, and spectral LDR measurements reveal that the slow-falling mode of particles is likely to be column/needle crystals, which we argue are a result of a secondary ice process. These crystals are horizontally oriented, and have a small thickness, which makes them Rayleigh scattering at all frequencies. Meanwhile the fast-falling particle mode is observed to have strong non-Rayleigh characteristics, with faster particles having larger spectral dual frequency ratios. We attempt to constrain the properties of this mode of particles by constructing a spectral triple-frequency diagram, and comparing it to simulated scattering properties of rimed and unrimed snowflakes. The results suggest that a range of different degrees of riming were present throughout the case, and we argue that the riming of the snowflakes generated the secondary ice particles via the rime-splintering process.

ID: 201, Poster presentation

A NEW HIGH-RESOLUTION STEREO IMAGER TO MEASURE THE SHAPE OF RAINDROPS AND OTHER HYDROMETEORS

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Interpretation of dual-polarisation radar measurements of precipitation requires an accurate model of the shape and orientation of the hydrometeors. In rain, measurements of differential reflectivity are sensitive to the average drop shape, while measurements of co-polar correlation coefficient are controlled by the variability in drop shape. This variability has two sources: (i) the fact that there is a distribution of drop sizes (each having a different average shape), which is typically what we want to retrieve information about, and (ii) through drop shape oscillations, which lead variation in shape for drops of the same size. Therefore, an understanding of the full PDF of drop shapes as a function of their size is highly desirable.

Although there has been much progress on this topic in past decades, unfortunately, many details of the non-spherical shapes of raindrops and their oscillations remain unclear, and this is in part because of the lack of high-resolution measurements of drop shapes in natural rainfall. Observations with the 2D video disdrometer have guided past studies of raindrop shape distributions, but the resolution of this instrument is very coarse (on the order 0.15mm), which makes it very difficult to robustly characterise the shape of small drops with small non-sphericities. Meanwhile, much progress has been made recently in the field of high-resolution snowflake imaging (e.g. the Multi Angle Snowflake Camera and Video In Situ Snowfall Sensor). Unfortunately, these instruments are optimised for snow. Raindrops are small, but fall very fast in comparison to snowflakes: this means that high resolution (and therefore magnification) is required, as well as extremely short exposure times to freeze the rapid fall motion of the drops, and avoid distorting their shapes in the images.

To address this measurement gap, we have developed a new stereo imaging system for deployment in natural rain conditions. Drops fall through a 20cm diameter octagonal opening. A pair of orthogonal laser beams directed to photodiodes on the opposite face of the aperture monitors the volume close to the centre of the aperture for drops. When the beams are obscured, a pulse is sent to two digital machine vision cameras with macro lenses which capture a high resolution image of the drops, backlit against small high-intensity LED panels. The exposure time of these images is 1 microsecond, to avoid blurring of the drop outlines. These stereo image pairs are then acquired by a Raspberry Pi single-board computer, and stored along with timestamp information.

In this poster, we will show information about the development of this new instrument, example data from laboratory-generated drops, and observations in real rainfall events.

While the focus of the work has been on raindrops, the instruments is suitable for collecting observations of hail, graupel, snow and other precipitation types; we have also observed images of flying insects such as moths in the summer months which may be of interest for radar aeroecology studies.

ID: 206, Oral presentation

A DEEP EVALUATION OF SEVERE HAIL ALGORITHMS USING CONVENTIONAL RADAR METRICS AND A NEW CNN-BASED APPROACH APPLIED TO MÉTÉO-FRANCE RADAR NETWORK

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In 2022, severe convective storms caused significant damage in Europe, particularly in France, where large hailstones (> 5 cm) have been reported several times. However, Météo-France currently lacks an operational algorithm to estimate the largest hailstone sizes. The operationnally used Al-Sakka et al. (2013) hydrometeor classification algorithm has only one class for "large hail", which includes all sizes above 2 cm.

The purpose of this work is to compare common radar metrics (POH, POSH, MESH, VIL, ECHOTOP45) and a newly developed convolutional neural network-based algorithm on a large number of hail cases. To do so, a quality-controlled dataset of radar samples is built along with verified hail reports on the ground from the European Severe Weather Database (ESWD). Because the performance of all tested methods is related to the samples in the dataset, many precautions were taken to build the dataset. A "nonsevere hail" dataset was first built with instances where severe hail did not occur on the ground. This was done by selecting convective cell objects (i.e., with a reflectivity > 45 dBZ) above densely populated areas with no hail report (neither from ESWD nor from Meteo-France crowd-sourcing application). The "positive" severe hail reports from the ESWD were also manually verified.

This work will first present the statistical characteristics of the different metrics tests for negative and positive cases, as well as for different hail size classes. The artificial intelligence algorithm and its performance will also be described along with the impact of hyperparameter tuning on the results and the effect of the different variables tested as features.

ID: 207, Oral presentation

THE AROME-MESONH RADAR DUAL-POLARIZATION FORWARD OPERATOR: RECENT PROGRESS AND OUTLOOK

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Thanks to their ability to provide information about the nature and shape of hydrometeors, dual-polarisation radar data is particularly interesting for verification, improvement or assimilation in NWP models (Ryzhkov et al., 2020). However, to carry out direct comparisons, model variables must be converted into synthetic polarimetric variables using a polarimetric radar forward operator.

Such a forward operator has been developed at Météo France by Augros et al (2016). It uses T-matrix scattering (Mishchenko, 2014) and its density, particle size distribution parameters were defined in order to be consistent (whenever possible) with the model microphysical parameterization. Recent technical developments of this code make it easily adaptable for (offline) use with either the research MesoNH model (Lac et al, 2018) or the NWP convective scale AROME model (Brousseau et al., 2016). However, this forward operator has, for the moment, only been used for model and microphysics scheme evaluation (Taufour et al, 2018; Mazoyer et al, 2023) and is not currently used operationally in the AROME model for radar reflectivity assimilation. Instead, a simpler radar forward operator with Rayleigh scattering hypotheses is used in AROME (Wattrelot et al, 2014; Martet et al, 2022). With these simpler options, the forward operator can be more easily linearised and an adjoint operator can be built, which are prerequisites for use in a 3D or 4D VAR framework.

A new evaluation of the dual-polarization radar forward operator with recent options (new mixed phase parameterisation, hail options) both for AROME and Meso-NH model will be presented. The evaluation will focus particularly on severe convective cases, including the 18 August 2022 derecho case that hit Corsica. This new evaluation of different forward operator options (Rayleigh or T-matrix) together with different microphysics options will help determine the remaining deficiencies in the model microphysics and/or forward operator. The purpose of this evaluation is also to consolidate this forward operator so that it can be considered as our best reference, before we investigate using a machine learning approach, for example with a neural network inference code that could include tangent linear and adjoint versions such as done by Scheck et al (2021).

LIGHTNING FORECAST IMPROVEMENT THROUGH LIGHTNING DATA ASSIMILATION. RESULTS FOR A TWO-SEASONS PERIOD OVER ITALY USING THE WRF MODEL.

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Lightning is a serious threat for public safety and economic activities. An accurate lightning forecast is of paramount importance over the Mediterranean area, which is frequently impacted by flashes.

This work shows the impact of lightning data assimilation (LDA) on the lightning forecast for the following 6h. We used the Weather Research and Forecasting (WRF) model coupled with the Dynamic Lightning Scheme (DLS), assimilating lightning by nudging. We used one grid with a 3km spatial horizontal resolution and four simulations per day. Two complete seasons with different lightning characteristics are analyzed: summer 2020 and fall 2021. Two sub-periods are verified: 0-3h and 3-6h after assimilation. For the 0-3h period, LDA has a positive impact on strokes forecast, improving the control forecast. This improvement is found in many characteristics: refining an already good control forecasts, reducing the false alarms, predicting flashes not predicted by the control forecast or spatially redistributing strokes in better agreement with observations. Impact of LDA on the strokes forecast changes between summer and fall. The difference is strictly related to the differences in lightning distribution over the Italian territory between the two seasons. In summer lightning occurs mainly over the Italian mainland while in fall the main lightning activity is over the sea. The improvement given by LDA can be seen mainly over the land in summer and over the sea in fall. The forecast at the short range (0-3h) is applicable to issue warnings and alerts as the storm is approaching. For the 3-6h period, the impact of LDA on strokes forecast is negligible.

A verification of the precipitation prediction against combined radar-raingauge rain observations is also shown.

ID: 219, Oral presentation

DOUBLE MOMENT NORMALIZATION OF HAIL SIZE NUMBER DISTRIBUTIONS OVER SWITZERLAND

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The Swiss network of automatic hail sensors collects measurements about hailstone size and kinetic energy in three regions of Switzerland since September 2018. In this study, we propose the use of the double moment normalization to model the hail size number distribution (HSND), which is defined as the number of hailstone impacts measured, for each diameter size, by one instrument during one (entire) hail event, using measurements from September 2018 to August 2023. This method uses two of the empirically estimated moments of the HSND to compute a normalized distribution. While the HSND is dependent on the duration and intensity of the event and on the detection area of the sensor, we show that on the contrary, the normalized distribution has limited variability across the three geographical regions of deployment of the sensors in Switzerland. Thanks to its invariance in space and time, a generalized gamma is used to model the normalized distribution, and its parameters have been determined through a fit over approximately 70% of the events. The fitted model and the previously chosen pair of empirical moments can be used to reconstruct the HSND at any location in Switzerland. The accuracy of the reconstruction has been evaluated over the remaining 30% of the dataset. An additional evaluation has been performed on an independent HSND, made of estimates of hailstone diameters measured by drone photogrammetry during a single event. This HSND has a much larger number of hailstone impacts (18000) than those of the hail sensor events (from 30 to 400). The double moment normalization is nevertheless able to reproduce well the HSND recorded by the hail sensors and the drone, albeit with an underestimation of the number of impacts at small diameters. These results highlight the invariance of the (double-moment) normalized distribution and the adaptability of the method to different data sources.

ID: 223, Poster presentation

RETRIEVAL OF THE HAIL SIZE NUMBER DISTRIBUTION FROM POLARIMETRIC C-BAND WEATHER RADAR USING DOUBLE-MOMENT NORMALIZATION

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We propose a new technique using polarimetric C-band radar observations to estimate the hail size number distribution (HSND), defined as the number of hailstone impacts measured for each diameter size by one instrument during one event. Several features based on polarimetric variables are extracted and are fed into a statistical model to estimate two empirical moments of the HSND. Thus, the HSND is reconstructed using a double-moment normalization (similarly to Raupach and Berne (2017) for the raindrop size distribution retrieval). The technique takes advantage of the invariance of the normalized HSND distribution and the adaptability of the method to different data sources (e.g. drone data on a larger scale, see Ferrone et al. (2024)). Our model is trained with respect to the measured moments by a network of hail sensors and it is thus conditioned by the presence of hail on the ground. The model is tested in three different regions of Switzerland using independent events from hail sensors and drone photogrammetry data. Kinetic energy flux, and maximum hailstone diameter are derived from the radar-derived HSND. The proposed method is compared against existing methods for radar-based estimates of kinetic energy flux and maximum diameters, in particular, Waldvogel et al. (1978) and MESHS (Maximum Expected Severe Hail Size), respectively. Combining our model with a hail detection algorithm would permit the retrieval of the HSND for the whole Switzerland and, in turn, an attempt of deriving kinetic energy and a first-guess of maximum hailstone size.

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ID: 227, Oral presentation

CLOUD DSD DISPERSION AND SENSING THE ONSET OF COLLISION-COALESCENCE AND DRIZZLE FROM REMOTE AND IN-SITU MEASUREMENTS

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Simultaneous lidar and radar observations of clouds and precipitation are becoming more common. In response to such opportunities, a measure of droplet size, RLED = D_{62}, was introduced in [1] and [2]. While the Gamma distribution of drop size was used in [1], a non-parametric approach was used in [2], and it was shown in [2] that RLED performed well in estimating liquid water content (LWC) of warm clouds. Our purpose here is to point out that D_{62} is significantly affected by the drop size distribution (DSD) dispersion and can serve as a rough distribution of relative and absolute DSD dispersion. This is important as the relative dispersion of DSD plays an essential role in terrestrial radiative transfer [3]. The RLED appears sensitive to the onset of collision-coalescence because of its sensitivity to the large drop tail of the DSD. Hence, RLED can serve as an indicator of drizzle onset. As such, it may discriminate between drizzling, mixed and non-drizzling clouds. The usefulness of RLED in estimating DSD dispersion is demonstrated by analyzing in situ cloud probe measurements.

Remote and in situ measurements were analyzed to investigate the onset of collision-coalescence and drizzle. Combining hydrometeor cloud and drizzle classification and reflectivity, LWC, and RLED estimation from remote measurements, the standard deviation of DSD was investigated. The retrieved RLED, Z, and LWC from radar and lidar measurements show RLED reasonably discriminates between drizzling and non-drizzling clouds. The standard deviation of DSDs increases as RLED increases. This result is consistent with large droplets with broad distribution cloud microphysics. Since RLED is directly estimated from radar and lidar measurements, the standard deviation of DSDs can be estimated using remote measurements. Analysis of detailed in-situ cloud and drizzle probes of liquid droplet spectra shows RLED tends to increase with the breadth of the size distribution.

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CONVERGING THE ICON 2-MOMENT MICROPHYSICS TO OBSERVATIONS: EVALUATION IN POLARIMETRIC RADAR OBSERVATION SPACE

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Polarimetric radar operators like EMVORADO (Efficient Modular VOlume scan RADar Operator) enable direct comparisons of model-based, synthetic polarimetric variables with actual radar observations. On the other hand, recent research achieved considerable improvements in the accuracy of polarimetric microphysical retrievals. This enables a dual strategy for a detailed model validation exploiting radar polarimetry: (1) in the polarimetric radar observation space comparing simulated and observed radar parameters and (2) in retrieval space comparing modelled quantities with polarimetric microphysical retrievals (see contribution by Steinheuer et al.). This contribution focuses on first, i.e. the evaluation in polarimetric radar observation space.

Recently, forecasting using the ICON-D2 with Seifert-Beheng two-moment microphysics (2mom-ICON) became pre-operational. Studies of polarimetric signatures and Z-R relations suggested a tendency to excessive riming and graupel production in 2mom-ICON, similar to other numerical weather models. As a consequence, oversized graupel also results in too large drop sizes below the melting layer. Furthermore, the radar bright band was found to generally appear too smeared out in the radar forward operator simulations, both regarding reflectivities and the polarimetric parameters.

Multiple experiments with adapted microphysical parameters in ICON (e.g., sticking efficiencies, riming efficiencies, terminal velocities, parameters governing the ice/snow- graupel partitioning, shedding parameters) and modified assumptions within the radar operator EMVORADO (e.g. wet growth parametrization within the melting scheme) have been performed. Resulting synthetic radar observations have been investigated and evaluated against measurements from the operational DWD C-band radar network. Clear improvements in stratiform situations, e.g., reduced ZH and ZDR deviations in and below the melting layer, have already been achieved. Further adjustments are tested, and their results will be presented.

ID: 242, Oral presentation

INVESTIGATING ICE MICROPHYSICAL PROCESSES IN THE DENDRITIC GROWTH LAYER BY COMBINING POLARIMETRIC CLOUD RADAR OBSERVATIONS WITH MONTE-CARLO PARTICLE MODELING

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The dendritic growth layer (DGL), centered around -15°C, plays a key role in the formation of precipitable ice and snow particles. Particle growth by vapor deposition and subsequent aggregation are strongly enhanced in the DGL. As a result, multiple radar observables display distinct features related to the plate-like particle shapes as well as rapid formation of aggregates. Specifically, enhanced ZDR and KDP are frequently linked to the depositional growth of plate-like particles and the increase in DWR to aggregation. However, radars only observe the effect of ice microphysical processes (IMPs) on the observed particle distribution, not the IMPs themselves. Therefore, especially the origin of the enhanced ZDR and KDP are not fully understood. Common hypotheses include plate-like growth of ice crystals which sediment into the DGL from colder temperatures, primary nucleation due to an updraft and local activation of INP and secondary ice production (SIP), possibly ice-ice collisional fragmentation.

In this contribution, we combine zenith triple-frequency (X, Ka, W-band) and slant-viewing W-band spectral polarimetric radar observations with Monte- Carlo Lagrangian particle modeling. The Monte-Carlo model McSnow allows us to describe IMPs on the detailed particle level. Recently, a habit prediction scheme which simulates the evolution of ice crystal shape and density has been implemented. Ice habit, particle size, density and fall velocity are core information for radar forward simulations, facilitating the comparison with radar observations and allowing to link the radar observations to specific IMPs. Initial laboratory studies on ice-ice collisional fragmentation allowed us to implement a new simple fragmentation scheme in McSnow. To make full use of the rich information content of the McSnow simulations, a new radar forward operator has been developed. The forward operator is based on DDA calculations of more than 1000 ice crystals with varying habits, as well as approximately 600 aggregates with varying degrees of riming. McSnow simulations suggest that the particles responsible for the increase in ZDR need to be produced within the DGL, either via primary or secondary ice production. The simulations further suggest that the increase in KDP at -15°C might be linked to fragmentation. Surprisingly, our study also suggests that the increase in KDP is not necessarily caused by ice crystals, aggregates also have a significant contribution to KDP.

A CLIMATOLOGICAL STUDY ON THE MERGER-FORMATION BOW ECHOES IN CHINA

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Bow echoes produce damaging surface winds and heavy rainfall. Previous studies normally explained bow echoes using the classical theory that emphasized the importance of rear-inflow jet, and such echoes are termed as the classical bow echoes (CBEs) in this study. Additionally, the warm moist environmental conditions over South China facilitate bow echo formation through merger process between linear systems and convective cells. Bow echoes formed in this manner are termed as the merger-formation bow echoes (MFBEs). Due to the small-scale and fast-evolving process of merging, MFBEs are rarely documented in previous literature. This study firstly investigates the spatiotemporal distributions of MFBEs over South China using 5-year radar observations, pointing out the MFBEs account for more than half of the total bow echoes and cause more high-impact weather in metropolitan area than CBEs. In addition, we propose a new Merger-Classical index to distinguish the environments for MFBEs and CBEs. The differences between MFBEs and CBEs are statistically significant at the 95% confidence level. This paper emphasizes a new perspective on the environment in which bow echo forms by merger process, underscoring the need for more in-depth research in the future.

ID: 253, Poster presentation

AN OVERVIEW OF THE WESCON-WOEST FIELD CAMPAIGN IN SOUTHERN ENGLAND IN SUMMER 2023

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The Wessex Convection Experiment (WesCon) - Observing the Evolving Structures of Turbulence (WOEST) field campaign took place in southern England during Summer 2023. The aim of the project was to obtain novel measurements of turbulent processes in the pre-convective boundary layer and during the development of convective clouds, to compare with and constrain their representation in next generation weather and climate models. The field project involved five dual-polarisation Doppler research radars, the FAAM aircraft, multiple radiosonde launch sites, ground-based observations including lidars, radiometers, wind profilers and flux stations, and UAVs making vertical profiles. Two X-band systems (NXPol-1 and NXPol-2) performed routine 5-minute volume scans over the target domain suitable for dual Doppler analysis, along with the UK Met Office Wardon Hill C-band radar that could adopt the same strategy when not needed operationally. An automated tracking algorithm was used to identify convective cells and direct the aircraft to make in-situ measurements whilst the S-band Chilbolton Advanced Meteorological Radar (CAMRa) and a Ka-band cloud radar (Kepler) performed a series of RHI scans from separate locations through the same cells, enabling the retrieval of 3D wind and turbulence parameters. This presentation will provide a general overview of the field project and show some examples of the data collected with a focus on the radar measurements.

ID: 271, Oral presentation

NEAR-SURFACE TORNADO THERMODYNAMICS FROM RADAR AND IN SITU OBSERVATIONS

K. Kosiba[1,2], J. Wurman[3,2]

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Understanding the tornado evolution, intensity, and structure is enhanced by having integrated wind and thermodynamic data near the tornado. In addition to the calculation of 3D vector winds, multi-Doppler wind retrievals can be used to derive thermodynamic quantities, which can provide information about parcel origins and buoyancy of the near-tornado air, allowing for examination of tornado evolution, intensity and structure as relates to local buoyancy. Often, though, thermodynamic observations are unavailable to compare to the multi-Doppler thermodynamic retrievals so the representativeness of these retrievals is unverified. Uniquely, over the last 20 years, the Doppler on Wheels (DOW) mobile radars have collected multi-Doppler data in tandem with in situ instrumentation in 8 tornadoes, and in several tornadoes with single-Doppler and in situ instrumentation. This presentation examines the common effects of different base state assumptions on the Doppler retrievals and how they compare to in situ observations. Preliminary analyses will be presented that show distinct air masses surrounding the tornado. Generally, a region of more buoyant air is found north of the tornado. Dual-Doppler analyses, and proximal soundings, when available, help diagnose the origins of this near-surface air. These are compared across a range of tornado intensities, inferred structure, and evolution.

ID: 272, Oral presentation

TORNADIC SUPERCELL STRUCTURES, BEST TORNADO STUDY, EXTENDED TORNADO CLIMATOLOGIES

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Case studies of tornadic storms have shown the importance of downdrafts and associated gust fronts in low-level and tornado genesis. But, the existence of the features alone is not sufficient for tornadogenesis. The Doppler on Wheels (DOW) radars have collected dual-Doppler in eighteen supercells, some tornadic, some non-tornadic, which allows for the characterization of these features using fine-scale resolution vector wind fields permitting structures, convergence/divergence, and vorticity to be diagnosed. Ongoing intercomparison efforts will be presented.

A focused tornado observational field project, the Boundary-Layer Evolution and Structure of Tornadoes (BEST) project will be conducted in May-June 2024. The major goals of BEST are to resolve tornado and near-tornado kinematic and thermodynamic structures with unprecedented detail, using very-short baseline (3-6 km) dual-Doppler, ground-based in situ observations, and lagrangian drifter sondes ingested into tornadoes. Preliminary results will be presented.

Progress on the ongoing DOW tornado climatology, extending the number of individual tornado cases from the 120 (1995-2006) to about 250 (adding 2007-2024), and additional tornado structure metrics including the radial dependence of winds, vorticity, and convergence will be presented.

ID: 273, Poster presentation

THE FLEXIBLE ARRAY OF RADARS AND MESONETS (FARM)

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The Flexible Array of Radars and Mesonets (FARM) Facility is an extensive mobile multiple-Doppler radar and in-situ instrumentation network.

The FARM comprises four mobile / quickly-deployable radars: two X- band Doppler On Wheels DOW6/DOW7, the C-band On Wheels (COW), and the Configurable Radar On Wheels (CROW) which can be configured as a C-band mini-COW, the Rapid-Scan DOW (RSDOW) or an X-band DOW.

The FARM includes 3 mobile mesonets (MM) with 3.5-m masts, an array of rugged weather stations (PODNET), weather stations deployed on infrastructure including light/power poles (POLENET), and other instrumentation.

The FARM's integration of radar, in situ, and sounding systems provides robust kinematic, thermodynamic, and microphysical observations. FARM has deployed to >30 projects, obtaining pioneering observations of a myriad of small spatial scale and short temporal scale phenomena including tornadoes, hurricanes, lake-effect snow storms, aircraft-affecting turbulence, convection initiation, microbursts, intense precipitation systems, boundary layer structures and evolution, airborne hazardous substances, coastal storms, wildfires, weather modification, and mountain/alpine weather.

Proposed major upgrades to the FARM targeted observing network are being proposed.

The Bistatic Adaptable Radar Network (BARN), an inexpensive, portable and adaptable, bistatic network employing simplifying technologies, communications networks, and board-based processing. A next-generation long wavelength adaptable/targetable research radar network, comprising an array of truck-borne scanning 10-cm radars, S- band On Wheels (SOW), can provide fine-scale S-band observations of the atmospheric boundary layer, convective, and other precipitating systems, simultaneously measuring dynamically meaningful fine-scale vector wind fields.

ID: 274, Poster presentation

PROPAGATION AND EVOLUTION OF ROTATION IN LINEAR SYSTEMS (PERILS): ATTRICUTES OF TORNADIC AND NON-TORNADIC VORTICES

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The multi-year Propagation and Evolution of Rotation in Linear Systems (PERiLS) field project took place in early 2022 and 2023. Data were collected to help understand mechanisms for mesovortexgenesis and tornadogenesis in quasi-linear convective systems (QLCSs) using targeted instrument network, including mobile and deployable radars, sounding systems, mesosnets, and in situ surface weather stations. In order to investigate formation mechanisms, all observed rotations by the PERiLS radars were categorized based on storm mode (QLCS or supercell), inferred formation mechanism (parent vortex or shearing instability), intensity, and proximity to other vortices. Storm characteristics were examined including gust front structure, such as slope and height, width of the shear zone, and proximity to mesoscale updrafts, in order to diagnose favorable characteristics for vortex generation. This presentation will provide an overview of the aforementioned bulk characteristics relative to formation mechanism and intensity observed during PERiLS.

ID: 277, Poster presentation

WINDS AND STRUCTURES IN HURRICANE BOUNDARY LAYERS EXPERIMENT (WASHABLE)

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The Winds And Structures in Hurricane Boundary Layers Experiment (WASHABLE) is planned for late summer and early fall of 2024, starting shortly before ERAD-2024. A network of mobile X- and C-band DOW/COW radars, and in situ instrumentation will be used to characterize the evolution of the hurricane boundary layer as hurricanes make landfall, and relate these structures and windspeeds to observed damage. Dual-Doppler vector windfields will enable momentum and energy fluxes to be calculated. The design and, if fortunate, very early hot-off-the-press very preliminary results will be presented.

ID: 280, Poster presentation

THE COLORADO STATE UNIVERSITY SEA-GOING AND LAND DEPLOYABLE POLARIMETRIC (SEA-POL) RADAR

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The Colorado State University (CSU) Sea-Going and Land-Deployable Polarimetric (SEA-POL) radar is a requestable Community Facility (CIF) supported by the U.S. National Science Foundation (NSF). The radar is designed to be portable and rugged from a mechanical and electrical perspective, and was constructed to be operable in harsh environments. SEA-POL can be deployed on ships and remote field sites around the world. It offers platform stabilization for oceanic environments while still having high-quality polarimetric capabilities for all-purpose use.

SEA-POL has participated in both ship and land deployments since its inception in 2017. Oceanic deployments encompass the eastern Pacific during SPURS-2 (2017), the western Pacific during PISTON (2018/2019), and the tropical Atlantic for PICCOLO (August – September 2024). Two land-based deployments include an island in Japan for PRECIP (2022), and an upcoming winter experiment S2noCliME in Steamboat Springs, CO (winter 2024-25). The data collected by SEA-POL have provided valuable observations to aid scientific analysis of cloud and precipitation processes in remote regions of the globe. An overview of the radar and its specifications, as well as highlights from the resulting science, will be presented along with information on requesting the facility for interested potential users.

ID: 285, Oral presentation

MICRO RAIN RADAR BASED ANALYSIS OF RAINFALL EVAPORATION EFFECTS DURING THE LIAISE FIELD CAMPAIGN

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Irrigation in semi-arid regions may produce important contrasts between surface characteristics in nearby irrigated and rainfed areas. In 2021, within the framework of the Global Energy and Water Exchanges (GEWEX) programme, the “Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment” (LIAISE) field campaign was performed in NE Spain. One of the aspects studied during LIAISE was the effect of surface conditions on precipitation processes. Specific instrumentation for this purpose was deployed at three different sites including three vertically pointing Micro Rain Radar units (one MRR2 and two MRR-Pro) collocated with PARSIVEL disdrometers and automated surface observations. MRR spectral raw observations were processed with the publicly available RaProM and RaProM-Pro python libraries (Garcia-Benadi et al 2020, 2021) calculating different variables such as radar reflectivity Z, liquid water content LWC, or precipitation type. Results indicated that on the irrigated area the cases potentially affected by rainfall evaporation where less frequent than in the rainfed areas but, when they occurred, changes in the LWC or Z vertical profiles were similar in both areas as suggested by Contour Frequency Analysis Diagrams. Further insight was obtained in a case study comparing MRR precipitation profiles with a simple one column drop size distribution evolution model considering size sorting and evaporation effects, confirming the importance of the latter to reproduce the observations. This research was supported by projects WISE-PreP (RTI2018-098693-B-C32), ARTEMIS (PID2021-124253OB-I00) and the Water Research Institute (IdRA) of the University of Barcelona.

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ID: 293, Poster presentation

INTRODUCING THE VIDEO IN SITU SNOWFALL SENSOR FOR ADVANCING RADAR RETRIEVALS

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We do not know the exact pathways through which ice, liquid, cloud dynamics, and aerosols are interacting in clouds while forming snowfall but the involved processes can be identified by their fingerprints on snow particles. The general shape of individual crystals (dendritic, columns, plates) depends on the temperature and moisture conditions during growth from water vapor deposition. Aggregation can be identified when multiple individual particles are combined into a snowflake. Riming describes the freezing of cloud droplets onto the snow particle and can eventually form graupel. This leads to a large variability of snowfall particle properties limiting our ability to quantify snowfall with radar. In order to understand the natural variability of snowfall particles, the accociated formation processes, and to advance remote sensing retrievals, optical in situ observations are required.

The Video In Situ Snowfall Sensor (VISSS) was specifically developed for a campaign in the high Arctic (MOSAiC) to determine particle shape and particle size distributions. Different to other sensors, the VISSS minimizes uncertainties by using two-dimensional high-resolution images, a large measurement volume, and a design limiting the impact of wind. Tracking of particles over multiple frames allows determining fall speed and particle tumbling. The instrument design and software are released as open-source. Here, we present the design of the instrument, show how particles are detected and tracked and show the potential for combined radar in situ observations from campaigns in the high Arctic (MOSAiC), in the Colorado Rocky Mountains (SAIL), and in and Hyytiälä (Finland).

ID: 296, Oral presentation

ADVANCED CLOUD DETECTION AND VELOCITY UNFOLDING TECHNIQUES FOR 94-GHZ CLOUD RADAR

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Understanding the macro- and microphysics of clouds is crucial for comprehending their impact on Earth's radiation budget, climate, and the water cycle. Cloud profiling radar (CPR) is an instrument in providing detailed vertical profiles of cloud properties. However, CPR data can be susceptible to contaminants and noise, potentially leading to misclassifications in cloud masks. This paper presents an improved cloud detection method tailored for the 94-GHz W- band radar (HG-SPIDER) developed and utilized by NICT in Japan. The method entails a multi-step process to detect hydrometeors and generate a cloud mask, including noise power determination, initial cloud mask creation, spatial and temporal box filtering, threshold assessment, stability criterion, and a 2-D spatial filter. This algorithm accurately discerns hydrometeors while mitigating false detections and ensuring robustness across diverse atmospheric conditions. Compared to traditional methods reliant on constant noise thresholds, this innovative approach demonstrates superior performance in cloud detection.

Additionally, accurate Doppler velocity measurements are essential for target discrimination and improving the precision of cloud microphysics systems. Velocity folding, a common issue in radar measurements, occurs when the phase shift detected between sequential radar pulses exceeds the Nyquist velocity (Vn) in Cloud Profiling Radar (CPR). This paper proposes a novel velocity unfolding technique based on Z and V relation, incorporating gradient analysis, normalization of velocity and reflectivity, trend relation computation, and specific conditions for identifying velocity folding effects. The proposed method achieves higher accuracy in velocity correction, further validated by considering the correlation with velocity measurements by Doppler lidar.

In conclusion, the proposed velocity unfolding method signifies a significant advancement in radar data processing techniques, offering superior accuracy and performance compared to conventional approaches reliant on a fixed velocity threshold. Its validation against lidar measurements underscores its efficacy and suitability for meteorological applications, where accurate velocity data is pivotal for various analyses and predictions. The methods developed in this study are also planned to be implemented in JAXA L2 algorithms for CPR onboard JAXA-ESA joint mission EarthCARE.

Keywords: Cloud mask, CPR, LIDAR, Velocity unfolding

ID: 307, Oral presentation

DROPLETS SIZE COMPARISON FROM DIFFERENT RETRIEVAL ALGORITHMS: A CASE STUDY AT CLOUDNET GRANADA STATION

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Clouds have a significant impact on both the earth's radiative balance and the hydrological cycle. They are a key component to regulate surface temperature and to conduct precipitation patterns. Nevertheless, due to a lack of ground- based observations of cloud properties, they are still not quite well understood. Especially in regions experiencing intense weather phenomena such as the Mediterranean Basin. In this study, we present an analysis of cloud microphysical properties in southeastern Spain, in the western Mediterranean. In particular, 94-GHz cloud doppler radar reflectivity, ECMWF temperature profiles, and microwave radiometer liquid water path (LWP) at the ACTRIS-CCRES AGORA observatory in Granada are used. AGORA is the only CCRES station operated in Spain, with more than half a decade of cloud remote sensing observations. Here, a comparison of different droplet effective radius retrievals proposed by Knist et al., 2014 and Frisch et al., 2002 (designated as cloudnet, cloudnet-corrected, Knist, cloudnet scaled to LWP and cloudnet-corrected scaled to LWP) is presented. The data showed a monomodal distribution of effective radius for liquid clouds, with no significant differences in the size distributions for the different retrievals. For mixed-phase clouds, a bimodal distribution is observed and retrieval methods using LWP exhibit a broader distribution and large discrepancies are found with non LWP-scaled methods. According to our results, the analysis of liquid droplet size in mixed-phase clouds is still quite challenging and affected by large uncertainties. The presented case studies are a first step on cloud retrieval evaluation, but more extended analysis will be performed to come to robust conclusions.

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ID: 309, Oral presentation

VARIABILITY OF THE WEATHER RADAR ALGORITHMS ACROSS THE ITALIAN TERRITORY

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Weather radar algorithms for quantitative precipitation estimation (QPE) are often derived by applying regression methods in the radar observable vs. rain rate domain obtained from simulated scenarios thanks to microphysical and electromagnetic assumptions of falling hydrometeors and the knowledge of drop size distributions (DSD). Sets of DSD can be both theoretically reproduced or come from long-term disdrometer measurements. The use of

measured DSDs is supposed to produce algorithms that are adequately representative of the climate of the region in which the measurements are collected, and consequently should provide radar estimates that adhere more to reality.

Disdrometers are reputed to be the most reliable instruments for estimating DSD at ground, but their use has been limited to sparse research sites or field campaign limited in time. A unique community effort to achieve a federated, nation-wide, disdrometer network is ongoing in Italy owing to the Italian Group of Disdrometry (GID). The GID (https://www.gid-net.it/) was set up in 2021 thanks to a spontaneous collaboration of different Italian institutions (including research centers, universities, and environmental regional agencies) that manage disdrometers over Italy. The main aim of GID is to create a network between owners and users of disdrometers data in Italy in order to capitalize the instrumental resources and the available know-how, and to maximize the usefulness of these measures in various fields of application. In these two years, the GID network enlarged including a higher number of devices, researchers and institutions. Right now, there are 23 laser disdrometers in the GID network.

Due to orography and different prevailing atmospheric circulation characteristics radar QPE algorithms can vary in the different regions of Italy. In this study the data collected by the GID network is used to evaluate the variability of the precipitation characteristics along the Italian territory. Furthermore, weather radar algorithms are obtained for C- and X-band, and their variability, as function of the geographical location, is investigated.

ID: 310, Oral presentation

OBSERVATION OF FLOW STRUCTURE IN A THUNDERSTORM BY SHIP RADAR

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The information about the inner structure of cumulonimbus is very important for understanding the development and decay processes of convective storm. One of the best choices may be a phased array weather radar. As a more conventional instrument, the ship radar is also available. The ship radar has high range resolution of 10 m and it can make RHI scan every 3 seconds when it rotates vertically. Therefore, the detailed reflectivity in the vertical cross section of the cumulonimbus can be obtained at a high temporal resolution. We can measure the flow field of cumulonimbus by tracking echo pattern. The present observational study aims to examine the availability of the ship radar as a weather radar and investigate the inner structure of cumulonimbus.

We also make PPI observation of a polarimetric radar simultaneously. Then, we make hydrometeor classification in the cumulonimbus. When the polarimetric radar captured thunderstorm in summer, we make the RHI scan of the ship radar. The wind velocity is estimated by using particle image velocimetry technique. The validation of the measured velocity is made through the comparison with wind profiler data.

The wind velocity in the thunderstorm is found to be properly measured. The strong updraft, weak draft and vertically rotating flow were observed at each life stage of the thunderstorm. The strong updraft was observed in the upper layer where the graupel exist.

ID: 313, Poster presentation

OVERVIEW OF THE "ANALYSIS OF OROGRAPHIC IMPACTS ON PRECIPITATION MICROPHYSICS AND SATELLITE-DERIVED ESTIMATES" (ARTEMIS) FIELD CAMPAIGN IN THE EASTERN PYRENEES

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The ARTEMIS project is focused on the study of cold season precipitation on complex terrain. The project consists of a field campaign on the Eastern Pyrenees where a small network of three nodes, each equipped with a Micro Rain Radar (MRR) and a laser disdrometer (PARSIVEL) was deployed to sample the precipitation variability both on the horizontal and vertical scale during the winter and spring season of 2024. The purpose is to assess the effects of local scale variability of radar reflectivity, Doppler fall speed, precipitation type and characteristics of particle size distributions on operational remote sensing products such as weather radar derived precipitation estimates and precipitation type and satellite products such as the Integrated Multi-Satellite Retrievals for GPM (IMERG). The field campaign network was designed to cover different terrain characteristics including valleys and ridges. The analysis will be completed with case studies performed with high resolution numerical weather prediction models which will be compared with observational data sets acquired during the field campaign. This research is supported by project PID2021-124253OB-I00 and the Water Research Institute of the University of Barcelona.

ID: 318, Poster presentation

VARIABILITY OF MESOSCALE CLOUD AND PRECIPITATION STRUCTURES DURING NEAR-FREEZING SURFACE CONDITIONS USING GROUND-BASED RADAR OBSERVATIONS FROM WINTRE-MIX

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While near-freezing precipitation events have large impacts on human and natural systems, fundamental challenges remain in our ability to adequately observe, diagnose, simulate, and predict these events. The Winter Precipitation Type Research Multiscale Experiment (WINTRE-MIX) was designed to study the multiscale processes influencing the variability and predictability of p-type (rain, drizzle, freezing rain, freezing drizzle, wet snow, ice pellets, and snow) and the amount under near-freezing surface conditions. The experiment was conducted in February-March 2022 in the vicinity of Montreal. The field campaign utilized operational networks (New York State Mesonet, Canada Foundation of Innovation Climate Sentinels) and research instruments like the NRC Convair-580 research aircraft with a suite of in-situ and remote sensors, one C-band on Wheels (COW), and two X-band Doppler on Wheels (DOWs) radars, four mobile sounding systems, and four manual p-type observation stations. We will analyze the variability of mesoscale cloud and precipitation structures and mesoscale flow during near-freezing conditions using ground-based radars. Small-scale vertical motions within clouds (convective generating cells, coherent wave motions, and shear-driven turbulence) are shown to enhance the formation of ice in supercooled clouds, leading to the enhancement of surface snow or rain. Mesoscale precipitation bands, produced by either convergence of mesoscale terrain-channeled flows or by embedded disturbances within synoptic storms, locally enhance vertical motion, increase cloud depth, and intensify precipitation rates.

ID: 319, Oral presentation

HOW IMPORTANT IS TURBULENCE FOR THE FORMATION OF SNOW AGGREGATION AND RIMING IN ARCTIC CLOUDS?

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Turbulence in clouds is known to enhance particle collision rates which has been demonstrated for warm rain formation. It was often discussed and assumed that a similar effect should also exist for ice processes but so far strong observational evidence for this assumption was missing. We will present the results of a statistical analysis of a 15-month W and Ka band cloud radar dataset which allowed us for the first time to quantify the impact of turbulence on snow aggregation and riming in Arctic low-level mixed-phase clouds. We find that increasing Eddy Dissipation Rate (EDR, derived with mean Doppler velocity time series) correlates with the formation of larger snow aggregates revealed by dual-wavelength ratios. In temperature regimes more favorable for riming, higher EDR is associated with dramatically higher particle fall velocities (for same liquid water path category) indicative of markedly higher degrees of riming. The polarimetric observations at Ka band also indicate that ice fragmentation processes might also be enhanced by turbulence, especially in the temperature region where dendritic particles grow.

ID: 327, Oral presentation

DIFFERENTIAL ABSORPTION G-BAND RADAR FOR ARCTIC CLOUDS AND WATER VAPOR OBSERVATIONS

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Millimeter wavelength cloud radars have emerged as state-of-the-art instrumentation to advance cloud and precipitation microphysical studies in past decades. In the Arctic, where climate is changing at fast pace, highly resolved, continuous radar measurements are indispensable to improve the understanding of cloud feedback processes and their representation in models. Compared to existing W-band radar technology, radar observations at higher frequencies such as the G-band are required to improve the sensitivity to small ice hydrometeors and super-cooled liquid droplets in prevailing mixed-phase clouds.

We present the novel and worldwide unique G-band Radar for Water vapor profiling and Arctic Clouds (GRaWAC) system. GRaWAC is a FMCW G-band radar with Doppler- resolving capabilities and simultaneous dual-frequency operation at 167.3 and 174.7 GHz. The Differential Absorption Radar technique is applied to GRaWAC measurements to derive temporally continuous water vapor profiles in cloudy and precipitating conditions.

First measurements from a mid-latitudinal ground site reveal continuous, weather-insensitive, and automatic measurements with a vertical resolution of up to 20m. The lower channel reaches a sensitivity of -43dbze at 1 km, 1 s, with 30 m vertical resolution . Depending on the radar's vertical and temporal resolution, water vapor profiles with up to 200 m vertical resolution can be derived. Additional airborne test flights in Northern Sweden highlight the improved sensitivity of GRaWAC compared to W-band radar observations in detecting fog over ice. We highlight future applications of multi-frequency Ka-, W-, and G-band radar measurements at the German-French AWIPEV research base in Ny-Ålesund, Svalbard. These measurements will benchmark model evaluation studies targeting an improved representation and understanding of mixed-phase clouds in the Arctic.

ID: 328, Poster presentation

COMPARATIVE ANALYSIS OF TWO ALGORITHMS FOR ESTIMATING LARGE HAIL OCCURRENCE USING RADAR DATA

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In recent years, large hail has emerged as a significant meteorological concern due to its increasing frequency and the substantial damages it causes to agriculture, infrastructure, and vehicles. Numerous algorithms have been proposed in the literature to detect the presence of large hailstones and estimate their diameter using weather radar data, which have the advantages of wide spatial coverage, high temporal and spatial resolution and three-dimensional scanning capability.

The northern Italy environmental protection agencies, ARPA Piemonte and ARPAE Emilia-Romagna, manage a total of four C-band polarimetric weather radars and have implemented and operationally deployed two algorithms to estimate large hail occurrences. ARPA Piemonte employs the "50 dBZ hail nomogram" algorithm, originally introduced by the Australian Bureau of Meteorology, which utilizes the 50 dBZ reflectivity echo top height (ETOP50) and the freezing level height (FL) to identify the presence of hailstones larger than 2, 4, or 6 cm. ARPAE Emilia-Romagna has implemented the algorithm proposed by Amburn and Wolf in 1997, which discriminates severe hail (diameter > 1.9 cm) setting a threshold of Vertical Integrated Liquid Density (VILD) of 3.5 g/m^3.

ARPA Piemonte and ARPAE Emilia-Romagna, in the framework of a partnership with the National Civil Protection Department, attempt to identify the best-performing algorithm in order to apply it to the whole Italian weather radar network. This preliminary study presents a comparative evaluation of the two aforementioned methods, in various large hail events that occurred during the summer of 2022 and 2023 in Piemonte and Emilia-Romagna. The outputs of the algorithms are compared with reports of large hail provided by the Meteonetwork-Pretemp organizations to identify their performances. Furthermore, an attempt to identify false alarms has been undertaken, filtering out events that occurred in sparsely populated areas or during nighttime, as such events are more likely to go unreported.

ID: 337, Oral presentation

MULTI-WAVELENGTH RADAR RETRIEVALS IN WINTER STORMS

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Multi-wavelength radar measurements have become commonplace in space with the advent of the Global Precipitation Measurement (GPM) satellite mission, as well as from airborne field campaigns in winter storms (e.g., GCPEX, OLYMPEX, IMPACTS). Compared to single-wavelength methods, these retrievals excel at characterizing ice water content and particle size distributions in ice clouds, especially when implemented using physically- constrained neural networks. However, previous work focused on landfalling cyclones and orographic precipitation in the Northwest US (OLYMPEX). Here, we expand our retrievals using data from IMPACTS, a field campaign that targeted cyclones in the Eastern US.

In this presentation, we will extend our neural network retrievals using measurements from IMPACTS, a field campaign that observed cyclones in the Eastern US. These storms, observed in the US East Coast and Midwest, contain different meteorological conditions than in OLYMPEX, and allow us to extend our retrievals into more diverse conditions, including mixed-phase and melting conditions. Using data from IMPACTS, we will develop training datasets that include these conditions and test those retrievals using colocated in situ measurements. We will examine neural network retrieval performance using training datasets with and without mixed-phase conditions to examine their performance in a variety of conditions. Finally, we will use these new retrievals for process studies, examining the microphysical characteristics and drivers of cyclone-associated snowbands in the Eastern US.

ID: 338, Oral presentation

CLOUD RADAR DEPOLARIZATION SIGNATURES OF SNOWFLAKES

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Riming and aggregation of snowflakes play significant roles in the precipitation processes of ice and mixed-phase clouds. Cloud radars provide observations of vertical structure of cloud systems, evolution of which can be used to investigate prevailing precipitation processes. Distinguishing snowflake aggregates from rimed particles is one of initial steps in these studies. In this study we analyze cloud radar spectral linear depolarization ratio (LDR) observations in variety of snow events. Contrary to our initial expectations we find that low-density snowflake aggregates exhibit relatively high LDR values in the order of -25 to -20 dB. The LDR observations of rimed particles exhibit similar values only for graupel particles that are larger than 5 mm.

The analysis is based on data collected at the University of Helsinki Hyytiala station during several snowfall events that took place during winters 2021/2022 and 2023/2024. The cloud radar measurements were supplemented with collocated surface-based particle imager observations of particle fall velocities and particle shapes. These observations provide information on prevailing particle types occurring during the observation period.

We show that cloud radar LDR observations, which are mainly used to identify melting layer and presence of needles, carry much more information about different ice particle types. The finding of this study allows to improve characterization of processes that take place in ice and mixed-phase clouds.

ID: 339, Poster presentation

RAPID-SCAN POLARIMETRIC RADAR OBSERVATIONS OF A SEVERE DOWNSLOPE WIND STORM DURING CACTI

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Strong downslope winds in the lee of mountains can cause damage to structures and generate severe turbulence for aircraft. Such "downslope windstorms" are thought to arise from nonlinear dynamical processes involving stably stratified air passing over terrain with a steep lee-side slope. Gravity wave breaking is thought to play a major role in accelerating the downslope flow, although the presence of a low-level layer with large static stability also has been found to be important.

Here, we present an analysis of a downslope windstorm in the lee of the Sierras de Córdoba mountains in northern Argentina that occurred during the CACTI project. The downslope wind storm occurred after the passage of a mesoscale convective system (MCS), within its stratiform precipitation region. Multiple hours of fine spatiotemporal resolution (~40-s updates) hemispheric RHI scans collected by the second generation polarimetric C-band ARM Scanning Precipitation Radar (CSAPR2) afford an unprecedented view of the evolving structure of the intense (>30 m s^{-1}) downslope wind event as it interacted with the stratiform precipitation. The observations include perturbations to the melting layer height >500 m, a ~2-km deep hydraulic jump at the base of the terrain and associated strong vertical motion, and vertically propagating gravity waves. We leverage the rapid-scan dataset to quantify temporal variability in the downslope flow speed and depth for the first time.

Further, we hypothesize that the interaction of the MCS with the terrain contributed to downslope wind storm formation in this case, through (i) the interaction of the MCS’s rear-inflow jet with the terrain, and/or (ii) rain evaporation contributing to increased low-level static stability and maintenance of the cold pool as it descends the lee slope. An idealized numerical simulation of this event, in conjunction with analysis of the Doppler and polarimetric radar observations, will be used to test these hypotheses and identify the dynamical processes involved.

ID: 347, Oral presentation

ANALYSIS OF KA-W RADAR RETRIEVALS OF THE DSD FOR THE PARAMETERIZATION OF RAINDROP COLLECTION AND BREAKUP PROCESSES IN BULK MODELS

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One of the remaining least known rain microphysics process is the breakup of raindrops (via dynamical and collisional mechanisms). It is challenging to observe and hence, rare laboratory observations or purely empirical approaches have led to vastly different versions of a parameterization, which combines the self-collection and breakup processes.

A recently developed retrieval based on the combination of Ka and W-band Doppler spectra was shown to provide accurate drop size distribution (DSD) profiles with high spatial and temporal resolutions. In combination with a method for determining the raindrops trajectories in the observations of profiling radars, the temporal variation of the total raindrop concentration can be estimated. The analysis of the data recorded during two clearly distinct precipitating systems allows to derive a unique relation between the raindrop concentration rate and the mean volume diameter. Results show that even if they produce variations in raindrop concentration of the same order of magnitude as the observations, the parameterizations currently used in bulk models diverge from the observations. By exploiting the statistics derived from this radar retrieval, new parameterizations of the self-collection and breakup processes and of rain self-collection efficiency are developed and can be implemented in two- moment bulk microphysics schemes.

ID: 349, Oral presentation

EARTHCARE - STATUS UPDATE ON PROCESSOR AND PRODUCTS

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The joint efforts of the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA) have led to the development of the Earth Cloud Aerosol and Radiation Explorer (EarthCARE), a satellite mission to study global aerosol, cloud and precipitation properties as well as radiation interactions that affect the Earth's energy balance. In order to fulfil its objectives, the EarthCARE mission will collect co-registered observations from a suite of four instruments located on a common platform.

The optical payload encompasses ESA's Atmospheric LIDar (ATLID), Multi- Spectral Imager (MSI) and BroadBand Radiometer (BBR), as well as JAXA's Cloud Profiling Radar (CPR). Together, these instruments provide a multi- dimensional view of the atmosphere and improve our understanding of cloud- aerosol dynamics. The active instruments (ATLID and CPR) provide vertical atmospheric profiles, while the passive instruments (BBR and MSI) provide contextual information that is crucial for interpreting the data.

The presentation will give an update on the status of EarthCARE processors and products and provide insights into the ESA ground-segment data processing chain, which includes the generation of calibrated instrumental data (Level 1) and retrieved geophysical data (Level 2). Further, we will provide an overview of the data quality strategy for the mission, both for the commissioning phase and for the operational phase, to ensure that users are provided with high-quality data.

ID: 350, Poster presentation

COMBINING IN-SITU AND CLOUD RADAR OBSERVATIONS TO QUANTIFY RIMING

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Riming is a highly effective process for snow formation, and is estimated to contribute over 50% of the total snow mass in some cases, but it is unclear how the various cloud processes interact when riming particles. The influence of riming to snowfall is usually characterized by analyzing its effect on the sedimentation velocity and shape of snowflakes through in-situ data, radar-based observations, or a combination of both. However, due to the limitations of current in-situ instruments and the complexity of relating remote sensing observations to physical quantities, these estimates are subject to significant uncertainties. The Video In Situ Snowfall Sensor (VISSS) is a new instrument that allows for ground-based in situ observations of snowfall. It has an unprecedented combination of a large sampling volume and high optical resolution, which enables detailed and statistically robust characterization of snowfall over long periods of time. Here, we present the application of a combined in-situ and remote sensing retrieval of normalized rime mass based on VISSS data products and cloud radar observations. Additionally, a pure in-situ method and a Doppler radar-based method for estimating the rime mass fraction, that are both based on sedimentation velocity, are applied and compared to the results of the combined method.

ID: 360, Poster presentation

DYNAMICS AND INTERNAL STRUCTURE OF THUNDERSTORMS IN SWITZERLAND FROM A DUAL-DOPPLER RADAR PERSPECTIVE

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Dual-Doppler radar observations, based on one X- and C-band weather radar, are used to investigate the three-dimensional wind field and hydrometeorological structure of thunderstorms intersecting a highly populated area (the metropolitan area of Zurich) during the summer months of 2023. In this study, operational weather radar data from the MeteoSwiss C-band system at Albis and from a mobile X-band weather radar, operational from June to November 2023 at Oberwagenburg (Zürich, Switzerland), 16 km NNE from the city center of Zurich, are used. During this period, multiple convective cells, some including hail, crossed the observational area between the two radar systems. The combined X- and C-band measurements obtained during these events allow for detailed analyses of hydrometeorological properties, dominant wind fields, and attenuation during intense precipitation and hail over a densely populated urban area.

Measurements from conventional volume scans of the two weather radars are primarily used to derive the horizontal and vertical wind estimates by employing the Python-based Multiple Doppler Wind Retrieval Package (PyDDA, Potvin et al., 2012; Shapiro et al., 2009). With the X-band system, additional RHI scans towards the C-band weather radar at Albis were performed every 5 minutes. These RHI scans, with high vertical resolution, are optimal for studying the structure of hydrometeor distribution in combination with the observed wind field in the surrounding area. Here, we focus on the most intense thunderstorms that crossed the target area during summer 2023 (June-August). Furthermore, insight into potential attenuation issues of the operational weather radar data will be provided.

ID: 361, Oral presentation

RADAR-FOCUSED HAIL RESEARCH AT NSSL: IMPROVING THE DETECTION AND QUANTIFICATION OF HAIL

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Real-time hail detection and size estimation has traditionally relied heavily on the identification of high radar reflectivity (ZH; e.g., with the Maximum Estimated Size of Hail, or MESH, algorithm), and the now widespread use of polarimetric radars has improved the ability to identify hail through subjective (e.g., identifying high ZH coincident with relatively low differential reflectivity ZDR, specific differential phase KDP, and copolar correlation coefficient ρhv) and objective (e.g., Hail Size Discrimination Algorithm) means. However, there are still well identified limitations and uncertainties to these hail-detection methods. This presentation provides a summary of recent radar- relevant hail research at the National Severe Storms Laboratory, including the use of polarimetric data (in particular, negative ZDR and low ρhv within or adjacent to the updraft) to identify large hail (and its growth) aloft, the potential for backscatter differential phase to provide value for large hail detection, and the use of KDP to improve radar- based hail detection. In addition, because the associations and algorithms used for hail detection are informed by observations of hail whose characteristics may have high natural variability (e.g., in shape, size distribution, density, composition, and fall behavior) that is not well quantified, we present the NSSL HailCam, a high-resolution, high-speed, stereographic imager designed to observe large hailstones in natural free-fall. Preliminary field observations from the HailCam show promising potential for measuring 3-dimensional velocities of sampled hailstones as well as fall behaviors (e.g., quantifiable tumbling and gyrations) and microphysical processes (e.g., distribution of liquid water on the surface of hailstones, drop shedding, etc.). These difficult- to-observe structures and processes will serve as important data for improved polarimetric radar forward operators and radar-based hail detection algorithms.

ID: 362, Oral presentation

ASSESSMENT OF HAIL DETECTION CAPABILITY OF HYDROMETEOR IDENTIFICATION ALGORITHM OVER C-BAND NETWORK

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The present work analyzes the capability of the Dolan et al. (2013) Hydrometeor Identification Algorithm (HID) to detect hail across different organization convective modes in Argentina. Data from C- band polarimetric radars belonging to Argentina's national meteorological radar network (SINARAME) and hail reports from the South American Meteorological Hazard and Impact Database (SAMHI, https://samhi.cima.fcen.uba.ar/) were used.

To assess the efficacy of the HID hail detection, our methodology relies on the hail reports from the South American Meteorological Hazard and Impact Database (SAMHI, accessible at https://samhi.cima.fcen.uba.ar/, Salio et al., 2024) within the operational coverage of C-band polarimetric radars, covering 2018 to 2023. In order to do so, we further employed radiosonde data coincident with the radar observations to evaluate vertical temperature profiles. Employing the Python ARM Radar Toolkit (PyARTs, Helmut et al., 2016), we applied the Z-PHI method (Testud et al., 2000) to adjust horizontal reflectivity (Zh) values for attenuation resulting from intense rainfall. Subsequently, the corrected differential reflectivity was recalculated using the attenuation-corrected Zh. To calculate the Specific Differential Phase (KDP), the differential phase (PHIDP) values underwent preprocessing steps including despeckling, unfolding, and smoothing. The temperature profiles essential for th HID classification were extrapolated from the nearest radiosonde data, both temporally and spatially.

The algorithm was then applied to 143 events distributed across central and northern Argentina, and its probability of detection was evaluated against in-situ SAMHI hail reports. Additionally, events were classified into four convective modes based on cell organization and estimated maximum hail diameter. In summary, the HID exhibited a high probability of detection (around 70%), the predominant convective mode was multicellular (over 70% of cases), and the predominant hail category was Non-Severe, with a maximum diameter below 2 cm.

Finally, of all the events analyzed, there are four case studies where in addition to the methodology described above, the HID was run using data from two radars operating at different frequencies but covering the same area: the RMA5: Bernardo de Irigoyen radar located in Argentina (C-band) and the Cascavel radar located in Brazil (S-band).

ID: 369, Poster presentation

INVESTIGATING THE RELATIONSHIPS BETWEEN ROTATION AND HEAVY RAINFALL ALONG THE MEI-YU FRONT DURING PRECIP 2022

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Extreme rainfall is an important weather phenomenon due to the high potential for loss of life and property; however, our forecast skill remains limited, especially on smaller spatial scales. Recent research has shown a positive relationship between the strength of low-level mesoscale rotation and rainfall rates through nonlinear dynamic accelerations driven by negative pressure perturbations. This relationship has been explored in continental convective storms and a landfalling tropical storm, but has not yet been explored in the context of mei-yu frontal precipitation. Recent results from a numerical simulation show a positive relationship between potential vorticity and rainfall rates in association with meridional moisture flux and isentropic ascent along the mei-yu front. Other nonlinear interactions between vorticity and the boundary layer can also produce localized ascent, including boundary layer convergence underneath rotating flow and isentropic ascent ahead of PV anomalies in sheared flow. The relationships between rotation and rainfall, and which of these mechanisms plays a role in the context of mei-yu frontal precipitation, remain to be explored.

This study analyzes Doppler radar data from operational and research radars collected during the NSF-funded Prediction of Rainfall Extremes Campaign in the Pacific (PRECIP) experiment held in Taiwan and southern Japan in 2022. Multi-Doppler analyses generated by the SAMURAI-terrain software are used to compare the kinematic and precipitation structures during the 2022 mei-yu period. Over 540 analyses across 8 days were generated from 6 radars, including NCAR's S-Pol radar. The three-dimensional analyses provide best estimates of vertical motion, vorticity, and precipitation characteristics to evaluate the relationship between rotation, ascent, and rainfall intensity.

This study examines mei-yu frontal convection over two intensive operating periods during the 2022 mei-yu season to examine the statistical relationships between these quantities on different spatial scales. A positive relationship between rotation and rainfall is identified, as the vorticity distributions shift to higher values with increasing rain rates. The strongest relationship occurs at 5-km altitude, though a weaker signal is present at 1.5- and 8-km altitudes. Vertical profiles of vorticity and convective-stratiform classification show a mixture of convective and stratiform precipitation that becomes increasingly convective as rain rates increase. Vertical profiles of divergence are consistent with this trend of increasing convective precipitation at higher rain rates, as low-level convergence and upper- level divergence increase alongside the rain rates. This study will also evaluate the role of the aforementioned mechanisms linking rotation with rain rate intensity.

ID: 371, Poster presentation

PERFORMANCE OF THE THIES CLIMA 3D STEREO DISDROMETER: EVALUATION DURING RAIN AND SNOW EVENTS

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Imaging disdrometers are widely used in field campaigns to provide information on shape of the hydrometeors, together with the diameter and the fall velocity, which can be used to derive information on the shape-size relations of hydrometeors. However, due to their higher price compared to laser disdrometers, their use is limited to scientific research purposes. The 3D Stereo (3DS) is a commercial imaging disdrometer, recently made available by the manufacturer Thies Clima and on which there are currently no scientific studies in the literature. The most innovative feature of the 3DS lies in capturing images of the particles passing through the measurement volume. This ability is of crucial importance to provide an accurate classification of hydrometeors, especially in the case of solid precipitation.

CORE-LAQ (Combined Observations of Radar Experiments in L'AQuila) campaign gave the opportunity to assess in both rain and snow the 3DS, before its installation at the Mario Zucchelli station in Antarctica on January 2024 (PNRA Antarctic Precipitation Properties project). The performance of the new device was analyzed by comparison with the Laser Precipitation Monitor (LPM) from the same manufacturer, which is a widespread device used in many research works. The data used are obtained from measurements of the two instruments carried out at the Casale Calore site (42.383081 N, 13.314806 E, 683 m ASL) in L'Aquila, managed by CETEMPS.

The objective of the comparison analysis between the two Thies Clima disdrometers (i.e. LPM and 3DS) is to analyze the performance in terms of hydrometeor classification, number and falling speed of particles, precipitation intensity and total cumulative precipitation for each considered event. As regards the classification of precipitation, the two instruments are in excellent agreement in identifying rain and snow; greater differences are noted in the case of particles in mixed phase (rain and snow) or frozen phase (hail). Due to the different measurement areas and measurement geometry of the two disdrometers, the 3DS generally detects more particles than the LPM. The performance differences also depend on the size of the hydrometeors (the overestimation of 3DS is greatest in the case of small particles, i.e. $D < 1$ mm). In the case of rain events, the two instruments are in agreement with the Gunn and Kinzer terminal velocity model for drops with a diameter of less than 3 mm, while for larger particles there is an underestimate by both the disdrometers compared to the model; the agreement between the two instruments in terms of total cumulative precipitation on event basis is very good.

An advantage of the 3DS is its ability to capture images of hydrometeors, that can be very interesting in particular for snow events. Up to four images per minute can be provided by the 3DS, but generally not all of them provide a good representation of the hydrometeor.

ID: 381, Poster presentation

FLUX OBSERVATIONS FOR PROCESS-INFORMED QUANTITATIVE PRECIPITATION ESTIMATES

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The evolution of rain rate within an atmospheric vertical column is influenced by process rates, changes to condensed liquid water mass in time, and advection of the liquid water content. Phased array radar (PAR) technology offers unprecedented spatial and temporal sampling to derive changes in liquid water content in time and space allowing for estimates of precipitation rate at the surface and classification of processes in the atmosphere. Probabilistic precipitation estimation techniques utilizing spatial and temporal observed changes to the liquid water content are explored from observations in Norman, Oklahoma using measurements from a ground-based phased array radar collocated with a spatially-distributed guage-corrected surface precipitation product from the Multi-Radar Multi-Sensor System (MRMS).

ID: 383, Poster presentation

CLASSIFICATION OF PRECIPITATING ICE PARTICLES BY COMBINING MRR AND DISDROMETER MEASUREMENTS DURING FIVE YEARS OF ANTARCTIC COASTAL PRECIPITATION

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Solid precipitation is the most significant positive term of the surface mass balance of the Antarctic Ice Sheet, yet quantitative snowrate estimates (SR) are lacking at continental scale. Ground and space-borne remote sensing techniques seem the best way to ensure adequate spatial coverage, resolution and temporal sampling, but retrieval models suffer from high uncertainties caused by the great microphysical variance of the ice particles.

Specifically, SR retrieval models based on the radar equivalent reflectivity factor (Ze) measured by a radar highly rely on assumptions about the shape (e.g. needle, plate, dendrite) and habit (e.g. pristine, aggregate) of the ice crystals and snowflakes, leading to relative variations larger than 100% in the total water-equivalent accumulated precipitation. Ground-based instruments capable of estimating some microphysical features, like disdrometers, can be affected by disturbances related to the harsh meteorological conditions of Antarctica (e.g. strong katabatic winds).

In this framework, an SR retrieval method has been developed (Bracci et al., 2022) that leads to an unprecedented agreement between estimates and reference weighing rain gauge measurements at the Italian Mario Zucchelli Station (MZS) in Terra Nova Bay, Antarctica. The method exploits the synergy between the measurements collected just 100 meters above the ground by a K-band vertically pointing Doppler radar (MRR-2) and a co- located Parsivel laser disdrometer, identifying the prevailing hydrometeor type on a 10 minutes basis, among six different ones which were identified clustering those described by Kuo et al. (2016). Consequently, the most appropriate Ze-SR relationship for the identified hydrometeor is selected. A procedure to mitigate wind-induced errors in the disdrometer measurements is also applied.

The method was initially tested with data from the Antarctic summers 2018- 2019 and 2019-2020. This study, adding the most recent three years (2021-2023), considers a total time span of over five years (non continuous due technical difficulties experienced during the Antarctic winters). This work also investigates improvements to the classification method, like the use of different scattering databases for ice particles, even including rimed particles, as well as the contribution to the classification process of an imaging disdrometer (Thies Clima 3DS), recently installed at MZS (Angeloni et al., 2024), during an Antarctic summer case study.

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A PRACTICAL MODEL TO DETERMINE THE RADAR CROSS SECTION OF RANDOMLY SHAPED RAIN DROPS BASED ON SELECTED SIZE PARAMETERS

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If raindrops are in the state of equilibrium, their shape is well understood. Most probable rotational symmetric contours for a given diameter can be used to describe and model their shape. This size-shape-relationship is true for rain drops that show no oscillations. In turbulent weather situations often non-rotationally symmetric rain drops can be observed. Such drop shapes can occur because of winds and collisions that can induce asymmetric drop oscillation modes. With optical disdrometers that provide front and side view of individual rain drops, the actual three-dimensional shape of such non-rotational symmetric drops can be reconstructed and visualized, and with appropriate scattering software also scattering parameters can be calculated. In a few recent studies, scattering parameters of thousands of individual drops were determined for C- and S-Band weather radar frequencies. It could be shown that simulated polarimetric weather radar parameters fitted better with actual weather radar measurements, if the actual non-rotationally symmetric shapes of the individual drops were considered for the simulation instead of most probable drop shapes – especially during turbulent weather situations and storms. However, the modeling and the scattering calculation of individual drops is a computationally complex task. An approach with an artificial neural network revealed that it is possible to predict the scattering properties of non-rotationally symmetric rain drops quite precisely, even when only a few characteristic parameters of the drops are known. The present study makes an effort to provide a model where size parameters, frequency, and polarization can be used as inputs and scattering parameters like radar cross section (RCS) are provided with negligible computational complexity. The proposed approach can make realistically modelling of the propagation effects in rain more practical and can thus be relevant for a variety of applications.

Operational aspects

ID: 14, Oral presentation

RADAR-BASED STUDIES OF TERRAIN-INDUCED WINDSHEAR AND MICROBURSTS NEAR THE HONG KONG INTERNATIONAL AIRPORT DURING THE PASSAGE OF SUPER TYPHOON SAOLA IN SEPTEMBER 2023

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A network of weather radars operated by the Hong Kong Observatory (HKO) including Terminal Doppler Weather Radar (TDWR) at Brothers Point (BP), X-band Phased Array Weather Radar (PAWR) at Sha Lo Wan (SLW), X-band dual-polarisation Doppler weather radar at Siu Ho Wan (SHW) and S-band long-range surveillance radar at Tate's Cairn (TC) was used to study the characteristics of terrain-induced windshear and microbursts that affected the Hong Kong International Airport (HKIA) during the passage of Super Typhoon Saola on 1-2 September 2023 with maximum sustained wind near its centre exceeding 200 km/h. The atmospheric conditions based on radiosonde ascent at 20:00 Hong Kong Time (HKT, UTC + 8 hours) on 1 September 2023 were near neutral stability with no temperature inversion inside the atmospheric boundary layer while the average Brunt-Väisälä frequency was estimated to be 0.014 s^{-1} below 2 km above mean sea level (amsl). The spatial density map showing the frequency occurrence of windshear and microbursts alerts issued by the BP TDWR and SHW X-band radar from 16:30 HKT on 1 September 2023 to 07:00 HKT on 2 September 2023 was compiled. The map suggested the presence of two NNW-SSE orientated high wind streaks propagating southeastwards from two major mountains (Castle Peak and Kau Keng Shan with heights over 500 m amsl and 400 amsl respectively) to the north of the HKIA when local prevailing winds were from the north to northwest. As Saola moved further west in the early morning of 2 September 2023 and local winds veered to the directions of east and southeast, more windshear and microbursts alerts were triggered which were associated with three separate WNW-ESE orientated high wind streaks emanating from the northwestern side of the mountainous Lantau Island to the south of the HKIA. Those high wind streaks tied in well with the positions of Por Kai Shan (over 400 amsl), Nei Lak Shan (over 700 m amsl) and Cheung Shan (over 400 amsl) respectively.

Detailed analysis of radial velocity fields from 0.9° scans of SHW X-band radar around 16:30 HKT on 1 September 2023 showed NNW-SSE orientated high and low wind streaks when the prevailing winds were from the north to northwest. Similar observations were found in Shun and Lau [1] and Chan and Hon [2]. The high wind streaks with width of around 1-2 km exhibited meandering wavy characteristics which suggested the possible existence of vortex shedding. From 16:29 to16:32 HKT, pockets of high wind (radial velocity more than 20 ms^{-1}) were observed bursting out from the Castle Peak and propagated southeastwards with a speed of around 90-100 km/h. The Eddy Dissipation Rate (EDR) at 1 km height estimated using spectral width data from the weather radar at TC and SLW PAWR showed high EDR values (0.45 - 0.50 $m^{2/3}s^{-1}$) southeast of the Castle Peak, indicating the occurrence of severe turbulence. When low-level winds changed to east to southeasterlies, bursting of high wind pockets (radial velocity over 17 ms^{-1}) from Nei Lak Shan was observed by BP TDWR at 0.6° scan in 02:51–02:54 HKT on 2 September 2023.

The pockets propagated west-northwestwards with a speed of around 80-90 km/h. The 1-km height EDR values to the west of Nei Lak Shan were in the region of 0.35 - 0.40 $m^{2/3}s^{-1}$

(moderate turbulence). The SLW PAWR provided useful observations of the vertical structure of those high wind streaks. When surface winds prevailed from the north to northwest such as 16:30 HKT on 1 September 2023, cross section of radial velocity from SLW PAWR showed that the jet core of the NNW-SSE orientated high wind streaks was around 0.6 to 1 km in height. When surface prevailing winds were from the east to southeast as in the case at 03:06 HKT on 2 September 2023, the jet core of the WNW-ESE orientated high wind streaks was about 1 km in height but the core thickness grew further downwind with a tendency to spread downwards closer to the ground beyond 5 km from the coast of the Lantau Island. Similar heights for the jet cores of the above NNW- SSE and WNW-ESE high wind streaks were also observed through the cross sections of radial velocity from both BP TDWR and SHW X-band radar. In addition, cross section of spectrum width from SLW PAWR at 02:55 HKT on 2 September 2023 showed apparent sign of turbulence with spinning eddies below 2 km. The above observations suggested the downward transport of momentum and vorticity aloft.

In summary, the passage of Saola on 1-2 September 2023 provided an invaluable opportunity to study the characteristics of terrain-induced windshear and microbursts caused by gale to hurricane force low-level winds first from the north and then the south relative to the HKIA. The complementary use of radar observations from a network of weather radars in Hong Kong helped to characterise those high wind streaks generated as a result of Saola's circulation and their relations to the mountains/peaks to the north and south of the HKIA. The study enhanced understanding of terrain-induced windshear and microbursts during the passages of tropical cyclones which was essential for the operations of landing/departing aircraft at the HKIA. More in-depth meteorological analysis supplemented with various radars' observations would be covered in this paper.

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OBJECT-BASED ENSEMBLE PREDICTION SYSTEM KONRAD3D-EPS

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The precise forecast of convective cells is essential for meteorological services as they can be accompanied by life-threatening severe hail, wind gusts, or heavy rain.

However, state-of-the-art NWP models usually possess update frequencies of several hours so that forecasters must use predictions that are outdated when new thunderstorm cells develop. NWP models do often accurately simulate the intensity of convective cells, but with shifts in space and time.

Object-based nowcasting algorithms with higher update frequencies became necessary to deliver information on the evolution of convective storms for the first two hours since observation. Furthermore, the combination of nowcasting and model data enables the relocation of simulated cells towards observed cells.

Many deterministic object-based nowcasting tools as DWD's KONRAD3D algorithm assume that detected cells will have persistent intensity.

Within the SINFONY (Seamless INtegrated FOrecastiNg sYstem) project at DWD, we aim at modelling the life-cycles of storm cells in a truthful way and capturing the uncertainties of object-based nowcasts. Hence, we extended our nowcasting algorithm towards an ensemble prediction system called KONRAD3D-EPS. Each ensemble member is initialized by drawing from parameterized distributions of storm lifetime and maximum severity. Inspired by previous studies, e.g. Wapler (2021), KONRAD3D-EPS uses a set of horizontally flipped parabolas to model the life-cycle of convective cells in terms of their severity. In case of redetection of a convective cell, the algorithm corrects the previously estimated lifetime and severity maxima. Thus, the parabolas can be adapted individually for any convective storm in any weather condition. Currently, work is in progress to incorporate additional data sources as lightning and mesocyclones to separately address the lifecycles of particularly intense cells.

Besides life-cycle predictions, KONRAD3D-EPS delivers information on the probability of thunderstorm occurrence for the next 2 hours depending on detected cells and their severity. In order to condense the ensemble data, we also provide the representative member for each convective cell. This is done by applying the pseudomember algorithm by Johnson et al. (2020) to the ensemble data.

We will give an overview of our probabilistic object-based nowcasting algorithm KONRAD3D-EPS and present its predictions for prominent example cases. Moreover, we will show first verification results.

OPERATIONAL WIND TURBINE CLUTTER REMOVAL IN THE FINNISH WEATHER RADAR NETWORK: METHODOLOGY AND IMPACT ON DATA QUALITY

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Wind turbines can cause significant impacts on weather radar data. In addition to the attenuation of the radar beam behind the turbines, the strong reflections from the turbines lead to high reflectivity clutter in the data. The wind turbine clutter is detectable by the radars from distances of up to 150 kilometres depending on propagation conditions, orography, and the turbine configuration. The clutter can lead to severe artefacts in radar-based products; for example, the strong clutter causes regular false alarms in the automatic Cumulonimbus (Cb) detection used in aviation weather services by the Finnish Meteorological Institute.

Removing the wind turbine clutter from the radar data can be complicated. Compared to ground clutter, the wind turbine clutter cannot be removed by Doppler ground clutter filters due to the non-zero Doppler velocity values caused by the moving turbine blades. Instead, removing the wind turbine clutter requires separate filtering algorithms. Here we describe the wind turbine clutter removal algorithm implemented operationally in the Finnish weather radar network. The algorithm, based originally on work by Keränen et al. 2014, aims to remove the strong clutter located at the turbine sites by applying several threshold values based on polarimetric and noise variables. The filtering is applied only in locations of known wind turbine sites to decrease false removals.

In addition to the methodology, we present validation results of the removal algorithm, including the impact of the algorithm on the number of false alarms in the automatic Cb detection. Additionally, we present results of the extent of wind turbine clutter in Finnish radar data based on statistical analysis from the five weather radars that are most impacted by wind turbines.

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ID: 30, Oral presentation

THE NEW CANADIAN WEATHER RADAR NETWORK - FROM PROJECT TO OPERATIONS

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Since 2017, the Canadian Weather Radar Network (CWRN) has undergone significant transformation through the Canadian Weather Radar Replacement Program (CWRRP). By the conclusion of 2023, all 33 new radars have been successfully installed nationwide, with 32 currently operational. This presentation offers an insightful overview of the accomplishments in renewing the radar network, highlighting key lessons learned from the project's implementation. Additionally, we will discuss operational challenges encountered, including monitoring and life cycle management of the network, dealing with TR-limiter degradation, as well as increased contamination due to radio frequency interference. Finally, the talk will outline future endeavors aimed at further enhancing the effectiveness and reliability of Canada's weather radar infrastructure.

ID: 42, Poster presentation

AN INTER-RADAR INTERFERENCE SUPPRESSION METHOD FOR WEATHER RADAR DATA WITHOUT MODIFYING THE RADAR'S INTERNAL SIGNAL PROCESSING

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Public distribution of raw data from the Ministry of Land, Infrastructure, Transport and Tourism's (MLIT) parabolic dual-polarization radars began in 2022, allowing private commercial use of radar data in Japan. Recently, we found that the MLIT's X-band parabolic dual-polarization radar data still contains signals that appear to be interference from other radars, even though the radar's internal signal processing includes interference suppression. When private operators use radar data, these interference signals must be properly suppressed, but each operator cannot modify the radar's internal signal processing. The aim of this study is to suppress interference signals from the distributed radar data without modifying the current radar's internal signal processing.

This study analyzed the interference signals mixed in the radar data from the KANTOU and FUNABASHI stations of the X-band parabolic dual-polarization radar at dates and times when the coverage of each radar was mostly sunny. The interference signals were continuously mixed in the range direction at different azimuth angles (sectors) depending on the time and were distributed in a linear or fan shape on the PPI. Based on the characteristics of the radar reflectivity ZH and the differential reflectivity ZDR, it was found that these interferences can be roughly classified into three groups: 1. Groups where the interferences cover more than five sectors, the maximum value of ZH is more than 30 dBZ, and the maximum value of ZDR is more than 10 dB; 2. Groups where the characteristics of the interferences coverage and the maximum value of ZH are similar to group 1, while ZDR is mainly negative and the minimum value of ZDR is less than -10 dB; 3. Groups where the interferences cover 1 to 5 sectors, ZH is mainly less than 30 dBZ, and ZDR is mainly ± 5 dB or invalid.

In addition, we evaluated a proprietary method for suppressing interference signals without modifying the radar's internal signal processing using the real radar data. As a result, we confirmed that the interference signals were suppressed by the proprietary method in a total of 31 cases, including all the three groups.

RADAR OPERATIONAL NETWORK AND PRODUCTS IN FRANCE

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Weather radars have been used for decades to observe precipitation events, due to their ability to observe these phenomena with high space and time resolution. Although still concerned by errors inherent to the kind of instrument used (beam volume and height, attenuation, ground clutter, electronic calibration, reflectivity to rain conversion, etc), scientific advances permits continual improvements of the accuracy of radar measurements and quantitative precipitation estimation. For this reason, meteorological radar network is a key observation system for rainfall and snow events and consequently for hydrological applications.

Météo-France operates a radar network composed of 33 radars in the mainland France area as well as 6 radars in the French overseas territories. The latter are important in case of cyclonic events in the Caribbeans and Pacific and Indian ocean. In addition, data from a number of external radars (partner institutions and neighboring countries) are processed. institutions and) . This extended network is mainly composed of C-band radars but also includes several S-band radars (for locations impacted by intense events) and X-band radars (as gap-filling measures in mountains and atthe airports). It hence permits a coverage of the entire country. The radar products are elaborated at the Météo-France production site, using to the centralized operational system (SERVAL) that allows to efficiently integrate and process a real-time radar observational data as transmited from the network, in particular volume reflectivity and polarimetric variables in polar coordinates with 0.5°/240 m resolution. The 5-minute products (individual products, composites) are available to a range of radar users: from Météo-France applications (forecasting, automatic production for real-time warning, nowcasting and hydrology, numerical weather prediction mesoscale model assimilation, etc) to a use in decision-making tools for external users (public stakeholders, private companies).

In the presentation, focus is on the radar network and processing algorithms, followed by the main radar observation products from Météo-France such as reflectivity, wind and precipitation estimation). A brief description of current R&D activities with the objective to improve the quality of radar observation and products is also foreseen.

A QUALITY INDEX FOR RE-SITING A WEATHER RADAR WITHIN A NETWORK

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The Meteorological Service of Catalonia (SMC) operates a network of four weather radars, covering a relatively small but complex territory.

One of these radars, the Creu del Vent (CDV), is located on an elevated plateau with wind conditions suitable for the deployment of windmills. Given the European and regional renewable energy promotion policies, the number of windmills deployed and approved for deployment in the close vicinity of the CDV radar is increasing rapidly.

The SMC, after unsuccessfully pursuing the establishment of a law-protected radius around the radars, has been requested to study the re-siting of the CDV radar to any of the areas in the territory that are already protected for unrelated reasons.

With the literature about weather radar data quality characterization as a reference, we have designed a pixel-based, siting-dependent data quality index (QI) for the selection of the best new site among present candidates.

The QI presented is a combination of three individual QI(i), each related to a quality indicator: beam blockage factor, beam height above terrain and size of sampled volume. The functional form of the individual QI(i) is, as far as possible, designed to resemble the dependence of the reflectivity error on the particular quality indicator.

The use of a normalized QI has allowed a direct comparison between the different site candidates, both individually and as part of the radar network, with the objective of sub-setting the most appropriate locations in terms of territory coverage and data quality. The final subset will go on for further inspection based on practical suitability factors (accessibility, energy supply, local permissions, etc.).

ID: 60, Poster presentation

METHODS USED TO ESTIMATE DIFFERENTIAL PHASE DERIVED BASE DATA WITHIN THE BARON PROCESSOR SUITE

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In recent years, dual-polarization systems have become more common within operational weather radar networks yielding new measurements and information that provide valuable new insights into cloud and precipitation processes over conventional weather radar observations. One of the polarimetric variables, Differential Phase (Ψ_{DP}), serves a crucial role in accomplishing these goals primarily because of its independence from power attenuation and radar miscalibration. The Baron processor suite allows for the estimation of the different base

data derived from Ψ_{DP} including specific differential phase (K_{DP}), forward scattered differential phase (Φ_{DP}) and back scattered differential phase (δ) at S, C and X Bands in real time and always makes them available to the user. A brief description of the various implemented algorithms followed by a performance discussion of data cases under different weather conditions will be presented.

ID: 63, Poster presentation

QZDRCAL: AN UPDATED FULL SEASON ZDR CALIBRATION ALGORITHM USING DRY AGGREGATED SNOW IN U.S. NEXRAD OPERATION

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Differential reflectivity (Z_{DR}) is an important variable observed by dual polarimetric radars and its calibration is crucial for any quantitative applications involving Z_{DR}. In the ZDR Calibration Algorithm (QZdrCal), we focus on the use of dry aggregated snow (DAS) routinely observed just above the melting layer (ML) and below the dendritic growth layer (DGL) in stratiform precipitation during the warm season and above ground level during the cold season when ML is not identified, assuming that the intrinsic value of Z_{DR} in DAS varies between 0 and 0.2 dB depending on the intensity of snow and its degree of aggregation. We utilize range-defined quasi-vertical profiles (RD-QVPs) of the polarimetric radar variables to reduce measurement noise and provide accurate estimates of Z_{DR}. The critical part of the calibration methodology is to identify DAS as opposed to other snow types that exhibit a wider distribution of Z_{DR}. Criteria for DAS *identification include the value of Z above the ML during the warm season or above ground level during the cold season, the vertical gradient of Z in snow, the minimal value of the cross-correlation coefficient in the ML, the depth of the cold part of the cloud above the ML and below DGL, and the depth of the seeding part above the DGL top to echo top height. We used a K_{dp} threshold of 0.1 deg/km for DGL identification for the full season QZdrCal, and it has been successfully implemented into the Open Radar Product Generator, which will be released in Build 23 this fall. Initial white testing suggests high accuracy (up to 0.06 dB) and more stable (low standard deviation, less than 0.1 dB) measurements of Z_{DR} bias compared with the traditional dry snow method where no DAS limit is applied.

ID: 87, Poster presentation

LEVERAGING FAIR PRINCIPLES FOR EFFICIENT MANAGEMENT OF METEOROLOGICAL RADAR DATA

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Radars play a critical role in meteorology due to their high spatio-temporal measurement resolution, enabling early detection and tracking of severe weather phenomena. These capabilities empower meteorologists to issue timely alerts and warnings, thereby safeguarding lives and reducing property damage. Beyond immediate surveillance and forecasting needs, radar data serves many offline applications, including statistical analyses of clouds and precipitation, climatological studies, and data analysis for insurance risk assessment, among others. These products rely on analyzing radar data as a time series, underscoring the versatility and utility of radar information in long-term meteorological studies. A radar volume scan, comprising data collected through multiple cone-like sweeps at various elevation angles, often exceeds several megabytes in size every 5 to 10 minutes that is usually stored as individual files. Consequently, national weather radar networks accumulate vast amounts of data with non-interconnected files over extended periods spanning several decades. This presents significant challenges in data storage and availability, particularly when treating radar data as a time-series dataset, which parallels the complexities of managing big data.

Traditionally, radar data storage involves proprietary formats that demand extensive input-output (I/O) operations, leading to prolonged computation times and high hardware requirements. In response, our study introduces a novel data model designed to address these challenges. Leveraging the Climate and Forecast (CF) format-based FM301 hierarchical tree structure, endorsed by the World Meteorological Organization (WMO), and Analysis-Ready Cloud-Optimized (ARCO) formats, we developed an open data model to arrange, manage, and store radar data in cloud-storage buckets efficiently. This approach uses a suite of Python libraries, including Xarray (Xarray-Datatree), Xradar, Wradlib, and Zarr, to implement a hierarchical tree-like data model. This model is designed to align with the new open data paradigm, emphasizing the FAIR principles (Findable, Accessible, Interoperable, Reusable). Focusing on the Carimagua, Colombia radar data, we demonstrate the efficacy of querying, selecting, and computing monthly rainfall accumulation in radar coordinates using our proposed hierarchical tree-like data model stored in ARCO format. Our results reveal significantly faster data processing times than legacy data models on standard hardware configurations, such as an Intel Core i7 processor, 32 GB DDR4 RAM, and an NVME solid-state disk drive laptop. Furthermore, FAIR open radar data represents a promising solution for managing large, live-updating radar datasets within cloud platforms. By adhering to the open science principles, this approach makes scientific data more accessible across all levels of society.

ID: 102, Poster presentation

COMPARISON OF CONVENTIONAL AND NOVEL TECHNIQUES FOR REFLECTIVITY CALIBRATION MONITORING

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Meteorological radar plays a critical role in monitoring and predicting weather patterns, providing essential information for disaster preparedness, resource management, and public safety. Accurate calibration of reflectivity measurements is key to interpreting radar data effectively. It is important to continuously monitor reflectivity quality during radar operation to quickly identify and address any calibration issues that may arise. Several existing methods use rain as a reference target for the monitoring. In this study, we evaluate four calibration methods. Two methods use rain properties from a disdrometer and a micro-rain radar to calculate expected reflectivity values for comparison with meteorological radar measurements. The difference between expected and measured reflectivity is used as indicator of the calibration quality. The third method is the well-known self-consistency approach, leveraging relationships between reflectivity, differential reflectivity, and propagational differential phase. The fourth method introduces a new technique based on drop-size distribution profiling from a W-band radar. Our analysis is based on data from a collaborative measurement campaign organized by the German Weather Service (DWD) and Radiometer Physics GmbH. The campaign took place at the DWD meteorological observatory in Hohenpeißenberg, Germany in 2021. The site, equipped with a C-band radar, disdrometer, and micro-rain radar, was enhanced with a scanning dual-polarimetric W-band radar for a three-month period.

A UNIFIED FRAMEWORK FOR STUDYING WEATHER RADAR NETWORKS

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In recent decades, a large body of scientific literature on networked weather radar systems has been produced. Whilst many intriguing concepts and research directions have been outlined, there still appears to be a notable lack of coherence and uniformity in the definitions used by scientists to study, develop and improve the components of a weather radar network. Uniform nomenclature and a clear high-level conceptual framework for such systems can contribute significantly to this field as many operational weather radar systems move towards networked environments.

To address this issue, we conduct an extensive literature review of networked weather radar systems. The review yields a simple, yet general, system description which is common to any weather radar network. This new framework is applied to well-known examples of radar networks across the world using a simple graphical representation to demonstrate its usefulness. Studying these networks in this common unified framework allows for a better understanding of key similarities and difference between networks, their capabilities and their level of complexity.

In addition to providing a system description, we review popular terms like adaptive, collaborative and cognitive weather radar which are commonly found in the literature yet poorly defined and often ambiguously used in the context of weather radar. By presenting these concepts through the lens of this new framework, we aim to present a much clearer vision of where the field has been headed and which key challenges lie ahead. We aim to facilitate understanding the current literature by promoting uniform nomenclature whilst charting a course towards fully realising the potential weather radar networks have.

DATA CENTER: TOWARD PREDICTIVE MAINTENANCE

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Historically, maintenance approaches largely centered on corrective and preventive measures, often depending on on-site actions. However, with the advent of technology and the influx of big data, there's been a significant transition to more forward-thinking techniques, embodying the principles of data-driven predictive maintenance. This abstract explores the progression from traditional corrective maintenance to advanced predictive maintenance.

Given the vast quantities of machinery and telemetry data available, we have an opportunity to monitor machines in real-time across the globe. By integrating artificial intelligence and machine learning methodologies, this method allows for trend forecasting, proactive identification of possible machine breakdowns, and estimation of machinery components' remaining lifespan. This strategy in industrial maintenance is termed as data-driven Predictive Maintenance.

For this purpose, Leonardo Germany established an International Data Center. This data center will be a foundation for achieving unparalleled global quality assurance, real-time monitoring, and as data-driven predictive maintenance for radar systems. The architecture for a system that focuses primarily on the smooth integration of data streams from radar units across the globe and involves the systematic gathering of electronic data, telemetry, and monitoring parameters using local analyst databases, RAVIS, and Rainbow software. The Data Center is the hub for data consolidation, made possible by cloud-based technology that ensures accessibility and security. The implementation of modern AI models and machine learning algorithms gives the ability to predict possible breakdowns in the system. A real-time alert system supports this preventative approach by giving our customers immediate alerts and actions, improving operational availability, and enabling the transition to digital transformation. This initiative is in alignment with our strategic goals and will help us get more connected to the day when predictive maintenance is a reality and no longer just a theory.

ID: 123, Poster presentation

PROVISION OF HIGH-RESOLUTION X-BAND WEATHER RADAR DATA FOR AGRICULTURAL PRACTICE IN NORTHEAST GERMANY

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In June 2020, a ground-based, dual-polarised Doppler X-band weather radar from FURUNO Deutschland was installed in Neubrandenburg in north-eastern Germany, which has been continuously recording data within a radius of 70 km since October 2020. Between autumn 2020 and summer 2021, the scan settings were repeatedly changed experimentally to find an optimal setting for the radar. From August 2021, the FURUNO radar will carry out a series of scans with an update time of five minutes. Each five-minute scan includes eight elevation angles and finally a 90° scan. The X-band weather radar has been in operational use since spring 2022 and the WRaINfo software (Künzel & Mühlbauer et al. 2023 - 10.5334/jors.453) is used to provide spatially and temporally high-resolution precipitation products close to the ground. The focus here is on the DEMMIN monitoring network in Mecklenburg-Western Pomerania, which is characterised by intensive agricultural use and at the same time has over 40 climate stations that contribute to the validation of the precipitation products of the weather radar. The great advantage of the spatially high-resolution precipitation products is the visualisation of precipitation amounts at intra-specific site level. This makes it possible to optimise management measures, such as irrigation. This allows a farmer to see which areas in the field need to be irrigated more and which need to be irrigated less. In addition, this data can also form the basis for analysing yields, as the amount of precipitation during the vegetation period is decisive for yields. This spring, it will be possible to obtain this data via an "XRegnet" user interface.The study deals with the validation of a high-resolution X-band weather radar for the years from 2022 to the present and shows an user interface for farmers.

ID: 131, Poster presentation

ADVANCEMENTS IN RADAR-DRIVEN CONVECTIVE CELL DETECTION AND NOWCASTING AT DEUTSCHER WETTERDIENST (DWD)

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At Deutscher Wetterdienst (DWD), today, a semi-automated process is employed to warn the public about thunderstorm hazards such as large hail, wind gusts, and heavy rain. Human forecasters are assisted by algorithms and meteorological products that consolidate information from various data sources, including weather radar, satellite imagery, and Numerical Weather Prediction (NWP).

One cornerstone of this infrastructure is KONRAD3D, a tool designed for the detection, tracking, and nowcasting of convective cells, particularly thunderstorms. Currently, KONRAD3D primarily utilizes three-dimensional quality-controlled radar reflectivity data from DWD's radar network as its main data source. Additionally, it incorporates lightning data and DWD's dual-polarization hydrometeor classification system, HYMEC, to assess the risk of hail. Furthermore, the system provides radar-based wind gust and heavy rain warnings.

To determine the initial motion of convective cells upon detection, an optical flow estimator is applied to a radar reflectivity composite. Throughout the lifecycle of a cell, a Kalman filter is employed to stabilize radar-based estimates of its centroid, velocity, and acceleration. To reduce false detections, such as those caused by remaining wind turbine or ship clutter, a special filtering strategy is utilized. This strategy takes into account the vertical extent and "Vertically Integrated Liquid Water" (VIL) of a cell, lightning activity, and the presence of already approved cells in the vicinity.

The scheme has been in operational service at DWD since April 2023. However, KONRAD3D is continuously evolving towards a multi-data application. Recently, DWD's mesocyclone detections based on Doppler radar data have been incorporated to enhance the wind gust warning component. Additionally, the assessment of heavy rain risk has been refined to incorporate rain-gauge-adjusted radar information. Furthermore, data from vertical NWP profiles (such as shear information) and satellite-derived products (like cloud top height) have been integrated to be linked in real-time with cell detections.

This contribution highlights the basic functionality and these latest advancements of KONRAD3D, how it fits into DWD’s warning infrastructure and presents statistical results assessing its performance.

ID: 134, Poster presentation

MONITORING AND QUANTIFYING WIND TURBINE CLUTTER (WTC) IN DWD WEATHER RADAR DATA

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Wind turbine clutter (WTC) poses a significant problem to the quality of weather radar data und radar based (warning) products. There are no reliable weather radar measurements in the presence of wind turbines. Up to distance of about 5 km beam blockage effects due to a wind turbine are relevant which affects the whole observation range in line of sight. Static beam blockage correction cannot be applied because of the turbine's moving blades. Those moving blades affect the full Doppler spectrum of the backscattered signal so that the weather signal is hard to recover. So far there is no operational filter available that is able to separate the weather signal from WTC. A new algorithm to dynamically detect WTC based on the analysis of Doppler spectra has been implemented in the radar signal processor of the 17 DWD (German Meteorological Service) weather radars since 2021 (Gerhards and Tracksdorf, 2021).

There is a strong political push to increase wind energy production in Germany. As a consequence of this push, the previously restricted 5 - 15 km radius from radars was opened for potential installations of wind turbines. In order to monitor and quantify the existing and future WTC situation in the vicinity of our weather radars, a monitoring framework has been developed for the DWD weather radar network. Such monitoring is expected to be important in the future. It provides an objective basis for possibly new regulations that protect weather radar sites and radar measurements. The detected WTC flags, their timestamp, location and corresponding radar moments are stored in an InfluxDB data base for the lowest 5 elevations of the volume scan. Using this large data base we present a verification of the WTC detection algorithm. We define locations as significantly impacted by WTC if a WTC flag is present in more than 50% of the time during a chosen time interval. So far, the most affected radar site Ummendorf shows that 3% of the area in the 5-15 km range are disturbed by wind turbines. Radar data are affected up to an elevation angle of 2.5°. To consider the operation state of a wind turbine and the current weather conditions in the verification of the WTC algorithm, we use wind and disdrometer measurements at the radar site as proxys. For the continuous monitoring of WTC, a Grafana dashboard has been developed to provide easy access to key WTC parameters for the whole radar network.

ID: 156, Poster presentation

WEATHER RADAR DATA EXCHANGE FORMATS AND CONVENTIONS FROM THE DATA PROVIDER POINT OF VIEW

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There are only a few cases where a region-wide weather radar network is homogeneous and consists of radars from the same vendor who is responsible for integration of the data exchange within the network. A much more common case is when the network is heterogeneous and the problem of sharing and combining data from incompatible data sources is brought to the forefront.

The WMO standards like GRIB and BUFR were designed for other types of data and were not well suited for weather radar data exchange without extensions. One huge, and still relevant, step was the introduction of the Universal Format (UF) by NCAR in the 1980-es[1]. The next important milestone was an introduction of the NORDRAD network by the consortium of Northern European countries [2]. NORDRAD has introduced the first HDF5 data format Information Model (also known as "data schema"). What came next is European wide data exchange program using Operational Programme for the Exchange of Weather Radar Information (OPERA) HDF5 format based on the original NORDRAD HDF5 data schema [3]. OPERA also extended WMO BUFR code tables with its own “local” weather radar specific code tables. The parallel efforts in the US resulted in the development of the CF-compliant netCDF based data schema for the "Level 2" (polar weather radar) data sets [4]. Currently, WMO is preparing to adopt NetCDF CfRadial 2.0 as the recommended exchange format.

However, we have found the practical use of HDF5 and NetCDF schemas are only considered as a guideline with several regional/local customizations, augmentation, or differing interpretations of the schema contents. Additionally, the metadata definitions within current schemas may not be totally applicable to differing models of radars, especially with calibration values due to possible differences in methodologies. As a result, every weather radar vendor is forced to support several or all of these formats and can never assume the bi-directional conversion of 'common exchange formats' will work from one project to another.

The most important question is: should weather radar vendors accept one of the available formats as an internal data format. The answer is not straightforward and depends on how that format will be used. In some use cases a schema defined for Google Protocol Buffers or a schema defined for JSON is a better choice for a number of reasons:

- pragmatically, via IDE (Interface definition Language), enforced data schema
- automatically generated binding for major programming languages
- existing off the shelf frameworks to implement data storage and data generation services, such as RESTful web API and gRPC (Google RPC).

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ID: 158, Poster presentation

ARM RADAR DATA QUALITY AND CALIBRATIONS FOR THE SAIL AND EPCAPE FIELD CAMPAIGNS

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The Atmospheric Radiation Measurement (ARM) user facility operates mobile sites (AMFs) around the world. Recently, this included the Surface Atmosphere Integrated Field Laboratory (SAIL) campaign in the mountains of Colorado from Fall 2021 to Summer 2023, and the Eastern Pacific Cloud Aerosol Precipitation Experiment (EPCAPE) in La Jolla, California from Spring 2023 to 2024.

These campaigns each had scientific questions that relied on well calibrated and consistent radars for use in the analysis of snowfall and precipitation characteristics. Providing well calibrated datasets across a distributed network of radars operating at multiple frequencies requires a series of cross-comparison techniques and procedures. This poster will discuss how these radar calibrations were determined and tracked across the network and over the duration of the campaigns.

Each of these deployments offered a unique set of challenges. For the SAIL campaign, ARM deployed a vertically pointing radar (KAZR) in concert with the CSU X-band radar located nearby in mountainous terrain. This campaign had challenges of complex terrain with a distributed radar network and heavy winter snowfall that had to be considered during calibration. Meanwhile, EPCAPE was focused on the study of marine clouds and the effects of man-made aerosols on them. ARM deployed a KAZR at the main site, as well as a KA and W band scanning radar (KA/W SACR) at a nearby mountain top. This campaign brought challenges of a distributed radar network, complex terrain, sea clutter, and biological signals.

To create the calibrated datasets for each of these campaigns, cross-comparisons between all deployed radars, as well as the WSR-88D, are utilized to help determine reflectivity offsets. Direct comparisons with disdrometers in light rain and the wet-radome attenuation calibration technique with disdrometer measurement are used to examine the calibration offset for the KAZR reflectivity. Inter-mode comparisons are used to determine the reflectivity offsets between the general and moderate sensitivity modes for KAZR.

This work will show how the combination of multiple techniques and cross comparisons with external instrumentation can be used to calibrate and improve radar data quality for both campaigns, allowing for high quality calibrated and characterized datasets for scientific analysis.

ID: 173, Oral presentation

IMPROVING ZDR COLUMN DETECTION WITH THE "HOTSPOT METHOD"

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Polarimetric radar variables offer valuable insights into the dynamics and microphysics of thunderstorms, and multiple „polarimetric signatures“ linked to specific thunderstorm processes have been identified in recent years. ZDR columns, for instance, represent local positive anomalies of differential reflectivity above the melting level caused by the lifting of large liquid drops, and are closely linked to thunderstorm updrafts. Information about location, size and other properties of ZDR columns holds potential for enhancing warnings or as input for the initialization of convection-permitting numerical weather prediction models.

However, the automated detection and operational use of ZDR columns and other signatures remain challenging due to their wide variety in appearance and issues of data quality. Here, we introduce the “hotspot method”, a novel algorithm aimed at detecting and tracking ZDR columns, designed to mitigate common errors arising from ZDR miscalibration or differential attenuation. We present results obtained from applying the algorithm to S-band data from the WSR-88D NEXRAD network and to C- and X-band data from Austria, comparing them with detections of other existing techniques. Furthermore, we highlight a potential application of the hotspot algorithm for the nowcasting of hail size.

ID: 175, Oral presentation

APACHE AIRFLOW BASED RADAR DATA PROCESSING ARCHITECTURE AT THE FINNISH METEOROLOGICAL INSTITUTE

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To meet the evolving needs, a completely new radar data processing architecture has been implemented at the Finnish Meteorological Institute (FMI). The goal of the renewal was to get rid of all the unnecessary complexities and manual tweaks in the old data production, that had accumulated through many years of development. The aim was to make the data production more reliable, more efficient and easier to maintain. The new architecture is built using modern day tools and it relies heavily on Apache Airflow.

Airflow is an open-source platform used for orchestrating complex workflows and data pipelines. It allows users to programmatically author, schedule, monitor, and manage workflows as Directed Acyclic Graphs (DAGs). Airflow is designed to handle workflows of any complexity, it’s highly extensible and can be run on various platforms.

DAGs are defined in python code, which makes the workflows extensible and easy to integrate on external plugins. Airflows web-based UI offers interactive and scalable visualization of the workflows, performance metrics, retry and error handling, easy access to task level logs, which is a huge step up from the old cron-based data pipelines. Moreover, Airflow's dynamic triggering capabilities enable workflows to be initiated in response to external events, such as file arrival or task completion, a critical requirement for time-sensitive radar data processing tasks.

In summary, the implementation of Apache Airflow within FMI's radar data processing architecture marks a significant advancement in efficiency and real-time responsiveness. This presentation will focus on the core features of Airflow in radar data processing and the lessons learned at FMI during the transition from the old architecture to the new one.

ID: 180, Poster presentation

TROPICAL RAINFALL ESTIMATES FROM COMMERCIAL MICROWAVE LINKS IMPROVE BY RELATING RAINFALL RETRIEVAL ALGORITHM PARAMETERS TO LOCAL NETWORK AND ENVIRONMENTAL FEATURES

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Potentially the greatest benefit of Commercial Microwave Links (CMLs) as opportunistic rainfall sensors lies in regions that lack dedicated rainfall sensor networks, most notably low- and middle-income countries. However, current CML rainfall retrieval algorithms are predominantly tuned and applied to (European) CML networks in temperate or Mediterranean climates. In this study we investigate whether local quantitative precipitation estimates from CMLs in a tropical region, specifically Sri Lanka, can be improved by optimizing two dominant parameters in the rainfall retrieval algorithm RAINLINK, namely the wet-antenna correction factor Aa and the relative contribution of minimum and maximum received signal levels ɑ. Using a grid search, based on ten months of CML data from 22 link-gauge clusters consisting of 105 sub-links that lie within 1 km of a daily rain gauge, optimal values of Aa and ɑ are first derived for the entire country and compared to the default RAINLINK values, which are tuned to Dutch climate and CML networks. Subsequently, the CMLs are grouped by link length, frequency, climate zone, and daily rainfall depth classes, and Aa and ɑ are derived for each of these classes. Calibrating for a single country-wide parameter set only leads to minor improvements compared to using the default algorithm values. The actual optimal Aa and ɑ values do depend on the performance metric favored. Calibrating on local network properties, particularly short link length and high frequency classes, does significantly improve rainfall estimates. By relating the optimal Aa and ɑ values to known network meta data, the results from this study are potentially applicable to other tropical CML networks that lack nearby reference rainfall data.

ID: 188, Oral presentation

DEVELOPMENT OF AN OPERATIONAL SURFACE HYDROMETEOR CLASSIFICATION ALGORITHM FOR THE NEXRAD NETWORK

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Complex cold-season precipitation types (e.g., ice pellets, freezing rain) present a major nowcasting challenge. Dual-polarization radar data can help diagnose precipitation type through so-called hydrometeor classification algorithms (HCAs). However, these algorithms typically operate on the radar conical surface, missing processes occurring below the radar beam where ice pellets and freezing rain typically form. Exacerbating this issue, there is no distinct polarimetric signature that distinguishes freezing rain from rain. Therefore, the successful diagnosis of these complex surface precipitation types requires incorporating thermodynamic data from numerical weather prediction (NWP) model guidance.

This work presents a novel surface precipitation type algorithm ("sfcHCA") being developed and tested for potential use on the United States' WSR-88D radar network that introduces two novel classes to the existing operational HCA: ice pellets (PL) and freezing rain (ZR). A one-dimensional discrete particle model is run at each grid point that explicitly calculates the effects of sublimation, evaporation, melting, and freezing on particles of various sizes. The model is initialized using environmental data from a high-resolution NWP model and a particle size distribution aloft diagnosed from polarimetric quasi-vertical profiles. After the model is run, surface precipitation type is diagnosed based on the relative fractions of fractal ice (i.e., snow), solid ice, and water. These classifications are then merged with the existing HCA classes from the 0.5° elevation angle PPI to create a blended sfcHCA product. A novel method for combatting background model error and providing evolution of the environment at sub-hourly timescales is introduced by comparing the observed melting layer top height of each volume scan with the model wetbulb-zero height and adjusting the environment to be in agreement with this pseudo-observation. Preliminary results from a diverse set of cases validated against surface precipitation-type reports indicates the sfcHCA algorithm can provide operationally meaningful information to forecasters, particularly in challenging PL and ZR events, with qualitatively good performance and improvements observed due to the aforementioned melting-layer adjustment.

ID: 209, Poster presentation

EXAMPLE OF USE OF THE ITALIAN DISDROMETER NETWORK FOR RADAR CALIBRATION CHECKS: THE ABRUZZO REGION CASE STUDY

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Data quality in weather radar applications is of fundamental interest because it directly links to quantitative radar-derived product quality (eg. rain rate retrieval, hydrometeor classification, etc…). Among the various source of uncertainty in radar data (e.g. clutter, path attenuation, non-uniform beam filling, etc…), the radar calibration is one of the most hostile. Radar calibration is aimed to define the variations of the radar constant that include the knowledge of several radar system characteristics which may deteriorate over time. Typically, such system deterioration is compensated during maintenance controls. However, remote continuous calibration monitoring could help for the maintenance operations optimizing their costs.

In this work, radar calibration using disdrometer data at the ground, belonging to spontaneous Italian network named GID (https://www.gid-net.it/network/), is presented. Although the topic is not scientifically new, the application of the radar vs. disdrometer can hide some details that merit attention (eg. take into account the sedimentation time of hydrometeor to synchronize the radar and disdrometer data).

The analysis presented shows comparisons considering the radars managed by the Regional Agency of Civil Protection, namely: one C-band radar positioned at 1700 m asl. and two X-band radars on coast sites for data collected over one year. Two laser disdrometers, one on the coast side and one inland are used as surface reference.

Results indicates a good radar-disdrometer agreement with the radar bias found of the order of tenths of a dB.

ID: 212, Oral presentation

MITIGATING RADIOFREQUENCY INTERFERENCE IMPACTING CANADA'S S-BAND WEATHER RADARS

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Environment and Climate Change Canada (ECCC) has completed the installation of thirty-two operational S-Band weather radars across Canada. However, the coexistence of communication towers and weather radars, where these structures are in proximity has led to receiver intermodulation. This issue is triggered by the band 7 signals from the telecommunication transmitters, causing Radio Frequency Interference (RFI) in some of the S-Band weather radar systems.

At ten Canadian radar sites, the radial interferences have reached levels significant enough to present challenges for weather data monitoring by forecasters hindering effective detection and response to weather-related hazards.

The prototype bandpass filter was tested at eight sites and resulting in RFI elimination and minimally reducing radar sensitivity.

For the conclusive assessment, a set of filters (H channel and V channel) was installed at the two of the radar sites for a trial period, with data evaluation performed by the Science and Research group. Subsequently, the Science and Research team approved the data quality achieved with the filters in place. The bandpass filters effectively removed the moderate RFI contaminations, however for the places where the strong RFI contamination persists, the removal was incomplete. Activating moderate RhoHV software filter could effectively eliminate more RFI. Topics:

- ECCC's weather radar upgrade.
- Radar colocation with Telecommunication Tower.
  - Impact of Radio Frequency Interference (RFI) :Comparison between the C-Band and S-Band Radars. RFI Impact on Radar Product.
- User's Feedback: The RFI lead to erroneous interpretation of the data causing forecasters to miss crucial weather signatures.
- Receiver Intermodulation: Frequencies around 2685 MHz, 2150 MHz, and 2117.5 MHz have been identified as potential sources of receiver intermodulation.
- Bandpass Filter Design, Test Results, and Product Evaluation: Deployment of a universal filter solution and effectively eliminating RFI contamination across the S-band weather radar network. Challenges in eliminating strong RF signals at 2.687 MHz prior to its ingress into the analogue receiver assembly. Addition of a moderate filter further eliminated RFI, but with the risk of also filtering out genuine meteorological signals.

USE OF DUAL-POLE RADAR DATA IN OPERATIONAL NOWCASTING INFORMATION AT DWD

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Based on the modernisation of the radar network with the introduction of dual-polarimetric Doppler C-band radar data and the fusion of the resulting hydrometeor classification data both with 3D NWP data and observational data near the ground, the national German weather service (DWD) has both designed new nowcasting products and has further developed existing nowcasting products. After a thorough evaluation process, these products have been operationalised, gradually. Further product improvements are already in development and evaluation.

The presentation will discuss case studies with the most sophisticated operationally used radar-based nowcasting products (e.g., KONRAD3D, NowCastMIX). In addition to the nowcasting of convective summer events (e.g., thunderstorms, mesocylones, heavy rain events, hail occurrence), the spotlight has been broadened on winter events (e.g., detection of snow and freezing precipitation) in the recent years. Thus, the dual-polarimetric hydrometeor classification at radar beam height has been refined for precipitation type analyses near the ground and in the characterisation of convective events (e.g., by modifying and extending warning attributes). Case studies focusing on these aspects will also be presented.

ID: 226, Oral presentation

RAPID-SCAN OBSERVATIONS OF TORNADOGENESIS AND SENSITIVITIES TO RADAR-BASED THRESHOLDS: TRENDS, QUESTIONS, AND OPERATIONAL IMPLICATIONS

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Multiple studies over the past decade have sought to identify the spatio-temporal evolution of rotation just prior to and during tornadogenesis in order to answer the question: Does a tornado form from the top-down, bottom up, or simultaneously over between the cloud and the ground? (French et al. 2013; Houser et al; 2015, 2022; etc.) Traditionally, the answer to this question has been illuminated by studying the time-height progression of the tornadic vortex signature (TVS). However, owing to a plethora of non-meteorological considerations (e.g. distance between the radar and the tornado, beam width of the radar, height of the beam, etc.) there is no quantitative definition of what constitutes a small-scale vortex as a TVS. Indeed, velocity differential values ($|v_{in} - v_{out}|$) defining tornadoes in the literature is found to range between 12 m s^{-1} for WSR-88D's (Trapp study of 88Ds) to upwards of 55 m s^{-1} for close-proximity mobile radars (Weinhoff et al 2020)

This presentation provides a basic overview of radial velocity observations from the Rapid-scan X-band polarimetric (RaXPol) radar that illustrate the time-height evolution of 8 tornadoes, many of which have data collected down to heights O (10 m above radar level) using five different metrics: three different thresholds of "TVS" definitions (30, 35, and 40 m/s); pseudovorticity, and maximum differential radial velocity; to quantify a "tornado". The onset time of the tornadic debris signature at the lowest elevation angle available is incorporated to provide insight as to when debris becomes lofted and is visible in the data. It is found that in some cases, the time-height evolution is consistent regardless of the parameter used. However, for a minority of cases, the vertical sense of evolution is actually dependent upon which parameter is used. Thus, caution should be exercised when analyzing results based only upon a single parameter. Furthermore, it is not always clear when a radar-observed vortex is a tornado. For several cases, TVS's are only seen at heights < 1 km above ground level. It is shown that this affects the ability of operational radars to detect the tornadoes, and even has an impact on tornado climatology as these tornadoes are at times missing from the US storm events database. Lastly, in the context of these observations, operational challenges and strategies for moving forward are highlighted.

ID: 229, Oral presentation

EUMETNET OPERA - IMPLEMENTATION OF NEW PRODUCTION LINES: PERFORMANCE AND DELIVERY OF OPERA RADAR PRODUCTS

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The EUMETNET Operational Program on the Exchange of Weather Radar Information (OPERA) plays a pivotal role in coordinating weather radar cooperation among European national weather services, facilitating the exchange of radar data to produce European-scale composite products of maximum reflectivity and instantaneous surface rain rate, as well as providing quality-controlled volume data for Numerical Weather Prediction (NWP) assimilation (www.eumetnet.eu/opera). From 2011 to 2024, production operations were managed at the OPERA Data Center (ODC), commonly known as "ODYSSEY." To support further development and ensure future-readiness, during the programme phase spanning 2019 to 2023, new production lines were developed, gradually implemented, and fully deployed for operational use in 2024.

The new production framework comprises three distinct lines: i) the CUMULUS/STRATUS line manages the intake and distribution of incoming radar data, with potential also for future provision of data for independent processing outside OPERA; ii) the CIRRUS line generates a high-resolution maximum reflectivity composite, with updates every 5 minutes at a horizontal resolution of 1 km; and iii) the NIMBUS line produces precipitation composites (2 km, 15- min) and offers quality-controlled volume radar data tailored for NWP assimilation. Throughout the implementation process, the performance of these production lines was studied and evaluated. Although the developed products aimed to mirror those of ODYSSEY, changes were inevitable due to updated requirements and new software, notably impacting the used compositing algorithm in NIMBUS and subsequent product outputs.

In 2024-2025, OPERA participates in the RODEO project, a collaborative initiative involving eleven European National Meteorological and Hydrological Services (NMHS), the European Centre for Medium-Range Weather Forecasts (ECMWF), and EUMETNET, funded by the EU Digital Europe Program (DIGITAL) and EUMETNET. The RODEO project focuses on developing a user interface and Application Programming Interfaces (APIs) to facilitate access to meteorological datasets identified as High Value Datasets (HVD) by EU Implementing

Regulation (EU) 2023/138 under the EU Open Data Directive (EU) 2019/1024. Furthermore, plans are underway to make OPERA radar data and products available under an open license, utilizing machine-readable formats accessible via APIs and bulk downloads.

At the upcoming conference, we will present the new production lines, their performance, the impact of these upgrades on product quality, and outline future strategies for data dissemination through the APIs developed within the RODEO framework.

WIND TURBINES ACROSS THE CANADIAN WEATHER RADAR NETWORK

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Wind turbines cause echoes that can confound the ability of weather radars to detect meteorologically interesting echoes. Environment and Climate Change Canada (ECCC) has 33 radars across Canada. These radars provide a look at wind turbine echoes on a continental scale in a number of climate and geographical regimes.

Monthly statistics of reported reflectivity are created in ECCC and that data can be extracted at known turbine locations. Segregation by range show the unsurprising result that wind turbine echoes generally reduce with range. However, the strength and persistence of echoes depend on location as well. In one example, echoes from turbines at 118 km on a mountain are stronger than echoes from others 30 km away in a valley below a radar, even though line-of-sight exists in both cases. Another finding is that although the moving blades are a well-known issue because they avoid Doppler clutter filters and produce excess reflectivity, the stationary towers of turbines near a radar can exceed a radar’s capability to separate moving and stationary echoes and occasionally result in holes in the data. In some areas seasonal variation is present due to the occurrence of anomalous propagation and, at one radar, turbines have been detected more than 300 km away over flat terrain and water. In hillier terrain long-range detection is due to turbines on high terrain.

The presentation also addresses some of the issues related to quantifying turbine impact. For example, the mean inferred rain rate could be a measure of hydrological impact, but the statistics are highly non-normal so the median might give a better sense of “typical” behaviour. Alternatively, one can look at the percentage of observations above some reflectivity threshold. A visibility analysis for assessing wind farm proposals has also been tested against the echo statistics.

ID: 235, Oral presentation

ADVANCED RADAR CALIBRATION: PULSE COMPRESSION VS. CONVENTIONAL SYSTEMS

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We present findings from several radar calibration experiments conducted in the US and Switzerland, involving multiple radars operated by the Colorado State University (CSU), the Advanced Radar Research Center (ARRC) in Oklahoma, and EPFL in Switzerland. The experiments were based on the comparison between measured radar variables and the properties of artificial point targets that were electronically generated with a polarimetric radar target simulator. Radars under test included the two magnetron-based radars CHILL and its mobile version SPLASH from CSU, ARRC's solid-state X-band radar PX-1000, and EPFL's new solid-state radar StXPol manufactured by ProSensing. Our focus with PX-1000 was put on determining the transmitted differential phase, an aspect garnering increased attention recently. Many dual-polarization weather radar systems transmit waves with unknown polarization states. Recent efforts aim to estimate the phase difference between the two polarization components using either external single polarization receivers with adjustable polarization angles or by observing ρhv during bird-bath scans, a relatively new and still evolving technique. With our polarimetric measurements, an excellent agreement was found with estimates obtained with single polarization over-the-air transmit power measurements conducted during changing polarization states of the transmitted wave. For the CHILL and SPLASH calibration measurements in Colorado, a mobile lifting platform was employed that elevated the target simulator instrument to approximately 15 m above ground. By creating various targets, a direct comparison between the electronically generated targets and the measured polarimetric variables became feasible. In addition to the simulated targets, the experiment was also carried out with real calibration targets (spheres and a corner reflector) that were attached to a drone. While the SPLASH radar exhibited good Z_{dr} and sufficient Z_h accuracy, remarkable precision and stability were found in CHILL's reflectivity data time series, where the reflectivity bias compared to the virtual target was less than 0.2 dB over a one-hour time series. Calibration issues that arise with solid-state radar systems were investigated with experiments conducted with EPFL's new StXPOL radar. This pulse compression system transmits a linear frequency-modulated long pulse as well as a non-modulated short pulse for observations at close ranges. The two pulses are separated in frequency by 50 MHz and consequently, calibration targets were generated independently for the two channels. Excellent stability and accuracy were found for Z_{dr} in both channels. An initially persisting reflectivity bias that was induced by a matched filter effect could be eliminated by carefully placing the electronic target in the center of the range gate. We will delve into the advantages and disadvantages of the different calibration techniques employed, along with insights gained from various radar types ranging from standard magnetron systems

to solid-state transmitters.

ID: 240, Poster presentation

REAL-TIME TORNADO DETECTION SYSTEM USING DEEP LEARNING - TOWARDS MITIGATION OF LOCALIZED AND SUDDEN METEOROLOGICAL DISASTERS

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Introduction - Background and Purpose of the Research

Meteorological disasters induced by violent atmospheric phenomena can have a profound impact on societal safety and economic activities. Sudden and localized wind phenomena, particularly tornadoes, are challenging to predict. Early and accurate detection of their occurrence is crucial for reducing disaster risk. To address this situation, our meteorological research institute, in collaboration with railway operators, has been advancing the development of a system to detect gusts using deep learning models based on meteorological radar data. We believe that this initiative will not only improve the safety of railway operations but also contribute to reducing the risk of meteorological disasters in other sectors. In 2023, building on the results of these efforts, we initiated a new research project titled "Collaboration with Startups for Local and Sudden Severe Weather Countermeasures: Construction of a Real-time Disaster Prevention Field Using AI." This project focuses on tornadoes, which are a particularly challenging aspect of localized and sudden severe weather, and aims to develop technologies that effectively contribute to real-time disaster prevention and mitigation for society at large, not just for railways. The project is driven by industry- academia-government collaboration and actively seeks partnerships with startup companies to provide solutions for societal challenges through rapid and flexible development, meeting the needs of various businesses that require windstorm information.

Overview of the Project

The project aims to develop a method for accurate detection, tracking, and trajectory prediction of tornadoes and to provide precise disaster prevention information based on the recipient's location by combining this information with GPS positional data. To achieve this goal, the project is advancing research to detect tornado vortex patterns with high accuracy from meteorological radar data, utilizing the strengths of deep learning models, including CNNs (Convolutional Neural Networks), architecture search, and transformer-based approaches. Furthermore, to enable users to respond swiftly and reduce disaster risk, we are developing technology to distribute the results in real time through the internet and devices such as smartphones. This presentation will specifically describe the project's approach, outline the results of the first year, and discuss the future direction of research and development.

Acknowledgments

Funding: This research was partly supported by funding from the Cabinet Office of Japan. Additionally, we are utilizing the achievements obtained through joint research with East Japan Railway Company.

ID: 243, Poster presentation

MULTI-FREQUENCY RADIO FLUX OBSERVED BY SIX DUAL-POLARIZATION WEATHER RADARS IN SWITZERLAND: A QUANTITATIVE COMPARISON WITH DRAO (CANADA) AND TWO RSTN SITES (ITALY AND AUSTRALIA)

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A proper calibration of dual-polarization receiver chains is of crucial importance for weather radar performance. Solar radio noise has proven to be an effective reference for checking the relative calibration of the receivers and for monitoring their stability over time. For this purpose, it would be beneficial to have measurements of solar emissions in the same (C- and X-) bands of the six Swiss weather radars, especially when the Sun is active. Since the radio output of the active Sun varies considerably in frequency and time, these measurements should be made around 11 UTC so as to minimize atmospheric propagation and refraction. However, the most reliable and accurate solar reference signals are those provided by DRAO (British Columbia, Canada) around 20 UTC and at S-band only. Their unique reference values are converted to our bands using a standard formula, although its use should be limited to periods when the Sun is quiet.

Depending on a suitable observation site of the mobile X-band radar, two periods (2 solar rotations long) at the beginning and end of summer 2023 were selected for a daily intercomparison between the DRAO reference values and the observations of the six (5 C-band) radars.

During period1, the relative calibration and agreement is good at both C-band (median correlation coefficient, r~0.866) and X-band (r~0.843); this for both polarization states, which are, as expected, highly correlated (r~.985). During period2, the relative agreement is less good at C-band and very poor at X-band, perhaps due to the simultaneous operation of a nearby X-band bird radar. It should be noted that the level of the signal (Sun+ unavoidable noise) is only 5 dB above noise at X-band.

This difference in agreement is also found using reference solar measurements from two NOAA Radio Solar Terrestrial Network sites: Learmonth (LM) (5 UTC), and San Vito (SV) dei Normanni (11 UTC). These reference values are NOT derived from transposed S-band observations, but obtained at 4975 MHz and 8800 MHz, which is relatively close to the Swiss radar operating band (5400 and 9400 MHz). It appears that the relative inter-agreement (with DRAO and all the radars) is better in period1 than in period2; it is also better at C-band than at X-band. Surprisingly, the SV-radar agreement (close longitude, same band) is no better than the DRAO-radar agreement (BC longitude, S-band transposed observations).

Regarding absolute calibration, all dual-pol radars are in good agreement with DRAO. However, SV is too high at C-band (~0.6 dB above LM and slightly higher than the DRAO transposition at 5400 MHz); LM is too low at X-band (~2 dB below DRAO and SV). We therefore conclude that there is a clear need for a precision solar radio telescope in Europe operating at 5400 and 9400 MHz.

ZDR BIAS MONITORING – ECCC’S NEW S-BAND RADARS

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Environment and Climate Change Canada (ECCC) has recently completed a major project to replace 31 late 1990’s C-Band radars (Magnetron – 200kW, Vaisala/SIGMET) with new S-Band radars from Leonardo (Klystron, 1MW). As of the summer of 2024, all the radars have been replaced.

The systems’ Z_{DR} offsets are a combination of system and manual transmit and receive side offsets. System transmit and receive side offsets are derived from the system’s internal calibration measurements and external information. However, not all of the parameters from internal calibrations are available in the system outputs. The BALTRAD solar processing toolbox provides solar flux data which is used with the radars recorded Z_{DR} offsets to remove Z_{DR} system offsets from the transmitter chain to estimate Rx side bias. In this manner, receive side system offsets are determined from solar hits collected from operational data.

Two methods for assessing and monitoring the total system Z_{DR} bias have been developed and are being used. Inter radar matching (IRM), which looks at Z_{DR} distributions in overlapping radars, provides a relative bias between radars in the network. At the moment we only use this method occasionally as it depends on wide scale precipitation midway between radars. The second method, which estimates total system Z_{DR} bias, uses light rain and snow measurements when sufficient precipitation echoes are present around the radar. The Z_{DR} biases from individual scans in precipitation allow us to monitor variations.

With these bias estimates, we are able to adjust the systems’ Z_{DR} offsets to minimize the Z_{DR} bias and monitor it for drift or changes due to system adjustments or hardware replacements.

In 2024 a new release of Leonardo radar software enabled the output of additional Z_{DR} related parameters which allows us to further refine the system related offsets. In combination with precipitation determined offsets we are then able to compensate for Z_{DR} biases in the radars.

An operational version of this system will be tested during 2024.

SYSTEM DIFFERENTIAL PHASE – A HISTOGRAM APPROACH

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Phase-based polarimetric variables bear several advantages and thus are increasingly exploited for quantitative precipitation estimation and other microphysical retrievals, but also very beneficial for hydrometeor classification. Furthermore, the possibility to correct for (differential) attenuation using propagation differential phase is among the great achievements of polarimetric measurements. However, mandatory processing of the phase measurements can be very challenging, especially in light rain or when resonance scattering occurs. For operational aspects measurements of differential phase are also used to monitor the system status.

Part of the processing challenge is to determine system differential phase PhiDP (the system inherent phase difference), which may also vary with azimuth and time due to internal and external influences.

This work introduces a new approach to estimate system PhiDP based on the distribution of all PhiDP measurements within a sweep (or ray), more precisely the system PhiDP is determined using a statistical measure of this distribution (histogram approach). By differentiating between ray- and sweep-based processing clutter interferences and other perturbations can be minimized. The performance of the method introduced is demonstrated on several datasets of European C-Band and X-band radar systems for different case study days. Therefore, a comparison with to date widely used methods to determine system PhiDP is presented, e.g. using the median of the first bins with rain. Additionally, the new histogram approach can be exploited for several applications more, e.g. to determine beamblockage, non-uniform beam filling, and noise.

ID: 256, Oral presentation

OPERATIONAL SATELLITE PRECIPITATION PRODUCTS COMBINED WITH GROUND OBSERVATION FOR HYDROLOGICAL PURPOSES: CASE STUDIES AND APPLICATIONS

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For more than 15 years the EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (H SAF, http://h-saf.eumetsat.int) has been providing near real-time operational products to supply the main hydrological variables: precipitation, soil moisture and snow. A continuous quality assessment service is also provided for all products generated and specifically for precipitation products using space-borne and ground based radars. More than twenty operational products are provided, characterized by different spatial coverages (Europe, MSG Full-disk or global) and temporal frequencies (ranging from 15 minutes for instantaneous products, to hourly or daily accumulated ones, up to monthly averages), offering data characterized by high temporal and spatial resolution. The Fourth Continuous Development and Operation Phase (CDOP-4), started in 2022, has as main objectives the promotion of products usage among the user community by providing applications, case studies, tools and training and the development of new products to fully exploit primary EUMETSAT missions (MTG and EPS-SG).

Operational ground-based networks, such as weather radars and rain gauges provide precipitation products with limited coverage area. The observed area is widely extended with the synergistic use of operational satellite products. This work show the operational use and advantages of combined observation in several case studies, covering severe floods and intense rainfall events over Europe in recent years.

ID: 259, Poster presentation

AUTOMATIC RADAR QUALITY CONTROL FOR AUTO METAR IN SWISS CIVIL AIRPORTS

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METeorological Aerodrome Reports (METARs) describe the meteorological conditions at aerodromes and are used for flight planning. Local routine reports (MET REPORTs) and local special reports (SPECIALs) are more detailed and are used by air traffic controllers for take-off and landing clearances, among others. When produced automatically without human intervention, they are called AUTO METAR / AUTO MET REPORT / AUTO SPECIAL, which we refer to as “automatic reports”.

At MeteoSwiss weather radar and lightning data are used for the detection of convective phenomena in automatic reports at Geneva airport, such as cloud type (CB or TCU), thunderstorms (TS, VCTS), showers (SH, VCSH) and hail (GR). The quality of automatic reports depends thus on the reliability of the input weather radar and lightning data. This abstract deals with the quality of radar data.

While there is already an advanced calibration, monitoring and data quality control system, there are still some residual cases where artefacts in radar products affect the quality of the automatic reports. An artefact could be caused by various reasons, e.g. any type of hardware instability, electromagnetic interferences, a human error during radar maintenance or software issues. Of particular interest are the artefacts that cause a positive bias, which might create a false alarm for convective phenomena.

In order to automatically discard the radar images contaminated by artefacts, we analyze the spatio-temporal properties of the radar fields such as the mean reflectivity, the temporal autocorrelation, as well as the similarity of distributions (histograms). The values before and after the potential radar incident are compared. The algorithm is searching for temporal differences, or “jumps”, in statistics of consecutive images. If a detected difference exceeds a pre-defined threshold, which represents the natural variability of precipitation fields, the data are discarded. Preliminary results indicate that neither a single statistical variable nor a single threshold is sufficient to automatically detect and discard radar images affected by artefacts. Instead, we need a combination of statistical variables and thresholds adapted for each variable. Another method that we are exploring is the monitoring of the stability of ground clutter, which would depend less on the analysis of temporal differences but provide a better reference for comparison.

ID: 266, Poster presentation

INNOVATIONS IN OPERATIONAL RADAR PRODUCTS AND POST-CWRRP PRODUCTION STATUS

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The Operational Remote Sensing Section (CMOT) at ECCC plays a critical role in developing, generating, delivering, and supporting remote sensing products in real-time for various users and clients. This includes ensuring the quality and timeliness of products for internal users within the Meteorological Service of Canada (MSC), such as operational forecasters and Numerical Weather Prediction (NWP) systems. Additionally, CMOT provides data in user-required formats to external agencies, including international meteorological services and private entities. The team is also responsible for archiving raw radar data, products, and retrievals upon request.

Following the completion of the CWRRP project, which aimed to replace the Canadian C-Band radar network with 32 dual-polarized S-Band radars, finalized in August 2023, CMOT continues to collaborate to lead innovative projects and maximize the utilization of these new technologies. CMOT takes this opportunity to present the major projects our team is working on, including the integration of Machine Learning/Artificial Intelligence (ML/AI).

WEATHER RADAR NETWORK QUALITY CONTROL AND OPERATIONS IN BRAZIL - CHALLENGES OF A MULTI-OPERATORS ENVIRONMENT

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Over the past decade, Brazil has significantly increased its weather radar coverage from 23 single-polarization radars to 24 additional dual-polarization radars, mostly S-Band, with a concentration in the southern region. This area is prone to severe weather, mostly related to Mesoscale Convective Systems, and is the primary economic area with agriculture and energy production, responsible for over 35% of hydropower energy generation used in the country. Precipitation distribution, water availability, and severe storm impacts directly affect the region. Weather radars in southern Brazil are essential in quantitative precipitation estimation and severe weather monitoring and forecasting. The operational volume coverage pattern for the Brazilian Weather Radar Network is updated every 10 minutes, but this update cycle is expected to lose information from severe weather events. In areas more impacted by severe weather, such as the southern states, specifically Parana, which has three meteorological radars operated by the Parana Meteorological System (SIMEPAR), the operational volume coverage pattern is every 5 minutes. The national network is integrated by collaboration, with several partners with different objectives, radars of various manufacturers, frequencies (mostly S-Band, but also one C-Band and several X- Band), and even transmitters (mostly magnetron and klystron, a few solid-state). Developing a reasonable quality control system adapted for all unique types of equipment and conditions required significant effort. We have created a series of APIs based on Python, especially using Py-ART and Wradlib, to read raw volume data of several formats and vendors (e.g., HDF5, NetCDF CF/Radial, SIGMET, EDGE, MDV), process and perform quality control of that data before being disseminated. Additionally, we have created several other products for QPE and nowcasting to be disseminated through web applications. We have streamlined the script development, testing, and communication of results between developers, facilitating the improvement and fine-tuning of functions and filter parameters to achieve the best outcome for each of the network's radars, considering their particularities. This work presents our experience with radar data analysis and networking, for single and dual-polarimetric systems, where we developed a radar server for data storage, conversion, processing, and dissemination in real-time, in an environment with several radar operators, with different radar specifications and operations in southern Brazil.

ID: 275, Oral presentation

ROC/NSSL RADAR PRODUCT IMPROVEMENT: AN R2O SUCCESS STORY

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The Radar Product Improvement (RPI) Service Level Agreement (SLA) between the National Weather Service (NWS) Radar Operations Center (ROC) and National Severe Storms Laboratory (NSSL) provides support for NSSL/OU CIWRO scientists to conduct applied research with the goal of developing new science and signal processing techniques to address operational problems and emerging requirements for the NEXRAD network. NSSL scientists and engineers have been supporting the ROC by providing hardware and software development and improvements to weather radar algorithms and applications since 1987, when the existing ROC/NSSL Technology Transfer SLA began. Improvements to the WSR-88D system associated with hardware and processor software (but not applications software) were transferred to the NEXRAD Product Improvement (NPI) program that started in the late 1990s. NPI's primary purpose was to replace the Radar Data Acquisition (RDA) and Radar Product Generation (RPG) subsystems with open system hardware and software (ORDA and ORPG) and to implement dual polarization capability on the WSR-88D system. Although direct Congressional funding for NPI ended in 2013, the need for continued infusion of new capabilities continued by establishing RPI at that time.

This presentation will summarize the history, successes, and opportunities for RPI. The iterative nature of the R2O process taken by the ROC and NSSL/CIWRO will be highlighted with past and current examples in developing new signal processing techniques and radar science for the ORDA and ORPG. A brief summary of RPI's current projects and status will be highlighted, with an emphasis on recent and imminent R2O transitions in improving signal processing techniques (e.g., range oversampling), quantitative precipitation estimation, and improving dual pol capabilities and data quality (e.g., range-defined quasi-vertical profiles and a new method to estimate Zdr bias) to better observe and predict severe weather hazards. In addition, R&D initiatives for new or evolving requirements like wind turbine clutter mitigation will be highlighted, along with some strategies for field engagement and training. Potential future directions and topics for RPI priorities will also be presented (e.g., area-based cell identification, machine learning approaches), with an emphasis on the ongoing collaboration between NSSL and the ROC to transfer R&D for both the WSR-88D and a potential radar follow-on system.

ID: 283, Poster presentation

TOWARDS A SINGLE GLOBAL STANDARD FOR POLAR WEATHER RADAR DATA REPRESENTATION WITH FM301 – CFRADIAL2

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Standardized representation of weather radar data is being addressed by the World Meteorological Organization's (WMO) Joint Expert Team on Operational Weather Radar (JET-OWR) and Task Team on CFNetCDF, starting with the representation of moment data in original polar/spherical coordinates. In April 2021, the WMO's Infrastructure Commission (INFCOM) approved experimental use of data representation using the Climate and Forecasting (CF) Conventions and the Network Common Form (NetCDF) file format. Two pilot data types were identified for such experiments, one of which is weather radar data. FM301 is the new WMO use of CF and NetCDF, with standardized profiles for each data type. For weather radar moment data, the FM301 profile is CfRadial version 2 (CfRadial2).

In March 2023, the FM301 profile was approved for inclusion in the WMO Manual on Codes by the 76th session of the WMO Executive Council (EC- 76). This decision clears the way for FM301 to transition from experimental to operational status. Efforts to support the adoption and use of FM301 are underway under the auspices of the WMO:

3 A software library has been prepared for reading/writing FM301, with the intent of it constituting a reference implementation. This software is being used with radar data in Australia, Canada and the United States to demonstrate its use with, and the natural variability of, radar data from different countries.

4 The use of FM301 with the WMO Information System (WIS) version 2.0 is being investigated. JET-OWR will explore how these data can be best integrated into future WMO data exchange functionality.

5 Guidance on the use of FM301 has been included in Volume VI of the Guide to Operational Weather Radar Best Practices developed by JET- OWR, that was also approved for publication at EC-76. Additional supporting documents such as FM301 migration guides from existing common formats such as ODIM_H5 and CfRadial1 are also under development.

This poster will address the status of FM301 and these ongoing activities.

ID: 284, Poster presentation

USING NOISE DATA TO MONITOR DUAL-POLARIZATION RADAR RECEIVER GAINS AND CORRECT FOR DRIFT DURING OPERATIONS.

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NSF NCAR/EOL deployed the S-Pol sband dual-polarization radar to Taiwan for 4 months during 2022, to participate in the PRECIP field project. During this project the radar was operated in staggered-PRT simultaneous (slant 45) transmit mode. This means that calibration and monitoring techniques relevant to alternating H/V transmit mode are not available. During the second half of the project the H channel receiver exhibited some instability and drift, leading to errors in both reflectivity and, to a more serious extent, in ZDR. S-Pol can be operated in vertically-pointing mode in rain to enable ZDR calibration checks. However, during that phase of the project rain events at the radar were quite rare, so this check was not routinely available. During the data QC processing phase of the project, EOL developed a noise-based method for monitoring changes in the individual receiver gains for each channel. This involves computing the observed noise in long-range gates at high elevation angles, and at pointing angles that are not close to that of the sun. Because the radar was operated routinely in RHI mode, there are many high-angle observations available in the time series data set. Using this method, we were able to identify changes in the receiver gains, and correct for those changes at a reasonably fine time resolution. Combining this method with vertically-pointing scans in rain when available, along with clutter power monitoring, we were able to correct for receiver gain drift and produce a reliably-calibrated quality-controlled data set.

ID: 291, Poster presentation

ATMOSPHERIC RADIATION MEASUREMENT (ARM) USER FACILITY: RADAR OPERATIONS AND DATA QUALITY CHARACTERIZATION

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The Department of Energy's Atmospheric Radiation Measurement (ARM) user facility has strategically deployed cloud and precipitation radar systems across fixed sites in Oklahoma, Alaska, and the Azores, as well as three ARM Mobile Facilities (AMFs) globally. These radars operate across various frequencies to enhance our understanding of cloud, precipitation, and wind dynamics crucial for improving climate and weather modeling. This presentation provides an overview of the current year's roadmap for radar operations across the ARM sites, radar data quality evaluation and characterization at different ARM radar data levels. Additionally, it outlines priorities of radar plans in the upcoming year to enhance operational capabilities. The ARM facility is committed to ongoing engagement with communities to explore the utilization of radar data and to enhance operational efficiency.

ID: 292, Oral presentation

USING DUAL POLARISATION WEATHER SURVEILLANCE RADAR TO DETERMINE TEMPORAL AND SPATIAL PATTERNS OF THE FLYING ANT EMERGENCE IN THE UK

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[4]*National Centre for Atmospheric Science,*

Weather Surveillance Radar (WSR) is a meteorological tool which incidentally records volant animals including insects. The UK's "Flying Ant Day" is characterised by the mass emergence of winged ants (predominantly Lasius niger and Lasius flavus species) . Although the UK's Met Office highlights this phenomena in its radar each year, the radar signatures of this phenomenon has not been studied in detail. Using anatomical scans of male and queen ants, the radar cross-sections (RCS) were simulated using electromagnetic modelling software. These values were used to estimate the biomass and number of ants on Flying Ant Days, verified through a Citizen Science Survey of over 4500 responses in 2021-2022. The biomass concentrations varied on both a temporal and spatial scale. Temporally we tended to see two peaks during the day, typically one smaller followed by one larger. These peaks were recorded at a maximum of 100 mg per m 3 on the 9th July 2021 and 30 mg per m 3 on 7th July 2022. In addition, using a geodesic approach to the radar beam, high fidelity altitude measurements were made, showing ants routinely detected at altitudes of 2 km and a swarm was observed above 5 km in altitude for around 40minutes on the 17th July 2022. This study highlights the untapped potential of using WSR in aeroecology and aeroentomology to shed light on the complex behaviours of flying ants, revealing significant insights into their emergence, biomass distribution, and altitude preferences during the UK's Flying Ant Days. By bridging the gap between meteorological observation and ecological research, we pave the way for future interdisciplinary studies to broaden this approach providing insight into both local ecosystems and global biodiversity.

ID: 294, Poster presentation

SNOWFALLL CAMERA OPERATIONS FOR INSECT DETECTION TO CORROBORATE RADAR OBSERVATIONS

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Accurate monitoring of insect populations is spatially and temporarily limited using traditional biological techniques. Radar aereocology has the potential for widespread monitoring, however although estimates of insect numbers can be made and general trends observed, collocation between radar and in-situ measurements are a step forward to help determine taxonomy of insect species. Here, we show the potential of using a camera system combined with computer vision image processing for non-destructive Pterygota monitoring. For this, we use the open source Video In Situ Snowfall Sensor (VISSS), which is an instrument development for characterizing particle shape and size in snowfall but incidentally also captures insect observations.

The VISSS is composed of two cameras with approx. 60 um resolution which center on a joint observation volume of approximately 6 cm3, with telecentric lenses that enable accurate measurements of size. The cameras record shadow images of particles within the observation volume illuminated by green LED backlights at a frame rate of 140Hz. A proof of concept algorithm splits images between hydrometeors and possible insects. This is further refined, through masking of the insect, categorizing the relative size and flight path information. We will show how this can be used to monitor Pterygota for daily and seasonal cycles and how this can inform radar outputs in aeroecology.

ID: 304, Poster presentation

QUALITY ASSURANCE OF THE NEW DUAL-FREQUENCY DOPPLER CLOUD RADAR OPERATING IN THE SOUTHERN OF THE IBERIAN PENINSULA

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Significant efforts have been made to improve our knowledge of clouds and a better understanding of precipitation. In Europe, despite the valuable information provided by the CLOUDNET network on cloud properties by combining radar data with auxiliary lidar and radiometer instrumentation, there is an evident bias towards studies conducted in Northern and Central Europe compared to those in the South. One reason is the lack of instrumentation in these regions. In this regard, the Atmospheric Physics Group of the University of Granada (GFAT) has recently initiated research efforts in the field of cloud structure, microphysical properties, and their relationship with radiation and precipitation. With this aim, GFAT incorporated a fully-equipped CLOUDNET station to the Andalusia Global Atmosphere Observatory (AGORA) —managed and operated by the GFAT—, in the Southern region of the Iberian Peninsula, being one of the few stations in Southern Europe. To go beyond the state-to-the-art, a dual-frequency radar system, named NEBULA, has been recently deployed in March 2024. Dual Wavelength Ratio (DWR) and Dual Doppler Velocity (DDR) analysis provide insights into the microphysical properties of hydrometeors, enabling the detection and differentiation of various precipitation types. However, given the criticality of accurate meteorological observations, ensuring the reliability and correctness of radar data is paramount, with its operation relying on meticulous calibration and validation protocols. Thus, this study presents the quality assurance procedures implemented for NEBULA, leveraging the Dual Wavelength Ratio (DWR) and Dual Doppler Velocity (DDV) techniques. By scrutinizing the consistency and coherence of DWR and DDV data, potential anomalies or discrepancies indicative of radar malfunctions or calibration errors are identified. The findings highlight the effectiveness of employing DWR and DDV as complementary tools for quality assurance of dual-frequency Doppler cloud radars.

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MITIGATION OF PERSISTENT CLUTTER IN SWEDISH WEATHER RADAR PRODUCTS

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The Swedish weather radar network currently consists of twelve C-band dual-polarimetric Doppler weather radars operated by the Swedish Meteorological and Hydrological Institute (SMHI). Between 2014 and 2021 the network was upgraded to dual-polarimetric capacity.

Initially, the magnetrons were operated out of specification and failed prematurely. Since June 2023 all radars are running H mode only and with a reduced duty cycle to extend the lifetime of the magnetrons. To restore full dual-polarimetric functionality, it has been proposed to match the impedance between magnetron and power supply and to automatically regulate the magnetron heater power in order to keep the heater temperature constant and independent of magnetron output power and duty cycle.

SMHI’s wildfire risk analysis is based on quality-controlled radar data. However, users have noted that large precipitation amounts, e.g. caused by persistent wind turbine clutter, might lead to an underestimation of the wildfire risk. For the ongoing wildfire season we have implemented a simple method based on a 60-days accumulation of precipitation amount. Any pixel with a value greater than 600 mm is considered invalid. Meanwhile we are developing a new method based adaptive compositing of quality volume data (ACQVA). This method can also be used to mitigate blocked sectors. At the conference we will present preliminary results and future plans.

CML APPLICATIONS WITHIN EMILIA ROMAGNA WEATHER SERVICE, ARPAE SIMC.

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Monitoring precipitation by opportunistic sensors (OS) means using instruments not primarily designed to accomplish this task but capable of producing sensitive information relative to this type of phenomenon. Precipitation estimates through OS may not be as reliable as observations from conventional sensors (CS), but access to this virtually free information can improve monitoring capabilities over a given territory. Opportunistic sensors include commercial microwave links (CML). CMLs are used in telecommunication networks: the microwave signal transmitted between antennas can be attenuated by the precipitation that occurs along the signal path. By exploiting the physical relationship between the rain rate and signal attenuation, it is possible to reconstruct the average precipitation between the antennas for a given instant.

In Emilia Romagna (IT), real-time CML data are collected and stored since June 2020 from the Hydro-Meteorological and Climate Service of the Region (Arpae-SIMC). The data are shared by the company Lepida ScpA and consist of couples of instantaneous transmitted (TSL) and received (RSL) signal power levels (expressed in dBm) at one minute resolution, integrated by metadata about the locations of the antennas and the signal properties. CMLs from Lepida are primarily located in mountainous area (the Apennines), with many crossing valleys and irregular terrain, which pose particularly difficult conditions for rainfall field reconstruction at ground level using radar alone.

The strategic location of the network and access to real-time data creates an opportunity to use this CML network as an operational tool for improve the estimate of precipitation at the ground. This goal is pursued by Arpae-SIMC through the activities presented here, which are part of the EU LIFE project CLIMAXPO and the MODMET, agreement between Arpae-SIMC and the Italian National Civil Protection Department. The activities conducted involve the creation of a real-time precipitation product from CML and a combined CML-CS product in which the precipitation estimate from the network is used to correct the estimated rainfall field from the radar. The performance of these products is defined by the comparison between the CML and the conventional available sensors, namely radar and rain gauges. The development of the techniques used is also based on the knowledge developed under the European COST Action CA20136, OPENSENSE: reference community for the use of opportunistic sensors, in which Arpae-SIMC is an active participant.

MONITORING THE QUALITY OF OPERA RAINFALL COMPOSITES FOR REAL-TIME FLASH FLOOD FORECASTING IN THE EDERA PROJECT

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The EUMETNET-OPERA surface rainfall rate composites have been an essential input to hydrometeorological applications (e.g., pan-European flood hazard assessments and forecasts induced by heavy rainfalls for real-time early warning). These composites benefit from their extended coverage at high resolutions (2 km and 15 minutes). However, the systematic monitoring of the quality of the precipitation composites is still necessary to guarantee the performance of such a warning system. Additionally, OPERA has recently renewed the production lines replacing the generation of rainfall rate composites from ODYSSEY to NIMBUS.

This presentation will focus on the comparisons of rainfall accumulations estimated from October 2023 to June 2024 from ODYSSEY and NIMBUS composites, and available gauges throughout Europe. The comparison also includes the derived gauge-adjusted OPERA products generated for flash flood forecasting within the ongoing project EDERA ("Early warning Demonstration of pan-European rainfall-induced impact forecasts"), funded by the EU Civil Protection Mechanism. The impact of different rainfall inputs on the flood hazard assessment and forecasts will be also analyzed with selected cases.

IMPLEMENTATION OF OPEN-SOURCE SOFTWARE IN AN OPERATIONAL RADAR PROCESSING CHAIN USING RAINBOW

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The Royal Netherlands Meteorological Institute (KNMI) operates two identical Meteor 735CDP10 Magnetron based C-band Dual polarization weather radars from Leonardo, located in Herwijnen (5.1379E 51.8370N, WSG-84) and at a naval base in Den Helder (4.78997E 52.9533N, WSG-84). After elementary signal processing and data reduction on-site at the radar locations, data is aggregated in a central Linux-based server at Amazon Web Services (AWS) for further processing and compositing into data products. The proprietary software Rainbow from the radar manufacturer is used in the operational processing chain to benefit from monitoring capabilities and version control in software upgrades. A drawback of using proprietary software is the limitation of implementing customer-specific algorithms into the processing chain. Research and development in radar software is often conducted using open-source software, such as the python based packages of PyART, and wradlib. Some algorithms in open-source software cannot be implemented as a precursor to Rainbow or after output from Rainbow, but need to be implemented at a specific step in the processing chain, e.g. dual-pol clutter correction algorithms. Implementation of such algorithms would require implementation by the manufacturer into Rainbow, despite it being readily available in open-source software. In order to ensure a rapid implementation of such algorithms and any foreseen further developments in open-source software, a connection of Rainbow with open-source packages has been developed. This manuscript describes the implementation of the dual-pol clutter correction algorithm, available in wradlib into the operational cloud-based data processing chain of KNMI.

CLEAR AIR AND WIND SHEAR MODES ON THE SOLID-STATE MOBILE RADAR

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Our solid-state C-band mobile weather radar has undergone testing with two distinct scanning strategies. The initial setup prioritized windshear detection during episodes of deep moist convection proximate to the radar. Subsequently, a secondary scanning strategy was developed to detect wind shear in clear-air conditions, devoid of precipitation in the radar's vicinity. This strategy aimed to enhance radar sensitivity.

In this poster presentation, we present a comparative analysis of these two scanning strategies, detailing their respective advantages and limitations. Through empirical data and case studies, we illustrate the efficiency of each strategy in detecting wind shear phenomena.

The first strategy, focused on convective conditions, demonstrates robust windshear detection capabilities during active weather events. However, it is limited in its applicability during periods of clear-air turbulence. Conversely, the second strategy, tailored for clear-air scans, showcases wind shear features in non precipitation events. We provide examples of measured data from both scanning strategies to underscore their performance in detecting wind shear events.

This poster offers insights into the operational utility of these scanning strategies for enhancing wind shear detection capabilities on solid-state mobile radar systems.

ID: 353, Oral presentation

ARE "IMMENSE" SUPERCELL UPDRAFT CORES A SUFFICIENT CONDITION FOR TORNADOGENESIS?

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Recent theoretical arguments and idealized modeling results have provided some evidence that larger supercell updrafts, at both storm mid and low levels, are associated with and even predictive of stronger tornadoes via angular momentum arguments and scaling relationships among the sizes of the updrafts, downdrafts, mesocyclones, and tornadoes. Eventually, a wider updraft would lead to larger tornado if a tornado were to form, and wider tornadoes are then assumed, generally, to be more intense than narrower tornadoes. Follow-up observational studies using remote sensing proxies for supercell updrafts have provided additional evidence of a relationship between updraft size and tornado strength. However, other idealized modeling studies have argued that mesocyclone properties, rather than updraft properties, partially modulate tornado intensity.

The original arguments regarding supercell updraft size have not extended to tornadogenesis and are only focused on tornado intensity. There have been no claims that wider supercell updrafts should result in a greater probability of imminent tornado formation compared to supercells with smaller or narrower updrafts. However, curiously and unexpectedly, previous work by the authors did find evidence of just such a relationship. In a comparison of ~45 non-tornadic and ~150 tornadic supercells, we used a novel algorithm to detect and partially automate the sizes of ZDR columns at ~1 km above the 0˚C level as a proxy for updraft size, and more likely, as a proxy for updraft core size. We found that tornadic supercells have larger ZDR column areas than non-tornadic supercells in the minutes before tornadogenesis (or peak low-level rotation in non-tornadic supercells). In addition, non- tornadic supercells also are more likely to have no ZDR column than tornadic supercells at these same times. One way to succinctly summarize the results: In ~45 non-tornadic cases studied during two volume scans each (~90 samples), there were zero occurrences of updraft area ≥ 40 km2, while there were ~75 such occurrences in the ~300 samples studied for tornadic cases. Herein, we refer to supercells with ZDR column areas ≥ 40 km2 as having presumed "immense" updrafts.

In this follow-up study, we pose a simple question: Is the presence of an immense supercell updraft a sufficient condition for imminent tornadogenesis? To address this question, we examine a much longer set of data for the aforementioned non-tornadic cases, so that we are examining hundreds of scans rather than ~90. We aim to gain a better estimate of the true relative frequency of immense supercell updrafts within non-tornadic supercells so that we may determine the viability of using immense updrafts as a skillful predictor of imminent tornadogenesis. Implications of the results on both basic research and operational nowcasting of tornadoes also is discussed with an emphasis on the practical limitations of the algorithm, case selection, data quality, and real-time use in a warning environment.

ID: 372, Oral presentation

IMPACT OF DIFFERENT REFLECTIVITY RADAR-BASED PRODUCTS ON THE PERFORMANCES OF A METEOROLOGICAL FORECASTING MODELING CHAIN

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The extreme meteorological events that have caused, especially in the last years, huge damages and casualties in Italy and in the whole Mediterranean area, drive the scientific community and the meteorological centers to increasingly invest in developing tools for nowcasting (up to 6 h ahead), short-term and longer term forecasting (up to 12 h and to 48h ahead, respectively). The main objective remains an accurate (in space and time) forecasting of the extreme weather events well in advance, but the present widespread diffusion of social media for the real-time dissemination of information is reducing the time-to-react to adverse weather, thus enhancing the role of short and very short-term forecasts, that can be also particularly reliable in terms of accuracy.

Radar products derived from the national meteorological networks play a fundamental role in this context. The Italian Department of National Civil Protection (DPCN) provides different radar products to the various regional meteorological centers. High-resolution numerical modeling can exploit these radar products with data assimilation (DA) processes. Among the state-of-the-art techniques, the three Dimensional variational technique (3DVar) is a well-established assimilation methodology with affordable computational costs for regional-scale meteorological centers.

This work aims at showing the impact on operational forecasts of a modeling chain that makes use of 3DVar using two different products provided by DPCN: the CAPPI (Constant Altitude Plan Position Indicator) and the volumetric data from which CAPPIs are calculated. CAPPI are in fact not fully representative of the entire volume of the observed reflectivity, even if their use brings computational and data pre-processing advantages (e.g. for the thinning).

The chosen limited-area model is a state-of-the-art model, WRF-ARW, with its data assimilation package, WRFDA, allowing the assimilation of radar data both directly, in terms of reflectivity, and through an inversion operator, in terms of hydrometeors mixing ratios, specific to the selected microphysical scheme.

As comparative test we focused on the case study of Nov. 2, 2023 flood, that hit the Tuscany region (central Italy) with a very heavy toll both as material damages and as casualties.

For this event, the model with no data assimilation underestimated the cumulated precipitation and localized the phenomenon further north than the area actually affected. The test we have carried out aims at showing benefits and limits of the model chain with data assimilation chain, that uses radar observations, evaluating the contribution of the different reflectivity products that can be assimilated in the forecast process.

ID: 374, Poster presentation

COMPUTING ECHO TOP PRODUCTS WITH FAST QUALITY-WEIGHTED SLIDING WINDOWS

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Echo top height provides information on the dynamics of precipitation phenomena, for example in distinguishing strong convection. In theory, defining echo top height is straightforward: it is the highest altitude where radar reflectivity exceeds a given threshold, say 10 or 20 dBZ.

As to practical computation, the geometry of radar measurements brings in a challenge. Typical operational scanning routines consist of azimuthal sweeps at a relatively small number of elevation angles. By traversing a single radar beam it is basically easy to track the bin(s) where the reflectivity decreases and passes the reflectivity threshold - but for a practical, viewable product the set of those bins is too sparse. This means that heuristics like interpolation and extrapolation are needed for approximating echo tops in the complete measurement area.

In the algorithm proposed in this paper, we consider three categories of measurements: strong echoes (equal or larger than the threshold), weak echoes (lower than the threshold) and empty bins (no detectable echo). The basic idea is to investigate vertical columns, recognising five classes of computational conditions: 1) the highest bin with a strong echo having a weak echo above, 2) the highest bin with a strong echo having an empty bin above, 3) the highest bin with a strong echo that is also the highest measurement, 4) only weak echoes have been detected, and 5) only empty bins in the column. These classes are also associated with numerical quality (reliablity) index, descending in the respective order. The first case implies that the echo top can be directly interpolated. The second case becomes similar, if the empty bin is handled like a bin with a very low reflectivity, say -30 dBZ. The third case suggests extrapolating upwards with an assumed or approximated reflectivity decay rate or alternatively, towards a fixed "dry point" aloft (which can also be seen as virtual interpolation). The other cases – only weak echoes or no echo detected – involve a possibility that a strong echo, hence an echo top, may still be hidden under the radar beams.

As a central idea, the proposed approach involves propagating reflectivity decay information from reliable areas – the interpolated areas – to less reliable areas using quality-weighted image window operator. We illustrate the he algorithm in different precipitation conditions and evaluate the performance using pairwise comparison of overlapping radars.

ID: 382, Poster presentation

ASSESSMENT OF RADAR QUANTITATIVE PRECIPITATION ESTIMATION OBTAINED BY THE X-BAND NETWORKED RADARS OF ARPA LOMBARDIA

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ARPA Lombardia (the Regional Environmental Agency of Lombardy) has strengthened its rainfall monitoring capabilities through the installation of three X-band dual-polarization meteorological radars between 2021 and 2022. Two of them are fixed systems with transmitters based on Solid State Power Amplifiers, installed in the municipalities of Flero (BS) on top of a piezometric tower in a position of optimal visibility over the central-eastern plain, and Desio (MB) in an ideal position for monitoring the Milan metropolitan area. The third one is a mobile system, also with dual polarization, temporarily installed in southern Lombardia. The three radars operate in a network providing mosaic precipitation and nowcasting products, based on the NSF LROSE suite. The applications concern the mitigation of risks related to adverse weather events, but also the optimal management of infrastructures in one of the most densely populated areas in Europe (2,036 inhabitants/sq km), support for major social events, and agriculture. In addition to the new radar systems, ARPA Lombardia enhanced the existing dense network of traditional rain gauges by incorporating six new laser disdrometers. These networks of in-situ instruments are ideal for evaluating the performance of single-radar and network products, particularly those based on different dual-pol algorithms whose behaviour can be better analysed with disdrometers. Since the installation of the radars, many storms including hail-generating, deep convective storms and windstorms occurred in Lombardy. A thorough comparison of the QPEs performance is shown. Overall, the radar network underwent rigorous testing in challenging scenarios typical of X-band systems, such as significant signal loss caused by wet radomes, path attenuation, hail, and mixed-phase precipitation.

Weather radar and climate

ID: 78, Oral presentation

A CLIMATOLOGY OF HEAVY CONVECTIVE PRECIPITATION OVER EUROPE

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The annual, seasonal, and diurnal spatiotemporal heavy convective precipitation patterns over a pan-European domain are analyzed in this study using a combination of datasets, including the EURADCLIM climatological gauge-adjusted radar precipitation dataset, OPERA ground-based radar derived precipitation rates, IMERG precipitation rate product, E-OBS ground-based precipitation gauge data, and ERA5 total and convective precipitation products. ATDnet lightning data is used in conjunction with EURADCLIM and IMERG precipitation rates with an imposed threshold of 10 mm hr^{-1} to classify precipitation as convective. Annually, the largest convective precipitation accumulations are over the European seas and coastlines. In summer, convective precipitation is more common over the European continent, though relatively large accumulations exist over the northern coastal waters and the southern seas, with a seasonal localized maximum over the northern Adriatic Sea. Activity shifts southward to the Mediterranean and its coastlines in autumn and winter, with maxima over the Ionian Sea, the eastern Adriatic Sea, and the adjacent coastline. Over the continent, 1 – 10% of the total precipitation accumulated is classified as convective, increasing to 10 – 40% over the surrounding seas. In contrast, 30 – 50 % of ERA5 precipitation accumulations over land is produced by the convective parameterization scheme and 40 – 60% over the seas; however, only 1% of ERA5 convective precipitation accumulations are from rain rates exceeding 10 mm hr^{-1}. Regional analyses indicate that convective precipitation rates over the inland mountains follow diurnal heating, though little to no diurnal pattern exists in convective precipitation rates over the seas and coastal mountains.

ID: 31, Oral presentation

WILDFIRES OBSERVED BY SURVEILLANCE WEATHER RADARS AT 3, 5 AND 10 CM WAVELENGTHS

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Observations by weather surveillance radars of several wildfires over contiguous US are presented. Weather Surveillance Doppler 1988 (WSR-88D) polarimetric radars have 10 cm wavelength and because of their widespread distribution these can observe most, if not all, wildfires in the US. Their polarimetric capability enables discerning smoke plumes from other distributed scatterers. In addition, Terminal Doppler Weather Radars (TDWR) have also captured data from wildfires, but do not have dual polarization capability and radiated 5 cm wavelength signals. Data obtained whereby both WSR-88D and TDWR observed same wildfire from similar range but opposite viewing angle are presented. Use of Computational EM solvers is applied to a leaf model at the two wavelength. Comparing result of this model with observations indicates the major contribution to reflectivity is from leafs ash having area of about 400 mm^2.

Data from a widespread wildfire over three states was collected with these two radar types as well as with a 3 cm wavelength polarimetric radar. The volumes observed by the radars were non-overlapping. Therefore, independent statistical analysis of polarimetric data is conducted to discern the dependence on wavelength. Moreover, an attempt is made to deduce the distribution of sizes contributing mostly to the smoke plume. From this event and a few others including a prescribed burn, it is observed that a depression in differential reflectivity indicates location of pyro-updrafts. This has operational value as it indicates progression of fire on the ground, thus enabling deployment of fire extinction crew to the right location.

ID: 97, Poster presentation

AN EVALUATION OF DWD'S LONG RUNNING ADJUSTMENT METHOD FOR THE REAL-TIME AND CLIMATOLOGICAL RADAR-BASED PRECIPITATION PRODUCTS

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At the German Weather Service (DWD), quantitative radar-based precipitation estimates are derived through a combination of the 17 C-band radars, that deliver nationwide spatio-temporal high-resolution data, and hourly gauge values. The key to this system is the RADOLAN (Radar Online Adjustment) process, which has been operational since 2005. RADOLAN is used to adjust the radar-based precipitation estimates using the hourly gauge values. This ensures that the final precipitation data is both spatially detailed and calibrated to ground-based observations.

RADKLIM, the radar climatology of precipitation, is based on RADOLAN but uses additional daily station measurements that are disaggregated with radar data. If gauge values are corrected later on, they can be incorporated into RADKLIM with the corrected values. In RADKLIM, the type of data has been the same since 2001. Each of the 17 C-band radars provides data at a 1 km resolution for a range of 128 km with a 5-minute temporal resolution. Only the single-polarized moment Zh (reflectivity) is used in the RADKLIM dataset.

To overcome the technical limitations of RADKLIM, a new version called POreClim is currently under development. POreClim uses input data with a 250 m resolution and a 150 km range, which provides more overlapping radar areas. Additionally, POreClim utilizes dual-polarized moments where possible, which should lead to a "best possible" precipitation climatology.

The results of RADOLAN, RADKLIM, and POreClim should be similar, but it is important to understand the strengths and weaknesses of each dataset. To evaluate their performance, a new dataset of gauge data that has not been used in RADOLAN or RADKLIM will be used for comparison. This will allow for an independent assessment of the accuracy and correctness of the adjusted and unadjusted precipitation products. By comparing the different datasets, we can determine if the adjustment process in RADOLAN and RADKLIM is effectively improving the precipitation estimates and whether the newer, higher-resolution and dual-polarized data in POreClim is leading to better results.

ID: 107, Oral presentation

MERGING WITH CROWDSOURCED RAIN GAUGE DATA IMPROVES OPERA RADAR PRECIPITATION ACCUMULATIONS

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There is a need for adjustment with rain gauge data to obtain radar precipitation accumulations with reasonably accuracy. However, the network density or availability of real-time rain gauge data from government agencies is typically low. This could potentially be mitigated by crowdsourced rain gauge networks given their much higher density and potential real-time availability. Here, a 1-year personal weather station (PWS) rain gauge dataset from the brand Netatmo, over the period 1 September 2019–31 August 2020, is merged with pan-European radar accumulations from the EUMETNET programme OPERA. Gauge data from National Meteorological Services (NMS) are not employed in the merging. Quality control is applied to these ~5-min accumulations employing neighbouring PWSs and, after aggregating to 1-h accumulations, employing unadjusted radar data. Finally, the 1-h radar accumulations from each clock-hour are spatially adjusted with the corresponding quality controlled 1-h PWS rain gauge accumulations. The unadjusted and adjusted radar precipitation estimates are evaluated against rain gauges mostly sourced by NMS from the European Climate Assessment & Dataset (ECA&D). Due to the merging, the average underestimation of daily precipitation decreases from ~28% to ~3%. Spatial verification shows that the relative bias in 1-h precipitation is still quite variable with stronger underestimations for colder climates. These are likely caused by the absence of a heating element in the PWS rain gauges. Performance is also compared to that of the European climatological high-resolution gauge-adjusted radar precipitation dataset EURADCLIM. Concluding, crowdsourced precipitation data comes a long way to improve (near) real-time radar precipitation products.

ID: 114, Oral presentation

IMPROVEMENTS IN THE SNOWFALL SAMPLING DUE TO THE WIVERN CONICALLY SCANNING RADAR

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Mass loss from the Antarctic and Greenland Ice Sheet leads to sea level rise and can impact on the ocean surface temperature, salinity, thermohaline circulation and ecosystems. Accurate snowfall measurements at polar regions are fundamental for the estimation of the mass balance of ice sheets; however, the snowfall is hard to quantify with in-situ measurements in those locations. In this context, spaceborne radar and radiometers atmospheric missions can help in the assessment of snowfall at high latitudes.

While the NASA's CLOUDSAT mission provides valuable climatological information, due to its very poor sampling its data cannot be used as inputs for the surface mass balance of the ice sheets especially at short time scale and fine spatial scales. WIVERN (WInd VElocity Radar Nephoscope), one of the two remaining candidates in the Earth Explorer 11 program, carries a conically scanning 94 GHz Doppler radar and radiometer with the aim of measuring global in-cloud horizontal winds and precipitation. Its conically scanning system, with a 41.6 degrees incidence angle, allows the mission to have a swath width of 800 km and 70 times more sampled points than a fixed looking instrument. This translates in much better sampling, highly improving the accuracy of the snowfall measurements, crucial for understanding the ice sheet dynamics.

The error in the snowfall measurements arises from various factors, including the diurnal cycle, uncertainty in the Z-S relationship, and the sampling error. This study quantifies each of these contributors individually through simulations of WIVERN and CLOUDSAT orbits and radar illuminations and by using the ERA5 0.25°x0.25° reanalysis hourly snowfall rates as a realistic reference field. Notably, it identifies the sampling error as the predominant source of error in snowfall retrievals.

The improved sampling is demonstrated, with a focus on some specific regions and sectors of Antarctica and Greenland with substantial ice mass loss, by computing the sampling error at different temporal (e.g. bi-weekly, monthly and yearly) and spatial scales. A comparison between the performance of the two satellites highlights how the WIVERN conically scanning system significantly reduces the uncertainty in the snowfall rates estimation thus enabling accurate retrieval of snowfall accumulation at monthly and regional scales, key observables for ice sheet mass balance studies.

ID: 124, Oral presentation

A DETAILED CALIBRATION STUDY AND 10 YEAR CLIMATOLOGY OF QUASI-VERTICAL PROFILES IN STRATIFORM RAIN

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A climatology of quasi-vertical profiles (QVPs) of polarimetric variables based on the measurements of the X-band radar located in the city of Bonn in western Germany performed between 2013 and 2023 is presented. QVPs with stratiform rain are selected and special emphasis is given to the signatures in the melting layer (ML) and the dendritic growth layer (DGL). Due to the unprecedent sample size and the inclusion of all seasons, this comprehensive climatology enables the verification of existing hypotheses with statistical evidence and enables a better understanding of microphysical processes. This comprehensive climatology at X-band can also serve as a reference for detailed numerical model evaluation and parameterization development. Before creating the climatology, the radar reflectivity factor (ZH) is calibrated exploiting the relationship between ZH and (calibrated) differential reflectivity (ZDR) in light rain. This ZH calibration method is highly dependent on an accurate calibration of ZDR. We draw attention to shortcomings that may occur when using the often preferred birdbath scan technique to correct ZDR and compare according results with an alternative calibration method using QVPs in light rain. Only in the time period between April 2014 and March 2017 the ZDR offsets calculated with the two different methods are in agreement, otherwise inaccuracies up to 0.2 dB occur. These uncertainties can possibly be attributed to various changes/replacements in the radar software and/or hardware. The obtained ZH offset values are validated using both satellite information and self-consistency relationships applying the specific differential phase, demonstrating the suitability of this method. The climatology is presented by utilising contour-frequency temperature-diagrams of polarimetric variables, where statistical methods, e.g. correlation matrices, are used to analyse polarimetric variables related to the ML and DGL, e.g. ML thickness or maximum ZH within the DGL/ML. This unprecedented database enables to identify the dominant microphysical processes throughout each season and allows to verify associated hypotheses from past studies, such as the seasonality of the ML thickness.

ID: 182, Oral presentation

LATEST RESULTS OF INCLUDING ZDR COLUMN FOR ENHANCED RADAR DATA ASSIMILATION AT GERMAN WEATHER SERVICE (DWD)

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Radar data assimilation has been operationally used in the short-range ensemble numerical weather prediction (SRNWP) system (ICON-D2-KENDA LETKF system) at DWD since 2020 (radial wind from March 2020 and reflectivity from June 2020). It is in addition to the traditional Latent Heat Nudging (LHN) of 2D radar-derived precipitation rates.

Moreover, the study of radar data assimilation in NWP models and its effect particularly on short-term forecast has been intensified recently at DWD. In particular, the seamless Integrated ForecastiNg sYstem (SINFONY) project that leads a short-term forecasting system focusing on convective events from minutes up to 12 h shows clearly the benefit of radar data assimilation in improving the short-term forecast.

Furthermore, the integration of polarimetric radar parameters as a novel observational source into the data assimilation system at DWD has been considered recently at DWD. One of the most notable parameters is the so-called Z_{DR} column, defined based on the differential radar reflectivity (Z_{DR}), indicating a narrow vertical layer of positive Z_{DR} above the 0°C level. This feature is closely linked to deep convective storms and can serve as an indicator of large raindrops or hail particles. We will present our latest results on incorporating the ZDR column as a new observational input in Observing System Simulation Experiments (OSSE) complementing radial wind and reflectivity data, based on the operational data assimilation framework used at DWD.

ID: 224, Poster presentation

SETTING THE BASIS: EXPLORING Z-R RELATIONSHIPS IN X-BAND RADARS IN THE LOMBARDY REGION

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Radar measurements for precipitation estimation are highly valuable in capturing its spatial variability. Therefore, a comprehensive understanding of radar measurements and optimal algorithms for precipitation retrieval is essential for enhancing weather forecasts and their relevance in hydrological applications. The present study focuses on quantitative precipitation estimation through radar-based measurements in the Lombardy Region using basic Z-R relationships. Specifically, data from the two newly installed X-band radars by the Regional Environmental Protection Agency of Lombardy Region (ARPA Lombardia) are utilized.

The aim of the study is to establish the basis for quantitative precipitation estimates using X-band radars, allowing for the comparison of more advanced techniques and algorithms with the basic precipitation retrieval provided by calibrated Z-R relationships.

The methodology involves comparing rainfall intensity measured by the rain gauge network of ARPA Lombardy with the radar reflectivity factor measured by the radars within the scanned volume. Event-based calibration of Z-R relationships is conducted by considering rainfall intensities from rain gauges and radar reflectivity factors at the height level where the strongest correlation between these data is identified. Specifically, focusing on the Po Valley region helps overcome challenges associated with orographic influences on precipitation retrieval. Adjustments for wind velocity are taken into consideration when correcting rain gauge precipitation estimates. Additionally, comparative analysis with established Z-R relationships from literature, such as the Marshall-Palmer relationship, is carried out using common statistical indices, while the parameter variability is underscored across different events.

With this approach, calibrated Z-R relationships are derived for various events. Therefore, comparisons with future results involving new developments, for instance, accounting for the orography in the studied area, utilizing polarimetric variables such as specific differential phase, specific attenuation (which are less influenced by the characteristic attenuation of X-band radar measurements), or even implementing state-of-the-art techniques involving machine learning and deep learning algorithms, can be performed.

MAPPING RAIN: NAVIGATING THE MAZE OF PRECIPITATION DATASETS ACROSS EUROPE

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Accurate precipitation data is crucial for a range of applications and sectors, from water resource management to climate studies. Here we present a comprehensive comparative analysis of gridded precipitation datasets over Europe and particularly over Germany. The datasets selected include products obtained from satellite platforms with gauge-adjustment (e.g. IMERG Final Run), from ground-based radars with gauge-adjustment (e.g. RADOLAN), and from gauge networks only (e.g. GPCC, HYRAS); the latter are used as reference datasets. Additionally, we include precipitation data from the ERA5 reanalysis and from a 12 km simulation from the TSMP regional climate system model (with COSMO atmospheric model). We examine their spatial and temporal characteristics, accuracy and reliability with metrics like bias, root mean square error, and probability density functions; and consider different precipitation features like frequency, intensity, timing, and yearly and monthly totals. We evaluate timescales from the interannual scale to the subdaily scale, in the period 2000-2020 (depending on availability of the datasets).

Distinct characteristics and biases among the datasets have been identified. E.g., IMERG exhibits large positive biases compared to all other estimates, even in Germany where the rain gauge network is dense and IMERG is supposed to be heavily gauge-adjusted. Ground-based radar datasets provide high-resolution precipitation estimates but suffer from attenuation and beam blocking issues, among others. Nonetheless, their performance is good and the results are close to those from purely rain-gauge-derived datasets. On the other hand, the performances of ERA5 and the TSMP simulation fall within the range of uncertainty of the observational datasets, but biases in precipitation totals and in the timing of the diurnal precipitation cycle are evident. Overall, the quality of most products seems to improve with time as they converge in the last years of the analyzed period, and which we attribute to improvements in the quality and availability of data from the different instruments.

ID: 245, Oral presentation

A CLIMATOLOGICAL STUDY ON THE TWO TYPES OF BOW ECHOES OVER SOUTH CHINA

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Classical bow echoes (CBEs) normally develop due to rear-inflow jets, while merger- formation bow echoes (MFBEs) evolve from the merger between linear systems and preline convection. MFBEs are rarely documented before, and the key processes remain unclear because of the small-scale and fast-evolving merging processes. Using radar observations during 2015–2019, this study examines the characteristics of these two types of bow echoes over South China. Eighteen MFBEs and 11 CBEs are identified, accounting for 62% and 38% of the total 29 bow echoes, respectively. MFBEs commonly occur over coastal regions in the afternoon, where southerly sea breezes provide favorable thermodynamic conditions. About half CBEs develop over mountainous areas in the morning, and northerly winds enhance the local baroclinity and kinematic convergence. A new Merger-Classical index is proposed to distinguish the environments for the development of two types of bow echoes, disclosing the more favorable near-surface thermal conditions for MFBEs. In addition, more severe weather occurs in metropolitan area near the Pearl River Delta region during MFBEs, in which the accumulated precipitation is about 2.5 times higher than that during CBEs. This study reveals the discrepancies between MFBEs and CBEs over South China, emphasizing the MFBEs account for more than half of the total bow echoes and cause more high-impact weather in the metropolitan area. This study proposes a new perspective on the environment in which bow echo forms by merger process over South China, urging for more research to explore the underlying processes.

ID: 267, Poster presentation

A DEEP LEARNING MODEL WITH EXPLICIT TEMPORAL ENCODING FOR ENHANCING RAINFALL NOWCASTING

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Short-term rainfall prediction, crucial for flood warnings and infrastructure management, is the domain of rainfall nowcasting. Traditional methods rely on tracking rainfall movement in radar images but struggle to accurately capture the development and evolution of rain fields, especially for longer timeframes. Deep learning offers a promising alternative by learning complex patterns from historical data. However, existing DL models can struggle with capturing the long-range dependencies in rainfall data, often leading to blurred predictions and inaccurate nowcasts, particularly during heavy rainfall events. This study proposes a deep learning model which incorporates separate modules for capturing spatiotemporal relationships within rainfall data. The model uses Depthwise Separable Convolutional layers within the encoder and decoder to capture spatial correlations, and a dedicated temporal unit to capture temporal dependencies. We implemented the model in three different configurations: a single- step prediction, a multi-step implicit encoding and a multi-step explicit encoding. A comparison between these configurations is presented. Furthermore, we evaluated our model's performance against existing methods such as PySTEPS and RainNet. This evaluation uses UK Met Office's radar rainfall data from the NIMROD system. The results demonstrate the effectiveness of our model in improving high-rainfall intensity prediction and generating sharper forecasts.

Keywords: radar; deep learning; spatiotemporal rainfall nowcasting; optical flow

ID: 286, Poster presentation

CLASSIFICATION OF CONVECTIVE SYSTEMS YIELDING TORNADOES IN JAPAN

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Tornadoes frequently occur in Japan. Japan Meteorological Agency (JMA) listed them in the database with environmental situation or synoptic disturbances. The kinds of convective system yielding tornadoes, however, have not been classified yet. We plan to establish tornado climatology depending on the types of convective systems. The risks of tornado damage will be evaluated easily based on the types of them. The present research aims to classify the parent convective systems of tornadoes based on the shape of radar reflectivity.

The tornado events those located within the observation range of JMA radars are picked up from the tornado database. Analysis periods are 7 years from 2017 to 2023. The kinds of convective system are classified based on the shape and size of strong echo region more than 40dBZ in reflectivity. The vortices in the convective system are also detected based on a caplet of maximum and minimum Doppler velocities. Then we evaluate the characteristics of the vortices, e.g., diameter, velocity difference and moving velocity.

As the results, the parent convective systems were classified to 6 kinds. Isolated cumulonimbus is a relatively small scale and consecutive strong echo region is not seen in surrounding area. This is the second most system. Supercell is also isolated from surrounding area, but its' strong echo region is quite larger than that of the isolated cumulonimbus. It also has a large-scale vortex called as mesocyclone. Cloud cluster is composed of many convective cells but their cells cannot be distinguished with each other. Then, Strong echo region of it is extended to relatively large area. Squall line is a kind of linear rain band and moves fast at a large angle for its direction. Local front is also a kind of linear rain band composed of small-scale cells. It is relatively small and moves slowly. The inner rainband of typhoon is the case the vortex locates in the eye wall of typhoon. The most major system was the cloud cluster and second one was the isolated cumulonimbus. The isolated cumulonimbi occur on the sea and coastal area. They tend to occur in autumn evening. The supercell occurs with a typhoon. The cloud cluster occurs south coast of Japan faced on the Pacific Ocean and Tohoku district faced on the Sea of Japan. They sometimes occur in the inland at summer morning. The local front occurs in the Sea of Japan. The vortices were found to shrink their diameter after landfall. The vortices whose maximum velocity, i.e., the sum of tangential velocity and moving velocity, is not exceed 21 m/s are found not to cause damage on the surface.

ID: 301, Poster presentation

QUALITY MAPS FOR HAIL MONITORING AND HAIL ANALYSES AND A LONG-TERM HAIL SIZE ARCHIVE FOR AUSTRIA

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Hail is a rare but serious weather phenomenon, and a comprehensive and area-wide recording of hail is subject to many uncertainties. New hail hazard maps for Austria were published on the internet platform HORA - Natural Hazard Overview and Risk assessment Austria (www.hora.gv.at) in 2024 to raise general awareness of the risk of hailstorms and improve the development of effective measures to mitigate damages. Fourteen years of three-dimensional radar reflectivity data (2009-2022) were quality controlled and analyzed to build a hail size archive. A comprehensive, quality controlled dataset of hail reports from eye-witnesses and fire brigade units was used to calibrate the hail size indicator MEHS (maximum estimated hail size, Witt et. al., 1998) to recorded hailstone sizes. The new hail size archive enabled studies on the distribution of hail size frequencies and maximum observed hail sizes as well as a metastatistical approach to estimate return levels.

An important question on the way to the final maps was how to deal with the different types of uncertainties. There are uncertainties related to the radar measurement due to measurement geometry and the derivation of hail parameters. And there can also be effects due to inhomogeneous radar settings within the radar network.

First, the method for creating a comprehensive hail size archive and the uncertainties that have arisen in the hail hazard studies in Austria are presented. An approach for analyzing and presenting these uncertainties is then presented and discussed.

ID: 332, Oral presentation

SUB-DAILY EXTREME PRECIPITATION TRENDS: NEW INSIGHTS FROM COMBINING RADAR DATA AND CONVECTION PERMITTING CLIMATE SIMULATIONS

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In this study, simulated and observed trends of heavy precipitation are examined, with a focus on short-duration convective events. The results serve as a basis for planning adaptation measures for the drainage system of Hanover, Germany.

Random differences, decadal variability, limitations of climate models and data limitations can lead to trends of heavy precipitation being obscured or exaggerated, thereby complicating interpretation. Regarding short convective events, changes in measuring instruments lead to additional uncertainties. On the other hand, there are relevant insights and recent advancements which contribute to a more comprehensive understanding. The creation and evaluation of radar climatologies such as the German product RADKLIM (DWD) serve as an important additional component. While the period covered by radar climatologies is still relatively short, events can be analysed in their spatial-temporal context and facilitate spatially aggregated assessments. The last ten years of RADKLIM data show a significant higher number of extreme precipitation events in the study area around Hanover compared to the decade before.

Convection-permitting climate models (CPM) with a horizontal resolution of 3-4 km depict precipitation more realistically than conventional regional climate models, according to recent studies. While mean and extreme daily precipitation totals are satisfactorily simulated, extremes of sub-daily precipitation still exhibit significant deviations compared to observations. Therefore, in this study, CPM data is combined with statistical relationships from observational data to better capture extremes for shorter durations, starting from daily values. An empirical statistical downscaling method from the Best-Prog family is employed, utilizing station and radar data. The results are evaluated and used as input data for the SIMBA# model, a combined sewer and wastewater treatment plant model, to simulate the impacts on Hanover's drainage system.

The Federal Ministry of Education and Research (BMBF) is funding the project „ZwillE – Digitaler Zwilling zum KI-unterstützten Management von Wasser-Extremereignissen im urbanen Raum“ within the „Wasser-Extremereignisse (WaX)“ funding measure as part of the federal research program on water “Wasser: N”. Wasser: N contributes to the BMBF “Research for Sustainability’ (FONA) Strategy”.

ID: 335, Poster presentation

DETECTING SMOKE FROM FOREST FIRES IN THE AMAZON WITH AMAZONIAN WEATHER RADAR NETWORK

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The Amazon is considered one of the richest environments in terms of biodiversity in the world. However, such greatness has not been respected and goes unnoticed by the interests of exploiters who seek to profit from the modification and use of the land. The advance of agricultural activity in the region has resulted in numerous consequences such as forest fires, a common practice used to clear large areas of pasture. Many of these fire events occur in hard-to-reach places in the Amazon, making it impossible for firefighting authorities to monitor them in loco. Thus, the use of remote sensing is essential to mitigate the impacts of forest burning, especially through environmental satellites. However, recent studies have shown that it is possible to detect smoke from forest fires, not only through satellite images, but also through weather radar images. Thus, the present study aimed to analyze the efficiency of meteorological radar in detecting fires in three places in the Amazon: Porto Velho-RO, Manaus-AM and Boa Vista-RR. To carry out this work, data generated by meteorological radar located in the 3 cities that make up the radar network of the Management and Operational Center of the Amazon Protection System (CENSIPAM) were used. The network is made up of 11 S-band Doppler type weather radars adjusted in the 250 km scan spread across the Amazon. To simplify the analysis, images without rainfall in the covered area and with occurrences of forest fires on the day in the vicinity of the radar were selected. In the 3 cities analyzed, the radars detected static reflectivities above 30 dBZ, which indicates the exact point where the forest burning was occurring, while smaller reflectivities (below 30 dBZ) were observed moving away from the maximum reflectance, which signals that it is the smoke plume from the fire. Thus, it is possible to conclude that CENSIPAM's radars in the Amazon were efficient in detecting both the displacement of the smoke plume, as well as in signaling its place of origin. However, its efficiency is limited to a radius of up to 100 km away from the radar, probably due to its physical limitations.

RADAR CHARACTERISTICS OF WIND HAZARDS ASSOCIATED WITH DEEP MOIST CONVECTION

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Low-level horizontal wind shear is one of the most prominent accompanying phenomena in convective thunderstorms. It poses a serious threat to aviation, especially for landings and takeoffs. Horizontal wind shear can also generate vertical vorticity, which can result in the development of mesovortices and tornadoes.

In our poster, we will discuss the amount of horizontal wind shear along squall lines and regions of mesocyclone within supercells and their proximity. We quantify these regions in detail in terms of horizontal wind shear in relation to the environment in which the convection developed. The environment that determined the development of convection will be studied using proximity soundings or parameters derived from the WRF model or the ERA-5 reanalysis. The main goal of the poster will be to establish the relationship between the convective environment and the radar characteristics detected and computed from the Doppler velocity data.

ID: 355, Oral presentation

THE ROLE OF METEOROLOGICAL CONTROLS ON ARCTIC CLOUD AND PRECIPITATION PROPERTIES FROM RADAR-BASED RETRIEVALS: RESULTS FROM MOSAIC AND SHEBA

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Knowledge of the processes controlling Arctic cloud and precipitation properties, especially from dynamical atmospheric drivers, remains limited due to the sparse number of non-spaceborne observations collected at high latitudes. Two shipborne expeditions that took place over the last 25 years in the Arctic, the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC; October 2019 through October 2020) and the Surface Heat Budget of the Arctic Ocean (SHEBA; October 1997 through September 1998), offer some of the most comprehensive multi-platform observations of collocated sea-ice, cloud, and precipitation observations in the Arctic sea ice. Between the two campaigns, nearly 600,000 radar profiles are available for use with a cloud and precipitation retrieval algorithm synergizing Ka- and W- band radar, depolarization lidar, ceilometer, radiosonde and microwave radiometer observations. The results of this algorithm show that mixed-phase clouds were observed 30% and 37% of the time during MOSAiC and SHEBA respectively, and observed year-round during both campaigns. Liquid precipitation was uncommon during both campaigns, but was observed 7.7% of the time for MOSAiC versus 4.7% of the time for SHEBA. Clear skies occurred 19% of the time during MOSAiC, whereas clear skies were observed 32% of the time during SHEBA.

To understand the meteorological context of these cloud observations, subsidence (vertical velocity) and estimated inversion strength (EIS) were computed from European Center for Mesoscale Weather Forecasting Reanalysis (ERA-5) data for (1) the MOSAiC campaign, (2) the SHEBA campaign, and (3) from 1959-2020 for each experiment domain. Differences in distributions of both EIS and subsidence for both campaigns with respect to their full ERA-5 climatological dataset were statistically insignificant, showing conditions observed during MOSAiC and SHEBA were climatologically representative of the larger sample. Near the Arctic Circle, EIS was positive over 97% of the time for both experiments, though the magnitude of EIS was typically greater during SHEBA by an average of 4K, which possibly explains why observed cloud fraction was typically greater during MOSAiC. The greater cloud fraction during MOSAiC might also be explained by the fact that atmospheric stability over the Arctic has decreased over the last 6 decades, with average EIS dropping an average of ~0.6 K per decade across the Arctic. Seasonality is also observed for both campaigns, with nearly all liquid rain and drizzle, the highest radar-observed cloud tops, and the highest reflectivity values occurring during the summer months. Finally, snow was observed 11.4% and 7.3% of the time for MOSAiC and SHEBA, respectively, with similar precipitation frequency in all atmospheric stability regimes. Transient cyclones, originating from the midlatitudes, almost always explain rain and drizzle events occurring in the non-summer months, with convection sometimes exceeding 5 km in height.

ID: 367, Poster presentation

A RADAR FOR WEATHER MONITORING IN AMAZON BASIN MINING CHAIN

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A new meteorological dual-polarimetric radar installed in the Brazilian Amazon has been used in mining chain operations. Planning to reduce operational downtime due to adverse environmental conditions helps to reduce accidents, production losses and optimize profits. This new data set based on 2 years of information represents the continuous 150-km volume scan and has been allowing new knowledge about rain cycles, storm characteristics and the relationship between these occurrences and the mining company's operational shutdowns. Beam Blockage was corrected using filters based on correlation coefficient and radial velocity. During the rainy season, rain occurs at any time of the day, but is more frequent between early morning and mid-afternoon. The dry season is characterized by 2 peaks of rain, one in the early morning and the other between late morning and mid-afternoon. The transition season between dry and rainy features rain between early morning and late afternoon, concentrated between late morning and early afternoon. In all seasons, the convective portion of the storms are more frequent between the end of the morning and the end of the afternoon, with a peak between 2 and 3 pm local time. The intense rains in a short period of time increase the number of operational stops and tend to moisten ore. In the same way that severe storms increase the number of stops because they create greater risk for workers.

ID: 368, Oral presentation

COMPARISON BETWEEN DPR VERSION 7 AND DISDROMETERS OVER ITALY

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Precipitation monitoring is crucial for understanding Earth's climate system and its impacts on various sectors such as hydrology, water management, and agriculture. Satellite-based measurements, particularly through missions like the Global Precipitation Measurement (GPM), have significantly enhanced our ability to observe precipitation patterns globally. Validating satellite-based precipitation measurements is crucial to ensure their accuracy and reliability. This process requires a comparison with ground-based observations, typically provided by rain gauges and weather radars. The agreement between ground and satellite observations is assessed through statistical metrics which assess how well satellite products capture the quantitative estimation of precipitation or the parameters characterizing

precipitation. In this context, the GPM mission developed the Ground Validation program which aims to validate and improve precipitation retrieval algorithms.

Onboard the GPM Core Observatory, a key instrument is the Dual-frequency Precipitation Radar (DPR), consisting of the Ku-band Precipitation Radar (KuPR), which operates at 13.6 GHz, and the Ka-band precipitation radar (KaPR) at 35.5 GHz. This work focuses on validating GPM DPR Level 2 Version 7 products over Italy using ground-based laser disdrometers networked by the GID (Gruppo Italiano Disdrometria, in Italian). The GID network includes, at the time of writing, 23 disdrometers, many of them recently installed.

Version 7 of DPR products is the first one that incorporates the scan pattern modification for the KaPR implemented on May 21, 2018. This change in the scan pattern enables the application of the dual-frequency radar across the entire observation swath of 243 km, along with algorithm advancements. The scan pattern encompasses 49 footprints of approximately 5 km in diameter each. This study uses the dual frequency-based 2ADPR-FS, the SF-based 2AKa-FS and 2AKu-FS Version 7 Level 2 DPR products. GPM data from May 22, 2018, to November 7, 2023, were analyzed. The comparison was performed applying different methods to match the satellite and the disdrometer measures. The following variables have been investigated: the reflectivity factors at the Ku and Ka bands corrected for attenuation, the rainfall rate, and the DSD parameters D_m and N_w. Statistical indices are used to assess the agreement between satellite observations and disdrometer data. Considering all the variables used for the comparison, dual frequency products do not produce a significant improvement, although, in most of the cases, the agreement is slightly better with respect to single frequency products. Moreover, rainfall rate and radar reflectivity factors show stronger correlations and relatively lower error rates across various products and comparison methods. However, there are disparities in the performance of rainfall and microphysical parameters, which are more pronounced in cases where disdrometers are located at high altitudes in complex orography.

The insights gained from the GPM validation studies, particularly regarding the use of ground-based disdrometers, provide a valuable foundation for developing validation strategies for other missions. This is especially relevant for the validation of cloud and precipitation products from the recently launched ESA/JAXA EarthCARE satellite. The EarthCARE satellite presents unique challenges for precipitation due to the adoption of the W band frequency and the lack of a scanning mode, which limits the opportunities for coincident measurements.

Weather Radar technologies

ID: 10, Oral presentation

THREE-DIMENSIONAL VARIATIONAL MULTI-DOPPLER WIND RETRIEVAL OVER COMPLEX TERRAIN

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The interaction of airflow with complex terrain has the potential to significantly amplify extreme precipitation events and modify the structure and intensity of precipitating cloud systems. However, understanding and forecasting such events is challenging, in part due to the scarcity of direct in situ measurements. Doppler radar can provide the capability to monitor extreme rainfall events over land, but our understanding of airflow modulated by orographic interactions remains limited. The SAMURAI software is a three- dimensional variational data assimilation (3DVAR) technique that uses the finite element approach to retrieve kinematic and thermodynamic fields. The analysis has high fidelity to observations when retrieving flows over a flat surface, but the capability of imposing topography as a boundary constraint is not previously implemented. Here, we implement the immersed boundary method (IBM) as pseudo-observations at their native coordinates in SAMURAI to represent the topographic forcing and surface impermeability. In this technique, neither data interpolation onto a Cartesian grid nor explicit physical constraint integration during the cost function minimization is needed. Furthermore, the physical constraints are treated as pseudo-observations, offering the flexibility to adjust the strength of the boundary condition. A series of observing simulation sensitivity experiments (OSSEs) using a full- physics model and radar emulator simulating rainfall from Typhoon Chanthu (2021) over Taiwan are conducted to evaluate the retrieval accuracy and parameter settings. The OSSE results show that the strength of the IBM constraints can impact the overall wind retrievals. Analysis from real radar observations further demonstrates that the improved retrieval technique can advance scientific analyses for the underlying dynamics of orographic precipitation using radar observations.

A NEW C-BAND DWR ARCHITECTURE WITH DUAL TRANSMITTER, MAGNETRON AND SOLID-STATE POWER AMPLIFIER, AT THE DWD METEOROLOGICAL OBSERVATORY OF HOHENPEISSENBERG BY EEC

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Over the course of the last years, the solid-state power amplifier (SSPA) technology has entered the weather radar industry as a potential substitution to currently operated transmitters such as magnetron or klystron tubes.

As the use of the SSPA implies different techniques regarding pulse shapes and sequences, as well as wave forms, it represents a challenge for national weather and hydrological services to evaluate the data quality of this new technology in comparison to the existing radar networks in operation.

We will present here the architecture of a newly installed SSPA transmitter with a peak power of 10 kW in parallel to the existing magnetron tube transmitter of 500 kW of the C-Band Dual Polarization Doppler Weather Radar of the German Meteorological service installed at the Meteorological Observatory Hohenpeißenberg in Germany.

The aim is to provide to DWD a power amplifier transmitter with all related wave form and pulse train capabilities that operates on the same analog transmitting and receiving path as the magnetron transmitter. Furthermore, the new SSPA transmitting path is ensuring the same sensitivity and resolution of the existing magnetron transmitter.

This unprecedented architecture allows for automatically switching between the operation in magnetron transmitter mode and the operation in SSPA mode at each volume or even at each sweep. The baseline configuration switches every 5 minutes, such that data quality can be evaluated for quasi identical meteorological situations. Beyond data quality, an end-to-end test will be performed by DWD in order to assess the radar product quality for both transmitter types. This is achieved by processing the Hohenpeißenberg test data in the operational DWD product processing chain.

In this contribution, the new hardware system and components including the new signal processing and radar software of the Dualpol Hohenpeißenberg research radar are described.

ID: 17, Oral presentation

NOVEL POLARIMETRIC WEATHER OBSERVATIONS ENABLED BY THE FULLY DIGITAL HORUS PHASED ARRAY RADAR

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Phased Array Radar (PAR) technology stands at the forefront of meteorological advancements, delivering unparalleled temporal resolution in atmospheric observations. These high-fidelity observations are crucial for deepening our understanding of dynamic and microphysical processes within the atmosphere, particularly in the study of convective storm environments. The Advanced Radar Research Center (ARRC) at the University of Oklahoma (OU) has pioneered in this field by developing "Horus," a state-of-the-art, fully digital, S-band, dual-polarization phased array radar. This innovation was brought to life with the support of the NOAA National Severe Storms Laboratory and has been operational since 2023. Horus plays a pivotal role in atmospheric science, conducting routine data collection experiments that yield revolutionary observations. Its cutting-edge technology enables the rapid acquisition of complete polarimetric data volumes in a matter of seconds through sophisticated electronic steering and digital beamforming techniques.

This paper showcases polarimetric weather measurements collected with novel scanning modes recently implemented on Horus. It begins with the presentation of data capturing convective storms within a 90-degree azimuth by 20-degree elevation sector, achieved in less than 3 seconds. This rapid collection is made possible through the use of broadened transmit beam patterns (“spoiled beams”), which illuminate extensive atmospheric regions. This approach, combined with digital beamforming, captures dynamic atmospheric events, including lightning and hail, in unprecedented detail. Highlighted findings include the real-time detection of lightning-plasma signatures within polarimetric radar variables, corroborated by a lightning mapping array. Furthermore, we will exhibit high-temporal resolution observations of stratiform precipitation in birdbath mode, which serve to confirm the polarimetric calibration of Horus. Lastly, this paper will demonstrate Horus's multi-functional capability, showcasing its simultaneous provision of polarimetric weather estimates and civil aviation aircraft detection and tracking.

The unique functionalities of phased array radar underscore its indispensable role in advancing atmospheric science. Through its innovative capabilities, Horus is not only enhancing our understanding of the atmosphere but also paving the way for future scientific breakthroughs.


ID: 18, Poster presentation

WEATHER RADAR CALIBRATION BASED ON FAR-FIELD ANTENNA PATTERN MEASUREMENTS WITH THE UAS-BASED RADIO FREQUENCY SONDE (RFSONDE)

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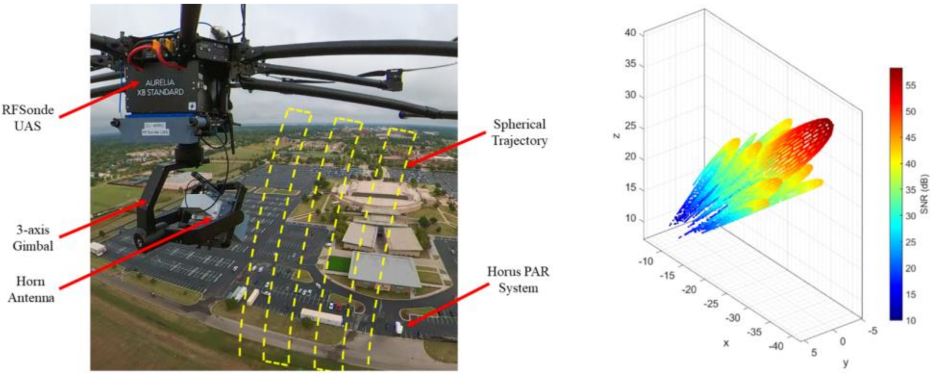
The increasing intricacy of weather radar systems underscores the critical need for meticulous in-situ antenna-pattern measurements, particularly for precise calibration of dual-polarization variables. Our research introduces a new instrument known as the Radio Frequency Sonde (RFSonde); a bespoke unmanned aerial system (UAS) custom-designed at the Advanced Radar Research Center (ARRC) at the University of Oklahoma (OU) for this purpose. This specialized UAS executes predefined flight paths to conduct measurements and reconstruct the radiation pattern within the far-field of the radar. Employing a distinctive 3-axis gimbal control strategy, the RFSonde conducts in-flight magnitude and phase measurements in the far-field region of operational radar antennas across a spherical grid. This approach ensures continuous polarization alignment with the antenna under test (AUT), thus adhering to Ludwig's III definition of cross-polarization and circumventing distortions caused by probe misalignment. Moreover, it optimally leverages the entire dynamic range of the onboard software-defined radio.

Through multiple field experiments, the RFSonde has demonstrated the effectiveness and repeatability of this methodology, accurately capturing both co-polar and cross-polar radiation patterns of X- and S-band weather radars. Notably, the system exhibits remarkable precision, with maximum absolute differences in azimuth and elevation beamwidth estimates of merely 0.011° and 0.006°, respectively. The minimal error contributions, constituting a mere 0.014% of the measured power, underscore the system's exceptional accuracy. These measurements were used to calibrate the differential reflectivity offsets in operational radars at the ARRC. Furthermore, our validation confirms that the dynamic gimbal scan algorithm accurately assesses the AUT without necessitating posterior probe correction. These findings establish a solid foundation for the continued utilization of UAS in on-site antenna pattern measurements, paving the way for the development of methodologies to calibrate and validate polarimetric observations in radar systems for weather research and operational purposes.



(left) Airborne RFSonde during an antenna scan. The camera was mounted on the drone to monitor and verify the angular movements of the 3-axis gimbal, (right)2D Measured antenna patterns on 6 September 2023.

ID: 28, Poster presentation

THE BENEFITS OF MULTI-DOPPLER RADARS WITH VARIOUS WAVELENGTHS IN WISSDOM SYNTHESIS

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Eleven meteorological radars with three different wavelengths (S-, C-, and X-band) are used in WISSDOM (Wind Synthesis System using Doppler Measurements) synthesis for 3-D (3-dimension) winds retrieval in Seoul city. The optimal combination of various wavelength radars will be investigated to get the best quality of the winds. A well-organized squall line passed Seoul city on 2nd Aug 2020; this case was selected in this study because the retrieved results are comparable with the typical kinematic structure of the squall line. There were four S-band, two C-band, and five X-band radars in the study domain; the discrepancies of retrieved winds between six scenarios were checked. These six scenarios are i) 4 S-band, ii) 2 C-band,

iii) 5 X-band, iv) 4 S- and 2 C-band, v) 4 S- and 5 X-band, vi) 4 S- and 2 C-band and 5 X-band. The preliminary results indicate that scenario i) reveals a weak updraft due to a less organized convergence zone along the squall line. The stronger updraft and continued convergence zone existed in scenarios iv) and vi). These results also imply the importance of various wavelength radars applied in WISSDOM; it will be beneficial in resolving the details of precipitation and flow characteristics with the squall line and the weather phenomena.

ID: 32, Poster presentation

GROUND CLUTTER RECOGNITION ALGORITHM BASED ON TIME-FREQUENCY CHARACTERISTICS OF PHASED ARRAY WEATHER RADAR IQ DATA

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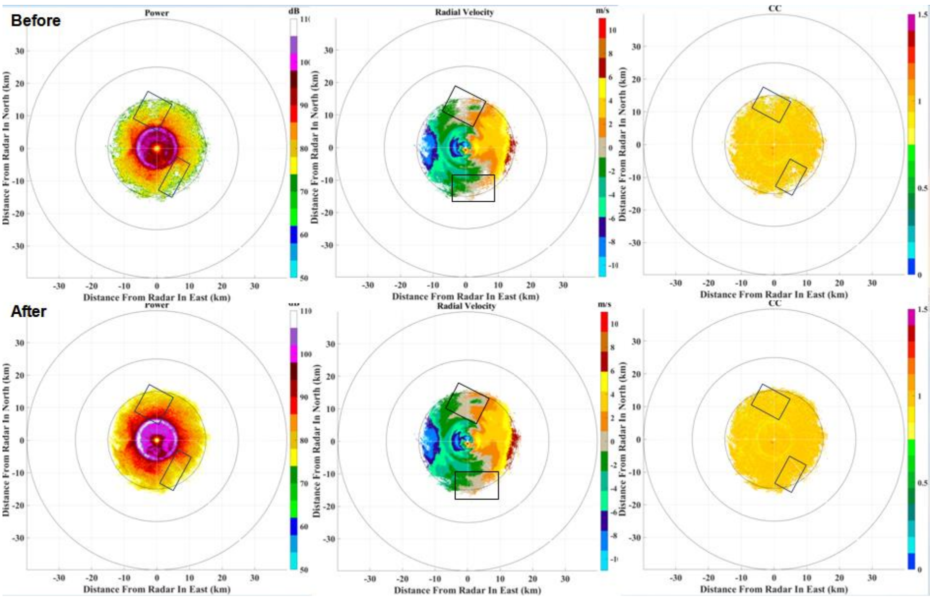
When the main lobe or side lobe of the radar beam irradiates the ground or objects on the ground and returns back to the radar, ground echoes, also known as ground clutter, will be generated. Ground clutter can cause deviations in the radar's measurement of weather. Ground clutter is easily confused with narrowband zero velocity weather echoes, and traditional clutter suppression methods may identify zero velocity weather echoes as ground clutter and filter them out, resulting in misidentification. Therefore, accurately identifying and suppressing ground clutter is particularly important in radar signal processing.

This algorithm is based on the amplitude frequency characteristics and time-domain pulse phase characteristics of ground clutter in the IQ data of X-band phased array weather radar. Three characteristic quantities for identifying ground clutter are proposed, namely spectral power factor (SPD), phase structure fluctuation factor (PSF), and spectral power width factor (SPW). Fuzzy logic is used to combine them for clutter identification. The results show that this algorithm can dynamically identify the position of ground clutter in real time. Compared with traditional Spectral Clutter Identification (SCI) algorithms, it has higher recognition accuracy, lower zero velocity weather misidentification rate, and better retention of meteorological target information.



ID: 33, Poster presentation

PRELIMINARY STUDY ON THE APPLICATION OF NETWORK WIND PROFILE RADAR INVERSION PRODUCTS IN VERTICAL OBSERVATIONS IN SHANGHAI

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Shanghai and the East China region frequently experience extreme weather, posing significant challenges in predicting and responding to hazardous weather. There is a gap in the existing urban observation network in terms of vertical profile meteorological observation. In order to solve this problem, Shanghai Meteorological Servive has launched a research project on vertical profile observation experiments and comprehensive application technology for ground-based remote sensing in large cities. It aims at filingl the gap in vertical observation by leveraging the advantages of advanced ground-based remote sensing detection technology, and conducting research based on observation data to improve urban disaster prediction capabilities and meteorological service quality.

This study utilizes high-precision and high spatiotemporal resolution vertical profile detection data from the Shanghai urban network wind profile radar. By using the "triangle method" to calculate the divergence and vorticity between radar stations, the distribution of horizontal vorticity and divergence at different heights before and after convective development during heavy precipitation process can be displayed. The results revealed the vertical structure of low-level convergence and high-level divergence in the atmosphere over the radar network area before convective triggering. On the other hand, it proved that the vertical wind field data provided by the network wind profile radar can timely and accurately reflect the upward movement within the development stage of strong convection, providing significant basis for nowcasting and early-warning of urban hazardous weather. Based on these work, the existing wind profile radar network observation area has been expanded with the newly deployed lidar in Shanghai, forming a more dense vertical wind profile detection network, further enhancing the application space range of vorticity and divergence calculation products, and thus optimizing he layout of laser wind radar observation stations.

ID: 34, Oral presentation

A WIND TURBINE CLUTTER MITIGATION SOLUTION FOR THE NEXRAD NETWORK

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Radar returns from wind turbines, commonly referred to as wind turbine clutter (WTC), can contaminate weather signals and cause significant biases in all radar variables. As wind energy generation continue to grow exponentially in the US, WTC contamination has become an increasingly critical issue for the NEXRAD network. The US Congress has encouraged the National Oceanic and Atmospheric Administration (NOAA) to "identify, test, and validate proposed technical solutions to reduce potential wind turbine impacts to NEXRAD radar data". Compared to stationary ground clutter, WTC are more challenging to mitigate because the blade rotation results in nonstationary signals with varying spectral contents. The characteristics of WTC depend on the environment and the location, size, orientation, and rotation speed of the wind turbines, making it difficult to design filters that perform well for a variety of realistic contamination conditions. Moreover, existing WTC mitigation techniques in the literature have not shown to be suitable for real-time implementation or to be compatible with operational radar scans. In this work, we present a signal processing solution for WTC mitigation that is targeted for operational implementation on the NEXRAD network. We combine a robust automatic detection algorithm based on computationally inexpensive features with a WTC filtering algorithm based on features from the short-time Fourier transform (STFT). The automatic detection algorithm focuses on discriminating between weather, ground clutter, and WTC signals to limit the application of the computationally expensive WTC filtering algorithm to range bins with dominant WTC contamination. Thus, it is a critical step to reduce the computational complexity for the entire mitigation solution. For a detected range bin, the WTC filtering algorithm leverages features in the STFT for WTC to identify and filter WTC spectral coefficients while preserving weather spectral coefficients. The performance of our mitigation solution is evaluated using real data with WTC contamination collected with NEXRAD radars under a variety of weather conditions. Our results show that the proposed mitigation scheme can detect and filter WTC contamination and ultimately recover the underlying weather signals.

ID: 37, Poster presentation

NEW RANGE UNFOLDING ALGORITHM SUITABLE FOR PHASED ARRAY WEATHER RADAR

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In the Doppler weather radar especially when observing middle-little scale system of strong convection weather in order to avoid velocity ambiguity high PRF is usually adopted. .Thus the far echo will be ambiguous and fixed together with the normal echo. The quality of the radar data will be decreased. For X band radars whose wavelength is shorter the ambiguity is particularly serious.

This paper proposes a new range unfolding algorithm for range folding echo recognition and suppression, based on the beam agility of array weather radar. The algorithm consists of three steps, including 1) identification of folded echoes2suppression of folded echoes3further combination with the traditional phase coding technology. Especially in step 1, The beam agility of phased array weather radar makes the first pulse of each wave position different from the one of the previous wave position in space and time, so only one echo can be received at the first time.

The new algorithm was applied to operational X-band array weather radars in Shanghai by comparing and analyzing the IQ data recorded with the range folded echo, it is considered that the algorithm can identify and filter most of the folded echo, and after filtering, all the polarizations appear as noise, and it has no obvious influence on the weather echo.

ID: 40, Poster presentation

ON THE USE OF POLARIMETRIC DOPPLER SPECTRA TO INVESTIGATE THE BOUNDARY LAYER OF TORNADOES

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Doppler spectra showing the distribution of reflectivity-weighted Doppler velocities within the radar volume in tornadoes have been collected from time to time using fixed-site and mobile Doppler radars since the late 1950s. Since the mid 1990s, many radar observations of tornadoes have been made at close range using mobile Doppler radars, of mean Doppler velocity, mean reflectivity, and spectrum width. Beginning in the early 2000s, polarimetric variables such as mean differential reflectivity and mean co-polar correlation coefficient have also been made, for which the tornado debris cloud has been detected as relatively low values of these quantities. Because tornadic debris (e.g., vegetation, dirt, rocks, man-made objects, etc.), air molecules, insects, and other radar targets such as raindrops and hailstones, may move at different velocities, owing to radially outward centrifuging of the heavier targets and drag, it is necessary to separate the two or more when attempting to analyze the wind field in the tornado boundary layer. One would expect that there should be a spread of Doppler velocities not only owing to the variation in space and time of the wind, but also owing to the variety of types of scatterers and their distributions. There has therefore recently been an effort to collect polarimetric Doppler spectra at close range in tornadoes using ground-based Doppler radars. Improvements in signal processing and increased data storage capabilities have made it possible to do this. From the point of view of hydrometeor classification, polarimetric spectra might be able to refine further the different types of scatterers in the radar volume.

Since 2018, our group has attempted to compute polarimetric spectra using the RaXPol (Rapid-scan, X-band. Polarimetric) radar, an X-band, polarimetric, frequency-hopping, truck-mounted, mobile Doppler radar. To do so, we have been collecting 360° volume scans in developing and mature tornadoes in rapid-scan mode. When a temporally coherent debris cloud was detected and/or seen visibly, however, we switched to sector-scan mode without frequency hopping and scanned much more slowly. Raw, I/Q time series data were collected in tornadoes and low-level mesocyclones in Kansas in 2018 and 2021, but the data were inadvertently collected with frequency hopping, so we have not yet been successful in computing spectra from these tornadoes with high enough signal-to-noise ratio (SNR), though efforts are underway to try to devise novel signal-processing techniques to do so.

In 2023, however, we finally succeeded in collecting raw time series data (at a constant frequency) at low elevation angles in a tornado in a supercell in central Oklahoma (southwest of Norman) on 11 May, during which visible debris was documented. In this talk we will present and discuss the polarimetric spectra in and near the tornado and its debris cloud. If time permits, we will also present polarimetric spectra from the Moore tornado of 20 May 2013

based on raw time-series data from the KCRI S-band fixed-site radar for comparison purposes, and possibly spectra from any successful upcoming data collection by RaXPol in spring, 2024. There are relatively low co-polar cross-correlation coefficients in the polarimetric spectra, indicative of debris, around 7.5 – 7.7 km range, at the location of the TVS.

ID: 41, Poster presentation

A STUDY ON MISSING DATA CORRECTION TECHNIQUE FOR WEATHER RADAR DATA USING MACHINE LEARNING

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Due to recent climate change, water disasters caused by localized torrential rains and tornadoes have become a societal problem, and there are high expectations for more accurate weather radar data used to predict these events. On the other hand, the weather radar observations are sometimes missed due to surrounding mountains, obstructions, and interference, which are considered problematic because they can miss the precursors of dangerous weather phenomena such as heavy rainfall.

Currently, missing data is interpolated using observation data from weather radars installed at different locations. However, when interpolating far away from the interpolating weather radar, the quality of the interpolated data deteriorates due to the deterioration of resolution caused by beam width expansion and misalignment of the interpolated data. Another approach is to utilize machine learning such as GAN and DNN to fill in the missing data. In this paper, using this principle, a missing data correction method with CNN-base model, which uses the previous period rainfall radar data and other elevation angle radar data as inputs in order to train the rainfall motion and precipitation information over the missing area, has been investigated.

The performance of the proposed method has been evaluated by using C-band parabolic multiparameter weather radar data in Japan. As a result, it was shown that, compared to the model trained with only missing data, the method using the previous period data may worsen RMSE when the missing azimuth width is large, while the method training with other elevation data improved the RMSE regardless of the missing azimuth width. In addition, compared to the method using other elevation data for interpolation, RMSE of the proposed method with other elevation data was improved by up to 21% for the missing width of 7° and by up to 7% for the missing width of 14°.

ID: 44, Oral presentation

PHASED ARRAY OR PARABOLA?

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Recent progress of information and communication technologies has been enabling us to realize a rapid scanning weather radar system. A single polarimetric Phased Array Radar (PAR) system at X band was developed and installed in Suita Campus, Osaka University in 2012. And then, Dual polarimetric PAR was also developed in 2017, and replaced in Osaka University in 2022. These PAR systems can scan the whole sky within 30 seconds up to 80 km in radius over 100 elevation angles with digital beam forming technique, and the initial observation results demonstrate the unique capability of the new PAR system. In this study, observations from parabola and phased array type radars are compared firstly and the comparison shows that both measurements are in good agreement basically. However, the PAR observation is sometimes seriously contaminated by strong ground clutter through relatively high sidelobes mainly from ground at transmitting stage. For this, a new clutter mitigation algorithm from adaptive beam forming technique on Minimum Mean Square Error (MMSE) formulation was investigated through numerical simulation, point target experiments and precipitation observation. Also, the accuracy of precipitation estimates from both radar systems is discussed through the comparison with rain gauges. Finally the advantages and disadvantages of the PAR will be discussed.

ID: 52, Oral presentation

DETECTION OF WIND TURBINE CONTAMINATION USING SPECTRAL DUAL POLARISATION AND A CONVOLUTION NEURAL NETWORK

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[3]NOAA/OAR National Severe Storms Laboratory,

The growing number of wind turbines, while supporting clean and renewable power, increasingly poses a threat to the data quality of weather radar networks in many countries. A surface rainfall estimate is usually more accurate if the measurement is made close to the ground, but if wind turbines (WT) are present, they can contaminate weather echoes and significantly increase the rainfall rate estimates over extended areas. Currently, the Met Office radar data processing pipeline uses a fixed mask of known WT locations and their heights to censor the contaminated lower elevation(s) data and uses a higher elevation measurement in those regions. This then requires a larger and more uncertain correction for the vertical profile of reflectivity, often leading to an underestimate of the surface rainfall rate measurement. Conversely, anomalous propagation of the radar beam can result in additional contaminated locations that are not included in the fixed mask. Thus, it would be better to perform WT contamination detection in real time so that all contaminated locations and only those with contamination are included. For example, in cases when the precipitation signal is sufficiently strong (i.e. in heavy rainfall) and overcomes the clutter signal from the wind turbines, censoring is not needed. Unfortunately, WTs are notoriously difficult to detect dynamically, because unlike stationary ground clutter that has a single peak at zero Doppler velocity, WT signals can have an additional multi-modal Doppler component due to the moving blades, resembling precipitation signals which renders the use of simple Doppler notch filters ineffective.

In this work, we make use of the bootstrap spectral dual polarisation estimator and a convolutional neural network (CNN) to classify between rainfall, stationary ground clutter and WTs. To train the CNN, we systematically combine random tiles of pure rainfall signals with tiles of “dry” clutter or “dry” WT signals to produce synthetic tiles with a range of clutter to signal ratios. We then use the trained neural network to determine when it is better to use unfiltered or filtered data, or to censor a given gate because of stationary ground clutter or WT clutter contamination. Offline testing with a 3h period of rainfall on both stationary clutter and land/sea-based WTs shows successful removal of clutter-contaminated data without the unnecessary gaps of a fixed censor map in rainfall accumulations. Operational testing is underway.

ID: 57, Oral presentation

POSTPROCESSING METHODS TO CHARACTERIZE MULTIMODAL PRECIPITATION IN DOPPLER SPECTRA FROM DWD'S C-BAND RADAR BIRDBATH SCAN

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Since modifying DWD's C-band radar (vertically pointing) birdbath scan in spring 2021, profiles of radar Doppler spectra are routinely recorded at all 17 operational weather radars across Germany every 5 minutes. These data allow a detailed analysis of the precipitating clouds above the radar sites by identifying simultaneously occurring precipitation regimes that appear as distinct modes in the Doppler spectra (e.g. rimed snow and pristine crystals or hail and rain).

This presentation summarizes the postprocessing chain used to filter out the non- meteorological contributions to the Doppler spectra, identify individual precipitation modes, and calculate characteristic modal and multimodal properties of the detected precipitation regimes. The analysis of Doppler spectra of snow relies on a novel spectral filter based on clustering to adaptively mitigate the impact of static clutter; in contrast, the analysis of the much broader Doppler spectra recorded in strong convective storms is less affected by clutter. We find that the estimated spectral moments of radar reflectivity, mean Doppler velocity, and spectrum width of the individual precipitation modes are relatively robust with low expected uncertainties of generally less than 10 %. The higher-order moments of skewness and kurtosis, however, sometimes show spurious artifacts that can accumulate during postprocessing, particularly during smoothing and interpolation of the filtered spectral data.

As a potential meteorological application of the presented spectral postprocessing routine for radar birdbath scans, we show an example of how the postprocessing output can be used as starting point for retrieving the hail size distribution near the ground in a supercell thunderstorm. The postprocessing methods will be published as an open-source Python package (after peer review).

ID: 59, Poster presentation

STAGGERED PRF PROCESSING WITHIN THE BARON PROCESSOR SUITE

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The world of weather forecasting is rapidly changing driven by exponential advances in radar signal and data processing technologies. Recent years have seen the development of the Baron Services Processor Suite which introduced new ways of collecting, storing, manipulating and transmitting radar data in addition to radically transforming the way we conduct and organize weather science. This paper will illustrate how the processor suite combats the doppler dilemna challenge by employing novel hybrid architectural concepts and effectively blending traditional signal processing techniques like Staggered PRF processing with innovative technologies like CLEAN-AP^{TM} for superior data quality (CLEAN-AP™ © 2009 Board of Regents of the University of Oklahoma). A brief description of the implemented algorithm followed by a performance discussion of data cases under a variety of weather conditions will be presented.

VERIFYING THE CLUTTER SUPPRESSION CAPABILITY OF X- AND C-BAND WEATHER RADARS EQUIPPED WITH SOLID STATE POWER AMPLIFIER TRANSMITTERS

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Efficient ground clutter suppression is one of the most important features provided by the Doppler processing of any weather radar system. Unsuccessful suppression may produce strongly biased estimates of the fundamental spectral moments like mean power, doppler velocity and spectrum width. Gaussian model adaptive processing (GMAP) is a frequency domain method that uses a Gaussian clutter model to adaptively adjust the filter width according to signal power, Nyquist interval, number of samples and assumed clutter width. The GMAP not only filters out clutter points but also attempts to recover weather targets that overlap with the clutter and would be removed in conventional filtering methods. Coherent SSPA technology together with the GMAP processing of the Vaisala RVP signal processor makes it possible to achieve clutter suppression ratios of up to 50 dB.

In this study, clutter filtering capabilities of two polarimetric Vaisala weather radars with solid state power amplifier (SSPA) transmitter technology are verified. Radar models are WRS400 and WRS300, X- and C-band weather radars respectively, both equipped with the Vaisala RVP signal processor. Clutter filtering is studied by collecting and comparing filtered reflectivity time series data with unfiltered reflectivity data from identified ground clutter target locations. The time interval used in the analysis included both clear weather and light to moderate precipitation. It is shown that both radars can reach suppression levels greater than 50 dB without sacrificing data from weather targets.

ID: 81, Poster presentation

COMPARING THE SENSITIVITY OF WEATHER RADARS WITH CONVENTIONAL MAGNETRON AND MODERN SOLID STATE POWER AMPLIFIER TRANSMITTER TECHNOLOGIES

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Minimum detectable weather signal, or sensitivity is one of the most essential parameters that describes the performance of a weather radar system. It gives answers to questions about how weak targets can be detected at a given range or what is the maximum range of detection for a target with a certain intensity.

The detected signal at the radar receiver is a combination of echo signal and thermal noise, and they both vary significantly from sample to sample. For this reason, certain threshold values for the signal-to-noise ratio (SNR) required for weather detection must be used. This threshold depends on expected fluctuations of the echo signal, signal processing techniques used, false alarm rate (FAR) and probability of detection (POD) accepted. In the literature, there are theoretically computed values available for SNR required for various kinds of fluctuations, FAR, POD, and number of samples averaged.

In this study, the sensitivity of three different types of polarimetric Vaisala weather radars are analyzed. Radar models are WRS400 and WRS300, X- and C-band weather radars respectively, both equipped with antenna mounted transceiver and based on solid state power amplifier (SSPA) technology. The third radar model is a C-band WRM200, equipped with a magnetron transmitter and a digital receiver in a separate equipment cabinet. All three radars use Vaisala RVP signal processor. The performance of all radars was concluded to be in line with the theoretical sensitivity calculations given by the traditional radar equation. The benefits of the SSPA transmitter technology and compact radar design with antenna mounted transceiver are also discussed from the point of view of sensitivity.

ID: 90, Oral presentation

CLOUDCUBE: ADVANCING ATMOSPHERIC PROFILING WITH MULTIFREQUENCY MM-WAVE RADAR

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CloudCube is a multifrequency (Ka-, W-, and G-band) low-cost atmospheric profiling radar developed at NASA's Jet Propulsion Laboratory (JPL). CloudCube instrument enables unprecedented mission concepts to improve our knowledge on cloud microphysical properties and their connection to precipitation, identify atmospheric winds and provide critical information about the lowest part of the atmosphere, the planetary boundary layer (PBL). CloudCube benefits from long-term research and development of solid-state millimeter-wave components to achieve a very compact architecture compatible with small spacecraft platforms. CloudCube facilitates low-cost constellation of identical instruments in low Earth orbits (LEO) to increase spatial and temporal global coverage or the deployment of a multi-atmospheric sensor payload to further enhance the scientific capabilities of a mission.

The absorption and scattering of electromagnetic radiation by hydrometeors depend on its fundamental state and varies with the frequency of the radar's transmitted signal. CloudCube operates at three different frequencies: 35, 94 and 240 GHz (Ka-, W- and G-band, respectively), and exploits the water-signal interaction behavior to detect and model different kinds of weather observables by measuring vertical profiles of the radar reflectivity factor at each frequency band and Doppler velocity at G-band.

CloudCube's radar electronics, designed with offset IQ up/down conversion and pulse compression techniques, minimize mass and power requirements while maximizing sensitivity. Modular in design, each frequency band (Ka-, W-, and G-band) fits within a 3U volume, offering flexibility for tailored mission objectives. The unique multifrequency capabilities of CloudCube, showcased in the EPCAPE (*Eastern* Pacific Cloud Aerosol Precipitation Experiment) campaign, offer unprecedented insights into clouds and light precipitation. These observations present a novel opportunity to study hydrometeor behavior, informing our understanding of cloud formation and evolution at the millimeter and submillimeter scale.

ID: 92, Poster presentation

THE EFFECTS OF THE ANTENNA APPROXIMATION METHOD ON THE CALCULATION OF THE POLARIMETRIC BIASES

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Modeling of the large antenna array patterns for polarimetric weather radar is dominantly based on the use of the array factor. The array factor is combined with embedded single element or single panel patterns to achieve the full array. Here, we explore the tradeoffs for these cases. Considered are three approaches: 1. Single-free space patch element; 2. Averaged patch element derived from a full-size 32 x 32 radiators square array. 3. Full array model simulated as the superposition of each patch radiation within the array. For cases 1 and 2 element patterns and array factor are combined to generate the results. Comparing these three approaches allows us to explore the tradeoff cost in simulating a large array's polarimetric biases. The comparison results are exact for the broadside direction, whereas in the case of beam steering the third approach does not consider the change of the active element impedance and thus is an approximation itself. Quantifying the discrepancy of these methods may help establish their applicability to calculating the polarimetric biases for large phased array antennas.

ID: 94, Poster presentation

ASSESSMENT OF EDDY DISSIPATION RATE ESTIMATION METHODS USING DOPPLER WIND LIDAR

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The observation of turbulence is crucial in aviation due to its impact on airplane safety. However, detecting the spatiotemporal distribution of turbulence with conventional sensors can be challenging due to its small spatial scales and unpredictable nature. Doppler wind lidar can provide continuous information on wind fields with high spatio-temporal resolution and is advantageous for observing turbulence. Eddy dissipation rate (EDR) is a quantitative measure of turbulence intensity. Various methods have been studied to estimate EDR using lidar. However, the estimated values depend on the methods and scan strategy of lidar. Therefore, it is still necessary to compare the methods to ensure accurate estimation.

This study compared EDR estimation methods using lidar for two scanning strategies: vertically pointed scanning (VP) and plan position indicator scanning (PPI). Four estimation methods based on VP (EDR_{VP}) were used: power spectrum, second-order structure function, variance, and structure function fitting. Additionally, a Velocity-azimuth display (VAD) EDR estimation method (EDR_{VAD}) based on PPI was employed. The accuracy of EDR_{VAD} was assessed for four elevation angles (80°, 45°, 30°, 20°) in comparison to sonic anemometers on 300 m height meteorological tower. EDR_{VAD} showed similar variations and high correlation (CORR > 0.6) with EDR estimated from the sonic anemometer. EDR_{VAD} was affected by elevation angle. The lower the angle, the higher the value of EDR was shown. When comparing by altitude, EDR_{VAD} at 80° elevation angle were closest to the results of EDR_{VP}. All methods of EDR_{VP} showed similar values (CORR > 0.9). The characteristics of each method are presented, considering the instrumental characteristics of lidar and the scanning strategy.

Keywords

Eddy dissipation rate, Turbulent energy dissipation rate, EDR, Doppler wind lidar, turbulence, aviation turbulence

Acknowledgement

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ID: 127, Oral presentation

A PHYSICS-INFORMED MACHINE-LEARNING ALGORITHM TO RECOVER CORRUPTED OR BLANKED DATA IN WEATHER RADAR VELOCITY MEASUREMENTS

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Weather radar locations often face the problem that they do not allow an unimpaired radar operation especially when scanning at low elevations. At airports, for example, where a weather radar is used to perform high-resolution wind shear measurements, tall buildings or safety-related precaution areas within the radar coverage must be omitted. Sited in open terrain, not only vegetation or hilltops, but also wind turbines or WiFi signals may have a significant impact on weather radar operations, as these can cause blockages or interferences.

Physics-Informed Machine Learning (PIML) is a research field in which neural networks are trained to solve partial differential equations (PDE) that describe physical phenomena. PIML, incorporates the Navier-Stokes equations as the underlying PDE, can be used to reconstruct 3D wind fields from radar radial velocity measurement data as boundary conditions. This approach offers the possibility to fill data gaps or corrupted range gates in V-PPI measurements of about 35° azimuthal width. Furthermore, the so-called cyclops dilemma can be overcome which refers to the fact that Doppler radars measure only line-of-sight (radial) velocity.

The advantage of PIML in contrast to data-driven ML models is twofold; firstly, the ML decision-making process offers more transparency to the user (white box approach) and secondly, the collection of a theoretically all-encompassing training dataset is not required. With PIML, a neural network is trained from scratch for each new set of measurement data. By using a pre-trained network (Transfer Learning technique), the training time of PIML can be accelerated to ensure a real-time capability while avoiding demanding hardware requirements. In this contribution, weather radar examples of reconstructed disturbed PPI sectors of radial velocity measurements are demonstrated. An error analysis of the radial and transversal velocity component based on two measurement campaigns using Doppler lidars is presented as well. Doppler lidars as the “clear air” complementary counterpart of weather radars with regard to remote wind measurement were used, because they have much more data availability than radars. Finally, run-time considerations for applying Transfer Learning methods will be discussed.

ID: 138, Poster presentation

LOOKING AT PULSED INTERFERENCE, FILTERS, AND PULSE COMPRESSION

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With the increased demand for electromagnetic spectrum, interference will become even more pervasive for weather surveillance radars in the future. Some types of electromagnetic interference are noise-like and are difficult to address though signal processing, but pulsed interference can be significantly mitigated in most cases through filtering. We describe the causes and types of pulsed interference including direct- and indirect-path interference. Direct-path interference occurs when the signal travels from the interfering radar directly to the receiving radar; the strength of the interference is determined by the radar antenna patterns. Indirect-path interference occurs when the interfering signal strikes hydrometeors and the resulting scattering is observed by the receiving radar. Indirect-path interference tends to be more widespread and looks more like weather. We developed an interference model to simulate both direct- and indirect path interference, and we use this model to study the performance of pulsed interference filters. Some examples of pulsed interference filters are discussed, and the effects of pulsed interference on radars that use pulse compression (often phased array radars) are explored.

ID: 146, Poster presentation

UNLEASHING THE POWER: REVOLUTIONIZING WEATHER OBSERVATION WITH THE ADVANCED TECHNOLOGY DEMONSTRATOR AT THE NATIONAL SEVERE STORMS LABORATORY

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The Advanced Technology Demonstrator (ATD) at the National Severe Storms Laboratory is the first full-scale, S-band, dual-polarization, active, electronically scanned phased-array radar (PAR) dedicated to weather observations. Operational since 2021, the ATD has played a critical role in demonstrating the feasibility of combining phased-array and dual-polarization technologies. Our success in achieving a robust and stable polarimetric calibration has enabled the collection of an unprecedented number of cases, showcasing the value of rapid-update polarimetric radar data to improve weather observations. The ATD also supports advanced scan strategies and can demonstrate other unique capabilities of PAR for improved weather observation. Recent upgrades to the system have unlocked several of these capabilities, which is the focus of this presentation. New ATD capabilities include the ability to run advanced rotating-antenna concepts of operations, to use spoiled transmit beams for even more rapid-update data collection, and to adaptively change scans for focused observations. The single-face, rotating phased-array antenna radar architecture may present an optimal balance between affordability and capabilities, and it is currently being explored as a potential candidate for the next generation of weather-surveillance radar in the US. The ATD was upgraded to combine mechanical and electronic beamsteering to demonstrate advanced concepts of operations involving the interlacing of multiple scans (e.g., PPI and RHI scans) both in stationary- and rotating-antenna operations. Another breakthrough capability involves the use of spoiled transmit beams to significantly reduce scan times. By transmitting a wider beam and digitally forming several simultaneous narrow receive beams, the spoiled-transmit-beam technique reduces scan times proportionately to the number of simultaneous receive beams (up to a factor of 9 on the ATD). This enables the collection of rapid-update polarimetric data and the exploration of important trade-offs between update time, radar sensitivity, and spatial resolution. The concept of adaptive scanning has also been integrated into the ATD. Adaptive scanning techniques dynamically adjust scans to optimize radar performance tradeoffs in response to atmospheric changes and/or user requirements. The scan flexibility inherent to PAR is pivotal in unleashing the full potential of adaptive scanning, allowing for automatic, real-time adjustments of scans to focus and tailor observations. Initially, the framework for adaptive scanning implemented on the ATD supports adaptive focused scans, which can be used to obtain high-quality, densely sampled, rapid-update data on areas of interest at the price of reduced performance on areas with no significant weather returns. This presentation will showcase examples of these advanced PAR capabilities to underscore how the ATD is providing critical insights into the suitability, maturity, and potential adoption of phased-array technology for the next generation of operational weather-surveillance radars in the US.

AN OVERVIEW OF THE PPAR ADVANCED TECHNOLOGY DEMONSTRATOR POLARIMETRIC CALIBRATION

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Polarimetric phased array radars (PPAR) stand as potential contenders for the forthcoming era of the next-generation systems. Their distinctive capability to electronically steer beams makes them invaluable for advancing weather surveillance strategies, with the aim of refining weather radar products. Nonetheless, before these technologies can be routinely deployed for weather surveillance, significant challenges must be resolved.

Foremost among these challenges are the biases in polarimetric measurements arising from the beam-steering-dependent horizontal (H) and vertical (V) copolar patterns, as well as the presence of considerable cross-polar patterns. The biases associated with copolar patterns, contingent upon scan direction, necessitate correction with precise values at each boresight position. These correction values must be derived by accurately characterizing copolar pattern main beams at relevant beamsteering angles.

Moreover, notable cross-polar patterns lead to cross coupling between returns from horizontally and vertically oriented fields, introducing biases in polarimetric measurements. Employing pulse-to-pulse phase coding in either the H or V ports of the transmission elements has been experimentally validated as a means to mitigate this effect. Notably, this method offers the advantage of circumventing the need for explicit knowledge of cross-polar patterns. Additionally, a slight antenna tilt has been proposed to aid in mitigating cross coupling. It should be noted, though, that the efficacies of these mitigation strategies are inversely related to the levels of cross-polar to copolar patterns.

In scenarios where cross-polar patterns exhibit significant strength, the previously described mitigation strategies may prove insufficient at certain beam-steering angles. In such instances, a correction strategy based on comprehensive knowledge of both copolar and cross-polar antenna patterns has been proposed. This approach is more intricate, demanding precise characterization of both cross-polar and copolar beams, while its experimental validation remains pending.

To assess the viability of PPAR technology for weather surveillance, the Advanced Technology Demonstrator (ATD) was installed at the National Severe Storms Laboratory (NSSL) in Norman, OK. The ATD, a full-size, S-band, planar proof-of- concept PPAR, serves as the focal point of PPAR polarimetric calibration research. To this end, the ATD setup incorporates a far-field calibration tower situated nearby. Positioned atop this tower is an S-band standard gain horn, affixed to a motorized platform allowing rotation about its axis to adjust polarization to horizontal, vertical, or to any desired orientation. This infrastructure facilitates the measurement of array parameters essential for weather calibration purposes. This presentation will delve into the latest endeavors concerning weather calibration efforts using the ATD and the associated calibration infrastructure.

ID: 151, Oral presentation

APPLICATION OF THE REGRESSION FILTER TO SZ PHASE CODING FOR UNAMBIGUOUS VELOCITY EXTENSION

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SZ phase coding is a signal processing technique used by the National Weather Service for separating multiple trip echoes thereby increasing the unambiguous velocity and range for pulse transmission radars. Typically, there is strong trip echo overlaid by weak trip echos. In order to estimate the weak trip velocity, the strong trip echo must be eliminated. To do this, a frequency domain 3/4 spectral notched is typically used. The SZ phase coding technique also requires a time domain window function such as the von Hann. The application of this window function effectively reduces the number of independent samples available for radar variable computation which intern increases the standard measurement error of the retrieved radar variable. In addition, if there is also ground clutter signal present, that too must be filtered. In this paper we show how the regression filter can be used to eliminate both ground clutter and the strong trip echo. The resulting weak trip velocity estimates show a significant improvement over the currently used NEXRAD SZ processing algorithm. Experimental NEXRAD data are given that demonstrate the improved weak trip velocity recovery.

ID: 153, Oral presentation

SOLID-STATE OR MAGNETRON? A FIRST LOOK AT DATA FROM THE DUAL TRANSMITTER RADAR AT DWD

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Only a handful of transmitter options are considered to be viable for weather radars. All of the 17 weather radars operated by DWD (German Meteorological Service) currently use a magnetron transmitter. The main characteristic of the magnetron transmitter is a short and powerful pulse. Thereby, achieving a high range resolution, sensitivity and overall range. However, maintenance costs and lead times of replacement parts for these transmitters are increasing. As such DWD decided to assess the viability of solid-state transmitters as an alternative solution. The peak power of a solid-state transmitter is in general much lower, even when using multiple transmission stages. To reach the same level of mean transmission power, the pulse length has to be increased by a factor of 100 from about 150m to 15km. The long pulses are frequency modulated so that a comparable range resolution can be achieved in the receiver. The Hohenpeißenberg dual pol research radar of the German radar network was upgraded with an SSPA transmit (8 kW peak power) and the required receive functionality in 2023. Through a waveguide switch, an alternating transmitter operation is now possible with the previously existing radar hardware. The goal is to sequentially observe weather situations with either transmitter on a sweep-by-sweep basis and compare and assess the resulting data quality and products. First data, including convective and stratiform precipitation events, were obtained in December 2023. Here, the standard DWD 5 minute scan cycle was used, alternating between both transmitters after each full cycle. The solid-state transmitter was set up to run a 2-Pulse scheme (long, short pulse). We checked for the consistency of the data in the transition from the short and long pulse regime, the overall sensitivity of the solid-state system, and possible artifacts due to e.g. range-side lobes. The initial assessment of the data already shows promising results. In particular the method to calibrate and match the short and long pulse region for several radar moments provides good results.

ID: 157, Poster presentation

SINGLE FM PULSE NEAR RANGE SIGNAL RECOVERY WITH OFF-THE-SHELF DSPS

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Pulse Compression capability has been incorporated into the Vaisala meteorological radar signal processors (starting from PVP8) for more than twenty years and used in close to 100 systems.

For quite some time it was almost an axiom that radar using long frequency modulated (FM) pulses can not retrieve data from the "near range" defined by the length of the pulse [1].

Engineers working on Solid State Power Amplifier(SSPA) based weather radar prototypes reported that they can see weather data in the near range. But those reports were dismissed as if what they observed was impossible.

The most common way to mitigate this blind zone issue is using the time-frequency modulated pulse [2,3], also known as the “hybrid pulse”, technique.

The "Progressive Pulse Compression" paper [3] was both revolutionary and eye opening. The reexamination of the old data and various SSPA transmitter configurations shows that one can retrieve near range weather data without any significant DSP modification. The most important requirement is to prevent or to reduce leakage of the transmitted signal into the receiver. In the most common configuration of Vaisala RVP900 DSP the sampled transmitted signal is multiplexed with the normal received signal. In that configuration the observed bright circle close to the radar is caused by range sidelobes (shoulders of the “ambiguity” function) from the sampled transmitted signal. The increasing of the range sidelobes suppression via filter optimization and attenuation of the sampled transmitted signal can push range sidelobes down to below noise level.

The new Vaisala RVP10 signal processor can use separate ADC ports and internal data buffers for the sampled transmitted signal and the received signal. In order to suppress leaked or sampled signal directly, RVP10 DSP has an ability to zero data in the received signal data buffer during the transmission.

Removing signal contamination restores ability to observe weather signal in the what used to be considered the blind zone. Nevertheless part of the transmitted pulse and only part of the downconversion matching filter are used in the ranges close to the radar and calibration parameters have to be adjusted for every range bin. One approach is to generate per range bin look up tables for transmitted energy, the filter gain, and the noise equivalent bandwidth of the partial filter.

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ID: 159, Poster presentation

DIRECT FILTERING VERSUS MULTI-STEP APPROACH IN THE WEATHER RADAR DSP

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The very first digital weather radar signal processors were using chains of short filters (cascading/multistage filters) for a simple reason – limited resources. The designers of SIGMET RVP8 digital signal processor (DSP) and, later, RVP9 (also known as Vaisala RVP900) focused on implementation simplicity and ease of use. It is easier to design and tune a single FIR filter than tuning a collection of filters in the chain. There was also a belief that the use of the "cascading/multistage filters" approach adds losses and reduces dynamic range of the weather radar DSP. Nevertheless, at least some custom build research DSPs, e.g. CSU CHILL DSP, use multistage filters and that arrangement performs well.

The technology is advancing and new SSPA radars require use of longer then before frequency modulated pulses. Modern ADC chips are also much faster – the new Vaisala RVP10 DSP can use 240MHz sampling frequency. As a result, the number of filter coefficients increased from several thousand to tens of thousands. E.g. 80μs FM filter in RVP9 configured to use 80MHz sampling rate has 6400 filter coefficients, but 200μs FM filter in RVP10 with its 240MHz sampling rate has 48000 filter coefficients.

We will present results of a comparative analysis of a single long FIR filter processing unmodified (no NCO) signal strait from ADC and a processing chain that consists of an NCO (Numerically Controlled Oscillator), a decimating bandpass FIR filter, and an NLFM decoding FIR filter.

ID: 161, Poster presentation

IMPROVING WEATHER RADAR IMAGE QUALITY USING NEW DIRECT DECONVOLUTION ALGORITHM

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Deconvolution of weather radar images has shown to be a challenging problem[1]. Some approaches to deconvolution algorithms have been developed in order to suppress the amplification of measurement noise, which makes straightforward inversion of the convolution process impractical, especially in the tangential direction from the radar. We investigate the feasibility of application of the newly developed deconvolution algorithm [2] to improve the resolution of the weather radar images. To adjust the novel deconvolution to the radar signal with its unique noise character (multiplicative as opposed to additive noise) we combine our method of deconvolution[2] with the Bayesian probabilistic treatment[1] specifically developed for the weather radar data. We are investigating the resolution improvement by comparing the error on the reconstruction and location of point targets and the sharpness of the edges of meteorological features. We also compare the computational complexity of the novel and the existing approaches.

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ID: 189, Oral presentation

PROPERTIES OF CONVECTIVE AND STRATIFORM PRECIPITATION OVER THE US

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The Echo Classification from COnvectivity (ECCO) algorithm provides classifications of radar echoes in three dimensional Cartesian grids. It separates radar observations into shallow, mid, and deep convective features, and low, mid, and high stratiform echoes. ECCO also provides convectivity, a quantitative measure of the convective or stratiform nature of precipitation, for each radar grid point in three dimensions.

ECCO was applied to three years (2021-2023) of combined reflectivity observations from the Multi-Radar/Multi-Sensor system (MRMS) over the continental United States and southern Canada. MRMS data consists of high- resolution observations, both spatially (in three dimensions) and temporally. It is now made available to the research community on a routine basis, which enables detailed climatological studies of 3D storm structures over the US. We explore how convective and stratiform storm properties vary spatially, and identify regions with significant occurrence of different types of precipitation. We also investigate seasonal and diurnal variations of 3D convective properties. A quantitative analysis of convectivity provides insight into extreme precipitation regimes.

ID: 192, Oral presentation

THE POTENTIAL OF THE POLARIMETRIC ATMOSPHERIC IMAGING RADAR (PAIR) FOR UNPRECEDENTED INSIGHTS ABOUT STORM EVOLUTION

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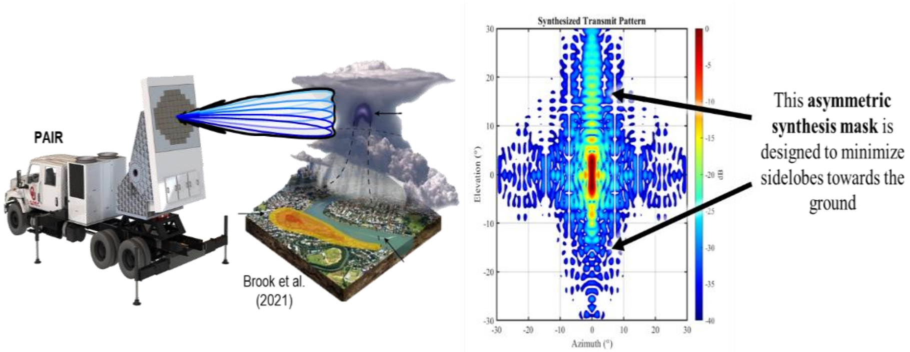

Sponsored by the National Science Foundation (NSF) in the US, a shared, mobile, polarimetric atmospheric imaging, Doppler radar (PAIR) that was designed and developed by the ARRC at the University of Oklahoma (OU). Polarimetric radar imaging has the potential to fundamentally transform how the weather is observed by radar. In this presentation, the development, specification, and potential applications of PAIR will be discussed. PAIR is a C-band active polarimetric phased array radar mounted on a truck for fast deployment. The selection of C-band has the benefit of less susceptibility to attenuation, while still providing a reasonable beamwidth of 1.5 degree given the antenna size limitations. PAIR is versatile in scanning mode, polarimetric diversity, and waveform flexibility. PAIR can operate in either imaging or pencil beam mode. The pencil beam operation is like the conventional range-time-indication (RHI) scan, but with electronic beam steering. In the imaging mode, the transmitted beam is spoiled in elevation to illuminate a wide field of view, and multiple narrow receive beams are formed simultaneously through digital beamforming (DBF) techniques. This unique imaging mode can provide continuous sampling in the vertical direction and faster update time compared to pencil beam operation. As a result, a volume scan of 360-degree in azimuth and 20-degree in elevation can be achieved in 6-10 seconds. Through antenna beam synthesis, PAIR can transmit with standard beam shape (spoiled fan beam or pencil beam) or customized beam pattern to minimize the clutter contamination, for example. In addition, PAIR is capable of different waveforms and can operate in the simultaneous transmission and simultaneous receiving (STSR) or alternating transmission and simultaneous receiving (ATSR). Circular polarization is also feasible with PAIR. These capabilities together with fast update times have the potential to enable many scientific studies, especially for those fast-evolving phenomena such as tornadoes, hail, downbursts, lightning, etc.

ID: 193, Poster presentation

CHARACTERIZATION AND DETECTION OF DOWNBURSTS AND THEIR PRECURSORS WITH AN ALL-DIGITAL POLARIMETRIC PHASED ARRAY WEATHER RADAR IN A CLUTTER ENVIRONMENT

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Wind hazards associated with downbursts can pose significant threats to aviation and public safety. Although conventional weather radars with Doppler and polarimetric capabilities have provided valuable observations of such fast-evolving phenomena, their update time and vertical sampling are often limited and thus can prevent timely detection and characterization of downburst precursors. The recent development of polarimetric phased array radar (PAR) with all-digital architecture provides great flexibility in scanning patterns that can address those limitations. For example, the imaging technique, where a spoiled transmitted beam is produced in the elevation direction and multiple narrow receive beams are formed simultaneously, can provide continuous vertical sampling within the spoiled beam and faster update times. In this presentation, a simulation framework based on the Cloud Model 1 (CM1) will be introduced to assess the trade-offs of different scanning techniques on the characterization and detection of downbursts and their precursors in a clutter environment. For an all-digital PAR, the ground clutter contamination can be mitigated using both beam synthesis (e.g., to put a null in the direction of ground clutter) and conventional ground-clutter filtering. In this work, we implemented imaging techniques with various transmitted pattens. In addition, the beam multiplexing technique, which leverages the beam agility of a PAR to improve the update time while maintaining data quality, is also be included. These scanning techniques will be compared to the conventional pencil beam operations for downburst observations. The downburst precursors under investigation include the descending reflectivity core, mid-level convergence, and specific differential phase core. The impact of these scanning strategies on the characterization and detection of downbursts and their precursors in the clutter environment is assessed both quantitively and qualitatively. Recommendations of PAR scanning strategies to provide early warning for and accurate detection of downbursts are made.

ID: 202, Poster presentation

RADARHUB: INTEGRATING OPEN-SOURCE ALGORITHMS INTO REAL-TIME WORKFLOW

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At the Advanced Radar Research Center at the University of Oklahoma, a new method for data sharing and on-line visualization has been developed, known as RadarHub. It serves as a hub to connect users and radars. Our mobile radars that are connected to the internet can seamlessly report to RadarHub in real-time, facilitating data transmission and system status updates. Also, RadarHub offers users a modern and user-friendly portal for accessing both real-time and archived data. Powered by a Python-based backend, RadarHub enables a seamless integration of high-level research algorithms that use radar moments or base products as inputs to produce new radar products. For example, a clean velocity field (unfolded) using artificial intelligence, an attenuation correction reflectivity field, and KDP field that is derived using differential propagation phase, just to name a few. These can be done on-the-fly as part of the data sharing workflow. Currently, users can browse and visualize archived data from the PX-1000 and RaXPol on the RadarHub website at https://radarhub.arrc.ou.edu

ID: 204, Oral presentation

CRMN - RADAR IMAGE SUPER RESOLUTION USING A CONVOLUTIONAL RECURRENT MIXER NETWORK

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Image super-resolution (SR) is a research field that focuses on recovering high-resolution images from their low-resolution counterparts, often corrupted by the physical limitations of the image acquisition sensor or by unsuitable environmental conditions. SR is a challenging task mainly because of the need to reverse the degradation process while preserving image quality, such as its high-frequency details. The range of applications for these techniques has constantly expanded to various fields, including video surveillance, remote sensing, medical, automotive industry, electronics, and image analysis. In that sense, solving SR problems is imperative for tasks involving the manipulation of radar meteorological images, where their spatial upscaled areas must be sufficiently clear to reveal essential details concerning precipitation data. Nowadays, advances in big data and computational power have prompted researchers to use deep learning to address the problem of SR. Such studies have shown superior performance than statistical methods such as edge, patch, and prediction-based ones. Besides closed formulations and statistical methods to cope with image SR, machine learning techniques build the upscaling model from a collection of low-and-high resolution images. Considered state-of-the-art, Convolutional Neural Networks (CNNs) deliver promising results but at the price of complex architectures, high computational burden, and storage costs.This paper proposes CRMN (Convolutional Recurrent Mixer Network), a hybrid convolutional- mixer deep learn-based SR technique, as an alternative to overcoming complexities CNNs face concerning radar meteorological image SR problems. Experiments were conducted on two public datasets (Berkley432 and T291) and a manually collected precipitation dataset (67,424 images over 25 months) from IPMET (Meteorological Research Institute - Brazil) showed that, for upscaling factors of two, three, and four times, CRMN achieves competitive results compared with state-of-the-art (SOTA) image SR methods but using fewer parameters. In the best-case scenario, CRMN achieved a The Peak signal-noise ratio is 45.15dB, surpassing DnCNN and its corresponding recurrent version, which does not use a non-local mixer module.

Regarding memory consumption, CRMN requires 176k parameters, while some SOTAs like DnCNN, ARCNN, and VDSR figure around 550k, 681k, and 664k parameters each. Future works will consider more upscaling factors and datasets.

ID: 205, Poster presentation

INTERCOMPARISON OF COLLOCATED PARSIVEL DISTROMETERS

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Drop size distributions determine the Z/R relation. They are usually measured on the ground using optical distrometers. We operate a network of more than 20 Parsivel optical distrometers. For quality assurance purposes, these distrometers have been collocated on our test field since December 2023 in a regular grid with a spacing of 1 m. We will compare the measurements of these devices in terms of the precipitation intensity, reflectivity, and reference diameter D_0 in order to identify miscalibrated or malfunctioning devices and to obtain an error estimate.

The temporal resolution will be reduced to 10 minutes as we are not interested in the precipitation but in the characteristics of the measurement devices. Data will only be processed for periods with several hundred drops per spectrum. Sparsely populated measurements introduce errors due to the random nature of the precipitation.

ID: 213, Oral presentation

UTILIZING RADAR OBSERVATIONS TO AUTOMATE CLASSIFICATION OF BOUNDARY LAYER ORGANIZATIONAL MODE USING CONVOLUTIONAL NEURAL NETWORKS

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Boundary layer observations are important for improving forecasts of warm season precipitation and air quality, as well as validating and more accurately initializing numerical models. In the convective boundary layer, different organized forms of convection develop, including horizontal convective rolls and cells, depending on the environmental conditions. Radar observations can be used to characterize different boundary layer convective modes, including cells, rolls, or no organized convection. Automated detection of the boundary layer convective mode from radar could improve numerical model forecasts as well as enable more extensive studies of boundary layer properties.

This study implements a novel machine learning approach to classify boundary layer convective modes using convolutional neural networks (CNNs). CNNs are widely employed in image classification tasks for extracting features from images through convolutional filters. Distinguishing reflectivity patterns of boundary layer modes can be conceptualized as an image classification issue. Using reflectivity data from weather radar, boundary layer types are grouped into three categories: cell, roll, and null. We utilized data collected during the warm seasons of 2014-2015 (April to September) for training and validation, while data from the 2016 warm seasons were employed for evaluation. The KTLX radar site was utilized for experimentation, with manually assigned labels of cell, roll, and null.

In the CNN application, reflectivity patterns of boundary layer modes are regarded as images, and cell, roll, and null as labels. Our experiments yielded an accuracy exceeding 80%, demonstrating high performance on more clearly distinguishable boundary layer modes, while also finding challenges in identifying the organization mode during transitional periods (roll-to-cell and cell-to-roll). Future work will focus on addressing these transition periods to further enhance classification ability. Probabilities for rolls and cells could be used to identify transition states when the probabilities are similar. In addition, the CNN will be applied to other NEXRAD radar sites to characterize boundary layer structures in different geographic regions and contextualized by other observing platforms.

ID: 234, Poster presentation

SOPHY: FIRST MOBILE X-BAND POLARIMETRIC WEATHER RADAR DEVELOPED IN PERU

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The development of the first mobile X-band dual-pol weather radar (SOPHy: Scanning-system for Observations of Peruvian Hydrometeorological-events), by the Instituto Geofísico del Perú - IGP, responds to the need to continuous monitor the precipitation over a certain area to study the meteorological processes that originates extreme weather conditions that impact on the Peruvian population causing natural disasters. By knowing the genesis of precipitation, as well as accurately QPE are necessary for accurate weather models and forecasts.

SOPHy is a portable mobile radar that allows scans in azimuth and elevation with a maximum range of 75 km and a range resolution as low as 60 m. The use of SDR devices for the transmission and reception systems allows flexible configurations, for instance a combination of short and long pulse compression was used to detect further echos and mitigate the blind range. Open source tools and languages such: GNU Radio which is used for programming the transmission and reception system, Python which is used for signal processing and a web-based application to configure and monitor the radar.

Additionally to the development of SOPHy, the polarimetric results form the first two campaigns carried out in the central Andes and the northern Peru are also presented.

ID: 257, Poster presentation

UNDER THE HOOD - HOW SIGNAL PROCESSING IN THE WSR-88D PROVIDES THE BEST QUALITY DATA

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Since the 1970s, the United States weather radars have undergone major hardware upgrades to incorporate Doppler and dual polarization (i.e., from the WSR-57 to the current WSR-88D) to enhance remote sensing of the atmosphere. Likewise, software upgrades to the WSR-88D are periodically deployed to either support hardware upgrades or introduce new scientific signal processing research to improve the quality of the weather radar data. Over the course of its life cycle, the WSR-88D has seen important data quality improvements directed at ground clutter mitigation, range-velocity ambiguity mitigation, and meteorological estimation. Here, we discuss some of these techniques and provide background on the successful integration of the techniques into the WSR-88D.

ID: 258, Poster presentation

CHARACTERIZATION OF WIND TURBINE CLUTTER (WTC) CONTAMINATION ON THE WSR-88D

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With the increasing desire for renewable energy, new wind farm development is on the rise. An increasing numbers of new wind farms are within the normal and anomalous propagating view of existing WSR-88D radars. These wind farms create unwanted reflections and obscurations that hinder the extraction of meteorological estimates from composite received signals. Consequently, the impacts caused by wind turbine clutter (WTC) contamination on weather-radar product interpretation become more challenging and automated algorithms become less dependable. The need for research into mitigating WTC contamination impacts through signal processing solutions is essential in providing reliable weather operations. In this paper, we present preliminary research results to identify WTC contamination with temporal and spectral features from recorded digital signals collected on operational WSR-88D S-band radar systems. Using the identified WTC signals, we attempt to characterize the effects that WTC contamination has on the weather estimates using simulations and real data. Using our newfound knowledge, we can create large training sets for a machine learning solution to identify WTC contamination of weather signals.

ID: 276, Oral presentation

PLANNING FOR NOAA'S NEXT GENERATION DOPPLER WEATHER RADAR SYSTEM

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The NOAA National Weather Service (NWS) is in the process of completing a Service Life Extension Program (SLEP) on the NEXRAD (WSR-88D) weather surveillance Doppler radar network. This life extension will keep the overall network operating beyond 2035. In this activity, the NWS completed upgrading and refurbishing the following components of the radar: Digital Signal Processor, Transmitter, Equipment Shelter, and backup power system including the Generator, Generator Engine, and the Automatic Transfer Switch. The antenna pedestals are also being refurbished and that work will be completed in 2024. However, this series of upgrades does not address radar component obsolescence, degradation of radomes, towers and other infrastructure, and the ability to infuse significant new capabilities.

Although the NWS Radar Operations Center has been proficient in maintaining a very high level of network availability, some issues are becoming apparent for the 40-year old radar system. Many components that were not addressed in the SLEP are reaching the end of their service lives, becoming obsolete, and/or have become difficult or exorbitantly expensive to repair or replace. It is likely that the system availability requirement will not be achievable by 2030, resulting in prolonged gaps in radar coverage. Because of these challenges posed by obsolescence in the current system, the demand for new capabilities, and the advancement of new technologies, in 2023, the NWS Office of Observations started the process to define new requirements through user engagement, evaluate new technologies, and initiate studies to define cost effective solutions to not only maintain current capability, but also to upgrade and extend radar data collection to provide critical data to underserved communities.

The authors will report on efforts to initiate the Radar Next Program office that will refine requirements, develop acquisition strategies, assess scientific and societal value of the new system, and encourage government and commercial partnerships. The expected outcome of the upcoming studies is to ensure the future radar system meets documented sustainment and availability requirements as well as those that could include improved scanning strategies that are adaptable and flexible, improved mitigation of interference, expanded coverage, and improved forecaster ability to identify severe weather and issue life-saving weather forecasts and warnings to the public. Beyond these studies, the Radar Next program is expected to design, develop, and deploy NOAA's next generation weather surveillance Doppler radar network.

ID: 305, Poster presentation

PERFORMANCE VERIFICATION OF DUAL-POLARIZED X-BAND PHASED ARRAY WEATHER RADAR AT OSAKA UNIVERSITY

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We have developed an X-band dual-polarized multiparameter phased array weather radar (MP-PAWR) in cooperation with Toshiba Corporation. One of the latest MP- PAWRs, the Suita MP-PAWR at Osaka University Suita Campus, Japan, was deployed in December 2022. The Suita MP-PAWR consists of 112 reception antenna units and 12 transmission antenna units, enabling electronic elevation beam steering with fan transmission beams through analog beamforming, and pencil reception beams via digital beamforming. It completes three-dimensional scans in either 30 or 60 seconds, combining electronic elevation scanning with mechanical azimuth scanning. This presentation will introduce the Suita MP-PAWR, discuss the qualification of polarimetric parameters such as reflectivity, differential reflectivity, differential phase shift, specific differential phase, correlation coefficient, and present several case studies from the initial operations.

ID: 351, Poster presentation

PY-ART 2.0: RADAR MEETS XRADAR

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The Python ARM Radar Toolkit (Py-ART) is an open-source toolkit, funded by the United States Department of Energy Atmospheric Radiation Measurement (ARM) user facility, focused on enabling open science. Initially released in 2013, Py-ART supports reading, analyzing, visualizing, and saving weather radar data. The open-source ecosystem has changed a great deal since its initial 1.0 release, most recently the release of the FM301/cfradial2 data standard. The World Meteorological Organization (WMO) adopted a new universal weather radar data standard, FM301, which is built around cfradial2 groups.

The open radar stack developers are in process of migrating all of the Input/Output functionality, which was previously in each radar package (Py- ART, wradlib, etc.) into a single package, xradar. Xradar is an in-memory representation of the FM301/cfradial2 standard. Once users read in their data using xradar, they can use accessors, which are connections to other toolkits. The wradlib library has already moved to 2.0, taking the approach of using accessors, which is the same plan for Py-ART, to be released in September 2024. This enables direct cross-compatibility between libraries, enabling seamless data cleaning, retrieval, classification, and visualization across the open radar stack. One common ARM data correction task in wradlib that would be helpful to use within Py-ART is beam blockage corrections. Users will easily be able to carry out this task using this ecosystem. We will provide an overview of the key components of Py-ART 2.0, with demonstrations of new scientific workflows enabled by the improved interoperable tools in the open radar stack.

ID: 352, Poster presentation

OBSERVATIONS USING AN X-BAND PHASED-ARRAY BISTATIC RADAR NETWORK

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The availability of low-cost electronic components for microwave signal processing has created new interest in the use of multistatic radar for weather observation [e.g. 1,2]. Multistatic radar networks consist of a single transmitting radar and multiple receivers positioned some distance away from the transmitter and each other. The remote receivers observe the forward scattering of the transmitted pulse by weather phenomena. By combining observations from multiple receivers, it is possible to obtain additional information on the scatterers. For example, multiple components of the velocity can be obtained from the Doppler measurements [3]. The use of a single transmitter and multiple passive receivers offers benefits over multiple independent radars both in terms of cost savings and in temporal synchronization of the measurements.

The Microwave Remote Sensing Laboratory at the University of Massachusetts Amherst, in collaboration with teams from Stony Brook University/Brookhaven National Laboratory (SBU/BNL) and the University of Oklahoma, are leveraging the SBU/BNL Skyler-2 X-Band mobile phased-array radar to construct a multistatic radar network using the phased-array as the transmitter. Skyler-2 is a low-power, dual- polarized, phased-array developed by Raytheon Technologies, now Collins Aerospace [4]. The multistatic network is to be used to study deep convection in storm cells. It will consist of multiple passive receivers synchronized to the transmitter using GPS disciplined oscillators, allowing the receivers to be positioned beyond the line of sight of the transmitter. We present preliminary results using the Skyler phased-array radar and a single GPS-synchronized low cost bistatic receiver.

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ID: 363, Poster presentation

PODRADS: LOW-POWER, LOW-COST VERTICALLY POINTING RADARS TO OBSERVE VERTICAL VELOCITIES IN TORNADOES AND CONVECTIVE STORMS

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Weather radars can provide a relatively safe way to observe tornadoes, but they generally do not provide information about the vertical flow field. Theory, laboratory models, and numerical simulations form the basis of our current understanding of the full 4-dimensional structure of tornadoes, but there have been precious few opportunities to obtain actual measurements (in situ or remotely sensed) of the vertical component for at least a few important reasons (e.g., difficulty in obtain photogrammetric results inside the debris cloud or condensation funnel, severe safety and equipment restraints associated with getting a mobile radar close enough to a tornado to sample the tornado at near- vertical elevation angles, etc.). However, there is some limited evidence (e.g., models and limited photogrammetry analysis) to suggest that the vertical winds in some tornadoes may exceed the horizontal winds, at least at some times in some locations. To address the dearth of information on vertical velocities in tornadoes, we are undertaking an ambitious project to develop PodRads — low-cost, low-power, vertically pointing, X-band radars designed to obtain, for the first time, the vertical profile of vertical velocities in tornadoes. Herein, we present primary considerations and constraints that have driven radar design and discuss the expected applications for these systems. If successful, the radars will be able to collect never-before-seen, high- resolution measurements of the vertical profile of vertical winds in tornadoes. Even in the absence of an in-situ tornado intercept, the radars are intended to collect very valuable information on the vertical structure of the updrafts and downdrafts within the parent convective storm.

ID: 366, Oral presentation

THE LIDAR RADAR OPEN SOFTWARE ENVIRONMENT (LROSE) SCIENCE GATEWAY: RADAR ANALYSIS IN THE CLOUD

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The Lidar Radar Open Software Environment (LROSE) is being developed to meet the challenges of complex radar and lidar processing needs faced by users in the research and education communities. Through support from the National Science Foundation (NSF), Colorado State University and the National Center for Atmospheric Research (NCAR) are developing the LROSE core algorithm modules for those typical processing steps that are well understood and documented in the peer-reviewed literature. LROSE focuses on key software building blocks for data processing and analysis workflows: Convert, Display, Quality Control, Grid, Echo, and Wind. Our current 'stable' release is called "Colette", which consists of a suite of well- documented software modules for performing radar and lidar analysis.

The LROSE team, in collaboration with developers from the Unidata Science Gateway, has developed a new version of the LROSE Science Gateway, which aims to increase accessibility to the LROSE applications in the cloud. The LROSE Science Gateway is hosted on JupyterHub servers deployed on NSF’s Jetstream2 supercomputer. One JupyterHub server will be open at all times for lower-usage testing by individuals, while other short-term, higher- usage, and customizable JupyterHub servers are deployed for workshops and classroom exercises. The JupyterHub servers host introductory tutorials that guide users through common scientific workflows and the only requirements are 1) a modern web browser and 2) a GitHub account.

Current tutorial offerings demonstrate how to calculate specific differential phase (KDP), run the NCAR particle identification (PID) algorithm, estimate precipitation rates, perform basic quality control procedures available in LROSE, create NEXRAD mosaics, and generate multi-Doppler analyses using FRACTL and SAMURAI. Some tutorials provide already completed parameter files to run applications, while other work flows guide users through the parameter files to help users to understand how to create their own workflows with their own data. These tutorials integrate LROSE applications with other open source packages (e.g., Py-ART) to show users how open source packages can work together. These tutorials are also available on GitHub for use on personal machines. Our first classroom exercise took place in the Spring 2024 semester, where a graduate radar class generated dual-Doppler analyses. Lessons learned and planned improvements from this initial classroom exercise will be presented.

Community members will learn how to access the JupyterHub server, contribute workflows to the LROSE Science Gateway, and set up educational workshops or classroom exercises. Future work including planned THREDDS servers for hosting workshop data and optimizing the Science Gateway for computationally intensive applications like SAMURAI will also be presented.

ID: 370, Oral presentation

THE NATIONAL SEVERE STORMS LABORATORY (NSSL) PHASED ARRAY WEATHER RADAR RESEARCH AND DEVELOPMENT PROGRAM: SUCCESSES AND OPPORTUNITIES

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After three years of continual use since its initial operational capability (IOC) in April 2021, the Advanced Technology Demonstrator (ATD), an S-band, dual-polarization phased array radar (PAR), is enabling engineering and meteorological research needs that are improving weather radar science and operational feasibility of PAR. The ATD has collected over 80 unique datasets spanning a variety of scientific and engineering objectives including severe and nonsevere weather events, a few of which will be highlighted. The ATD has implemented several techniques that PAR offers that conventional dish radars (e.g., WSR-88D) cannot achieve, including adaptive beamforming that is promising for mitigating interference within the sidelobe regions. Recent engineering developments on the ATD have demonstrated spoiled transmit beam operations that are being conducted in real-time for weather operations in 2024. Along with these spoiled transmit beam modes, NSSL is working towards implementing adaptive scanning techniques that will automatically prioritize which storms to focus on when there are multiple impactful events occurring simultaneously. In addition to these engineering and scientific advances, the PAR R&D program provides critical information to the National Weather Service (NWS) to inform their decision as to whether PAR is one of the viable solutions for the next operational national radar network.

ID: 376, Oral presentation

VERIFICATION OF THE CROSS-POLARIZATION CHARACTERISTICS OF POLARIMETRIC WEATHER RADAR ANTENNAS USING THE SUN AS A SOURCE

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For the accurate measurement of variables, a polarimetric radar requires an antenna with cross-polarization isolation sufficiently high to guarantee that the measurements are not significantly affected by instrumental errors.

Any reflector antenna has cross-polarization characteristics that are not ideal. Several factors can cause impairments in the cross-polarization isolation, compromising the quality of the products generated by the radar. The main deleterious factors are deformations of the reflector surface, misalignments of the feeder from its ideal position and orientation, errors in the orthomode transducer of the feeder, and other asymmetries. Some of them may increase with use and aging, requiring periodic checks.

We present a method that allows verification of the cross-polarization characteristics of the antenna using the sun as a microwave source.

The method uses the fact that the sun emits microwave radiation like a random noise source, so the signal received in the two polarizations used by the radar (horizontal and vertical) can be modeled as a pair of random processes completely uncorrelated. Another important fact is that the power spectral density of solar noise at the receivers is sufficiently higher than the noise spectral density added by the receiver chains.

For the measurement, the antenna beam scans the solar disk and the radar registers data received in both polarizations.

Based on the computation of cross-correlation functions as a function of the direction of arrival to the antenna, the radar estimates the cross-polarization characteristics of the system. These are used as an indicator of the polarization purity of the antenna, regardless of the matching of the two receiver chains provided that they are isolated.

ID: 377, Oral presentation

DUAL-POLARIZATION ANALYSIS CONCEPTS FOR APAR SIMULATION OF AIRBORNE PHASED ARRAY RADAR (APAR) ARCHITECTURE

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Airborne Phased Array Radar (APAR) is an airborne weather radar with dual-polarization and two-dimensional electronic-beam steering capabilities, which is to be mounted on C-130 aircraft. The dual-polarization capability allows us to obtain detailed physical information of storms, such as rainfall rate, particle-size distribution, and hydrometer classification. The electronic-beam steering enables to fast scanning to cover whole storm in a short time. While a combination of the capabilities of dual-polarization and phased array antenna gives the remarkable advantages, there exists a technical difficulties in dual-polarization measurements in off boresight. In addition the use of polarization itself changes from an airborne platform, in terms of look angle , tilt etc.. . In phased array antennas where antenna elements are uniformly installed in two dimensions, 'boresight' is defined as electronical steering to either longitudinal or lateral direction. Namely, 'on-axis' means that, when a beam is steered longitudinally, a beam is laterally perpendicular to the antenna plane, and vice versa. 'Off-axis' is defined as its otherwise. A significant technical difficulty in off-axes is that inputs of H- and V-ports are quite different from mechanical scanning antennas, which yields offset onto differential reflectivity (Zdr). Another issue is that mismatches between H- and V-beams, which may result in errors that need to be corrected. In this study, APAR observations are simulated is simulated with a simple phased array antenna to define the dual-polarization metrics for an Airborne platform.

ID: 378, Poster presentation

RMATOOLBOX: AN OPEN-SOURCE PYTHON LIBRARY FOR EXPLORATION OF DATA FROM THE ARGENTINIAN METEOROLOGICAL RADAR (V1.0)

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At the end of 2011, through the SINARAME project, the Argentine government promoted the creation of a unified national network of dual-polarization C-band weather radars.

Along with the design, manufacturing, and installation of the new Argentinian Meteorological Radars (RMA), a centralized control system was set up in Buenos Aires.

With the expansion of the network in the subsequent years, Argentina went from having only 2 isolated dual-pol weather radars in 2011 to centrally storing data from 15 radars at the National Meteorological Service (SMN) facilities in Buenos Aires.

The increasing number of available I/Q data, from the 13 RMA radars and the continuous push for improvement of RMA's signal processing algorithms paved the way for the creation of this library.

The goal of RMAToolbox is to assist the engineers and scientists who work every day to improve the quality of the data generated by RMA.

This first version of the libray provides routines for reading and writing level 1 data files (I/Q time series) and elementary functions that aid in the manipulation, filtering, and plotting of the radar data.

ID: 385, Poster presentation

IMPROVING DATA ACCURACY OF CLOUD RADARS WITH MULTIPLE CALIBRATION METHODS INCLUDING AN ACTUATED NEAR-FIELD SPHERE

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Maintaining and improving raw data accuracy of multi-band polarimetric cloud radars requires a coordinated and continual effort involving physicists, engineers, technicians, and data analysts. Calibration of hardware components is necessary at various points along the pathway to deployment and beyond. Various methods of calibration are shown to improve data accuracy and quality. When available, multiple observations are used simultaneously to improve certainty of calibration. Methods include end-to-end calibration with corner reflectors, absolute receiver calibration with solar intensity estimates, relative dual-pol calibration with light rain, and orientation calibration with celestial position models via solar scanning. Considering the coherence of a weather radar it will be shown that a novel technique is explored in detail using a metal sphere linearly actuated up and down range. The idealized scatterer is engineered with high precision at a radius well within the optical region. The sphere is mounted with a 3D printed material chosen for its electromagnetic transparent properties and is remotely moved with a servo mechanism in a variety of motion patterns. It is shown that the sphere acts like a termination standard when positioned correctly. Post-processing is then used to extract data beneficial for more accurately determining the radar calibration constant. With each calibration a variety of issues arise including system software instability, weather, environmental parasitics, and limited hardware component lifetimes. This project is funded by U.S. DOE.

Radar hydrometeorological applications

ID: 5, Oral presentation

EXPLORING PRECIPITATION INTENSITY-DURATION-AREA-FREQUENCY (IDAF) PATTERNS USING WEATHER RADAR DATA

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Extreme precipitation, the primary trigger of hazardous phenomena such as floods and flash-floods, poses a serious threat to human beings and livelihoods worldwide. Extreme precipitation is highly variable in both space and time, thus understanding and managing the related risks necessitates an improved knowledge of their probability at different spatial-temporal scales.

We employ the simplified metastatistical extreme value (SMEV) approach, a novel non-asymptotic framework, to estimate extreme return levels (up to 100 years) at multiple temporal (10 min–24 h) and, for the first time, spatial (0.25 km^2–500 km^2) scales using weather radar

precipitation estimates. The SMEV framework reduces uncertainties and enables the use of relatively short archives typical of weather radar data (12 years in this case).

Focusing on the eastern Mediterranean - a region characterised by sharp climatic gradients and susceptibility to flash floods - we derive at-site intensity-duration-area-frequency (IDAF) relations at various temporal-spatial scales. Comparison with extreme return levels derived from averaging 30-year daily rain gauge data over areas with dense gauge networks yields comparable results, demonstrating that radar data can provide important information for the understanding of multiscale extreme precipitation climatology.

We then examine the climatological differences in extreme precipitation emerging from coastal, mountainous, and desert regions at different scales. Three key findings emerge:

1. At the pixel scale, extreme precipitation exhibits a simple scaling relation with the duration, but this relationship breaks down with increasing area - this has significance for temporal downscaling.
2. Precipitation intensity is dissimilar for different area sizes at short durations but becomes increasingly similar at long durations - thus areal reduction factors may be unnecessary in the area when computing precipitation for long durations.
3. The orographic effect causes increased precipitation for multihour events (orographic enhancement) and decreased precipitation for hourly and sub-hourly durations (reverse orographic effect); however, this phenomenon decreases over large areas.

The study highlights the effectiveness of radar precipitation in estimating extreme return levels, enabling the derivation of high-resolution IDAF spatial patterns even in ungauged locations – thus broadening the application of extreme precipitation frequency analysis beyond the limitations of gauge station networks.

In an on-going continuing study, we explore the relationship between IDAF and flash flood generation, considering the catchment response space and time scales.

ID: 9, Oral presentation

HYDROLOGICAL MODELING OF PROBABILISTIC RAINFALL FORECASTS FOR IMPACT-BASED FLOOD WARNING SYSTEM

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Extreme precipitation events are significant natural hazards that impact economies and populations globally. These events are difficult to predict and exhibit high spatial and temporal variability, which in turn increases flood forecast uncertainties. Therefore, it is critical for warning systems to precisely estimate the severity and associated uncertainties for mitigating damages and enhancing preparedness, particularly in urban areas due to high population density, critical infrastructure, etc. The main objective of this presentation is the integration of operational radar products, provided by the Royal Meteorological Institute of Belgium (RMI), into a distributed urban-hydrological model towards the implementation of an impact-based flood warning system. This is achieved using Delft-FEWS, which is a platform developed by Deltares, that allows the integration of multiple datasets and models with high flexibility, compatibility and modularity. A distributed urban-hydrological model is designed such that it will couple a 1D model of the pluvial network in EPA SWMM with a 2D model mesh for the streets and inundation areas. Due to scarce hydrological data in urban areas, the model will be validated using the RADCLIM product for several precipitation events and a collection of flood reports to the Fire Brigade from the National Crisis Center. RADCLIM is obtained after merging Quantitative Precipitation Estimation (QPE), observed by the operational C-band weather radar network in and near Belgium, with rain gauge measurements. After model validation, probabilistic rainfall forecast products will be used to generate an ensemble hydrological forecast and estimate flood uncertainties for the impact-based flood warning system. The seamless precipitation forecast product is achieved by blending a probabilistic rainfall nowcast with precipitation fields from numerical weather prediction (NWP) ALARO/AROME models. This is a pre-operational RMI product developed based on the open-source Python library pySTEPS, spanning up to 12 hours lead time and 48 ensemble members. Although this warning system is in its early stages and further investigation is needed to implement the best operational practices, preliminary results for the city of Antwerp will be shown. This research will serve as the foundation for developing a Physically Informed Data-Driven Model for a rapid real-time impact-based flood warning system, spanning both urban and larger scales.

ID: 13, Poster presentation

CONVECTIVE GUST ALERTS GENERATED BY THE RADAR-BASED "SEVERE WEATHER INDEX" IN THE INCA-BE NOWCASTING SYSTEM

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In the course of 2023, a new radar-based product was developed focussing on the detection and warning against hazardous gusts during convective events, such as downburst. Our methodology involves feature detection in radar images, analysing both reflectivity and radial velocity, combined with a conservative extrapolation into future time steps. The first part, the feature detection, is carried by the Leonardo Rainbow® 5 software suite which offers comprehensive toolset for phenomena detection, like con/divergence and mesoscale rotation. The output, comprising polygons and point detections, is further transformed into a raster field with three warning levels (yellow/orange/red) for potential dangerous wind gusts, creating the "Severe Weather Index" (SWI) field. This field is integrated into our INCA-BE nowcasting system and is advected in time along with the system's precipitation forecast to ensure coherence in the output products. The advected SWI field is finally integrated in our system that generates notifications for hazardous weather sent out via the RMI smartphone app. These automatically generated notifications are referred to as "weather flashes" in order to make the distinction between RMI's official weather warnings manually issued by the forecasters.

The RMI weather flashes are organised at the level of the Belgian municipalities, aggregating several INCA-BE output fields to generate flashes for various phenomena. For severe convective gusts, flashes rely on the advected SWI field and are sent out with a lead time of up to 20 minutes before the SWI field impacts a specific commune. A certain fraction of the commune's surface should be affected for the flash to trigger. Managing expectations for the SWI product and the downstream flashes is crucial. Despite a year of testing and fine-tuning, limited case availability impedes a comprehensive evaluation. The tornado in Bouillon on 22/06/2023 revealed a significant signal in the product, even reaching the highest alert level. However, for another tornado in Onze-Lieve-Vrouw-Waver on 03/01/2024, a yellow zone (lowest level) appeared half an hour before the tornado in the thunderstorm cell's path, but the actual path was slightly southward compared to the predicted SWI zone. While promising, the product seems to perform better in the case of organised systems with substantial vertical extension.

ID: 16, Oral presentation

ASSESSMENT OF HYDROLOGICAL PERFORMANCE FOR TWO SHORT-TERM RAINFALL FORECASTING APPROACHES AMED AT FLOOD PREDICTION

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Predicting floods is still a challenging task, particularly for sudden flash floods occurring in basins with limited drainage areas (10^3 km² or less). In this work is presented a short-term flow forecasting system that exploits two short-term precipitation forecasting algorithms: Blending using Correlation for Meteo-nowcasting (BeCoMe) and Score-Weighted Improved NowcastinG (SWING).

A combination of a nowcasting algorithm and numerical weather predictions is utilized. The meteorological model is refreshed every 3 hours via 3DVAR assimilation through updated radar and lightning data. The nowcasting algorithm produces precipitation field forecasts every 10 minutes and are combined with the meteorological rainfall forecast every hour, offering a forecast window of 6 hours. Through a distributed hydrological model, rainfall forecasts are translated into flow predictions. The potential of assimilating both radar and lightning data, or solely radar data, was investigated. The system underwent testing during two periods of autumn 2019 lasting approximately 7-8 days each, characterized by significant precipitation events. Initial promising results lead to the implementation of the chain at national-scale as a valuable operational tool for managing intense weather events.

ID: 21, Oral presentation

A NEW METHODOLOGY FOR RAINFALL ESTIMATION USING SPECIFIC ATTENUATION

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Utilization of the specific attenuation A for rainfall estimation introduced a decade ago was a real game changer in radar QPE. The R(A) algorithm operationally implemented on the Multi-Radar Multi-Sensor (MRMS) platform in the US demonstrated well documented improvement in QPE for the nationwide network of the S-band WSR-88D radars. The most challenging part of the R(A) methodology is a real-time optimization of the factor $\alpha = A/K_{DP}$ used to convert a total span of differential phase along the propagation path in rain into the path-integrated attenuation PIA. In the current version of the algorithm, a single value of α is used for a whole radar PPI which is determined from the slope of the Z_{DR} vs Z dependence. Another problem with existing method is that it does not explicitly take into account the dependence of A on temperature.

Both these problems are addressed in the new R(A) algorithm that utilizes different equations, automatically determines an optimal value of α for each radial of data, and allows for changing temperature along the beam. Such optimized α can be also used for attenuation correction of the radar reflectivity factor Z. The new method avoids the need for the most cumbersome and time-consuming part of the existing algorithm – finding "the net α". It is demonstrated that the new version of the algorithm provides more accurate estimates of specific attenuation and rain rate in a wide range of situations. In this presentation, the performance of the new R(A) method will be illustrated for a number of rain events observed by the S- and C-band radars.

ID: 25, Oral presentation

CELL TRACKING -BASED FRAMEWORK FOR ESTIMATION OF NOWCASTING MODEL SKILL FOR REPRODUCING GROWTH AND DECAY OF CONVECTIVE RAINFALL

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The rapid temporal evolution of convective rainfall poses a challenge for radar-based rainfall nowcasting models, and so far, few studies have investigated how well the growth and decay of convective rainfall is reproduced by the models. Common grid-point-by-grid-point verification metrics used to validate model skill are often dominated by large-scale stratiform rainfall and penalise location errors. Additionally, averaging the metrics across entire precipitation fields obscures how accurately the models replicate individual convective cells, which makes it difficult to distinguish the model skill for growth and decay of convective rainfall.

Here we present a cell tracking-based framework for investigating how accurately a nowcasting model reproduces the growth and decay of convective rainfall. We differentiate the convective cells based on the cell status when the nowcast is created into either decaying or growing, which allows us to analyse the model skill separately for both stages.

The framework consists of first identifying and tracking the convective cells in the input observation rainfall fields and then identifying and tracking the cells separately in the reference observations and the nowcast rainfall fields by continuing the cell tracks identified in the observations. Features describing the convective cells and the cell tracks, such as the cell area and mean rain rate, are then extracted. In addition to the errors in these feature values, we estimate the skill of the models in reproducing the existence of the cells by calculating several contingency-table metrics, such as the Critical Success Index. The results allow us to analyse how well the models reproduce the growth and decay of convective rainfall and emphasise the difference in model skill between growing and decaying cells.

We demonstrate the framework using four openly available models: the advection nowcast, S-PROG, and LINDA implemented in the pysteps library, and L-CNN. Nowcasts with one-hour lead time and 5-minute temporal resolution are created for a dataset selected from the most precipitating days from the summers of 2021 to 2023 from the Swiss radar network. The performance of the models is then analysed using the approximately 150,000 cell tracks collected from these nowcasts and the corresponding reference observations.

ID: 28, Oral presentation

BLENDING OF RADAR, SATELLITE AND GAUGE RAINFALL DATA FOR HYDROLOGICAL APPLICATION

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The Australian Bureau of Meteorology collects rainfall data from various sources, including rain gauges, weather radars and satellites which come in a diverse range of spatial scales, accumulated over different time frames and collected in several formats. Each source offers unique benefits and has specific limitations, highlighting the necessity to blend these data into a single product that caters to an array of hydrological applications.

This research work aims to create a consolidated, reliable rainfall product by blending these various sources of data across Australia. This approach blends Rainfields data, which is quality-controlled rainfall data based on Australian weather radar network, with rainfall estimations from Himawari 8/9 Satellite data and observations from real-time rain gauges network. We use a Kalman filter to merge these data streams effectively. The process starts with an advection scheme that uses an optical flow from previously blended rainfall data as the initial background, which is then sequentially updated with inputs from satellite, radar and gauge data. To address the inherent uncertainties of each data source, we have integrated a spatial error field into our methodology. For radar data, the error variance is linked with both the rainfall intensity and the distance from each of the radars. For satellite data, error variance is a function of the rainfall intensity and the latitude with specific considerations for the tropics, sub-tropics and temperate zones. Currently, we are validating our methodology at hourly intervals on a continental scale, with plans to refine this approach to provide data at sub- hourly intervals which will help enhance the use of gridded rainfall information for a broad range of hydrological applications such as flash- flooding.

ID: 29, Poster presentation

COMPARISON OF HOMOGENEOUS AND VARIABLE ELEVATION SCANS ON THE UNCERTAINTY OF THE QUANTITATIVE PRECIPITATION ESTIMATION

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For the hydrological use of radar data, a reliable estimation of the amount of precipitation at the ground is necessary. Especially in mountainous regions with orographic rainfall, the uncertainty of precipitation measurement based on adjusted radar data increases with beam measurement height.

In Germany radar scans are taken of different elevations with a high spatial resolution (1° x 250 m). The orography following precipitation scan are the most common used data source for quantitative precipitation estimation. The second data source is the volume scan with static elevation settings. This case study aims to investigate the influence of both scan products on the quality of adjusted radar data.

The case study comprises data from the radar located in Essen (North Rhine-Westphalia) over a period of 1 year (01 November 2021 – 01 November 2022). Both radar scans presented the following characteristics:

- Precipitation scan; polar; spatial resolution 1° x 250 m; temporal resolution 5 minutes; variable elevation angle 0.78° - 1.26°; radar range 150 km
- Volume scan; polar; spatial resolution 1° x 250 m; temporal resolution 5 minutes; elevation angle 0.50°; radar range 180 km

The selected lowest elevation scan of the radar volume on the one side is clearly affected by partial beam blockage and ground clutter but on the other side has the lower measuring height and a homogeneous elevation in contrast to the precipitation scan.

The quality of both radar data sets datasets was were enhanced by data quality control algorithms for ground clutter, beam blockage, attenuation and advection correction. Beyond that, an adjustment was carried out by comparing both radar data scans with more than 850 quality checked rain gauge time series in a radius of 150 km around the radar site of Essen. The adjustment procedure combined factor field and difference field on a daily time interval.

The evaluation was performed by using approximately 170 independent validation stations. A comparison between rain gauge data and the corresponding radar pixel took place for each dataset by using the following criteria:

- daily precipitation sum
- yearly precipitation sum
- factor rain gauge /adjusted radar

As a result, the following conclusions can be drawn:

- there is a better consistency of the criteria between adjusted radar data and rain gauge data by using the lowest elevation of the volume scan than using the precipitation scan
- there are higher uncertainties in sectors with frequently changing radar elevation when using the precipitation scan than with the lowest volume scan
- there is a slightly higher uncertainty in areas of beam blockage and ground clutter by using the volume scan.

AUTOMATIC TRACKING OF TROPICAL CYCLONE CENTER USING OPTICAL FLOW TECHNIQUE COMBINED WITH THE KALMAN FILTER BASED ON WEATHER RADAR IMAGES

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To monitor and provide typhoons (tropical cyclones in the northwestern Pacific) center information, Weather Radar Center have developed the Automatic Center detection of Tropical cyclone using Image processing based on Operational radar Network (ACTION) (Mo and Gu 2023). The ACTION utilizes radar image data to extract motion vectors from temporal differences, and defines the typhoon center as the rotation center based on these vectors. Because typhoons are affected by both synoptic flow of the atmospheric and the rotational motion of the typhoon itself, the results of typhoon center detection using ACTION was occasionally inconsistent. To provide more accurate information to forecasters, we applied the Kalman filter to the ACTION algorithm to ensure the consistency of the typhoon's path linked to synoptic characteristics. In addition, other improved processes were added; minimizing errors through optimizing the Kalman filter application section, and sophisticated motion vector calculation, etc.

The ACTION and ACTION with the Kalman filter were quantitatively compared with the Korea Meteorological Administration's typhoon BEST track. It was confirmed that the Kalman filter-based ACTION traces the typhoon center more accurately than the original ACTION. The results of typhoon center path showed qualitatively high consistency, verifying the effectiveness using applying the Kalman filter. In this study, we found that the Kalman filter contributes to improve the accuracy of typhoon center detection in the ACTION algorithm. The results showed the increased consistency for the cases of typhoon approaching the Korean peninsula, which provides more accurate and effective typhoon information to forecasters.

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Keywords:

Kalman filter, TC center detection, optical flow, image precessing, operational network

ID: 36, Poster presentation

DETECTION OF CIRCULATION CENTROID IN MID-LATITUDE CYCLONE USING HIGH-RESOLUTION THREE-DIMENSIONAL WIND FIELDS DERIVED FROM NATIONWIDE WEATHER RADAR NETWORK

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Mid-latitude cyclones are medium-scale vortices of rising and converging air that circulates around a vertical axis. They are most often associated with a local region of low-pressure and fronts, and often cause significant damage due to strong winds and precipitation. For the routine process of weather forecasts, the forecasters indirectly determine the cyclonic system's movement by tracking the migration of their major precipitation regions using a weather radar network. However, if the main area of precipitation moves away from the center of low pressure as the low-pressure system stretches, or if the precipitation area is large and its movement varies from region to region, it becomes very challenging to determine the movement of the mid-latitude cyclone based on the tracking of the precipitation area. Therefore, we proposed the tracking technique of the mid-latitude cyclone system by detecting the cyclonic circulation centroid instead of the wide precipitation area in mid-latitude cyclones. The Weather Radar Center (WRC) of the Korea Meteorological Administration (KMA) provides real-time wind fields for the Korean Peninsula using high-resolution three- dimensional wind field products (WISSDOM) derived from the observation of radar radial velocity. In this study, we objectively analyzed the cyclonic rotation center according to variable characteristics such as wind direction, wind speed, and vorticity in WISSDOM wind field data calculated using weather radar. We also attempted to utilize this to analyze the development and structure of hazardous weather associated with cyclonic precipitation in 3-D in real-time. This technique consists of three steps; 1) Analyzing possible cyclonic center grid points using wind speed and vorticity 2) Analyzing cyclonic rotation area grid points using wind direction 3) Determining final cyclonic center grid points. As a result of applying this technique to six-teen events that occurred in 2023, eleven events were correctly detected, and the technique will be improved through optimization and modification of the algorithm. In the future, this technique will be applied to detect the centroid of tropical cyclones or mesocyclone, and furthermore, it is expected to be used for early monitoring of torrential rainfall.

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ID: 38, Poster presentation

ASSESSMENT OF VERTICAL PROFILE CORRECTION FOR QUANTITATIVE PRECIPITATION ESTIMATION USING OPERATIONAL S-BAND POLARIMETRIC RADAR OVER COMPLEX OROGRAPHY IN NORTHERN TAIWAN

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This study evaluated the vertical profile (VP) correction for the radar-based quantitative precipitation estimation (QPE) using S-band polarimetric radar and applied to various precipitation events from 2017 to 2024. The primary objective is to investigate the impacts of partial beam blockage (PBB) and beam broadening over complex orography on different seasonal precipitation events. To minimize the PBB effect and the uncertainties of specific differential phase (K_{dp}) in light rain, the retrieved (K_{dp}*) from self-consistency method was applied and investigated. Moreover, the effect of the VP variations of precipitation over complex terrain on several QPE algorithms was analyzed The VP correction uses the $R(K_{dp}*)$ relationship to recover the radar near-surface precipitation because of the limitation of vertical variation resulting from the propagation of the radar beam. The $R(K_{dp}*)$ with VP correction showed a significant improvement in this study.

Keywords: radar-based quantitative precipitation estimation; vertical profile correction; partial beam blockage; specific differential phase

ID: 40, Oral presentation

ASSIMILATING 3D RADAR REFLECTIVITY OBSERVATIONS IN COMPLEX TOPOGRAPHY

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MeteoSwiss operates a network of five C-band radars situated in the intricate topography of the Swiss Alps. The 3D measurements of reflectivity and radial winds encounter challenges, including high amounts of clutter and beam blocking by mountains, complicating their assimilation. In this study, we present initial efforts towards assimilating Swiss radar data into our high- resolution operational data assimilation system based on an ensemble Kalman Filter, the EMVORADO forward operator and the ICON model with a grid spacing of 1km. We will show results from case studies of convective and stratiform precipitation comparing reflectivity observations and model equivalents. Hereby, we focus on effects of the complex topography and discuss ways to handle them in data assimilation.

ID: 43, Poster presentation

A HYDROMETEOR CLASSIFICATION METHOD FOR DUAL POLARIZATION WEATHER RADAR BASED ON GAUSSIAN MIXTURE MODEL USING BAYESIAN INFERENCE

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In recent years, hail-related damage has rapidly increased worldwide due to climate change, making the development of hail forecast technology urgent.

In the development of hail forecasting technology based on conventional meteorological radar data, there has been a lack of a sufficient number of fixed observation points capable of detecting hail, which is a short-term and localized weather phenomenon. This limitation has made it difficult to evaluate and improve the accuracy of hail forecasts.

Therefore, we propose a new method (T-SHIBA: Two-Stage, Hydrometer classification and forecasting Induced By SNS, Algorithm), which utilizes the rapidly expanding use of social media platforms (SNS) in recent years. Through SNS posts by the general public about hail events, we identified approximate hail locations and times, enabling the evaluation and improvement of hail forecasting technology. This method consists of two stages: the first stage involves particle classification in three dimensions based on observations from meteorological radar, and the second stage forecasts hail locations in two dimensions (latitude and longitude) based on the results of the first stage.

This report presents the method for particle classification in the first stage. The forecast method for the second stage will be reported separately. To encourage user actions to reduce hail damage based on forecast results, it is essential to increase the reliability of these forecasts. Therefore, reducing false alarm rates is crucial, even if it means decreasing the accuracy of hail forecasts.

In traditional particle classification methods, heavy rain events without hail and hail events are grouped into the same category. This results in forecasting hail even in cases of heavy rain without hail, leading to a high false alarm rate. To address this issue, we created training data exclusively for heavy rain events without hail from SNS posts where no hail was reported. We applied a Gaussian mixture model using Bayesian inference to separate the hail and heavy rain categories. This approach allows us to build a classification model in a data-driven manner, eliminating the need to determine thresholds for each category based on an in-depth understanding of meteorological radar technology. As a result, we have introduced a hydrometeor classification method with distinct classifications for hail and heavy rain.

ID: 45, Oral presentation

PROPOSAL OF HAIL FORECAST METHOD AND PERFORMANCE EVALUATION UTILIZING SOCIAL MEDIA POST DATA

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This report presents the method for forecasts hail in the second stage. The hydrometeor classification method for the first stage will be reported separately. In hail forecast, the hail locations are forecasted using hydrometeor classification results for hail and the movement direction of rain cloud which is predicted using the advection vector of VIL (VIL: Vertically Integrated Liquid water) estimated from the three-dimensional observations of meteorological radar. However, numerical evaluation of forecast method for such weather phenomena was an issue because fixed observation data of localized weather phenomenon such as hail is often fragmented information. In this situation, we evaluated the hail forecast method by utilizing the locations and times of SNS posts about hail events. In this paper, we report the results of hail forecast for the hail cases in the Kanto region from June to October 2023.

ID: 48, Poster presentation

EXPLORING HEAVY RAINFALL EVENTS IN THE TROPICAL ANDES USING A SINGLE POLARIZATION X-BAND RADAR

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Floods cause significant damage to human life, infrastructure, agriculture, and the economy. Understanding peak runoffs is crucial for hazard assessment, but it is challenging in remote areas like the Andes due to limited hydrometeorological data. We explored the hydrological response of a 300 km2 catchment located in the Ecuadorian Andes for heavy rainfall events. To that end, we used precipitation data obtained from a high-resolution (5 min and 500 m) X-band weather radar deployed at an elevation of 4450 m over the period 2015–2021. We classified and characterized the rainfall for four different types, employing non-stationary rainfall- similarity indices: three heavy spatially clustered rain types (convective) and one spatially homogenous rain type (stratiform). The convective rainfall types differ in their advection properties, intensities, and spatial structure. Further, we examined the trajectories and origin of the storms using a back-trajectory model (HYSPLIT). Exploring different thresholds, we found that convective rainfall with a minimum duration of 2 h and intensity of 23 mm h-1 is required to potentially trigger high runoff events with peaks between 100 and 200 m3 s-1. The spatial distribution (localization of rainfall types in the catchment, area of the storm) and meteorological properties (volume, intensities, duration) of the heavy rainfall events triggering the high flow will be presented and discussed.

ID: 49, Poster presentation

INTEGRATING RADAR-INTERPRETED RAINFALL TO ESTONIAN OPERATIONAL FIRE WEATHER INDEX

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Estonian Environment Agency is upgrading the Fire Weather Index calculations from current rain-gauge based model to Canadian Forest Fire Weather Index. The sparse national rain-gauge network density poses challenges to detailed spatial rainfall distributions, which mostly rely on different interpolation methods. To increase the spatial resolution of the fire risk map, we integrated 24h radar-interpreted, advection corrected rainfall accumulations as precipitation estimation input for the Fire Weather Index. Using weather radar data introduces a new set of challenges to the system. Here, we present the complete operational workflow for the whole Fire Weather Index computation.

ID: 62, Poster presentation

RAINFALL RATE ESTIMATION IN NON-UNIFORM BLOCKAGE REGIONS: ADDRESSING CHALLENGES WITH THE SPECIFIC ATTENUATION METHOD

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The rainfall estimation using specific attenuation (A) is known to be immune to partial beam blockage in general. However, large variations in beam blockage along the integration path can introduce uneven effects on reflectivity (Z). Higher reflectivities may be observed in regions with minor blockages near the radar, while lower reflectivities occur as blockage increases with distance. Since A at any given gate is proportional to the ratio of Z at the gate over the integral of Z over the whole path, the uneven biases in Z can lead to corresponding biases in A, resulting in overestimation near the radar and underestimation far away. Consequently, the $R(A)$ estimation near the radar would have a wet bias, which has been observed in complex terrain environments. This study aims to address the issue of non-uniform blockages along the attenuation accumulation path and explore means to mitigate the corresponding biases in the specific attenuation-based rainfall estimation.

One approach to address this issue is to divide the integration path into smaller sections, each with relatively uniform blockage percentages. While increasing the number of sections theoretically enhances accuracy, smaller sections also introduce higher noises in the local specific differential phase (Φ_{DP}) span despite the quality control and smoothing processes applied to the Φ_{DP} field. Another method involves correcting Z measurements in blocked regions to minimize the biases in A. This study utilizes polarimetric S-band radar data from Taiwan, where rainfall estimation is particularly challenging due to the mountainous terrain. Preliminary results from Typhoon cases will be presented to assess the effectiveness of the proposed methods.

QUANTITATIVE PRECIPITATION ESTIMATION IN THE FRAMEWORK OF THE PROWESS PROJECT

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The PROWESS project (PRecipitation atlas for Offshore Wind blade Erosion Support System) main goal is to create a tool that allows managing offshore wind farms located in the Dutch North Sea according to the weather situation to reduce blade erosion and therefore extend the lifespan of the blades and reduce repairing costs. In order to develop this tool, a better understanding of the precipitation events that lead to erosion at a local scale is necessary. Consequently, high-resolution quantitative precipitation estimation (QPE) in the area, which is currently lacking, must be developed.

Within this context, SkyEcho is exploiting a high-resolution fully polarimetric X-band weather radar called MESEWI. The MESEWI radar is a Frequency Modulated Continuous Wave (FMCW) radar located on top of the roof of the faculty of Electric Engineering, Mathematics and Computer Science at the TUDelft Campus in Delft, the Netherlands. The site is approximately 15 km away from the coast and 50 km away from one offshore wind farm instrumented with, among others, a disdrometer.

The scanning strategy consists of a single PPI scan at 1.5° elevation repeated every minute and the range resolution is 100m, thus, high temporal and spatial resolution is achieved. A high Doppler velocity ensures that many samples are available, facilitating the data processing in the frequency domain.

Currently the data processing is being optimized in order to achieve the best QPE at 10 min resolution. This includes reflectivity bias correction, improved specific differential phase (KDP) estimation, precipitation-induced path attenuation correction and optimal combination of KDP and reflectivity-based rainfall rate estimators. Since the precipitation of interest is on the North Sea, no rain gauge merging is performed.

The resultant QPE product is compared with nearby rain gauges from two different datasets: One operated by the Dutch Meteorological Service (KNMI) and the other by Dutch Water Boards. The current real-time International Radar Composite (IRC) produced by KNMI is used as benchmark. This product merges radar data from the KNMI network with rain gauges operated by KNMI and by Met Services of the surrounding countries.

The objective set for the MESEWI 10-min QPE product is to demonstrate better performance in terms of normalized bias and correlation than the IRC real-time product when comparing with the Dutch Water Boards rain gauges, since it is an independent dataset for both products. Once this is achieved, the MESEWI QPE product will be an integral part of the windfarm management tool. Accurate precipitation estimation information will be combined with other parameters such as wind speed or temperature.

During the conference, details on the data processing and the QPE results will be provided.

ID: 75, Poster presentation

EVALUATION OF HOURLY PRECIPITATION SIMULATIONS FROM A NEW HIGH-RESOLUTION REGIONAL ATMOSPHERIC REANALYSIS ALADIN WITH GAUGE-ADJUSTED RADAR PRECIPITATION MEASUREMENTS

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Atmospheric reanalysis is a powerful tool to obtain three-dimensional information about the historical state of the atmosphere by combining observations and numerical weather prediction (NWP) modelling using different data assimilation schemes. Recently, several high-resolution regional atmospheric reanalyses have been produced for the European region. However, most of them are calculated using NWP models, where convective processes are parameterized, which leads to a major source of errors and uncertainties. From this reason, limited-area convection-permitting models have been used to reproduce high-resolution regional atmospheric reanalysis. One of them is a new ALADIN reanalysis providing a coherent description of the state of the atmosphere and near-surface layers at high horizontal (2.3 km) and temporal (1 hour) resolutions, covering a large part of Europe from 1989 to the present. Because precipitation can be highly variable in space and time, long-term, high-resolution observations are needed for the evaluation purposes. Therefore, gauge-adjusted radar precipitation measurements interpolated into the ALADIN reanalysis will be used to validate simulated hourly precipitation totals over the Czech Republic, Germany and the Netherlands during 18 warm seasons (April–October) in 2002-2019, separately for three model runs (two reanalysis and one historical run). The first, ALADIN/Reanalysis, includes the full assimilation of the observed data every 6 hours using a digital upper-air filter, which combines the high-resolution ALADIN guess with ERA5, the result of a global 4D variational analysis. The second, ALADIN/Evaluation Run, is also driven by ERA5, but this run uses no surface data assimilation and runs in a continuous computation mode. Comparing these two model runs will provide us with information about the level of physical description in the NWP model as well as the effect of assimilation on the resulting precipitation fields in the past. The historical reanalysis of ALADIN is then followed by a run of the ALADIN climate model to 2100, which should simulate the future climate scenarios. For validation purposes, a historical run of the climate model, referred to as the ALADIN/Climate, was created. As this is a climate model run, data validation with gauge-adjusted radar precipitation measurements will be done on a wider time scale, for example after five years, and only up to 2014, when the model run is terminated. Validation of simulated precipitation totals from the ALADIN/Climate will allow an assessment of the accuracy of the sub-daily precipitation totals simulated for subsequent decades.

ID: 79, Oral presentation

A NEW MICRO-PHYSICAL INTERPRETATION OF THE Z-R RELATIONSHIP FOR OPERATIONAL QPE APPLICATIONS

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It has been well known that the variation of the power law Z-R relationships ($Z=aR^b$) is related to the variability of raindrop size distribution (DSD). In this study, we propose a new micro-physical interpretation to investigate the variation of ***a*** and ***b*** based on the drop number concentration (*Nt* in m^{-3}) and drop mean diameter (*Dm* in mm). Compared to the previous proposals explaining the exponent ***b*** by shape parameter (*mu*) of the gamma function, the new interpretation doesn't take any assumption of analytical function on DSD and ***b*** is determined by the correlation between *log(Nt)* and *log(Dm)*, and the ratio of their variability. The coefficient ***a*** is determined by the value of ***b***, the mean values of *[log(Nt)]* and *[log(Dm)]*.

This new interpretation is consistent with the interpretations previously proposed in literature, such as the drops number controlled situation with ***b***=1.0, the drop size controlled situation with ***b***=1.63, the normalized concentration (*Nw* in m^{-3} mm^{-1}) controlled situation with ***b***=1.5. It

suggests three additional situations: the independent number-size situation with ***b***=1.63, the inverse drop number-size situation with ***b***=1.87 and a special situation with ***b***<1. From the 69 Z-R relationships quoted by Battan (1973), we found a constraint between ***a*** and ***b*** and it can be well explained by our interpretation.

To improve the operational quantitative precipitation estimation (QPE), we propose to determine the best local Z-R relationship through the Zh-ZDR relationship. According to the new interpretation, the slope of the Zh-ZDR relationship can be used to estimate the variability of *log(Nt)* and *log(Dm)*, and their correlation, so to determine the best exponent ***b***. The DSD and operational dual-polarimetric radar data collected in the south of France are used to illustrate the interpretation.

ID: 82, Poster presentation

DETECTION OF HAIL WITH A MACHINE LEARNING ALGORITHMS BASED ON WEATHER RADAR DATA

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Hail is a significant meteorological phenomenon from the point of view of damage to agriculture and property and the associated high economic costs, so it is important to keep improving the reliability of the hail detection. Machine learning algorithms are promising tools when it comes to classification problems. In this work the algorithms based on Support Vector Machines (SVM) and Random Forests (RF) techniques were developed to determine the class: hail or no hail. Both the methods require training and verification samples with relevant classes identified by observers from meteorological stations. The stations are limited to specific locations, but they are the most reliable and precise source of the data. The training was carried out on data from 2017-2021, in which 277 hail events were observed, whereas the verification was carried out on the 2022-2023 data, when 99 hail cases were recorded. The best results were obtained using the following radar parameters: vertically integrated liquid water over a given pixel (VIL) and the exceedance of 0°C isotherm by echo top (EHT) with reflectivity thresholds: 40, 45, and 50 dBZ. These results were compared with the algorithm currently working operationally for hail detection based on a fuzzy logic approach, that was developed and implemented in the Institute of Meteorology and Water Management - National Research Institute (IMGW) as a component of the system of detection and forecasting of dangerous weather phenomena for Poland territory.

PERFORMANCE OF A NEW RAIN RATE ESTIMATION METHOD IN AREAS OF WIND FARMS

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To meet requirements for clean energy, more and more wind farms are deployed globally. These present challenges for weather radar users. To mitigate the contaminations of wind turbines on radar measurements and accurately estimate rain rate in areas of wind farms, a new polarimetric radar QPE method mitigating wind farm effects is under development. First, the method detects the wind turbine contaminated radar echoes using the cross-correlation coefficient and local standard deviation of the differential phase. Second, it replaces the contaminated reflectivity measurements with median values of surrounding uncontaminated reflectivity. Third, the R(A) algorithm , where R is rain rate and *A* stands for specific attenuation, is utilized to estimate rain rate. To evaluate the performance of this new method, we found a rain gauge located in the area of a wind farm near Dodge City, KS for rainfall comparison. A precipitation system slowly propagating over the wind farm on June 3, 2023 is selected to examine the performance of the proposed QPE method. The wind turbines' echoes clearly showed in the observations of S-band WSR-88D (KDDC) at the elevation angle of 0.5^{o}.

The radar is at about 30 km from the wind farm. Three hourly rainfall amounts and 3-hour rainfall accumulations are compared between the measurements by rain gauge and radar QPE at elevation angles of 0.5^{o} and 0.9^{o}. The results demonstrate that the new radar QPE with suggested correction can mitigate the contamination of wind turbines and accurately estimate rain rates in the area of wind farms.

ID: 91, Oral presentation

OPTIMIZED RADAR RELATIONS FOR SNOW ESTIMATION VIA GROUND-BASED PARAMETER RETRIEVALS

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The largest contribution to uncertainties in radar snow quantitative precipitation estimation (QPE) comes from the natural variability in particle size distributions, diversity among snow growth habits, and modulations in snow densities. Compared to conventional radars, the abundance of additional information from the polarimetric measurements can significantly reduce biases and errors in radar snow QPE. Generalized polarimetric bi-variate power-law relations for snowfall rate estimation based on the joint use of radar reflectivity Z and specific differential phase Kdp (S(Kdp, Z); Bukovčić et al., 2020) that depend on the particle aspect ratio (a_r) and width of the canting angle distribution (σ), are updated to take into account the degree of riming (f_{rim}) and shape of the gamma particle size distribution (μ). In addition, bi-variate power-law relations based on reflectivity and mean volume diameter (D_m), also dependent on f_{rim} and μ, are introduced. The relations are optimized using the retrieved f_{rim}, particle orientation, and shape parameters (F_o and F_s – originating from σ and a_r) and the gamma size distribution parameter μ from the ASOS and Kessler's farm (the University of Oklahoma test site) stations measurements of extinction and snowfall rate. Optimized S(Kdp, Z) and S(D_m, Z) relations for snowfall rate estimation in heavy snow events are tested on the WSR-88D data against standard S(Z) and in situ measurements. S(Kdp, Z) and S(D_m, Z) estimates exhibit smaller biases compared to S(Z) close to the surface in cases when the low- altitude Kdp measurements (Kdp > 0.03-0.05 deg/km) or D_m estimates are reliable. S(Kdp, Z) usually performs poorly in heavily aggregated snow associated with weak or negative Kdp. One way for improvement is to replace S(Kdp, Z) with S(Z) if the latter (or some other) relations are known to work better for a given situation.

DEVELOPMENT OF A HYBRID RAINFALL DATASET USING WEATHER RADAR DATA AND GROUND RAIN GAUGES FROM THE THAILAND METEOROLOGICAL DEPARTMENT

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Weather radar can observe rainfall over wide areas with higher spatial and temporal resolution than other observation methods. The Thailand Meteorological Department (TMD) has installed 189 telemetric weather stations throughout Thailand to monitor rainfall. The average area covered by each station is approximately 2,734 km^2; however, the resulting data are both spatially and temporally insufficient. Most current studies on weather radar data in Thailand has focused on estimating rainfall intensity based on parameters that can be obtained from radar observations, such as radar reflection factors and interpolation phase differences, as well as composite processing. However, because the data distributed by the TMD are limited to hourly rainfall intensity data after composite processing, it remains difficult to estimate precipitation by performing composite processing on data with known quality issues. As described above, the weather radar data distributed by the TMD have high spatiotemporal error, and the quality of the data is not satisfactory. However, radar data used in other regions are considered useful as hydrological data. Therefore, in this study, we propose a new spatiotemporal interpolation method for weather radar data and explore the applicability of rainfall dataset generated by the new method.

The hybrid rainfall dataset proposed in this study was constructed through the interpolation of weather radar data for Thailand that are publicly distributed by the TMD, and its applicability to runoff analysis was evaluated and discussed. Temporal and large-scale spatial data gaps were interpolated based on ground rainfall data. Errors in the radar data were corrected through spatial interpolation using data values outside the error region, and several interpolation approaches were compared. The results of runoff calculations using rainfall dataset generated by this method accurately reproduced the observed runoff discharge. Therefore, the proposed dataset shows potential for application as input data for runoff analysis.

The TMD has installed weather radars throughout Thailand, and the resulting data are publicly distributed. Therefore, the proposed hybrid rainfall dataset is anticipated to be useful for clarifying actual rainfall in catchments where ground rain gauges are sparsely installed, which will be useful for flood management and water resource management applications, as well as reservoir operations.

ID: 99, Poster presentation

RAINCELL PROJECT: COMMERCIAL MICROWAVE LINKS TO ESTIMATE RAINFALL AT MÉTÉO-FRANCE

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Weather-sensitive applications and numerical modelling need more and more observations, but dedicated networks of sensors cannot increase in size without limits (sensors cost, maintenance). In order to complement its existing observation systems, Météo-France has been supporting for many years research works on the integration of new opportunistic sources of data in operational systems. Météo-France is leading the working group “crowdsourcing”, an EUMETNET action on opportunistic data, and participates to the Opensense COST action dedicated to opportunistic precipitation sensing networks.

Since 2017, Météo-France has been carrying out a project named Raincell with two partners, in order to use commercial microwave link (CML) data to improve quantitative precipitation estimation (QPE) in regions where standard sensors as rain gauges and weather radar have difficulties of measurement. The scientific partner is IRD (Institut de Recherche pour le Développement) which have a long experience on CML data use, particularly in Africa. The CML data provider is Orange a leading telecommunication operator.

The main feature of this project is to operationally retrieve in real time CML data over the whole country, in order to produce early (few minutes after measurement) a new fusion QPE product merging CML, radar and rain gauges data. The presentation provides an overview of the project and recent validation results.

ID: 100, Poster presentation

EVALUATION OF OPERATIONAL USABILITY OF CURRENT RADAR PRODUCTS IN ESTIMATION OF PRECIPITATION TYPE

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The Czech Hydrometeorological Institute (CHMI) operates two weather radars covering the area of the Czech Republic. Both radars were replaced in 2015 by C-band Doppler polarimetric radars Vaisala WRM 200.

Before modernization of Czech weather radar network, with single-pol radar measurements, the only radar-based estimation of precipitation type was discrimination between hail vs. no hail occurrence in convective storms. Two reflectivity-based algorithms for hail identification (POH algorithm proposed by Waldvogel and POSH/MEHS proposed by Witt et al.) were implemented in CHMI. After modernization, hail identification became possible also by Vaisala HYDROCLASS polarimetric hydrometeor classification algorithm. In this case we extrapolated presence of hail identified in the lowest PPI to the ground under rough assumption that hail will not melt completely. All of these hail detection algorithms have been evaluated against ground observations and proved their usefulness.

Polarimetric hydrometeor classification algorithms together with improved polarimetric bright-band detection enable general discrimination between solid and liquid phase and various hydrometeor types but unfortunately, contrary to user requirements, because of geometric limitations of radar measurements (over the Czech territory the lowest available radar measurement is typically several hundred meters above ground) they can’t discriminate precipitation type on the ground.

With the exception of hail, estimation of precipitation type on the ground is currently available in CHMI only as an output of ALADIN numerical model. As it is a forecasted field, it is affected by uncertainties of numerical model forecast both in location and precipitation type. Hence, there is room for improvement of numerical model outputs by combining them with radar data. Radar measurements might be used for correction of precipitation location. Polarimetric hydrometeor classification and bright-band height detection might be used for correction of precipitation type available from ALADIN in suitable cases and locations. Evaluation of possible corrections is now under way.

The contribution will present current work on implementation and evaluation of precipitation type based on above mentioned radar measurements and their combination with numerical model forecasts.

ID: 101, Poster presentation

IMPROVEMENTS OF CZECH COMBINED RADAR-RAINGAUGE QPE AIMED AT MEETING HYDROLOGISTS NEEDS

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The Czech Hydrometeorological Institute (CHMI) operates the Czech weather radar network (CZRAD) which consists of 2 C-band polarimetric doppler radars covering the whole area of the Czech Republic and its neighborhood. The CZRAD measurements are used mainly for convective storms warnings and quantitative precipitation estimates (QPE) and forecasts (QPF) based on the COTREC extrapolation method. Every 10 minutes, an advanced QPE merging algorithm MERGE2 is initiated that generates combined radar-raingauge QPE and also an adjustment coefficient applicable to radar-only QPE and QPF. Radar-only QPE and adjusted radar QPE and QPF are updated every 5 minutes.

Different radar-based QPEs are used by a wide range of users and applications, a very important part is hydrological modeling and warning. In the past, radar-based QPE and QPF were used mainly in standard conceptual hydrological models focused on larger areas and longer lasting precipitation events. In the recent years focus was shifted towards their utilization in flash flood nowcasting systems. Currently, both radar-based QPE and QPF are used in the CHMI operational Flash Flood Indicator (FFI) hydrological nowcasting system. Use of these products in FFI revealed some specific problems and new requirements that had to be solved. Development was mainly focused on new quality-based compositing of radar data, upgrade of adjustment coefficient algorithm and splitting of combined radar-raingauge QPEs into shorter intervals based on radar measurements. Recent development is focused on calculation of combined QPEs in situation when standard merging algorithm cannot be used because of limited number of available raingauge measurements or because of low correlation between radar and raingauge measurements caused typically be the limitations of uncertainty of radar measurements.

The contribution describes CHMI´s operational production chain composed of radar-based QPE and QPF and their use in hydrological application with focus on flash flood nowcasting. It discusses specific new requirements for radar-based QPE and QPF demanded by flash flood nowcasting applications, and the combined QPE calculation improvements that have been either implemented or that are currently under development to meet these new requirements.

ID: 103, Poster presentation

USE OF POLARIMETRIC RADAR DATA FOR BETTER NOWCASTING OF CONVECTIVE STORM SEVERITY

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Since 2015 the Czech weather radar network (CZRAD) consists of two dual-pol C-band weather radars. This fact allows us to use polarimetric radar data for many purposes including a better correction for attenuation which can give us a better data of precipitation estimations, better erasing of ground clutters and WLAN interferences or a better detection of hailstorms. Use of polarimetric data also should allow us to identify updrafts of convective storm cells based on the detection of so called ZDR-columns and newly also KDP-columns. These are column-like features with positive ZDR and KDP values which can reach altitudes up to several kilometers above the freezing level because of presence of liquid water droplets in the warmer updraft air and also their ability to stay in supercooled state for some time in a rapidly rising air parcel. The main goal of this study is verification of potencial of polarimetric data for a better nowcasting of storm cores behavior based on the detection of ZDR-columns and KDP- columns. Such a knowledge could notably help forecasters with severe weather warnings, especially in cases of severe hailstorms and flash floods. In the present analysis we have focused on case studies of several selected situations with large hail produced by long lived supercells and flash floods which occurred during the storm seasons since 2018 to 2023. We studied the ability of various data from ZDR- and KDP-column detection (its area, vertical development, integrated spatial volume and also their temporal variations) to help to predict severe behavior of the convective storms and their accompanied phenomena.

ID: 111, Poster presentation

EVALUATION AND IMPROVEMENTS OF A NATIONWIDE RADAR-BASED PRECIPITATION NOWCASTING

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Flood events occur worldwide and are the most common natural disaster. With climate change, such flood events may see their frequency increase. The recent catastrophic flooding in the Ahr Valley in Germany during the summer of 2021 demonstrated the need for an operational system able to predict such events. For short lead-time prediction of precipitation, a key tool for this purpose would be an accurate radar-based nowcasting algorithm for predicting precipitation trends. The Spectral Prognosis (SPROG, Seed 2003) model is a nowcasting algorithm based on the decomposition of the rain fields in the spectral domain and the filtering of the small scales of rain with a reduced chance of prediction. We present the Localized Spectral Prognosis (SPROG-LOC, Reinoso-Rondinel et al. 2022) model, an improved SPROG model that incorporates a localized filtering for a better spatio-temporal representation of the rain fields. Using state of the art polarimetric Quantification Estimates of Precipitation (QPE) for the operational C-band radar network in Germany, operated by the German Meteorological service, a detailed evaluation of SPROG-LOC is presented. First studies on the exploitation of polarimetric signatures for updrafts, i.e. size sorting and columns of enhanced differential reflectivity ZDR, to further enhance the skill of our model are included as well.

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ID: 112, Oral presentation

UTILIZATION OF VERTICAL PROFILE FEATURES FOR PRECIPITATION NOWCASTING

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Extrapolation-based methods have been widely used for radar-based precipitation nowcasting. As this approach does not predict growth or decay of precipitation, useful extrapolation nowcasts of convective rainfall are limited to a very short time range. In addition, information about the vertical structure of convective cells has not been extensively utilized. We propose a novel approach for this purpose. A scale-space blob detector is applied to identify cellular features from vertically integrated liquid (VIL) composites. Tracking the temporal evolution of the vertical profile features localized to each blob center is then done in the Lagrangian coordinate frame. The selected features include 30 dBZ echo top, 50 dBZ echo top above 0 C, vertically integrated liquid (VIL) and reflectivity at lowest altitude (RALA) that is our target variable. Time-lagged correlations between the features were analyzed within one-hour time range after applying temporal differencing. The analyses were done using the Multi-Radar Multi-Sensor (MRMS) radar mosaic that covers the continental United States. The study period was May-September 2023. Scale-dependency of predictability was taken into account by doing the analyses in a range of spatial scales between 1 and 32 km. Starting from the 4 km scale, significant correlations were found between the features for time lags up to one hour, although the analyses are affected by errors in the horizontal advection field. The results indicate possible causal relationships and the potential of using vertical profile features to predict the growth or decay of rain cells up to 30 minutes in advance. In particular, the 50 dBZ echo top above the 0 C level was found to consistently precede increase in the RALA in the 5-30 minute time range. The added value of the additional predictors was studied by applying a vector autoregressive model for predicting the temporal evolution of the four cell features in the one hour time range. The model skill was evaluated by using the equitable threat score (ETS) and root mean-squared error (RMSE), where up to 20% improvements were found compared to the baseline extrapolation method using only the RALA.

ID: 117, Poster presentation

PYRADMAN: A FLEXIBLE PYTHON FRAMEWORK FOR RADAR ADJUSTMENT USING CML AND RAIN GAUGE DATA

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Adjusting weather radar data with ground-based precipitation observations is an established way to overcome radar-specific uncertainties. For this purpose rain gauge data are most commonly used to improve the radar data quality. Commercial microwave links (CMLs) used in telecommunication networks offer another data source to estimate rainfall at ground level. In collaboration with Karlsruhe Institute of Technology, University of Augsburg and Ericsson we set up a system to perform almost real-time radar adjustment using CML and rain gauge data at DWD.

As input data we use radar data from 17 locations in Germany, ~1500 rain gauge data accessible by DWD and attenuation data of ~4500 CMLs covering Germany. For the latter a continuous data flow from Ericsson to DWD within 2 minutes has been successfully implemented.

For sensor combination we developed a python framework called pyRADMAN. It offers the possibility to select and combine the ground-based precipitation observations used in radar adjustment while keeping the aggregation times flexible. Due to the high temporal resolution of most rain gauge and all CML data the minimal possible aggregation time is given by the radar measurement interval of 5 minutes.

pyRADMAN can be driven in routine mode or recalculation mode. In routine mode pyRADMAN provides adjusted radar precipitation estimates (QPEs) for customers. The recalculation mode can be used to study the quality of adjusted radar QPEs or develop new adjustment procedures. The currently most stable adjustment procedure was adapted from the well known and tested software RADOLAN [1] running at DWD.

pyRADMAN has now been continuously operating at DWD in real time since August 2023 to provide input data for the project HoWa-PRO's [2] flood risk warning system. We will introduce the system of pyRADMAN and show quality analyses of adjusted radar QPEs using different ground sensors and aggregation times.

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ID: 121, Poster presentation

THE NEPTUNE EUROPEAN PROJECT FOR NOWCASTING AND IMPACT-BASED PREDICTIONS OF INUNDATIONS INMEDITERRANEAN CATCHMENTS: THE ALEX STORM CASE STUDY FOR THE TRANSBORDER CATCHMENT OF LA ROYA

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Short-lived extreme precipitations along the Mediterranean coasts can cause severe flash floods (FF), which are a significant contributor to weather-related fatalities and economic damages. These events are particularly dangerous due to their sudden onset, fast development, destructive power, and poor forecasting skills. Physically-based modelling chains used to predict FF impacts often suffer from large uncertainties, which can prevent accurate predictions in different modelling steps. In this context, the NEPTUNE European project aims to enhance preparedness and prevention in transborder areas affected by Mediterranean flash flood events. Focusing specifically on the French-Italian Roya catchment, it aims to improve cooperation between local operational actors through the development of forecasting tools and methods.

This poster presents a case study based on the Alex storm event of 2-3 October 2020, which severely impacted the Roya catchment. Two nowcasting procedures, from the PhaSt and pySTEPS methods, extrapolate the latest 10-min radar-based Quantitative Precipitation Estimate (QPE) grid, to produce 10-minute deterministic and ensemble Quantitative Precipitation Nowcast (QPN) grids for lead times up to 3-h. Two distributed rainfall-runoff models (Continuum hydrological model from CIMA and Spatially distributed Modelling and ASsimilation for Hydrology (SMASH) model from INRAE) ingest these QPN grids to calculate the corresponding flood discharge reforecasts and thus estimate peak flows and flood threshold exceedance for any point along the river network. Comparisons to observed flows and estimated peak flows for 4 gauged catchments show the usefulness of this information for operational actors, with an anticipation of several hours for flood warning level exceedance and good peak flow estimates. This study underlines the utility of accounting for the QPN uncertainty via ensemble forecasting in order to detect the probability of very high flows early on. Impact-based forecasts are then generated with an estimation of the corresponding inundation areas, in order to provide information on the assets potentially at risk. This enables the emergency services to better anticipate potential flooding and mitigate its impacts. As the anticipation is significantly impacted by the underestimation of real-time QPE products, it also emphasizes the need for improved radar-based QPE products in real time, by ingesting new satellite-based data from the HD Rain sensor network for example.

ID: 122, Poster presentation

PREDICTING CONVECTIVE CELLS BY COMBINING NOWCASTING AND NUMERICAL WEATHER PREDICTION MODELS WITH KONRAD3D-SINFONY

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Small-scale, convective summer thunderstorms are hard to predict by numerical weather prediction (NWP) models, but they can cause large damages. The SINFONY (Seamless INtegrated FOrecastiNg sYstem) at the German Weather Service aims to predict these storms up to 12 hours in advance by combining both nowcasting (NWC) and NWP results. We present here the cell-object-based prediction method KONRAD3D-SINFONY.

In the first step, the KONRAD3D tool identifies convective cell objects in the observed volume scan reflectivities from the German radar network. Next, the NWC ensemble system KONRAD3D-EPS predicts the future cell locations and severities while taking uncertainties into account. It comprises 20 members with stochastic variations of the positions and life cycles of forecasted NWC objects.

At this step, we add synthetic NWP cells from ICON-RUC-EPS (Rapid Update Cycle Ensemble) simulations, i.e., 20+1 members of a special ICON model with 2 km resolution, initialized hourly with a forecast horizon of 14 hours. Synthetic radar reflectivities are derived from the NWP model using the radar forward operator EMVORADO, and KONRAD3D detects and tracks cells in the synthetic radar data of each ensemble member. We combine nearby model cells into clusters and match these cell clusters to observed cells with similar properties. The similarity between observed and model cells is assessed with a total interest calculator that considers the cell location, size, severity, and vertically integrated liquid. Sufficiently similar model cells are then shifted to the position of the observed cell. The trajectories of the shifted NWP objects, together with the NWC objects, are used to forecast convective cells. In addition to the corrected cells, the ICON-RUC also predicts newly forming convective cells. Their location and other properties are less certain, as they cannot be tied to detected cells.

The resulting ensemble consists of 20 NWC member cells and an arbitrary number of cells from the 21 NWP members. We visualize it by showing both probability plots, depicting all cells, and pseudo member plots that display representative cells by combining similar cells into a single object. The resulting forecast is dominated by combined cells at first, but as most of them decay within about two hours, the prediction transitions seamlessly into a purely model-based forecast.

ID: 123, Poster presentation

ESTIMATION OF DESIGN PRECIPITATION USING WEATHER RADAR IN GERMANY: A COMPARISON OF STATISTICAL METHODS

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Estimation of design precipitation on various temporal scales and with high spatial resolution is crucial for risk management and hydrological applications. Typically, return levels are determined using extreme value statistics based on rainfall data from stations due to their long time series. However, the spatial representation of the point measurements is limited. Weather radars may provide this spatial information, but design precipitation and return level estimates from these instruments suffer from estimation biases and limited length of the available records, especially for rare events.

In the last decades a method based on the peak-over-threshold approach, assuming an exponential distribution (Gumbel distribution, shape parameter=0) was used by DWD to determine return levels from station data (KOSTRA-DWD-2010R). Estimated design storms using this method on radar data were clearly influenced by single extreme events and the resulting maps for Germany showed some instabilities.

In 2023 a new version of the official design precipitation estimation, called KOSTRA-DWD-2020, was published based on annual maximum time series from more than 1900 stations. The location and scale parameters of the generalised extreme value (GEV) distribution are fitted to the annual maximum series for each station and duration individually, based on the L-moments method. The shape parameter is fixed to 0.1 (Fréchet distribution). The annual maximum series intensities are then generalised over all chosen durations. Alternative methods based on non-asymptotic statistics can also be used to estimate design precipitation, e.g. the Simplified Metastatistical Extreme Value (SMEV) including also ordinary events and assuming a Weibull distribution.

We apply the KOSTRA-DWD-2020 method to 20 years of radar data. Resulting design precipitations are compared to results obtained with KOSTRA-DWD-2010R, SMEV and the stations based KOSTRA-DWD-2020. First results indicate that the differences between the two data sets are larger than the uncertainty in the statistical methods. However, the areal coverage of the radar network allows for better assessment of the spatial structure of design precipitation. This indicates that a combination of both data sources is desirable for reliable estimations of design precipitation and return levels. We will present a first concept for combining the robust values from interpolated station-based KOSTRA DWD-2020 with the spatial information from radar data.

ID: 126, Oral presentation

LEVERAGING DEEP LEARNING FOR SEAMLESS RAINFALL AND FLOOD PREDICTION IN BELGIUM

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Extreme precipitation events are anticipated to become more frequent and severe due to climate change (Fischer & Knutti, 2015). Urbanization exacerbates the impact of such events by increasing soil sealing and affecting more people and infrastructure in urban areas. Precipitation forecasting remains challenging due to its high spatial and temporal variability. Improved predictions are crucial for societal and economic stability, particularly for hydrological impact models, early warning systems, and informed decision- making.

The DERISC project utilizes deep learning (DL) techniques to enhance short- and medium-range precipitation forecasting. The objective is to develop a seamless ensemble from 5 minutes to 15 days ahead, integrating data from the Belgian RMI's RADQPE (Radar and gauge-based quantitative precipitation estimate) and NWP (numerical weather prediction) models. To verify the added value of DL, a non-DL baseline using simple blends is established and compared with a U-Net model (a type of convolutional neural network), representing the project's first attempt at a seamless DL-based ensemble. This blending task acknowledges the challenge hydrologists face in forecast selection for hydrological models, recognizing that their primary expertise lies outside meteorological forecasting. Early and frequent sharing of the experimental precipitation products with hydrological impact modellers ensures that the needs of stakeholders for reliable impact-based warnings are met. DERISC employs RADQPE as a ground truth signal. Multiple NWP output for various horizons, including ACCORD’s ALARO and AROME configurations at 1.3 km for short lead times (up to two days) and ECMWF's IFS for longer lead times. We aim to compare DL and conventional blending techniques from the meteorological perspective. Evaluation encompasses metrics such as Brier scores, continuous ranked probability scores, fractional skill scores, and visual comparisons against the currently used operational tool at the RMI.

ID: 129, Poster presentation

INTEGRATING NEW KONRAD3D CELL ATTRIBUTES INTO THE NOWCASTING GUIDANCE SYSTEM NOWCASTMIX AT DWD

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Short-term warnings for severe thunderstorms are generated at the German Weather Service (DWD) through the NowCastMIX system, providing automated warnings for the next 60 minutes. NowCastMIX processes meteorological fields from various sources, including NWP, radar, surface station reports, and lightning detections. Every 5 minutes, the system employs a hierarchy of fuzzy logic sets to calculate the potential for heavy rain, hail, and severe gusts based on available data. Categorical thunderstorm warnings are then issued for detected cells, and regions requiring warnings are identified by condensing the information into clusters.

NowCastMIX previously relied on the KONRAD and CellMOS cell detection schemes, which both utilized two-dimensional radar scans for automatic detection, tracking, and prediction of thunderstorm cells. In recent advancements, KONRAD and CellMOS schemes within NowCastMIX have been replaced by KONRAD3D. This novel scheme introduces new state-of-the-art approaches, providing three-dimensional objects of detected cells through 3D radar volume scans.

To leverage the enhanced capabilities afforded by three-dimensional cell information, new KONRAD3D attributes will be integrated into the fuzzy logic of NowCastMIX. Thus, enabling NowCastMIX to classify thunderstorms based on three-dimensional cell characteristics. On the basis of a reanalysis of 194 convective days, the fuzzy logic will be meticulously fine-tuned to be able to generate more accurate and comprehensive severe thunderstorm warnings.

ID: 136, Poster presentation

A STRAIGHTFORWARD ATMOSPHERIC-RADAR SIMULATOR FOR VERTICAL-AIR-MOTION ANALYSIS FROM FREQUENCY-MODULATED CONTINUOUS-WAVE-RADAR RAIN MEASUREMENTS

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Vertically-pointed Frequency-Modulated Continuous-Wave (FMCW) radar measurements of rain become highly biased by the strong vertical winds present in convective rain scenarios. In such cases, the radar-measured reflectivity spectrum undergoes a Doppler shift due to the vertical air motion (VAM), even creating aliasing in the velocity spectrum, which invalidates rain rate and drop-size distribution (DSD) retrievals.

In this work, we present a basic atmosphere-to-radar simulator based on forward modelling of the DSD, VAM and S-band FMCW radar parameters to study the impact of VAM on the retrieved radar products along with a discussion on the proposed objective functions and error formulations leading to a suitable VAM-correction strategy.

The method is tested with synthetic data and, preliminary, with two real precipitation cases (stratiform and convective rain), in the context of the Verification of the Origins of Rotation in Tornadoes Experiment-Southeast (VORTEX-SE), 2017.

ID: 137, Poster presentation

ASSESSMENT OF DETERMINISTIC AND ENSEMBLE HYDROMETEOROLOGICAL NOWCASTING METHODS: TWO CASES OF CONVECTIVE EVENTS IN ITALY

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The evaluation of nowcasting methods is of great interest for developing reliable early warning sys-tems. Temporal extrapolation of radar reflectivity is a frequently used approach to obtain Quantitative Precipitation Forecasts (QPFs) for short lead times. We compare different radar-based nowcasting methods to achieve precipitation forecasts, and we use precipitation output as input for hydrological modelling to get flow rate estimate for two convective events that occurred in the Marche Region (cen-tral Italy) on September 15, 2022, and in Calabria Region (southern Italy) on August 20, 2018. A radar composite product consisting of precipitation intensity as a result of reflectivity conversion, adjusted with rain gauge data, with a temporal resolution of 5 minutes and spatial resolution of 1 km, is used as a benchmark for the analysis. An optical flow method (Lucas–Kanade algorithm) is employed to com-pute the precipitation velocity field. Uncertainties on hydrometeorological forecasting can be evaluat-ed by generating ensemble nowcasts. In this study we consider some deterministic and ensemble methods available in literature: 1) simple extrapolation (semi-Lagrangian backward scheme),

2) Spec-tral Prognosis (S-PROG, Seed, 2003), 3) Short-Term Ensemble Prediction System (STEPS, Bowler et al., 2006; Seed et al., 2013), and 4) Short-Space Ensemble Prediction System (SSEPS, Nerini et al., 2017). The open-source nowcasting framework pySTEPS, which implements the above models, is adopted. We use standard metrics to assess the quality of deterministic and 20-member ensemble fore-casts, considering a maximum lead time of 1.5 hours. The best prediction skill is achieved by SSEPS (localized version of STEPS), which shows improvements for almost all adopted metrics compared to the other models. A maximum reduction in the Continuous Ranked Probability Score (CRPS) of 52.1% and 46.7% for the Marche and Calabria events, respectively, is observed for SSEPS compared to STEPS. Finally, we produce ensemble hydrological forecasts through the WRF-Hydro modelling sys-tem and the Cetemps HYdrological Model (CHyM), assessing the uncertainty associated with both the ensemble precipitation forecasts and the different hydrological modelling systems.

ID: 141, Poster presentation

PRECIPITATION MEASUREMENTS IN MARIO ZUCCHELLI STATION, ANTARCTICA

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The Antarctic ice sheet is the planet's largest freshwater reserve. Understanding the contribution of precipitation to the Antarctic surface mass balance is crucial in determining the ice-sheet's impact on the sea-level rise. However, due to harsh environmental conditions and objective difficulties in measuring solid precipitation, observations of precipitation over Antarctica are limited. This analysis presents an eight-year precipitation time series (2016- 2024) collected at the Italian Antarctic Station Mario Zucchelli (74°41′S, 164°07′E, 15 m a.s.l) in the Terra Nova Bay coastal area. A combination of different instruments, including a 24 GHz radar, a disdrometer, a weighing gauge, an automatic weather station, and a ceilometer, was used to determine precipitation time series quantities and characteristics.

ID: 142, Oral presentation

VERTICAL WIND AND DROP SIZE DISTRIBUTION RETRIEVAL WITH A G-BAND DOPPLER RADAR

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Macrophysical properties of clouds are driven by underlying microphysical parameters and processes. In practice, there is often an observational gap in bridging the two. For example, our current understanding about feedback effects of clouds and the onset of precipitation is hindered by a lack of robust measurements of the distribution of droplet sizes within clouds. Doppler radar measurements have proven useful in estimating drop size distributions (DSDs) but face an intermediate challenge of requiring a correction for the presence of vertical air motion. Past attempts at using centimeter-wavelength Doppler spectra for this analysis were generally unable to produce accurate values for the vertical air motion, leading to unreliable estimates of DSD parameters. Recent advances in millimeter wave technology, however, have made radar measurements at ever smaller wavelengths possible, allowing for analysis of non-Rayleigh scattering effects to back out estimates of vertical winds and thereby DSDs. In this work, we demonstrate our method of deriving range-resolved DSDs using 238 GHz Doppler spectra measured by the CloudCube atmospheric radar (developed at the Jet Propulsion Laboratory). The observations we utilize are of marine layer clouds during March and April 2023 in La Jolla, CA, USA, taken as part of CloudCube's participation in the Eastern Pacific Cloud Aerosol Precipitation Experiment (EPCAPE) campaign. Our method first identifies "notches" in the velocity spectra and compares them to the theoretical notch velocities predicted by size dependent backscattering and terminal velocity models to estimate the range-dependent vertical wind. After removing the vertical wind, we fit the shape of the zero-wind spectrum to a forward model of radar Doppler spectra to find the DSD. This represents one of the first examples of the utility of G-band Doppler spectra to constrain cloud microphysical properties.

ID: 143, Oral presentation

AN INNOVATIVE APPROACH FOR REAL-TIME HAIL SIZE ESTIMATION

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Hail phenomena pose a threat to various sectors, such as agriculture, infrastructure, and insurance industries due to the potential for substantial damage. Accurately detecting hail-affected areas and estimating hail size in real-time remains a challenging task. While individuals may document such events, the reliability and scope of these measurements are often limited. Several methods have been proposed to reconstruct continuous hail size information, many of which rely on meteorological radar data. In Italy, where single-polarized radars are present, methods such as the Vertically Integrated Liquid density and the Severe Hail Index may be employed. However, these algorithms require a comprehensive vertical profile of reflectivity for optimal performance, which may be challenging to obtain given the limitations of currently available Constant Altitude Plan Position Indicators data.

To address these limitations, we proposed a novel Machine Learning approach for hail dimension estimation that integrates radar and numerical data sources, and we tested it over the Italian territory. For model training, we utilized as ground truth the hail diameter reports collected by the PRETEMP association from individuals across Italy, covering the period from August 2022 to August 2023. These reports underwent post-processing steps to mitigate inherent temporal and geographical errors. Additionally, areas unaffected by hail were identified by selecting coordinates with low radar reflectivity, enabling the construction of a robust dataset comprising about 3000 hail and 15000 no-hail events. The model was cross- validated and tested by partitioning the data based on days in the mouth. Subsequently, the final model was re-trained using the entire dataset to analyze several case studies.

Our results demonstrate the effectiveness of the proposed method in detecting hail-affected areas and estimating hail diameters up to 5cm. However, accurately estimating larger hail sizes remains a challenge. This is partly due to constraints of C-band radars, which are not made for detecting large targets, and limitations in the selected numerical weather features. To refine the model, we plan to incorporate annual data collection, conduct re-training sessions, and integrate new features identified from recent literature studies.

ID: 145, Poster presentation

A NEW QPE METHOD FOR WINTER RAIN EVENTS APPLIED TO THE GERMAN RADAR NETWORK

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The RY precipitation product of the German Weather Service (DWD) is severely affected by the presence of the low melting layer. Frequently, circular features of enhanced precipitation are observed around the radar sites during the winter time, as well as an underestimation of the precipitation at distances beyond that.

A new methodology (PVPR - Polarimetric Vertical Profile of Reflectivity) developed by Ryzhkov et al. 2022 is tested here for which the radar reflectivity (ZH) is reconstructed to correct for the effect of the melting layer and snow beyond. In this methodology the melting layer is detected independently for each azimuth based on the values of ZH and ρHV (cross-correlation coefficient between horizontal and vertically polarized radar waves). In particular the range bin at which the melting layer was reached is recorded (mlb_r). The strength of the melting layer (ML_S) is defined based on how much the value of ρHV dropped within the melting layer. The values of ML_r and ML_S at a specific elevation are considered sufficient to characterize the melting layer, and are then compared with lookuptables which were generated by simulations of the melting layer effect on the radar beam. A correction factor is then applied based on the lookuptables to the ZH profile within and beyond the melting layer. A long term radar climatology of the melting layer and snow microphysics in Germany was used to adjust the parameters and regenerate the lookuptables to tailor them to this specific region. This results in a smooth field of reflectivity without the effects of the bright band and snow, which is subsequently used to calculate the surface precipitation.

Composites of the rain field over the DWD radar network using the PVPR method were validated against rain gauges for a few case studies. The new PVPR outperforms the previous methods (RY, as well as the R(A) and R(Z,KDP)) which do not take the ML impact or the overshooting of the beam over the freezing level into account. One remaining issue is that the ML rings are still observed when the ML is very close to the ground. One possibility to fix this issue is to further adjust the correction factor for these cases, and this is currently in the process of being tested.

The PVPR method is planned to be implemented soon in the POLARA processing chain of DWD. A full winter month will be used to test the performance of the PVPR over all Germany through statistical metrics. The performance will be compared against the RY product and other polarimetric QPE algorithms.

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ID: 147, Poster presentation

RECENT IMPROVEMENTS OF THE DUTCH REAL-TIME RADAR PRECIPITATION PRODUCT

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The Royal Netherlands Meteorological Institute (KNMI) operates two dual-polarization C-band weather radars. KNMI's real-time precipitation product (https://dataplatform.knmi.nl/dataset/nl-rdr-data- rtcor-5m-1-0) currently also employs data from three Belgian and two German radars. It forms the basis for an early and final reanalysis product, which are merged with daily accumulations from manual rain gauges. Many processing steps have been added as of February 2023 by the agile KNMI radar team, which consists of software developers and researchers. For most radars, dual-pol data are received allowing for non-meteorological echo removal via fuzzy logic. For each radar attenuation and vertical profile of reflectivity correction are applied. Quality information is used to convert the 3D to 2D (PPI) data. Further processing includes a statistical Gabella clutter filter, quality-based compositing, advection correction, and conversion of reflectivity to 5- min precipitation accumulations using the Marshall-Palmer relationship. Finally, a spatial adjustment factor field is computed employing 1-h accumulations from KNMI's 32 automatic rain gauges from the previous clock-hour. The adjustment method ensures robustness in case of sparse rain gauge networks. The adjustment factor field is applied to 5-min rainfall accumulations from the current clock- hour.

The first year of this renewed product is evaluated against independent hourly and daily rain gauge accumulations by means of scatter density plots and a spatial verification. This is contrasted with the performance of the old product from the previous year, that used a mean-field bias adjustment. Specific attention is given to the removal of non meteorological echoes through evaluating maps with annual and maximum precipitation and relative frequency of exceedance. The influence of severe beam blockage by a wind farm on annual precipitation is illustrated. An extreme precipitation case study is evaluated. The latency of rain gauge data currently prohibits merging of radar and rain gauge accumulations from the same time interval. By rerunning the adjustment procedure, it is assessed to what extent the precipitation estimates can be improved in case rain gauge data would have been available in real-time. Finally, we will provide a research and development outlook for this product, especially concerning the use of rain gauge accumulations from Dutch water authorities and foreign institutes or obtained via crowdsourcing.

ID: 154, Poster presentation

DETECTING LIGHTNING INITIATION SIGNALS USING A THREE-DIMENSIONAL DUAL-POLARIZATION RADAR DATA

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Over the past decade (2013-2022), an average of approximately 108,719 cloud-to-ground(CG) lightning strikes occurred on the Korean Peninsula, with a concentration during the summer months (June to August) (Lightning Annual Report, 2022). Most of these lightning events are associated with rapidly developing convective systems, resulting in significant societal, economic, and potential human impacts.

Korea Meteorological Administration (KMA) operates 21 LINET (LIghtning NETwork) lightning observation systems to ensure public safety and provide rapid lightning information. Furthermore, a radar-based lightning signal detection model has been developed and utilized for lightning forecasting. The radar-based lightning initiation signal detection technology identifies regions with a high probability of lightning occurrence by using 3-dimentional dual-polarization variables (reflectivity(Z), the differential reflectivity (ZDR), the specific differential phase(KDP), vertically integrated liquid(VIL)) and hydrometeor classification identification such as hail and graupel particles at altitudes below 0℃.

The detected lightning signals are provided to forecasters every 5 minutes with a spatial resolution of 500 meters, offering a lead time of approximately within 20 minutes. In evaluating the performance of detected lightning initiation signals, radar-based lightning detection regions was compared with observed lightning data for precipitation events accompanied by lightning from 2020 to 2022 (total of 213 days). The average Probability of Detection (POD) and Frequency Bias (BIAS) were found to be 0.82 and 3.58, respectively. The highest detection accuracy (POD=0.83) was observed during the Summer season (June to August), while the lowest detection rate (POD=0.77) was observed during the Spring season, characterized by lower lightning frequency and rainfall intensity compared to the Summer.

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ID: 160, Oral presentation

THE USE OF BULK ZDR TO MITIGATE BIASES IN MRMS SPECIFIC ATTENUATION BASED QPE

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Since 2020, the operational multi-radar multi-sensor (MRMS) Dual Pol radar based quantitative precipitation estimates (QPE) utilizes specific attenuation to estimate precipitation below the melting layer, specific differential phase wherever convective cores have reflectivities (Z) ≥ 50 dBZ's, and a selection of reflectivity-to-rain rate (Z-R) relations within and above the melting layer. While the QPE has performed well for widespread moderate to heavy rain events, a number of cases have significant wet bias. A wet bias occurs with convective cases where the parameter alpha, used in the path integrated attenuation calculation and estimated via the slope of differential reflectivity (Zdr) to Z, did not represent the local rainfall characteristics.

A more systematic wet bias was also found in cases where weak convection was mixed with large areas of stratiform rain in non-maritime regions. In these cases, estimating alpha via Zdr-Z slope is not optimum and a default alpha value (0.035) typically associated with efficient stratiform rain was initially applied to minimize underestimates in warm stratiform rain within maritime regions and precipitation associated with tropical cyclones or their remnants. However, the default alpha was found to cause overestimation in continental like rain regimes further inland from coastal regions.

This study shows how the bulk Zdr properties in the low (10 – 30 dBZs) and high (40 – 50 dBZs) reflectivity bands can be used to mitigate the aforementioned biases. For the first issue, bulk Zdr for low and high Z bands were used to ensure the slope derived alpha would better match the rainfall regime leading to more accurate hourly rain totals. For stratiform rainfall, bulk Zdr in the real-time data was used to determine dynamic alpha values instead of a fixed default value. To reduce uncertainties from calibration, partial correction of Zdr was included in this study. Case study analyses and the statistical results for over 100 precipitation events show significant improvement of the refined specific attenuation QPE in reducing the aforementioned errors and biases observed in the MRMS QPE.

ID: 162, Poster presentation

VERIFICATION OF SURFACE PRECIPITATION TYPES USING GROUND OBSERVATION DATA OVER THE COMPLEX TERRAIN IN KOREA

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Surface precipitation types, such as snow, rain, freezing rain or mixed phase, have tremendous impact on our daily lives, like public transportation, injuries from slippery roads, especially, the traffic systems for logistics. Therefore it is necessary to categorize precisely surface precipitation types using meteorological factors. Recently, KMA (Korea Meteorological Administration) has employed the optimized Hydrometeor Classification Algorithm (HCI, Vivekanandan et al., 1999) to classify 14 hydrometeors for each radar site. The HCI synthesizes 10 radar data every 5 minute for the lowest elevation angle which is not affected by beam blockage and ground clutter. However, due to the curvature effect of the earth and orographic influences, there are differences of altitude from 500m to 3km between the radar beam height and the ground level. Therefore, the effect of phase change is not considered when precipitation particles fall, which leads to difficulty in classification considering whether transitions such as melting of upper-level ice and snow into rain, refreezing of supercooled liquid water into freezing rain occur or not.

To address these challenging aspect, we estimated the melting and refreezing energy using meteorological parameters such as temperature, wet-bulb temperature from 3-dimensional numerical model data and critical thresholds derived from manned observation stations(MOS) data. These parameters enable classification of surface precipitation types into six types: hail, freezing rain, ice, snow, snow/rain, and rain. Thresholds for classification of surface precipitation types are derived from the MOS data.

The various observed data were used to evaluate the surface precipitation type. Snow, snow/rain, and rain were evaluated using the reports from the weather code measured at MOS and compared with HCI composites. Over the mountainous area, lacking the MOS, the new snow records from laser based snow gauges were used to verify snow identification in surface precipitation types. Observed hail cases at MOS were confirmed, while freezing rain cases were affirmed by using the reports on traffic accident caused by icing.

Keywords : hydrometeor classification, surface precipitation types, wet-bulb temperature

ID: 163, Oral presentation

COMBIPRECIP ENSEMBLE: GENERATION OF MULTI-MEMBER REALIZATIONS FROM A KRIGING-BASED RADAR-RAINGAUGE COMBINATION APPLICATION IN SWITZERLAND

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CombiPrecip is the operational algorithm that combines in real-time raingauge measurements with radar precipitation estimates across an extensive area of 710x640km^2, extending beyond the Swiss borders. The system utilizes a geostatistical approach known as kriging with external drift as an interpolation technique, offering probabilistic outcomes that provide both a mean value and a variance at each interpolated point. The purpose of our study is two-fold: (i) validate that the variance provided by the underlying geostatistical method of CombiPrecip can properly represent the actual interpolation error and (ii) develop a numerical method to build an ensemble of realistic members based on this geostatistical variance. To this end, we apply widely used probabilistic verification tools (such as reliability diagrams, rank histograms, and ROC curves) to analyze a comprehensive set of cross-validation data from 2016 to 2022. Furthermore, leveraging techniques from the nowcasting field, we generate ensembles of N realistic precipitation members that not only mimic the spatial autocorrelation and texture of the mean-value CombiPrecip but also reproduce the original computed kriging distribution. Overall, our results confirmed the kriging variance as a reliable measure of interpolation error, validated through probabilistic verification against raingauge observations.

ID: 166, Poster presentation

EVALUATION OF THE KIAPS LETKF-BASED RADAR REFLECTIVITY DA SYSTEM

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For very short range forecasts, KIAPS (Korea Institute of Atmospheric Prediction Systems) is currently developing a high-resolution (1- 5km) model targeting storm-scale high- impact weather over East Asia, centered on the Korean peninsula. In order to start developing methods for assimilating Korean radar reflectivity observations, we have developed a “testbed” system based on a high-resolution, limited-area version of WRF, configured by the Korea Meteorological Administration (KMA) to use the same physics packages as the Korean Integrated Model (KIM) – the global model developed by KIAPS that has been running operationally at KMA since 2022. The data assimilation (DA) system is based on the Local Ensemble Transform Kalman Filter (LETKF). Our LETKF system assimilates conventional observations provided by the KIM Package for Observation Processing (KPOP), and gridded radar reflectivity data derived from Korean radar observations.

After introducing the system, we will show some results from initial experiments that assimilate only conventional observations, including diagnostics showing the impact on analyses of near-surface conditions. We will then explain our method for assimilating radar reflectivity observations, including pre-processing techniques, the choice of observation operator, and the selection of LETKF localization scales. We will conclude by showing the impact of reflectivity assimilation in full LETKF cycling experiments.

ID: 169, Poster presentation

TOWARDS PROBABILISTIC EXTREME RAINFALL WARNINGS FOR BELGIUM

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Heavy rainfall with subsequent flooding is one of the most damaging weather phenomena (UNDRR, 2023), both globally and in Western Europe. Therefore, accurate forecasting of such extreme rainfall events is crucial for effective disaster preparedness and mitigation. The Royal Meteorological Institute of Belgium employs a warning system based on a deterministic approach at the municipal level, depending on the latest radar's quantitative precipitation estimation (QPE). However, the limitations of this method, including the typical binary decision process and the potential to overlook highly localized weather events, particularly in larger municipalities, highlights the need for improvement.

This study presents a novel probabilistic rainfall warning support system based on the seamless pySTEPS-BE ensemble nowcasting technique. This ensemble quantifies the uncertainty in the nowcast related to the growth or decay of precipitation fields, and incorporates the dynamical evolution of the ALARO-AROME mini-ensemble using an adaptive blending approach (Imhoff et al., 2023).

The new micro-warning support system involves comparing short-term (up to two hours) precipitation forecasts from each ensemble member against statistical reference rainfall return level maps (Van de Vyver, 2013, 2012). This yields the ensemble probability to exceed the rainfall rate for a given return level and period at each pixel (1 km2). Spatial maps illustrating the probability to exceed return levels for various return period and accumulation thresholds are presented and validated.

We propose this as an easily interpretable probabilistic alert product to be disseminated to users such as hydrological and emergency services. These maps serve as a proxy for hazard occurrence probability, which can be further combined with exposure and vulnerability maps to obtain probabilistic risk maps for flash floods.

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UNCERTAINTY ESTIMATION FOR CONVECTIVE CELL NOWCASTING: A KALMAN-FILTER IMPLEMENTATION OF ENHANCED TITAN

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Object-based nowcasting of thunderstorms using weather radar data is an important tool for forecasting and warning for severe weather and its impacts. While it has typically been applied within a deterministic framework, there has not been much investigation of probabilistic implementations of object-based nowcasting. The objectives of the work presented here are the improvement of the positional accuracy and the reduction of the variability of forecasted cell trajectories, as well the provision of estimates of related uncertainties. To achieve these objectives, we integrate a state-of-the-art object-based tracking algorithm (enhanced TITAN) (Muñoz et al, 2018) with a Kalman filter (KF)-based prediction method (Rossi et al, 2015) which allow for both deterministic ("filtered") and probabilistic nowcasting. Furthermore, based on comprehensive analysis of storm cell properties and tracking results, we introduce an empirical KF parameterisation. This enables a more dynamic and tailored estimation of prediction uncertainty according to rain cell properties and system-specific performance, thereby improving upon former heuristic approaches. The proposed approach was tested by computing 5-60 min nowcasts at five-minute intervals, utilising the Met Office 3D radar reflectivity composite across the UK over 32 convective days from 2020 to 2023. Model performance is assessed using complementary deterministic and probabilistic metrics, alongside visual inspection of forecast outputs. In terms of deterministic performance, non- filtered and filtered trajectories perform similarly in quantitative assessments, but filtered trajectories are smoother and more realistic. As regards probabilistic assessment, consistently positive Brier Skill Scores show that the probabilistic nowcasting has an improved accuracy over the deterministic one. Furthermore, the proposed physically-informed KF parametrisation yields more realistic and less uncertain estimates as compared to the heuristic parametrisation reported in the literature. In terms of reliability, the model with physically-informed parameters results in probabilities more in line with observed frequencies when compared with the heuristic parametrisation. The physically-informed model is running operationally at the Met Office and further tuning of the model is expected in the future once a larger dataset is available. Future work is being done to integrate the positional nowcasting model with a recently developed cell evolution prediction model.

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COMPARISON OF KDP ESTIMATION ALGORITHMS IN SUMMER RAINFALL OBSERVATIONS IN FINLAND

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The specific differential phase (Kdp) has proven its usefulness for quantitative precipitation estimation and attenuation correction. Kdp is computed from the range derivative of differential phase measurements (Phidp), which makes Kdp immune to attenuation, calibration issues, and partial beam blockage. Despite these advantages, accurate Kdp estimates require a rigorous post-processing algorithm to preserve crucial information from Phidp changes due to propagation through rain while minimizing noise and removing back-scattering differential phase. Currently, there are several algorithms presented in the literature, some of which are available as part of Python open-source- packages like Py-ART [1]. In this work, we aim at comparing their performance using actual radar rainfall observations. As a reference benchmark, we are using Kdp estimates (KdpSC) computed from quality-controlled Z and Zdr, and using a self-consistency relation between Kdp, Z and Zdr.

Since some algorithms allow users to change the tuning parameters, the selection of optimal parameters is performed by using the root mean square error (RMSE) with respect to KdpSC. The parameter(s) with the smallest RMSE was then selected for the algorithm comparison. The compared algorithm uncertainties are quantified by computing the Kolmogorov-Smirnov (KS) test and the RMSE with respect to the KdpSC. We also compute the RMSE as a function of reflectivity to compare the algorithms' performance at different rainfall intensities. Through comparison, it is shown that phase_proc_lp [2] and kdp_vulpiani [3], available in Py-ART, and Vaisala's implementation in IRIS software based on Wang and Chandrasekar's algorithm [4], denoted as kdp_iris, outperform the other algorithms, as evidenced by their smallest RMSE and KS statistics. Additionally, our findings show that these algorithms are the most consistent with each other, as evidenced by their highest correlation coefficient. The primary challenge for the algorithms in general is to retrieve accurate Kdp and find a balance between over- and under-smoothing the Phidp field. With the appropriate tuning parameter(s), the algorithms phase_proc_lp, kdp_vulpiani and kdp_iris, are shown to be more adept at achieving this objective compared to other algorithms.

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ID: 177, Oral presentation

TROPICAL RAINFALL NOWCASTING WITH COMMERCIAL MICROWAVE LINKS

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Accurate and timely precipitation forecasts are crucial for flood early warnings and mitigating other rainfall-induced natural hazards like landslides. The global distribution of high-resolution (gauge-adjusted) ground based weather radar precipitation estimates required to perform accurate short-term forecasts is, however, heavily skewed, largely favoring Europe, Northern America, and parts of East Asia. In many low- and middle-income countries, predominantly located in the tropics, weather radars are largely unavailable due to high installation and maintenance costs, and rain gauges are often scarce, poorly maintained, or not available in (near) real-time.

A viable and ‘opportunistic’ source of high-resolution space-time rainfall estimates in these parts of the world that largely lack dedicated rainfall sensor networks comes from the signal attenuation experienced by commercial microwave links (CMLs) in cellular communication networks. When it rains, the radio signal between two cell phone towers is (partially) attenuated, and this rain-induced attenuation can be used to infer the average rainfall intensity along the path. Typically, every 15 minutes the minimum and maximum received signal levels are stored in network management systems by mobile network operators for quality monitoring purposes. Based on these signal levels it is possible to estimate path-averaged rainfall intensities, which can be interpolated to produce high-resolution rainfall maps. To date, however, rainfall estimates from CMLs have mainly been applied complementary to existing dedicated rainfall sensor networks around Europe.

In this study, we present the opportunities for rainfall nowcasting using CML-derived rainfall maps in Sri Lanka. Based on a 10-month data set from 2020, consisting of 903 CMLs spread across the northern half of the country, we create spatial rainfall fields at 15-minute intervals. Using the nowcast algorithm pysteps, we perform deterministic and probabilistic nowcasts for different lead times and length scales. The nowcasts are evaluated at multiple catchments using 21 hourly rain gauges and compared qualitatively to combined radar-radiometer maps from overpasses of the Global Precipitation Mission core satellite.

This novel application of CML-derived rainfall maps, essentially providing a ‘weather radar’ in the tropics, highlights the potential impact and limitations for operational early warning services in regions that lack dedicated rainfall sensor networks.

ID: 179, Oral presentation

THE UPDATED OPENMRG: A UNIQUE OPEN MULTI-SENSOR PRECIPITATION DATA SET

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Open multi-sensor precipitation datasets including opportunistic sensor (OS) data are very rare. Anderson et. al.(2022) published the open dataset OpenMRG, containing composite radar, commercial microwave link (CML) and rain gauge data from official and municipal stations covering a three-month period in 2015 for Gothenburg, Sweden.

This dataset enabled testing of different CML methodologies and merging algorithms. The dataset, to be released on Zenodo, is now being expanded to additionally contain measurements of a selection of 30 NetAtmo gauge stations and volume data from nearby radars. This addition will open up opportunities for further development of more accurate precipitation derivation algorithms and quality control (QC) methodologies.

The data are assessed similarly to the contents of the original OpenMRG paper. Quality control of the NetAtmo gauges will be performed using the QC methodology of de Vos et al. (2019). Additionally, the CML data will be converted to rain rates using the methodology currently used at the Swedish Meteorological and Hydrological Institute. After quality control the individual data sources will be used to derive rainfall fields to illustrate their potential to describe the spatio-temporal behaviour of rain. Finally, a merging technique will be demonstrated to show the potential of merging multiple data sources into a single product.

This addition to the existing OpenMRG data will contribute to the work in COST action CA20136 – OpenSense (Opportunistic Precipitation Sensing Network).

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ID: 181, Oral presentation

COMBINING TITAN AND LSTM SCHEMES TO DEVELOP A NEW RADAR NOWCASTING TOOL TO PREDICT FLASH FLOODS

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This study presents a new methodology to forecast flash floods based on a precipitation nowcasting scheme that combines TITAN (Thunderstorm Identification, Tracking, Analysis and Nowcasting) and an artificial intelligence procedure known as Long Short-Term Memory (LSTM) model. In this new scheme, TITAN has been used to extract the temporal evolution of different properties (area, rain volume, mean and maximum precipitation, the major and minor precipitation radius, velocity and storm orientation) of the rainstorms and the LSTM recurrent neural network was employed to parametrize the temporal evolution of the rainstorms. This model consists of three LSTM layers with a dropout rate of 20% and a linear layer that interprets the results obtained by the LSTM layers. Moreover, the network was trained with 200 nodes using MAE as the loss. To train the algorithm, we have used 439 rainstorms observed with the Dual Polarization S-band Doppler weather radar from FCTH/DAEE - São Paulo, Brazil, during the period of 2016 to 2019. As a first procedure to evaluate this new algorithm, we performed an analysis to compute the skill as a function of nowcasting time (5, 10, 15, 20, 25 and 30 minutes) and input time intervals (starting at 10 minutes and going up to 50 minutes with 5 minutes intervals). Preliminary results revealed: a) as the input time interval increases the forecasting error decreases from about 22 km2 using 10 minutes of data to 11 km2 using 25 minutes of data; b) the longer the forecasting time the higher the root mean square error (RMSE). The model underestimates area after 10 minutes of forecasting and overestimates it at 5 minutes. Upon applying a bias correction to the area, the forecast error decreased by 3 km2 in some instances and increased by 4 km2 in others. Subsequently, with the corrected area, the POD value averaged was around 60%. Considering these results, the proposed LSTM model demonstrates acceptable performance in terms of forecast accuracy. For the conference, we will also present the influence of the TITAN-LSTM model on flood forecasting. The HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) is one of the most commonly used tools for flood forecasting, watershed hydrology, and precipitation-runoff modeling. By integrating the nowcasted precipitation and its area into HEC-HMS, we aim to simulate the hydrologic response of the watershed, which will allow us to forecast areas at risk of flash floods and to evaluate the severity of potential floods.

ID: 183, Oral presentation

CURRENT STATUS OF SINFONY – THE COMBINATION OF NOWCASTING AND NUMERICAL WEATHER PREDICTION FOR FORECASTING CONVECTIVE EVENTS AT DWD

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DWD's new Seamless Integrated Forecasting system (SINFONY) is targeted to improve very-short-range forecasting of intense convective events from observation time up to 12 h ahead for Germany. Weather radar is at the heart of it. The goal is to produce seamless ensemble forecast products in observation space, i.e., radar reflectivity composites, precipitation fields and convective cell objects, as well as informations on the probability of hazards like heavy precipitation, hail, wind gusts and lightning. These products will hopefully serve as basis to improve DWD's meteorological warnings (forecasters, automated systems) as well as the warnings of the German flood forecasting authorities.

There are different optimal forecast methods for different forecast lead times, and the idea is to improve and combine them in an optimal way. Focusing on convective events and their related hazards up to several hours, we developed in the last seven years in an interdisciplinary team

1. radar Nowcasting ensembles for areal precipitation, reflectivity (STEPS-DWD) and convective cell objects including hail and life cycle information (KONRAD3D-EPS) with good forecast quality up to 1-2 hours,
2. a new regional NWP ICON-ensemble model (ICON-RUC-EPS) with assimilation of 3D radar volumes, cell objects, Meteosat VIS and IR channels and hourly new forecasts on the km-scale, whose quality exceeds Nowcasting after forecast hour 1-2,

and to get the best of both worlds for our customers, an optimal combinations ("blending") of Nowcasting and NWP ensemble forecasts in observation space, which constitute the seamless forecasts of the SINFONY. Gridded combined precipitation and reflectivity ensembles are targeted towards hydrologic warnings. Combined Nowcasting- and NWP cell object ensembles help evolve DWD’s warning process for convective hazards towards flexible “warn-on-objects.

Common Nowcasting and NWP verification systems for precipitation, reflectivity and cell objects help to continuously improve the SINFONY components.

For 2), efficient forward operators for radar volumes (EMVORADO) and visible/infrared satellite data enable direct operational assimilation of these data in an LETKF framework. Advanced model physics (2-moment bulk microphysics with prognostic hail) contribute to an improved forecast of convective clouds, whose simulated life-cycle proofed to be surprisingly realistic.

For 3), the ICON-RUC-EPS forecasts output simulated reflectivity volume scan ensembles of the German radar network every 5’. Radar composites and KONRAD3D cell objects and their tracks are generated by the exact same methods as in the Nowcasting. These are seamlessly combined with the STEPS-DWD- and KONRAD3D-EPS Nowcasts with encouraging quality - resting upon the improvements for Nowcasting (1) and NWP (2).

Meanwhile the system has matured and is in the process of operational installation. A number of its components have been run continuously during the last four convective seasons. This presentation will give a short overview on the system components and its performance during the last years.

ID: 187, Poster presentation

RADAR POLARIMETRIC SIGNATURES OF SEVERE CONVECTIVE STORMS: TOWARDS AN EARLY WARNING SYSTEM FOR LAKE VICTORIA BASIN

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Lake Victoria is the largest freshwater lake in Africa, supporting the livelihood of more than 5 million people subsisting on its prosperous fishing industry and agriculture. However, the lake's surrounding complex topography and geographic location makes this region one of the deadliest regions of the world when it comes to weather-related accidents. It is estimated that more than 1,000 fishermen die yearly due to high waves produced by severe convective wind phenomena. Furthermore, lightning, severe hailstorms and flood-producing heavy rains events have increased in recent years in the broader East Africa region, resulting in increased weather-related fatalities.

In 2017, the World Meteorological Organization (WMO) launched the 3-year “HIGH impact Weather lAke System” (HIGHWAY) project with the main objectives to reduce the loss of lives and goods in the Lake Victoria Basin (LVB) region and to improve resilience for the local communities. The project included a field campaign in 2019 to provide forecasters with high-resolution observations and to study the storm life cycle over LVB, utilizing S- and C-band dual-polarization radars located along the lake.

In this study, we use the high spatiotemporal resolution radar data from the field campaign in 2019 to analyze two severe storms affecting the south and north shores of the lake in Tanzania and Uganda, respectively. We identify polarimetric signatures indicating severe weather and test the current capabilities of the radar's scanning strategies. The results show that polarimetric radar-based, severe weather signatures are present within these storms and that monitoring these signatures over time is an important component for early warning systems. Severe weather features observed as precursors to the near surface weather include differential reflectivity (ZDR) arcs denoting the increase in low-level rotation prior to the existence of a radial velocity couplet associated with possible waterspouts and enhanced ZDR regions evolving into ZDR columns in intensifying thunderstorms, indicating deep moist convection.

ID: 194, Oral presentation

INCORPORATING X-BAND RADAR OBSERVATIONS INTO THE GERMAN C-BAND NETWORK

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C-band radars provide relatively long-range coverage and experience less attenuation compared to higher frequency radars, making them effective for long-distance surveillance and tracking of weather patterns and phaenomena. On the other hand, X-band radars offer superior resolution compared to C-band radars, enabling detailed monitoring and analysis of localized weather conditions. Moreover, the lower purchase cost of X-band radars makes them a more economical choice for the coverage of a limited area.

The German Weather Service (Deutscher Wetterdienst – DWD) currently utilizes a network comprising 17 C-band radars, operating at a frequency of 5.6 GHz or a wavelength of 5.3 cm. Moreover, the DWD plans to integrate in 2025 four additional X-band systems into its infrastructure, operating at a frequency of 9.3 GHz or a wavelength of 3.2 cm. The objective of this project is to expand the network's coverage and enhance early detection capabilities for thunderstorms, thereby mitigating the risk of flash floods. Besides the meteorological radars, the DWD operates two Low Level Wind Shear Alert Systems (LLWAS) in the International Airports of Frankfurt and Munich, which are tuned at the X-band. Although these systems have a distinct focus, they provide comparable observables to meteorological radars.

As an initial step, we meticulously established the quality-assurance (QA) parameters by analyzing data from the LLWAS facilities, ensuring the reliability of our meteorological observations. Furthermore, we employed advanced techniques such as the T-matrix method for scattering simulations to calculate quantitative precipitation estimation (QPE) parameters specifically tailored for X-band. This meticulous calibration ensures that our forecasts are not only precise but also capable of capturing subtle nuances in precipitation patterns. Finally, to validate the robustness of our QA-processed observations and QPE formulas, we conducted comprehensive comparisons against disdrometer observations gathered from a German-wide network. This thorough validation process serves as a crucial checkpoint, affirming the fidelity of our meteorological products and instilling confidence in the forecasts and warnings.

ID: 195, Poster presentation

CONSTRUCTION OF TWO-DIMENSIONAL PRECIPITATION FIELD USING C-BAND TDWR AND S-BAND OPERATIONAL RADAR NETWORK: QUALITY CONTROL, RAINFALL ESTIMATION, AND COMPOSITION

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Since 2001, the Korea Meteorological Administration (KMA) has supported aviation weather information for the vicinity of Incheon International Airport by installing a C-band TDWR (Terminal Doppler Weather Radar) within the airport premises. Located at a low altitude in the central-western part of the West Sea, the Incheon TDWR has geographical advantages for monitoring precipitation systems flowing into the capital region, including Seoul. However, the Incheon TDWR had been operated a single-polarization radar and has encountered challenges in integration and utilization with the operational dual-polarization S-band weather radar network.

As the Incheon TDWR was upgraded to a dual-polarization radar in August 2022, the Weather Radar Center (WRC) has developed a multi-band based radar precipitation estimation and composition process. CLEANER (CLutter Elimination Algorithm for Non-precipitation Echo of Radar data), WRC's operational quality control algorithm for dual-polarization observation data, was applied to improve the removal performance for non-precipitation echoes. Especially, the performance of quantitative attenuation correction has also been improved through the dual-polarization based relations for C-band derived from the drop size distribution (DSD) data collected during 5 years in Korea. Then, the precipitation areas were classified into rain, hail, wet-snow, and dry snow using various relations or consistencies between dual-polarization variables along with radar observation characteristics. The rainfall estimation relations based on dual-polarization variables, derived from DSD observations in Korea or described in previous studies, were applied to each precipitation type. The correction equations for bright band layer were also developed and applied to wet-snow area to reduce the tendency of over- estimation. Finally, the signal loss areas due to severe rain attenuation in C-band radar observations were identified and were excluded in the composition with S-band radar data in real-time.

In the composite precipitation field produced through lowest altitude-based composition, the Incheon TDWR covers about 50% of the capital region and adjacent maritime areas, showing improved low-level(<1km height) observation rates and spatial resolution compared to the S-band based composites. Consequently, the detection rate for low-level precipitation developing low altitude has improved, and the mid-to-high-altitude echoes composited from S-band observations have also decreased. Furthermore, through developments and applications of various techniques for attenuation correction, classification of precipitation type, and rainfall estimation based on dual-polarization variables, radar-estimated precipitation amounts have become closer to ground observations, enhancing the monitoring capability of precipitation systems in the capital region. In the future, these techniques are expected to be expanded to additional TDWR data planned for installation at other airports, thereby supporting high- quality precipitation information for airports and surrounding areas.

The research was supported by the “Development of radar based severe weather monitoring technology (KMA2021-03121)” of “Development of integrated application technology for Korea weather radar” project funded by the Weather Radar Center, Korea Meteorological Administration.

ID: 196, Oral presentation

NOWPRECIP VERSION 2: NEW TECHNIQUES FOR AREAL PRECIPITATION NOWCASTING IN THE COMPLEX TERRAIN OF SWITZERLAND

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NowPrecip is a real-time probabilistic precipitation areal nowcasting application, operational in MeteoSwiss since 2020. The first version emphasized on a localization architecture and on capturing and reproducing the orographic precipitation behavior within the complex terrain of Switzerland. A new version has now been constructed which introduces a number of new elements: (a) a new optical flow module, (b) an innovative method of computing intensity-based growth and decay profiles, (c) approaches to take advantage of information from the NWP ensembles, (d) algorithmic techniques for temporal disaggregation of the nowcasting sequence and (e) use of ensembles of initial conditions for the nowcast. These techniques are powerful and straightforward in a programming sense; therefore, they can be useful and serve as modules in any other precipitation nowcasting application. The new techniques are responsible for a significant improvement in both speed and skill compared to the original version of NowPrecip. Our ultimate goal is the generation of multi-member ensembles in real-time, which, when achieved is expected to help considerably with the accuracy of rainfall-related severe weather warnings within Switzerland.

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ID: 198, Poster presentation

VARIATION OF BRIGHT BAND STRUCTURES BASED ON WIND PROFILER RADAR NETWORK

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The altitude and thickness of the melting layer influence the growth process of precipitation particles. As ice passes through the melting layer and melts, the difference in dielectric properties between ice and water leads to increased reflectivity, which is referred to as the bright band. The bright band makes it to quantitatively estimate the rainfall intensity from weather radars.

Wind profiler is an instrument to observe wind by emitting pulsed waves vertically into the atmosphere. Signal-to-noise ratio (SNR) and vertical velocity increase rapidly in bright bands, as does radar reflectivity. These properties allow us to determine the thickness and altitude of the bright bands, as well as identify structural changes over time.

In this study, we investigated the bright band structure in various rainfall cases such as typhoons, fronts, and heavy rain using data from Korea's wind profiler network, weather radar network, and radiosondes. The altitude of the bright band is generally influenced by latitude and surface temperature. However, as the typhoon approached, the altitude of the bright band increased. The bright band originating from the precipitation front maintained a constant height. By understanding the vertical structure and temporal changes in precipitation patterns, we aim to increase the utilization of remote sensing data and improve the accuracy of weather forecasts. This study aims to understand the vertical structure and temporal changes in precipitation patterns and improve the usability of remote sensing data.

ID: 199, Oral presentation

SPATIO-TEMPORALLY CORRELATED PROBABILISTIC QUANTITATIVE PRECIPITATION ESTIMATION (QPE) BASED ON A RANDOM FOREST APPROACH, ENSEMBLE COPULA COUPLING AND OPERATIONAL RADAR DATA

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Quantitative precipitation estimation (QPE) is crucial for hydrological, climatological and meteorological applications. To derive QPE from operational polarimetric radar observations, Wolfensberger et al. (2021) propose a random forest algorithm. This operationally implemented model “Rainforest” is trained with a database containing six years (January 2016 to December 2021) of collocated observations from 288 rain gauges and polarimetric radar observations from five dual polarization Doppler C-band radars (Swiss weather radar network). The model was thoroughly evaluated by Wolfensberger et al. (2021).

In this study, we further develop RainForest by applying new methods to derive probabilistic estimates that are correlated in space and time. We propose an approach that is divided into three parts: First, a quantile random forest regression is adapted to provide the whole empirical cumulative distribution function for each grid cell (instead of the conditional mean value). From this distribution, we randomly sample N values, where N is the number of ensemble members we want to generate. Since sampling is done independently at each grid cell, the spatial correlations are incorrect at this stage. Second, we derive spatio-temporally correlated perturbation fields following a similar approach as presented in pysteps (Pulkkinen et al. 2019). The spatial structure of the perturbation fields is derived from the classical random forest approach (Wolfensberger et al. 2021). Third, we employ ensemble copula coupling (Schefzik et al. 2013) to apply the correlation structure of the perturbation fields to the marginally calibrated members, yielding realizations of precipitation fields with a realistic spatio-temporal structure.

The spread and the accuracy of these probabilistic QPEs is evaluated using the continuous ranked probability score and rank histograms. The spatio-temporal structures are evaluated by comparing the radially averaged power spectra and the temporal auto-correlation of the generated members to the mean precipitation fields of the operational model (RainForest) and an operational radar-only benchmark model of MeteoSwiss.

In summary, we present a novel approach for probabilistic QPE at a high temporal resolution and a spatial resolution of 1×1 km^2 for Switzerland. Our approach shows great potential for meteorological and hydrological studies that require accurate, reliable and spatio-temporally correlated precipitation estimates.

ID: 203, Poster presentation

LONG-TERM INTERCOMPARISON OF RADAR PRECIPITATION NOWCASTING TOOLS ACROSS ITALY

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The ability to provide reliable predictions of rainfall and early warning is critical for practical applications to reduce damage caused by heavy rains, flash floods, and landslides. Traditionally, numerical weather prediction (NWP) models are used to forecast precipitation. At short time periods (up to a few hours), radar-based rainfall nowcasting techniques, which attempt to identify the future distribution of precipitation through a sequence of images, typically outperform NWP skills [1].

The main limitations of the NWP models arise from inaccurate initial conditions, outdated boundary conditions, or parametrization errors [2]. Weather radars, indeed, due to their fine spatial (0.5–1 km) and temporal (5–10 min) resolutions, are the ideal tools for estimating precipitation in real time and providing time projections for lead times of the order of a few hours or less.

At present, numerous radar nowcasting algorithms are available, and this study aims to compare some of them to each other over Italy. The algorithms considered are those based on the optical flow, namely Lucas Kanade (LK), Dynamic and Adaptive Radar (DARTS) and Variational echo tracking (VET), those in the pysteps Python package [3], two convolutional neural networks, namely RainNet [4] and SimVP [5], and a conditional generative adversarial network, named Rad-cGAN [6].

The radar dataset used spans over one year and a half from Feb. 2022 to Dec. 2023, and it includes rain rate regularly gridded products from the Italian radar network with a time sampling of 5 min and grid horizontal spacing of 1x1 km^2. A novel practical radar data screening, based on file size occupancy and Moran spatial correlation index, is applied before running the nowcasting algorithms to quickly exclude clear sky periods and spatially characterize radar data, respectively.

Results indicate variable performance of the different nowcasting algorithms implemented, leaving room for a categorization of the various nowcasting approaches as a function of several environmental factors (e.g., season, type of precipitation, geographical area).

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ID: 214, Oral presentation

UNLEASHING THE POTENTIAL OF CONVOLUTIONAL AND RECURRENT NEURAL NETWORKS AS A POWERFUL TOOL FOR RADAR ECHOES EXTRAPOLATION

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Short-term weather predictions are essential for mitigating extreme weather risks (Sukovich et al., 2014). This study investigates the potential of deep learning models (D. Han et al., 2023; Ravuri et al., 2021; Zhang et al., 2023), specifically Convolutional Neural Networks (CNNs) (Agrawal et al., 2019; G. Ayzel et al., 2019; L. Han et al., 2022) and recurrent architectures like ConvLSTM (Shi et al., 2015, 2017), to leverage high-resolution ground-based weather radar data collected in Cagliari, Italy, for radar echo extrapolation. We used data from the University of Cagliari's (9.1°E, 39.2°N) X-band radar (SuperGauge by Envisens) from April 2018 to December 2023. It scans at a single elevation and polarization, updating data every minute with a resolution of 60 meters close-in, at its 30 km maximum range, effectively monitoring the entire Cagliari area. A significant challenge lies in data preprocessing, which involves filtering for no trace (<0.5 dBZ of 10% of pixels) of rainfall and temporally sequencing radar images to capture the evolution of weather patterns. The core model architecture draws inspiration from the well-established U-Net structure (Agrawal et al., 2019), known for image segmentation tasks. Our study compares CNN, which extracts spatial features from radar images, and ConvLSTM (Shi et al., 2015), instead, captures the temporal dependencies between these images. The models are trained using sequences of radar images (last 20 minutes) captured at 5-minute time steps, paired with corresponding observed precipitation data in the next 1 hour. To evaluate the effectiveness of the proposed approach, we compared our model results with pySTEPS (Pulkkinen et al., 2019) and rainymotion libraries (Ayzel et al., 2019), which represent state-of-the-art optical flow methods. We further explore the impact of various loss functions on model performance, considering not only Mean Square Error (MSE) but also Balanced Mean Square Error (BMSE) and Balanced Mean Absolute Error (BMAE) to account for the inherent skewness in rainfall data distribution (Shi et al., 2017). We used a loss function, MCSLoss (Kim et al., 2024), which combines a robust loss function, CBLoss, with nowcasting metrics (CSI and FAR) for optimal performance which dynamically adjusts weights based on rain intensity. Model performance is comprehensively evaluated using a suite of metrics, including MSE, CSI, FAR, Probability of Detection (POD), and Power Spectral Density (PSD). The results of this investigation assess the efficacy of ConvLSTM & CNN models equipped with different loss functions against established optical flow techniques for precipitation nowcasting. This study aims to advance the development of deep learning methods for radar data-based extrapolation by focusing on data pre-processing and loss function optimization.

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AUTOMATIC TRACKING AND PREDICTING TROPICAL CYCLONE CENTER BASED ON RADAR-REFLECTIVITY-FIELD FOR THE TYPHOON HINNAMNOR (2022).

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The trajectory and location of Typhoon Hinnamnor's tropical cyclone center (TCC) were analyzed using S-band radar data from Gudeoksan Mountain, South Korea. Data collection is based on a repetitive sequence (typically 5 min) of conical scanning at several elevation angles. Reflectivity fields with 1-min resolution were generated via standard block matching techniques using two adjacent reflectivity fields. In this study, we only use a horizontal surface at 2500 m altitude with a grid step of 1 km covering 250 km. At the synoptic scale, typical motion and reflectivity fields appear as a spiral around a moving TCC. Compared to the reflectivity field, the circularity defect of motion streamlines is caused by the uniform advection of the tropical cyclone. In a TCC-relative frame without advection, motion streamlines and reflectivity fields are supposed not only to be circular and concentric also the echo motion vector to be orthogonal to the line passing through the TCC. Principle equations were established to estimate the TCC of each reflectivity field and applied to 1-min resolution data. Estimated TCC trajectories showed good agreement with the best track with high temporal resolution. Assuming that the speed of the TCC is equal to the progression of the cyclone, the TCC can be forecasted from the current TCC position.

ID: 220, Poster presentation

ENHANCING FLOOD PREDICTION USING X-BAND POLARIMETRIC RADAR DATA: TWO CASE STUDIES IN THE MARCHE REGION, ITALY

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Flood forecasting and early warning systems are critical for minimizing the impact of floods on communities and infrastructure. Traditional flood prediction methods often rely on historical data and numerical models, which may have limitations in providing timely and accurate predictions, especially in rapidly changing weather conditions. Nowadays quantitative rainfall estimation using X-band weather radar is indeed essential to meet requirements for flood forecasting, water management and other hydro-meteorological applications.

This study explores the potential of radar data assimilation and radar nowcasting techniques for enhancing flood prediction accuracy and lead time. In particular, it investigates the utility of Xband polarimetric radar data, obtained from a radar site situated in the Marche Region of EastCentral Italy, for improving flood prediction capabilities. The radar, operational since 2014 and managed by the Marche Region Civil Protection Service, offers valuable insights into precipitation patterns crucial for flood forecasting and water management. Measurements from Marche Region radar have proven to be a valuable tool for the observation and the quantitative estimation of rainfall fields.

In this paper, we analyze two distinct case studies representing convective and stratiform precipitation regimes observed in the region. The convective case (16 September 2022) exhibits rapid development of a v-shaped system, resulting in intense precipitation reaching 140mm within two hours, with maximum intensities of 40mm in 15 minutes. Conversely, the stratiform case (16 May 2023) spans over 24 hours, characterized by continuous and persistent precipitation associated with a trough and warm front.

To evaluate the impact of radar data on flood prediction, we employ the Cetemps Hydrological Model (CHyM) to simulate river discharge and assess hydrological stress indices. Three experiments are conducted: utilizing rain gauge data alone, radar data alone, and integrating radar data into an operational nowcasting chain to provide 1-hour forecasted accumulated precipitation fields.

We show preliminary results regarding the assimilation of radar data in estimating the effects of precipitation on the ground and improving the accuracy of flood prediction. This study highlights the importance of radar nowcasting techniques in improving flood forecasting capabilities, particularly in regions subject to sudden and intense rainfall events such as the Marche Region.

ID: 221, Oral presentation

ASSIMILATION OF RADAR REFLECTIVITIES AND WINDS FROM OPERA NIMBUS IN HARMONIE-AROME

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Recently, the EUMETNET Operational Program on the Exchange of Weather Radar Information (OPERA) has released its new production line NIMBUS. It generates continental precipitation composites and quality-controlled volumes containing radar reflectivities and winds. Both quantities can be assimilated in Numerical Weather Prediction (NWP) models.

ACCORD (A Consortium for convective-scale modelling Research and Development) is a grouping of National Meteorological and Hydrological Services (NMHSs) having decided to share the development of common computer codes for use in short-range NWP on limited area domains. Within ACCORD, the Swedish Meteorological and Hydrological Institute (SMHI) (member of the Meteorological Cooperation on Operational NWP (MetCoOp)), the Danish Meteorological Institute (DMI) (member of United Weather Centres (UWC)-West)), and the Agencia Estatal de Meteorologia (AEMET) have a long experience in assimilating radar reflectivities and winds in the operational NWP system HARMONIE-AROME. Currently, SMHI and DMI/AEMET are using radar data from the common MetCoOp data archive ARCUS and the OPERA Development Environment (ODE), respectively. However, it is intended to employ NIMBUS radar data in future.

To evaluate the impact of NIMBUS radar data on short-range forecasts, several parallel experiments have been performed for model domains covering different parts of Europe. At the conference, we will present the radar sources, the design of the experiments, and preliminary results. Moreover, we will highlight benefits and challenges of using NIMBUS radar data for data assimilation in HARMONIE-AROME as well as future plans.

ID: 223, Oral presentation

EXTREME EVENT EVALUATION OF RADAR-DERIVED POLARIMETRIC PRECIPITATION ESTIMATES USING A DENSE NETWORK OF RAIN GAUGES

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Radar-derived quantitative precipitation estimation (QPE) has become a key factor for many meteorological and hydrological analyses and applications. In hydrology, radar-based QPE products are commonly used as main input to rainfall-runoff models to simulate and predict streamflow, and their errors significantly contribute to the uncertainty in streamflow simulations. The QPE method for the U.S. Weather Surveillance Radar-1988 Doppler (WSR-88D) radars has evolved along with their hardware upgrades (e.g., polarimetry) since their deployment in the early 1990s. Many QPE studies during the last decade have focused on utilizing advantages of polarimetric observations and assessing a variety of approaches. The results from those studies demonstrated the improved accuracy and potential of polarimetric estimates in different conditions and cases. In this study, the authors use ground observations from a dense network of 171 rain gauges in the Kansas City area and evaluate radar QPEs. These precipitation estimates were derived from two polarimetric QPE algorithms based on specific differential phase and specific attenuation for recent extreme rain cases observed from two overlapping radars in Topeka, Kansas and Kansas City, Missouri. The performance of these estimates is also compared with that of the conventional algorithms derived from radar reflectivity observations. This comparison demonstrates that the two polarimetric algorithms outperform the reflectivity based one and reveals which QPE algorithm is suitable for extreme rainfall estimation and precipitation frequency analyses. The authors also examine the estimation performance of QPE algorithms in terms of the spatial variability and other relevant factors (e.g., presence of hail) for each extreme event.

RAINFALL VARIABILITY MEASURED AT SUB-HOURLY TEMPORAL AND SUB-KILOMETER SPATIAL SCALE

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Knowledge of short-duration, sub-kilometer-scale rainfall variability is needed for several meteorological and hydrological applications, particularly in urban environments due to their sensitivity to water-related issues. Variability at these scales is a blind spot for both operational rain gauge networks and operational radar networks. Reanalyzed measurements from a single-polarized X-band weather radar are available at high temporal (30 s) and range (60 m) resolutions within a scan radius of 20 km covering the urban area of Hamburg, Germany. This study compares the reanalyzed radar data from this local area weather radar (LAWR) with observations from two micro rain radars, an operational C-band radar, combined networks of 33 rain gauges, and the radar-rainfall climatology RADKLIM.

What is the added value of the LAWR compared to operational C- band radar systems? In fact, the continuous observations result in a closer agreement in terms of radar reflectivity with local radar observations by micro rains radars. However, this advantage does not translate in a better match to rainfall accumulations recorded by rain gauges, as uncertainty in the Z-R relation dominate the uncertainty both for LAWR and operational radar system. Nevertheless, the LAWR outperforms in describing spatial structure. As expected, RADKLIM underestimates rainfall variability due to the kilometer spatial scale. But interestingly, the operational C-band radar observations tend to overestimate spatial variability at sub-hourly temporal scale. This effect is caused by their intermittent scan strategy, taking just a snapshot every five minutes. We identify the benefits of the LAWR's scan strategy results to all measurements taken every 2.5 s. The refined spatio- temporal resolution and scan strategy is also important for capturing rainfall peaks. Finally, we demonstrate that the LAWR can monitor steeper spatial gradients. In summary, the LAWR is not able to provide better local rainfall rate estimates on the sampling scale of rain gauges, but still we can proof added value to characterize the local rainfall intensity and spatio-temporal rainfall variability.

ID: 230, Oral presentation

SNOW QUANTITATIVE PRECIPITATION ESTIMATION FROM THE CANADIAN S-BAND RADAR NETWORK.

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Quantitative Precipitation Estimation (QPE) from radar measurements for snow is challenging due to large variability in particle size distributions (PSDs), densities, shapes, sizes, and orientations of falling snow. Almost all current operational snowfall retrieval algorithms are based on horizontal reflectivity (Z) and are related to snowfall rate or liquid water equivalent by power law relationships. The Sekhon and Srivastava 1970 S(Z) relationship has been used in Canada to convert horizontal reflectivity to liquid water equivalent precipitation rate (mm/h) for decades and is still being used for many operational products.

The renewed network of Environment and Climate Change Canada (ECCC) ow provides routine polarimetric measurements in all weather conditions and we aim to improve snow liquid water equivalent estimates.

New relationships for snow water equivalent combining differential reflectivity (Z_{DR}), specific differential phase (K_{DP}) and Z are explored to determine whether they can improve overall snow QPE in an operational environment. Snow liquid water relationships utilizing Z_{DR} in an operational environment are limited by biases in Z_{DR} at individual radars in the network and by the stability of Z_{DR} over long periods. Though we have implemented bias estimation and corrections in post-processing software, snow liquid water estimates that employ Z_{DR} are deferred. At ECCC a hybrid algorithm comprising of S(Z) and S(Z, K_{DP}) for winter precipitation has been recently implemented in operations. S(Z) is applied for relatively low Z and low $K_{DP,}$ and S(Z, K_{DP}) is applied for larger values.

Surface snow measurements obtained from ECCC climate station networks provide hourly

precipitation liquid amounts from automated precipitation gauges and are used for evaluating the radar estimates. The presentation will highlight the ongoing analysis and performance of the snow QPE algorithms and challenges associated with snow liquid water estimates from the 3radar network.

ID: 237, Poster presentation

A STUDY ON THE ERROR OF INTERPOLATED PRECIPITATION BY GROUND PRECIPITATION GAUGE USING RADAR PRECIPITATION

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Quantitative spatial and temporal errors occur between observed and estimated areal precipitation because precipitation involves spatial and temporal uncertainty. In this study, the effects of watershed area, rain gauge density, and rain gauge spatial distribution on regional average rainfall estimates were evaluated by comparing the results of spatial interpolation. To this end, the interpolated watershed areal mean using radar grid corresponding to the rain gauge point was compared with the watershed mean all of the radar grid within the watershed. As a result of the study, it was found that the Inverse distance weighting method tends to underestimate the area rainfall. In addition, as the linearity of the rain gauge distribution increases, the number of rainfall events with outliers increases. This study showed that there is a limit to the areal rainfall estimation when using rain gauge observation in a small watershed.

Acknowledgments

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ID: 238, Poster presentation

DEVELOPMENT OF AN OBSERVATION OPERATOR FOR DUAL-POLARIZATION RADAR DATA ASSIMILATION

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To enhance the accuracy of mesoscale precipitation forecasting, assimilation of radar data with high spatial and temporal resolution is essential. The commonly used relationship between horizontal reflectivity (Z) and hydrometeor mixing ratio in radar data assimilation (DA) is based on a single-moment microphysical process. It includes several assumptions, such as treating the y-intercept of the hydrometeor number concentration as a constant and using the background temperature field to classify hydrometeors that can lead to large errors. Additionally, it tends to overestimate Z near the melting layer. Dual-polarization (dual-pol) radar variables, including differential reflectivity (ZDR) and specific differential phase (KDP) offer additional information of hydrometeor type, size, and water contents. A dual-pol operator based on scattering calculations with the T-matrix method for rain and the Rayleigh scattering approximation for ice can more accurately convert model state to observed variables. Thus, development and application of sophisticated radar observation operator that can calculate dual-pol radar variables using the microphysics state of a numerical forecast model is necessary.

In this study, a dual-pol radar operator is developed to calculate the microphysical state of a numerical forecast model specialized for the Korean Peninsula. The existing dual-pol radar operator have issues with the overestimation of Z, ZDR and KDP near 0℃ in convective precipitation. To improve these features, we assume that wet-snow and wet-graupel do not co-exist in areas of strong updrafts and downdrafts. Additionally, by applying the axis-ratio of snow obtained from ICE-POP 2018 data to the dual-pol operator, the issue of ZDR and KDP calculations being constant in subzero temperature zones are improved, and KDP, ZDR distribution for solid hydrometeors are more accurately represented. By applying the improved observation operator in DA experiments, the issue of underestimating the mixing ratio of solid hydrometeors was addressed. Further, results show that the precipitation forecasting accuracy can be improved for both summer and winter cases.

Key words: Dual-polarization radar operator, radar data assimilation, numerical model, microphysics

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ID: 239, Poster presentation

SEAMLESS PREDICTIONS AT THE ROYAL METEOROLOGICAL INSTITUTE OF BELGIUM

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Seamless prediction systems aim to provide rapidly updating forecasts that cover a broad range of timescales by combining the latest observations, including weather radar data, with numerical weather prediction models. End users such as hydrological services, local authorities, and the renewable energy sector demand not just rapidly refreshing and accurate forecasts; increasingly, they require uncertainty information through the use of ensembles.

To meet these needs, many national meteorological services have rolled out seamless prediction systems, of which the WD's SINFONY, MetOffice's IMPROVER, and Geosphere Austria’s SAPHIR are prime examples. In Belgium, the seamless prediction system, dubbed "Project IMA", is based mainly on the RMI’s RADQPE radar composite, the pySTEPS-BE probabilistic rainfall nowcasting system, the comprehensive INCA-BE analysis and nowcasting system, and the ACCORD numerical weather prediction (NWP) model configurations ALARO and AROME. New developments in project IMA focus on the integration of deep learning based QPE and blending methods. As such we aim to extend the range of the forecasts, and improve calibration, sharpness, and usefulness in general for hydrologists, crisis managers and other stakeholders.

IMA integrates research insights into operations, with an emphasis on leveraging open-source software such as pysteps. Contributing to open-source software not only promotes transparency and reproducibility, but also facilitates international collaboration, bringing us a step closer to the global aim of achieving "Early Warnings for All" by 2027.

ID: 244, Poster presentation

TRANSBOUNDARY PRECIPITATION FOR DIGITAL SEWER SYSTEM

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Extreme precipitation events pose an important challenge for sewer system management. In order to better understand and to be able to simulate the sewer system, a digital version of the sewer system of a pilot area of the city of Flensburg (Germany) was built as part of the Interreg Deutschland-Danmark project Neptun. This sewer system model together with radar-based precipitation observations and nowcasts form the backbone of an operational early warning system and enable network simulations. Major goals associated with this newly developed asset are to improve the management of combined sewer basins and to investigate the creation of natural retention areas.

The spatially distributed precipitation data needed in near real time for such a system can be derived from radar observations. Flensburg is situated in the very North of Germany on the border to Denmark. While the city area is well covered by the nearest radar of the German weather service, it is advisable to include Danish precipitation observations to improve the reliability of the precipitation information and the forecast horizon of nowcasting. The open data policy of both the German and the Danish weather service are highly beneficial in this respect.

The precipitation system consists of data of the German Boostedt radar (precipitation scan with a spatiotemporal resolution of 1° x 250 m and 5 minutes, 95 km South-South-East of Flensburg) and data of the Danish Römö radar (volume data with a spatiotemporal resolution of 1° × 1 km and 10 minutes, 70 km North-West of Flensburg) along with automatically reporting gauges of both weather services. We correct the radar observations from both instruments for errors including ground clutter and beam blockage with our software Scout. Another important correction, especially for fast moving precipitation cells often encountered in this region, is the advection correction. An adapted version of this advection correction is also used to produce data with a five minute resolution for radar Römö. Using appropriate weights, the corrected radar data is then mapped on a composite grid with a resolution of 1 km x 1 km. Afterwards this data is adjusted by Danish and German gauge data to improve the quantitative precipitation information.

The radar observations and nowcasts are provided in near real time as an input to the model and are displayed and stored in HydroNET, a cloud-based decision support system whose key feature is to bring together and visualize different data sources that facilitate operational water management. The model results are also fed into HydroNET and are displayed on customized maps that can provide visual alerts to water managers allowing them to react fast on potentially threatening situations.

ID: 247, Poster presentation

SUB-GRID VARIABILITY IN LOCALIZED INTENSE RAIN EVENTS USING HIGH-RESOLUTION OPERATIONAL RADAR DATA IN SWITZERLAND

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Localized intense rain events can cause significant societal and economic damages. By collecting distributed space-time observations, weather radars can provide useful information for the analysis of such events. In Switzerland, five operational dual-polarization C-band radars are scanning the atmosphere with a half-power beam-width of 1 degree and a pulse width of 500 ns up to a height of 18 km (20 interleaved sweeps updated every 5 minutes). Data are generated at a native radial resolution of 83 m. This information is then integrated at 500 m by averaging all clutter-free 83-m gates and quality-checked before being used in subsequent product chains. This integration may smooth out the variability within those localized intense rain events and, the information from high-resolution radar data might become valuable.

In this study, we analyze how the spatial integration of the native data at coarser polar radial resolutions of 500 m and 1000 m influences the captured spatial variability of rainfall peaks over such events. We focus on a case-study from June 11, 2018 when a localized intense rain event hit the city of Lausanne leading to the largest 10-min rainfall accumulation ever recorded by the Swiss rain gauge network (41 mm). We quantify the impact of the spatial integration by successively averaging all selected clutter-free high-resolution native data to the coarser 500 m and 1000 m radial resolutions, and then downscaling the integrated data back to the same 83 m resolution. We use the polarimetric information to remove strongly attenuated data and we apply Z-R or Z-S relationships - based on the hydrometeor type - on the remaining data to derive a corresponding “equivalent” rain rate (R_E) at the gate level for the different spatial resolutions.

Preliminary results indicate that the difference between the R_E estimates at the native resolution and after integration exhibits a strong spatial and temporal variability. By selecting gates with high reflectivity values (> 50 dBz), about 1% of the gates show differences of more than 50 mm/h between the R_E estimated at 83 m and at 500 m resolution, and 0.3% have a R_E that is twice larger at 83 m than 500 m. These values vary over the different 5-min timesteps. Despite the limitations associated to the application of single Z-R and Z-S relationships, these differences already provide initial indications on the added value of high-resolution radar data for the analysis of those localized intense rain events.

ID: 251, Poster presentation

NATIONAL SCALE DATA-DRIVEN CLASSIFICATION OF POLARISED WEATHER RADAR OBSERVATIONS IN THE UK

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Expanding Artificial Intelligence (AI) capabilities and increasing computational power help environmental scientists in two ways. On one side, they allow us to simplify and speed up already developed methodologies. And on the other, they open a door to potential discoveries and improvements in our understanding of processes taking place in the atmosphere. They provide us a capability to extract complex dependencies and relations in observational datasets. In the context of the polarised weather radar observations, this requires a thorough classification of archived multi-dimensional datasets.

This study provides an example a technique developed for the national-scale data-driven classification of archived weather radar observations in the UK. It discusses advantages and challenges of such a classification, followed by the possible interpretation of characteristics and behaviour of identified classes for description of environmental phenomena.

These in-depth insights can be instrumental for research of the fine-scale phenomena (such as insects' or birds' movements in the air or small-scale convective events) or for obtaining a data-based parameterization for a large-scale event (such as fronts and migrations of aero-ecological targets). The knowledge obtained by applying artificial intelligence techniques can be used to improve and expand current forecasting and nowcasting capabilities.

ID: 254, Poster presentation

ANALYSIS OF POTENTIAL EVAPORATION EFFECTS ON C-BAND WEATHER RADAR RAINFALL OBSERVATIONS IN A SEMI-ARID AREA

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Precipitation evaporation beneath the cloud layer is a classical mechanism causing sub-estimation of weather radar quantitative precipitation estimates (QPE). The objective of this study is to examine possible evaporation effects on radar reflectivity profiles using co-located automatic weather stations (AWS) providing ground-level air temperature, pressure and relative humidity. The study is carried out over The Land Surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE) domain, in the eastern Ebro valley in Catalonia (NE Spain) using C-band weather radar observations and AWS data from the Meteorological Service of Catalonia. The area is characterized by intense agricultural activity and is divided into two sub-areas: an irrigated area and a rainfed area, separated by an artificial channel.

As expected, the analysis of a six-year observational dataset indicated clear differences in average ground-level temperature and humidity between the irrigated and non-irrigated areas in dry days during the warm season. However, no clear differences were found on average precipitation frequency, intensity, amount and convective fraction between the two sub-areas. A more detailed study focused on cases prone to rainfall evaporation was conducted on reflectivity profiles occurring during the first 30 minutes of rain after a 24-h dry period. For those specific conditions, radar reflectivity observations at 1 km height did exhibit a statistically significant correlation with ground-level relative humidity for convective cases, irrespective of the sub area (irrigated or rainfed) considered. Moreover, after a 30-minute period of the rainfall onset, ground-level AWS temperature and relative humidity of both irrigated and rainfed areas -which were different before rainfall- tended to converge indicating that during rainfall ground level conditions are quickly homogenized. These results contribute to enhance our understanding of possible evaporation effects on weather radar QPE and may serve as a basis for the future development of an evaporation correction method. This study was supported by projects RTI2018-098693-B-C32 and PID2021-124253OB-I00.

ID: 260, Poster presentation

RECENT UPDATES IN THE UNITED STATES MULTI-RADAR MULTI-SENSOR QPE SYSTEM

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Since 2014, the operational Multi-Radar Multi-Sensor (MRMS) system in the United States has provided forecasters with high-resolution (1-km, 2-min) quantitative precipitation estimation (QPE) and severe weather products for various hazardous weather warning applications. The MRMS QPE includes two groups of products; one is primarily based on radar data, and another is a combination of radar, gauge, precipitation climatology and numerical weather prediction model forecast fields. The radar-based QPE has little latency (< 2 min) and is used for flash flood situational awareness in operations, and the multi-sensor combined QPE (~20 min latency) is a forcing to the National Water Model. The radar QPE is based on a dual-pol synthetic scheme that applies R(A) in areas where the radar observations are in pure rain, R(Kdp) in areas of potential hail, and R(Z) elsewhere. Here R is the precipitation rate and Z, Kdp, and A are reflectivity, specific differential phase, and specific attenuation, respectively. In recent years, several updates have been developed for the MRMS QPE system, which include

1) quality control of wind farm contaminations; 2) mitigation of corrupt radar data associated with hardware issues; 3) R(A) refinements to improve its representativeness of local scale drop size distributions; 4) machine learning QPE for complex terrain. The wind farm and corrupt data are specially handled because of the high variabilities in their dual-pol radar characteristics. In the R(A) refinements, physical constraints are added to a key parameter (alpha), which is derived from limited Z and Zdr (differential reflectivity) data samples in real- time and can be prone to skewed Zdr vs. Z distributions. A convolutional neural network with inputs from radar, terrain, precipitation climatology, and atmospheric environment data and a customized loss function is found to provide improved accuracies over the current radar-based QPE in the complex terrain of the western United States. An overview of these updates and examples of their impact on the MRMS QPE will be presented at the conference.

ID: 261, Poster presentation

COMPARISON OF SIMULATED AND OBSERVED RADAR DATA IN A TROPICAL MARITIME CONVECTION EVENT DURING THE 2022 PRECIP FIELD CAMPAIGN

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While 3-km grid spacing is often a target for regional and global "convection- permitting" simulations, it is unknown if such grid spacing is sufficient for accurately resolving tropical precipitation structure and evolution. This issue stems, at least partly, from the lack of detailed observations of tropical maritime convection. During the 2022 Prediction of Rainfall Extremes Campaign in the Pacific, a long-lasting maritime rainfall event occurred on 29 July 2022. A tropical squall line was sampled in detail with several observing platforms, including the CSU SEA-POL radar, regular soundings, and a disdrometer in Yonaguni. The rainfall event was also predicted by a 3-km ensemble produced with the PSU WRF EnKF modeling system. Although the 3-km model forecast predicted the moisture surge environmental condition, the detailed convective organization and evolution were not well represented. To investigate the discrepancies between the model and observations, the most accurate ensemble member is selected for resampling the simulation by a radar emulator. Analysis of the model data and emulated radar data is compared against sounding and radar observations, which will further help provide insights into the deficiencies of the model representation of tropical maritime convection.

ID: 263, Poster presentation

ANALYSIS OF HAIL SIZE AND VERTICALLY INTEGRATED LIQUID DENSITY OVER LIGURIA REGION IN NORTHWESTERN ITALY

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The Liguria region in Northwestern Italy is one of the areas most prone to severe convective storms in Europe throughout the year, including thunderstorms, windstorms and to a lesser extent hailstorms. Since no direct hail measurements (e.g. via hail pads) are available in Liguria, the aim of this work is, first, to collect an up-to-date dataset of hail events based on technical, citizen and press reports and, then, characterize them by means of radar data with a particular focus on storm severity and hail size, comparing different hail proxies such as Waldvogel probability of hail (POH) and vertical integrated liquid density (VLD).

For this purpose, 65 hailstorms occurred between 2017 and 2023 are analysed using the observations of the dual-polarimetric C-band meteorological radar located on Monte Settepani (at 1400 m a.s.l. in Ligurian Alps). In order to classify the dataset and investigate correlations with radar data, both a POH algorithm and a VLD one are implemented, the former based on the difference between zero-degree height and 45-dBz echo-top, the latter on the ratio between vertical integrated liquid and 18-dbZ echo-top. The VLD methodology offers some advantages: it is entirely derived from radar observations, whereas POH requires zero-degree height fields

e.g. from NWP models, which could be inaccurate in a storm environment especially during cold seasons; moreover VLD as a vertical density is less season-dependent. On the other hand, VLD is an indicator of the presence of hail at medium/high altitudes, as Settepani radar is too high up to detect hydrometeors close to the ground, and could be inaccurate especially when the freezing point is very high or hailstones encounters abundant liquid precipitation. Thereafter, each hail event (complete with information on hail accumulation on the ground and hailstone size if available) is associated with the maximum values of both POH and VLD, computed in a neighbourhood (both in space and time) of the hail report. It is worth noticing that reflectivity data are preliminary filtered in order to drop echoes from distinct nearby storm cells. Approximately two thirds of the events are characterised by small hail (1-2 cm) and hail accumulation is reported only for those events; hail size in the dataset ranges up to 6 cm (average: 1.8 cm, 75th-percentile: 3.0 cm), whereas maximum VLD ranges from 1.0 to 9.6 g/m^3 (average: 3.6 g/m^3, 75th-percentile: 4.6 g/m^3). A slightly correlation between maximum VLD and hail size is found with VLD greater than 5 g/m^3 associated with hailstones larger than 3 cm, providing a useful classification for nowcasting purposes. Further investigations will concern the evaluation of polarimetric variables.

ID: 269, Poster presentation

A MACHINE LEARNING APPROACH FOR QUANTITATIVE PRECIPITATION ESTIMATION IN THE OPERATIONAL CONTEXT OF SOUTHERN BRAZIL

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Effective operational hydrometeorology depends on precise and timely precipitation estimates, especially for short-term forecasting (nowcasting). Improving precipitation estimation has far-reaching implications for various socio-economic sectors, including agriculture and hydropower management. The higher accuracy of the precipitation estimates significantly benefits these activities by providing reliable information for decision-making processes. This study shows two machine learning (ML) methodologies for Quantitative Precipitation Estimation (QPE) to improve rainfall estimation applied operationally in Brazil, a region prone to severe weather events. The first methodology, QPE-RADAR ML, employs dual-polarization weather radar data (reflectivity, differential reflectivity, specific differential phase, and co- polar correlation coefficient) to refine the traditional Z-R relationship, which often needs more accuracy in areas with complex meteorological phenomena, such as convective events. The methodology uses tree-based ML methods, such as random forest and gradient boosting, to improve precipitation estimation precision by capturing intricate patterns within the Z-R relationship, particularly under challenging weather conditions. The second methodology (SIPREC-ML) is applied to the estimation of precipitation for the entire domain of Brazil. This methodology uses a random forest regression model to merge weather radar, satellite, and rain gauge data and produce a high-resolution precipitation grid. We used 271 rain gauges with hourly measurements for model training and evaluation. The input radar data is a composite of 17 radars in southern Brazil with a resolution of 4 km2. Kling-Gupta Efficiency (KGE), Root Mean Square Error (RMSE), and Mean Absolute Error (MAE) metrics were used to evaluate the predictive efficiency and accuracy of the models. Both models demonstrated a remarkable ability to estimate precipitation while preserving coherent spatial patterns. SIPREC- ML offers reliability, automation, and data fusion capabilities in operational meteorology, while QPE-RADAR ML enhances accuracy by revealing nuanced precipitation patterns. Combining these strengths equips meteorologists to make better-informed decisions grounded in a comprehensive understanding of precipitation dynamics. Integrating SIPREC ML and QPE-RADAR ML methodologies addresses severe weather challenges in Southern Brazil and improves forecasting accuracy.

ID: 278, Oral presentation

ADVANCED OPERATIONAL COMPOSITE FOR MULTI-FREQUENCY POLARIMETRIC WEATHER RADAR OBSERVATIONS IN COMPLEX TERRAIN: THE AQPI STORY

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Monitoring precipitation by weather radars with proper spatial and temporal resolution in complex topography is challenging; beam blockage, poor visibility, and distance from target areas degrade data quality, affecting quantitative precipitation estimations (QPEs) by large uncertainties. To overcome these limitations, small X-band polarimetric weather radars can fill the gaps by integrating conventional operational radar networks (typically at S-Band or C-band radars) with higher spatial and temporal cadence. Nevertheless, combining weather radar observations with different temporal and spatial resolutions and different scan strategies presents a number of challenges and is not a straightforward process.

The Advanced Quantitative Precipitation Information (AQPI) project in California, United States, involves the deployment of four polarimetric scanning X-band radars, complemented by various ground-based instruments including precipitation gauges and disdrometers. These instruments are strategically placed in regions characterized by complex terrain, where the operational NEXRAD network provides inadequate coverage. The X-band radars are able to better observe the lower atmosphere, where precipitation is occurring, yielding high-resolution data with very accurate QPE that supplements the existing NEXRAD network in the area. This study delves into advanced algorithms designed to mosaic weather observations collected at multiple frequencies aiming to enhance weather monitoring and forecasting. The specific methodologies considered include addressing temporal and spatial differences in sampling as well as different view directions, frequency of observations, and calibration differences between radar systems. In this paper, we describe the various techniques and algorithms to produce a composite product from different radar systems, with an emphasis on real-time implementation to be delivered to end users.

ID: 279, Oral presentation

CONVECTIVE RAINFALL INTENSIFICATION AND CHANGING SPATIAL PATTERNS IN URBAN AREAS

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There is evidence showing that urban areas can alter the intensity and spatial structure of heavy rainfall on small scales (i.e., at sub-hourly and sub-kilometer resolutions). However, we currently lack a clear understanding of the precise pattern of change and the mechanisms that drive these changes. Considering that the hydrological response in urban areas is highly sensitive to these factors and in light of the expected future increase in urbanization, it is important to understand these changes and their implications when it comes to triggering urban floods. We use 7 years of high-resolution C-band weather radar data (5 min and 1 km) to track the evolution of convective rain cells near urban areas using a storm tracking algorithm. We then assess changes in rainfall properties over, upwind, and downwind of each urban area. We focus on eight different cities with diverse characteristics within Europe and the United States. Our results show that heavy rainfall is intensified over or around the cities and that this effect is positively related to city size. We also find that the spatial structure of rainfall is altered, and rainfall usually becomes more heterogeneous. Finally, we demonstrate that there are increased storm initiations over most cities in the late afternoon, and we generally find that there are no changes in the frequency of storm splitting, merging, or terminating. Considering that future urban population is projected to increase, our results indicate further rainfall intensification, leading to an increased future flood risk in growing cities.

ID: 281, Oral presentation

SURFACE QUANTITATIVE PRECIPITATION ESTIMATES (SQUIRE) FROM THE X-BAND PRECIPITATION RADAR DURING THE SURFACE ATMOSPHERE INTEGRATED FIELD LABORATORY (SAIL) EXPERIMENT

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The U.S. Department of Energy Atmospheric Radiation Measurement (ARM) Second Mobile Facility (AMF2) was stationed in Crested Butte, Colorado from September 2021 to June 2023 during the Surface Atmosphere Integrated Field Laboratory (SAIL) experiment. One of SAIL's primary scientific objectives is to characterize the spatial distribution of orographic and convective precipitation processes in the Upper Colorado River Basin (UCRB) on diurnal to seasonal time- scales and how those processes interact with the large-scale circulation. Despite being the most hydrologically significant watershed in North America, observations of snowfall accumulation are lacking in UCRB, hence reliable quantitative precipitation estimates (QPE) is vital for water resource assessment, validation of hydrological modeling, and understanding of precipitation processes in complex terrain.Therefore, to provide precipitation estimates useful for this objective, we have developed the Surface Quantitative Precipitation Estimate (SQUIRE) product from the ARM-supported Colorado State University (CSU) X- band Precipitation Radar deployed during SAIL for winters 2021-2022 and 2022-2023. The CSU X-band radar was co-located with instruments measuring meteorological characteristics and precipitation accumulation at the AMF2 and at a long term measurement site in Gothic, CO.

To create these QPE products, we first applied correction algorithms from the Corrected Moments in Antenna Coordinates (CMAC) package on the CSU X-band radar data to remove clutter, calibrate the radar observations, correct for attenuation of the radar beam, and flag blocked radar beams. We then calculated snowfall rate S from the CSU X-band radar using an ensemble approach by calculating snowfall rate using various empirical relationships between radar reflectivity Z, differential reflectivity ZDR, and specific differential phase KDP and S developed in the literature for two cases with over 60 cm of measured snow accumulation over a 24 hour time period. We compare the radar-estimated daily snow water equivalent (SWE) against daily SWE from both the Pluvio rain gauge and Gothic measurements for each member of the ensemble in order to determine which provides the best estimate of S from the X-band radar data. Preliminary results show the potential importance of downslope flow in generating precipitation on the lee side of the mountains to the north of Crested Butte, CO, independent of the large-scale circulation. These findings show that orographic precipitation observations and process studies need to be considering holistically the impact of terrain on precipitation by looking across the windward, crest, and leeward sides of a mountain system.

ID: 288, Oral presentation

ELECTRICAL ALIGNMENT SIGNATURES OBSERVED IN AN ISOLATED THUNDERSTORM BY MULTI-PARAMETER DUAL-POLARIZED PHASED ARRAY WEATHER RADAR(MP-PAWR)

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The electrical alignment signatures of ice crystals in the upper parts of thunderstorms play an important role in detecting the electrification process of thunderstorms. Numerous studies exhibited the relationship between the alignment signatures with lightning activity in thunderstorms (Hendry and McCormick, 1976; Metcalf, 1995; Caylor and Chandrasekar, 1996; Krehbiel et al., 1996). Using an X-band Multi-Parameter Dual Polarized Phased Array Weather Radar (MP-PAWR), the electrical alignment signatures in negative K_{DP} have been observed in the evolution of an isolated thunderstorm.

By introducing the composite KDP, which is defined as the minimum KDP value in a vertical column of all elevation scans at each horizontal two-dimension grid point, similar to the definition of composite reflectivity (Witt, 1998), the alignment signatures associated with electrically oriented ice particles have been explored. During the early developing stage, approximately 7 minutes before the first intracloud (IC) lightning flash, average composite KDP values in layers at and above the ambient -20 ℃ layer tended to decrease, and the average composite KDP value at the ambient -30 ℃ layer reached a minimum negative value at 30 seconds before the first IC lightning flash. It probably suggested an initial electrification process in the early developing stage of the thunderstorm which indicated that the mean canting angle of ice particles within the upper regions of the cloud changed from a horizontal to a vertical or near vertical alignment by the built-up and accumulated electric field in the storm, with the increasing density of electrically aligned ice particles on the top of the cloud 30 seconds before the first IC lightning flash. Moreover, the electrical alignment signatures weakened with increasing average composite KDP values at and above the ambient -20 ℃ layer following the first IC lightning flash. During the evolution of the thunderstorm from the developing stage to the mature stage, the averaged composite KDP values at and above the -20 ℃ layer decreased with the increasing IC lightning flash rates before the lightning rate reached its peak of about 80 flashes/min, which probably associated with intensified electric field in the thunderstorm. It probably suggested that the average composite KDP could be used to qualitatively estimate variations in the average electric field intensity, thereby serving as an indicator of IC lightning activity potential in the isolated thunderstorm. In this paper, it is also observed that, at the end of the mature stage, the altitude of the regions with the local most negative values of average negative KDP descended, accompanied by increasing cloud-to- ground lightning flash activity.

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ID: 290, Poster presentation

SPATIAL ERROR IN QUANTITATIVE PRECIPITATION ESTIMATION ACCORDING TO RADAR OBSERVATION CHARACTERISTICS

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Quantitative precipitation estimates from radar include errors because precipitation involves horizontal and vertical observation uncertainties. In order to use rainfall radar for flood forecasting, it requires the advantage of detailed spatial and temporal observations as well as high consistency with ground rainfall. Against this background, this study analyzed 22 heavy rain events observed with five S-band dual-polarization radars installed and operated in Korea and derived error generation characteristics according to observation distance and elevation. As a result of the analysis, the distance error was found to be within 10% on average up to an observation distance of 100 km, but exceeded 30% at an observation distance of 150 km. And based on the operational elevation angle, the altitude error was about 10% or less up to the second elevation angle, but exceeded 20% above the third elevation angle.

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OPTIMAL EXPLOITATION OF POLARIMETRY AND OBSERVATION ERROR COVARIANCES FOR PRECIPITATION-INDUCED FLOOD FORECAST (POLARFLOOD)

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The incidence of flash floods triggered by intense precipitation poses a grave threat to life, and it is anticipated to rise further due to the persistent effects of climate change. The most recent extreme rainfall and flood events in the northern Italy have highlighted the inadequacy of Numerical weather Prediction (NWP) model in forecasting the intensity and location of the significant events in the complex terrain region. Within the science-4-services network in weather and climate (IDEA-S4S), the Italian and German partners join forces to address these deficiencies by concentrating on improving the prediction of moderate to extreme rainfall episodes that culminate in consequential flash floods across Northern Italy. By leveraging advanced polarimetric algorithms and techniques in data assimilation, this study aims to significantly enhance flood forecasting capabilities, thereby facilitating more effective disaster preparedness and risk mitigation strategies. Two key approaches are proposed: Firstly, the partners will additionally exploit polarimetric information content in data assimilation, specifically utilizing more accurate microphysical retrievals (liquid and ice water content) alongside reflectivities and radial winds of the Arpae and Arpae Piemonte radars and also include the additional gap filler X-band radar in Turin to improve the monitoring in this complex terrain. Secondly, the implementation of at least vertical, potentially also horizontal, observation error covariances for the radar data is envisioned in data assimilation. The fidelity of the proposed model configuration will be examined through the utilization of simulated data derived from past extreme events, spanning from 2020 to 2023, as well as any subsequent occurrences that may arise during the study's duration. This contribution will present the joint plans and give insights in experiences from recent events.

ID: 303, Oral presentation

ASSESSMENT OF SEVERAL MACHINE LEARNING APPROACHES FOR OPERATIONAL RADAR QPE

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As is well known, weather radar observations are affected by uncertainty, which limits their operational use. Statistical approaches routinely used to estimate the amount of precipitation may be inadequate to represent its phenomenological complexity, mainly because of the considerable spatio-temporal variability of the physical processes governing it, the sensitivity of observations to orographic context and instrumental characteristics, and hardware conditions.

The past two decades have been characterized by an increasing use of Machine Learning (ML) techniques in in any science field, including radar meteorology. First to solve estimation and classification problems, then for nowcasting purposes. Recently, it has been demonstrated how deep learning approaches can even provide superior performance compared to physics-based numerical models for mid-range global weather forecasting.

Taking in to account such continuing evolution, coupled with the availability of open source libraries, as well as the availability of high computing resources, exploring this technological momentum is a must-have opportunity even in operational frameworks.

This work describes the comparison of several ML approaches based either on ensembles of decision-trees or on deep neural networks trained using a dataset composed by about 12 months of C- and X-band polarimetric radar observations from the national weather radar network, by resorting to a supervised approach based on the availability of a dense gauge-network measurements.

The results confirm the potential of such methodologies in a particularly complex context, proving suitable for subsequent operational experimentation.

ID: 308, Oral presentation

ASSESSING THE ADDED VALUE OF HIGH-RESOLUTION X BAND RADAR MEASUREMENTS FOR RAINFALL ESTIMATION IN WESTERN GERMANY.

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High-resolved polarimetric quantitative precipitation estimates (QPE) for the Rhenish area located in Western Germany using a local X-band radar network and the overlapping DWD operational C-band radars are presented. The polarimetric X-band radars in Bonn (BoXPol) and Jülich (JuXPol) cover up to 150 km at different elevation angles, providing surveillance over Bonn, Jülich and surrounding areas with high spatial (~150 m) and temporal (~5 min) resolution. The radars' scanning strategy ranges from 1º (essential for accurate QPE) to 90º, generating polarimetric measurements of reflectivity (ZH), differential reflectivity (ZDR), correlation coefficient (ρHV), differential propagation phase (ΦDP), radial velocity, among others. The C-band radars (Essen, Flechtdorf, Neuheilenbach and Offenthal) provide polarimetric measurements with the so-called precipitation scan, i.e. a terrain-following scan covering up to 150 km with a gate resolution of 250 m every 5 minutes, and also a volume scan ranging from 0.5º to 90º with similar temporal resolution.

State-of-the-art and further extended methodologies to exploit the polarimetric capabilities of the radars for quality control, radar calibration monitoring, rainfall estimation and compositing of rainfall products are presented. For instance, the impact of non-meteorological echoes is mitigated using polarimetric-based approaches; Z_{DR} calibration (offset bias) is monitored using either vertical profiles (VPs) built from scans taken at a 90° elevation angle or quasi-vertical profiles (QVPs) built from high-elevation angle scans (~18°). A melting layer detection algorithm is applied to range- defined QVPs (RD-QVPs) to differentiate between hydrometeors in the solid or liquid phase; measurements of rhoHV are corrected for range-dependent biases, and phase-based variables, i.e. the specific differential phase (K_{DP}), the specific attenuation (A_H) and the differential attenuation (A_{DP}), allow implementing and optimising robust attenuation and partial beam blockage correction schemes. Finally, 2D composites of different hybrid rain rate (R) retrievals are generated with 100 m horizontal and 5 min temporal resolution and then evaluated for operational implementation using a dense network of rain gauges.

We show the results of the QPE evaluation for several case studies (including widespread stratiform events or thunderstorm events) and the critical challenges faced by generating the QPE products. The conclusion of this study is threefold:

1. The analysis revealed particular details regarding the calibration of the X- band radars. For instance, combining clutter echo measurements and attenuation correction results to monitor the calibration of X-band reflectivity allowed its monitoring on a daily basis when using the former and fortnightly using the latter, becoming an adequate strategy for the quality control of the X-band radar data. On the other hand, calibrating Z_{DR} measurements using a QVP-based method instead of the traditional method based on vertical measurements proved effective and sometimes even produced more stable results;
2. Combining local X-band gap-filling radars with operational C-band radars improves

monitoring rainfall events close to the ground. However, in complex terrain or in the presence of significant vertical gradients in the rain rate towards the surface caused by coalescence in warm-rain processes or evaporation, an additional vertical profile of reflectivity (VPR) correction scheme could be necessary. Future work will focus on analysing the frequency of such phenomena and the suitability of implementing the VPR correction scheme in operational usage.

3. There are clear benefits of using the $R(A_H)$ or $R(K_{DP})$ and hybrid $R(Z_H\text{-} A_H)$, $R(Z_H\text{-}K_{DP})$ estimators over traditional $R(Z_H)$ or $R(Z_H\text{-}Z_{DR})$ estimators as the former show a better performance in the presence of heavy rain when compared with rain gauge measurements.

ID: 311, Oral presentation

EXPLORING THE USE OF LIGHTNING CHARACTERISTICS TO IMPROVE THE RADAR-BASED DETECTION OF HAILSTORM SEVERITY

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The hailstorms are one of the most dangerous atmospheric phenomena for people and can cause significant damage to agriculture, infrastructures and cars. Weather radars appear to be invaluable instruments for the detection and the estimation of hail, thanks to their ability to provide key-information to infer the severity of convective clouds. Nowadays, the most-innovative approaches developed to distinguish between raindrops and hailstones take advantage of dual-polarization weather radar features, which allow to detect the hail precipitation through the differential reflectivity and the other polarimetric parameters (e.g. Bechini and Chandrasekar, 2015). Several techniques based on single-polarization systems have been also proposed. Such methods rely on some features in horizontally-polarized reflectivity measurements that can be used as proxies of the physical processes connected to the hail growth. However, the radar-based hail detection can be affected by some common range-dependent and systematic errors that that may locally introduce relevant uncertainties in the estimation of hail risk. For these reasons, several algorithms based on a proper merge between radar data and other meteorological measurements, such as in situ and atmospheric sounding data (e.g. Kunz and Kugel, 2015; Capozzi et al., 2018), have been developed to overcome these limitations.

In this study, we exploit the potentiality in severe hail identification of a combined method that incoporate radar data and several lightning characteristics. Recently, in fact, we have explored the relationship between lightning activity and large hail in the Italian territory obtaining very interesting results. More specifically, we focused on a specific feature of the lightning activity, the so-called "lightning jump" (hereafter, LJ), which can be defined as a sudden increase in the number of total strokes, typically observed in the early stage of thunderstorm activity. For the 75% of the analyzed case studies, we found that LJ signature is able to anticipate the hail risk for many areas by tens of minutes, giving a relevant added value in the monitoring of hail events. In addition, we discovered that an increase of cloud-to-ground (hereafter, CG) strokes above the 15-20% of the total lightning rises the probability of the hail-falling. Such preliminary results encourage to combine single or dual-polarization radars features with lightning variables for improving algorithms currently working in operative mode to identify and track the hailstorms (e.g. Capozzi et al., 2022).

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NOWCASTING OF RAINFALL IN THE TUSCANY TERRITORY

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This study delves into the rainfall nowcasting in the Tuscany region using radar measurements, which holds significant importance in various applications from weather alert activities, airport operations, to outdoor sports events. A procedure for nowcasting precipitation, using radar network of the Italian Civil Protection, designed for implementation on low-performance hardware, was applied for the Tuscany region, on a two-years rainfall dataset. Satisfactory results have been obtained, particularly for events characterized by abundant precipitation. The procedure's robustness was assessed across various area sizes, showcasing consistent prediction quality irrespective of the area size under consideration.

Utilizing Lagrangian methods for predicting precipitation nowcasting, the study specifically targeted a technique (based on rainymotion libraries) capable of forecasting both the movement and rotation of areas experiencing precipitation. This method is acknowledged for its good accuracy, although it requires moderate computational resources. This insight highlights the necessity for dependable methodologies capable of precisely capturing and extrapolating precipitation patterns. Additionally, the research clarified that the accuracy of nowcasting relies on the persistence of precipitation intensity throughout the forecasted time period.

The evaluation of nowcasting accuracy was conducted using Critical Success Score (CSI), Mean Absolute Error (MAE), and Root Mean Square Error (RMSE), providing comprehensive insights into the predictive capabilities of the implemented procedure. The analysis underscored the pivotal role of precipitation intensity and forecast lead-time in determining nowcasting performance, with higher intensities and shorter delays correlating with enhanced accuracy.

Future plans involve operationalizing the procedure for weather alerts managed by the LaMMA Consortium as the operational service of the Tuscany region, and more generally the feasibility to export the procedure in other regions covered by radar systems, including that of the Italian Civil Protection.

In summary, this study presents promising advancements in short-term precipitation nowcasting techniques, highlighting their critical importance in mitigating risks associated with extreme weather events, enhancing territory, and population management across various societal fields.

Keywords: Nowcasting; Radar images; Lagrangian models; Rainfall prediction; Tuscany; Civil Protection radar network.

ID: 316, Oral presentation

IMPROVING THE KNMI QPE PRODUCTS THROUGH THE USE OF SPECIFIC DIFFERENTIAL PHASE

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In the Netherlands we have two C-band weather radars that are operated by the Royal Netherlands Meteorological Institute (KNMI). Until now the operational QPE products rely primarily on the radar reflectivity (Z) and therefore do not fully exploit the potential of the dual-pol radar system.

We set out to explore the added value of using specific differential phase (K_{dp}) in addition to Z in order to improve the accuracy of the radar QPE product before gauge adjustment is applied. To this purpose we performed two studies, both focusing on hourly sums:

(1) a case study with extreme rainfall that led to extreme floods in the Ardennes and Eifel regions in July 2021 and

(2) a statistical analysis of a 12 month data set over the Netherlands covering all seasons (Sept. 2017 - Aug. 2018).

For the radars in Herwijnen (operated by KNMI), Houthalen-Helchteren (operated by Flanders Environment Agency, VMM) and Essen (operated by Deutscher Wetterdienst, DWD) three radar QPE test products were derived, all based solely on the lowest scan elevation: R (rainfall rate) derived from Z, R derived from K_{dp} and a hybrid product based on a combination of these two: $R(Z,K_{dp})$.

By comparing the $R(Z)$ products of each of three radars to rain gauges, we found systematic relative biases with increasing magnitude for the Belgian, German and Dutch radars respectively. The products making use of K_{dp} [$R(K_{dp})$ and $R(Z,K_{dp})$] showed substantially lower biases for all rainfall intensities except light rain. Furthermore we found that the K_{dp}-based products showed almost no systematic bias between the three radars.

In the analysis of the 12-month data set we focused on discrimination of seasonal effects and on emperical optimization of the optimal threshold value (in dBZ) for the hybrid product, i.e. the value above which K_{dp} is used to estimate R. We tested for thresholds ranging from 15 to 30 dBZ.

For low rainfall intensities the precision of $R(K_{dp})$ was found to be very low, leading to noisy images (even for hourly sums). For moderate to high rainfall intensities we found that throughout the year both $R(K_{dp})$ and $R(Z,K_{dp})$ perform systematically better than $R(Z)$ when compared to the rain gauges. This improvement is smallest in winter where the use of K_{dp} is limited because of temperatures below zero. The performance of the hybrid products $R(Z,K_{dp})$ was quite similar for the range of threshold values that was included in the test.

ID: 317, Poster presentation

CATCHING THE FIRST STAGES OF SUPERCELL STORMS OCCURRED IN NORTHERN ITALY ON JULY 2023 WITH RADAR, LIGHTNING AND NWCSAF SATELLITE DATA FOR EARLY WARNING PURPOSES

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During summer, northern Italy is frequently affected by severe thunderstorms, including supercells, which cause a lot of damage due to heavy precipitation, hail and strong winds. For this reason, products that allow them to be predicted and identified at a very early stage of development are very important for monitoring operations.

When regional meteorological centres issue a warning of strong convective phenomena for the following day, the presence of conditions that may favour the development of persistent thunderstorm systems, due to atmospheric instability and synoptic forcings with strong vertical wind shear, is taken into account, so rather wide areas (on the order of magnitude of hundreds of kilometres) are alerted. Therefore, tools that identify initiating convection during the monitoring phase, are mandatory.

While convective cells entering our territory can be identified and tracked with radar data and nowcasting techniques, thunderstorms developing suddenly in vulnerable areas must be identified early by observing the first stage of convection.

In this work we focus on supercells that affected Northern Italy on the 6th, 22nd and 25th of July 2023, causing severe damage by heavy hailstorms and strong winds. Convection products from NWCSAF are used to analyse the early stages of supercells development, using Convective Initiation (CI), and to identify the area and the characteristics of the top of the vertically developing cloud connected to the system, using Rapid Developing Thunderstorm (RDT) product. Then, lightning data from the LAMPINET network, managed by the Italian Air Force, and observations from Piemonte and Emilia-Romagna C-band radar composites and from the Italian radar network managed by the National Civil Protection Department are used to analyse the evolution of supercells.

A multi-sensor analysis is here presented to highlight the opportunities of a combined approach of different data, in particular satellite and radar data, for a more complete description of convective phenomena, particularly in its early stages, which is particularly useful for warning and monitoring activities.

ID: 320, Poster presentation

MERGING C-BAND AND X-BAND RADAR OBSERVATIONS IN THE ALPINE REGION

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The Italian territory is monitored by a network of C-band radars, but recent advancements have seen the installation of cutting-edge X-band dual-polarization systems in the Milano region. These state-of-the-art radars feature large antenna dishes (2.4 m) and solid-state transmitters, offering excellent angular resolution (< 1 deg), high sensitivity (-5 dBZ at 50 km), and an operational range of approximately 100 km, rivaling that of the established C-band systems. The strategic placement of these new radars, whose coverage largely overlaps with the existing C-band network, presents an opportunity for enhanced observations in the lower atmospheric layer. The resulting redundancy can be leveraged to effectively mitigate visibility limitations and path attenuation effects experienced at both C and X band during convective rainfall events. In fact, while dual-polarization facilitates path attenuation correction in rain relying on differential phase measurements, the presence of hail or signal extinction during intense storms can pose challenges for accurate reflectivity retrieval from individual radars.

This study introduces a novel composite product, amalgamating data from dual-polarization radars (two C-band and two X-band systems), with the primary objective of refining convective precipitation nowcasting across the Po Valley. The radar observations in polar geometry undergo correction for path attenuation utilizing information from differential phase data. Subsequently, these corrected observations are temporally aligned (using motion vector estimates) to synchronize with a common reference time, determined as the time of the most recent observations across all radars. Finally, the integrated data is seamlessly transformed into a Cartesian composite map. Notably, the entire mosaicking procedure is executed exclusively from the polar-format observations, circumventing the need for intermediate individual product processing. Consequently, the composite product is available shortly after the conclusion of the last radar scan, offering an up-to-date and accurate depiction of the prevailing weather conditions, ready for ingestion into the nowcasting process. By harnessing the strengths of radars operating at C and X-band, this initiative aims to significantly enhance forecasting accuracy in the Southern Alpine region (14 MM inhabitants live here) and improve response measures in the face of dynamic weather patterns.

ID: 323, Poster presentation

SEAMLESS ENSEMBLE RAINFALL FORECASTS WITH REAL-TIME EXTREMITY ASSESSMENT FOR SMALL CATCHMENTS

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Reliable and accurate short-term rainfall forecasts are crucial for effective weather warnings, particularly during the convective season. At Deutscher Wetterdienst (DWD), rainfall warnings traditionally rely on either nowcasting or numerical weather prediction (NWP). Recent advancements within the SINFONY project (Seamless INtegrated FOrecastiNg sYstem) aim to deliver seamless ensemble forecasts of short-term rainfall. In particular, flood forecasting is an important application and has gained more focus after the extreme event on July 14th, 2021. While hydrological models employed by German flood forecasting institutions perform well for large and medium-sized catchments, predicting floods in small catchments is challenging due to their rapid hydrological response.

This study presents rainfall forecasts utilizing a seamless combination technique that integrates radar nowcasts from DWD's STEPS implementation with NWP forecasts from the new rapid update cycle of the ICON-D2 model. The proposed method, named INTENSE (Integration of NWP Ensembles and Extrapolation), employs a Bayesian approach utilizing an ensemble Kalman filter considering the spread of the NWP ensemble. INTENSE delivers combined forecasts with a maximum lead time of 12 hours at a spatial resolution of 1 km² and a temporal resolution of 5 minutes.

To support flood forecasting, a novel post-processing product named AREA (Areal Rainfall Extremity Assessment) has been developed based on ensemble forecasts derived from INTENSE. AREA provides information on areal rainfall, derived from a 1 km² upscaling of a nationwide catchment delineation using a 50 m² digital elevation model. Areal rainfall is computed for catchments ranging from 10 km² to 500 km² in real-time and linked to corresponding statistical return periods to characterize the extremity of ongoing events. Prior to this, recalculations were performed using 20 years of rain-gauge adjusted radar observations, and individual extreme value distributions were fitted for each catchment.

This contribution offers a concise overview of the seamless INTENSE combination approach and presents verification results demonstrating its advantages over pure NWP and nowcasting approaches. Additionally, we provide a detailed explanation of the AREA method and present an event-based case study illustrating its utility.

ID: 324, Oral presentation

ASSIMILATION OF RADAR DATA IN ICON AT VERY HIGH RESOLUTION - THE GLORI PROJECT

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Numerical weather prediction is an essential tool to produce forecasts for a variety of weather phenomena at different spatial scales. However, the challenges posed by high-impact weather events, often associated with extremes, need to be addressed by pushing the weather forecasting tools beyond their current limits, and by empowering the connection with the end- users of the forecasts.

The GLORI (Global-to-Regional ICON) project was born from the trilateral collaboration between German, Italian and Swiss institutions. The aim of this project is the development of a global to regional digital twin based on the prediction capability of the ICON modeling system, improving, in particular, forecasts at different scales by exploiting the knowledge and capabilities known about high resolution.

In this context, short-range global predictions with ICON drive limited-area high-resolution (~2 km) runs over the Alpine region, with two-way nested domains at 1 km and 500 m. In the 2 km domain, we aim at assimilating data from the Italian, German and Swiss radar networks, for reflectivity volumes as well as radial winds.

The first experiments performed and that will be presented are relative to the flood events in the Emilia-Romagna region in 2023. In particular, results will show the improvement of forecasts initialized with analysis comprising the assimilation of radar data, with respect to the control run in which no radar data is assimilated. The impact of adding data from different networks (German and Italian) will also be assessed.

ID: 325, Poster presentation

USE OF OPERATIONAL WEATHER RADARS IN THE QUALITY ASSESSMENT OF EUMETSAT H SAF PRECIPITATION PRODUCTS

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Within the network of Satellite Application Facilities established by EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites), H SAF is dedicated to operational hydrology (http://h-saf.eumetsat.int). The facility develops and disseminates three categories of products: snow, soil moisture, and precipitation. The H SAF portfolio includes more than 20 operational products in NRT available via Eumetcast and ftp. Specifically, the Precipitation Product Validation Group (PPVG) within the Quality Assessment cluster accurately examines all operational precipitation products (OPP) to ensure quality and assess their performance over time.

The assessment methodology varies based on the type of precipitation, and operational weather radars are mainly used to compare instantaneous precipitation estimates. Long-term comparisons are made using GPM-DPR estimates as reference over the whole MSG full-disk coverage. In addition, case studies analysis is conducted using national radar and rain gauge data as reference, involving the eight European countries belonging to the consortium (Belgium, Bulgaria, Germany, Italy, Hungary, Poland, Slovakia, and Turkey). The consistent methodology for assessing the quality of all OPP is uniformly applied across all countries, using an internally developed high-performance software (Unique Common Code, UCC). At least, the use of radar data from the OPERA network for NRT comparisons over the European area is being evaluated.

The description of the methodology applied and of the results obtained by the comparison techniques will be illustrated, highlighting both strength points and limitations.

ID: 326, Poster presentation

DISTRIBUTING HYDROLOGICAL RADAR DATA PROCESSING THROUGH CLOUD COMPUTING: A CASE STUDY OF THE VEVA PROJECT'S PROCESSING CHAIN.

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Abstract

The VeVa project represents a pioneering endeavor to harness weather radar data for comprehensive hydrological applications across Denmark. Central to this initiative is the development of a processing chain deployed on the Amazon Cloud platform. This paper details the architecture, methodologies, and computational strategies in this processing chain, emphasizing the role of cloud computing in achieving scalability, reliability, and efficiency. Through the lens of the VeVa project, we explore the potential of cloud-based radar data processing in advancing hydrological science and water resource management.

Introduction

Accurate and high-resolution precipitation data is pivotal for effective water resource management, Weather radar technology has emerged as a key tool in capturing spatially and temporally precipitation patterns. However, the processing of radar data to generate actionable insights poses significant computational and methodological challenges. The VeVa project, through its deployment on the Amazon Cloud, addresses these challenges, showcasing a scalable, efficient processing chain for transforming raw radar data into valuable hydrological information.

Architecture of the VeVa Processing Chain on Amazon Cloud

The processing chain for the VeVa project is designed around a series of interconnected services provided by Amazon Web Services (AWS). These services facilitate the ingestion, storage, processing, and dissemination of vast quantities of radar data. Key components include Amazon Simple Storage Service (S3) for data storage, Amazon Elastic Compute Cloud (EC2) for data processing, and Amazon Relational Database Service (RDS) for managing processed data. This cloud-based architecture ensures high availability, fault tolerance, and scalability

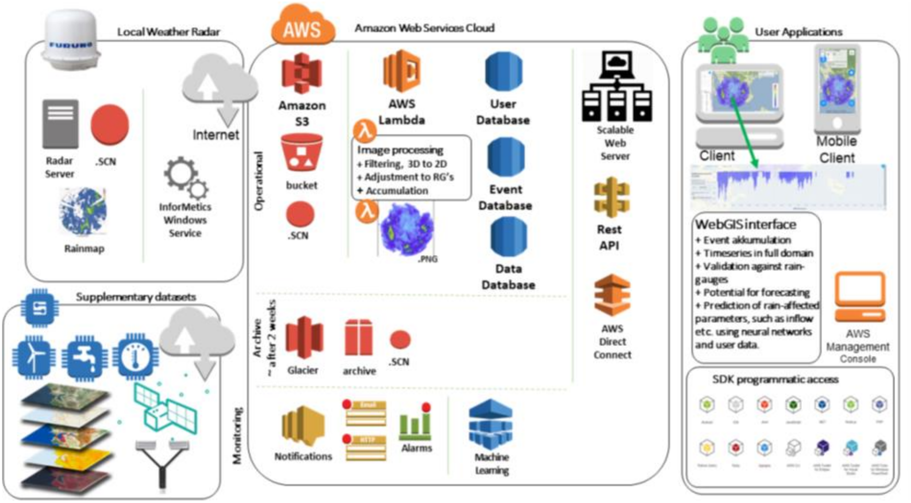

Figure 1 Overall IT infrastructure. Input on the left, the AWS components in the middle, and output on the right.

Data Ingestion and Pre-Processing

Raw radar data, primarily in ODIM_h5 format from both C-band from Danish meteorological Institute (DMI) and X-band radars (Furuno weather radars at Danish and Swedish utility companies), are ingested into the AWS environment.

Advanced Processing Techniques

The core of the processing chain involves algorithms for quality assurance. Advanced spatial interpolation techniques are applied to convert polar measurements into a Cartesian grid, aligned with the Danish Quadratic Network, facilitating uniform spatial distribution across the coverage area.

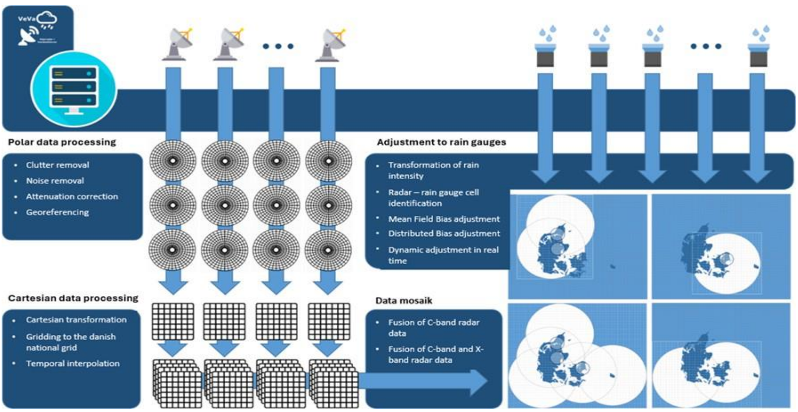

Figure 2 Processing of weather radar data in VeVa – Conceptual overview of the four overall elements

Adjustment and Validation

A critical phase in the processing chain is the adjustment of radar-derived precipitation estimates against ground-based observations from an extensive national network of rain gauges operated by DMI and utility companies. This adjustment is crucial for calibrating radar data to reflect actual precipitation levels, enhancing the accuracy and reliability of the output.

Results

The deployment of the VeVa processing chain on the Amazon Cloud has resulted in the generation of high-quality, gridded precipitation data in the VeVaDaM_h5 format (https://www.veva.dk/vevadam/). This data, characterized by its high spatial and temporal resolution, is instrumental in supporting a wide range of hydrological applications, from flood forecasting to climate adaptation planning. The cloud-based approach has demonstrated significant advantages in terms of processing speed, data accessibility, and the ability to scale resources dynamically in response to demand.

Discussion

The integration of cloud computing in the processing of radar data for hydrological applications marks a significant advancement in the field. The VeVa project's processing chain on the Amazon Cloud exemplifies how cloud services can be used o overcome traditional computational bottlenecks, enabling sophisticated and timely analysis of weather radar data, particularly in the areas of real-time data processing.

Conclusion

The VeVa project's cloud-based radar data processing chain represents a significant leap forward in the utilization of weather radar data for hydrological science and water management. By the power of cloud computing, the project has established a scalable, efficient framework for transforming raw radar observations into actionable hydrological insights.

Acknowledgments

The success of the VeVa project is a testament to the collaborative effort of Danish water utilities, academic institutions, private companies, meteorological agencies, and the support of the Amazon Cloud platform. This initiative exemplifies the synergy between advanced computing technologies and hydrological science, paving the way for future innovations in water resource management.

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IMPACT OF LATENT HEAT NUDGING ON ICON MODEL FORECASTS

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At the HydroMeteorological Service of the Regional Agency for the Environment and Energy of Emilia-Romagna (Italy), the ICON model provides deterministic and probabilistic weather forecasts over Italy at a horizontal resolution of 2.2 km.

In order to obtain the current operational configuration, the two components of the assimilation system were tested: the Local Ensemble Transform Kalman Filter (LETKF) scheme, employed for the assimilation of conventional observations and radar volumes of reflectivity and radial wind, and the Latent Heat Nudging (LHN) scheme, used to assimilate radar-estimated precipitation. Regarding the LHN, an in-depth study was carried out to determine the impact on the forecast of the assimilation of instantaneous precipitation fields, provided by the Civil Protection Department, on the Italian domain.

The verification of the forecasts obtained by applying the LHN over significantly long periods, characterized by different types of phenomena, will then be presented, considering both precipitation and upper-air and near-surface variables. In particular, the impact of taking into account the quality of the assimilated radar data will be shown.

ID: 330, Poster presentation

DEVELOPMENT OF AN OPERATIONAL SYSTEM FOR QUANTITATIVE PRECIPITATION ESTIMATION FROM C-BAND POLARIMETRIC RADARS IN THE FRAMEWORK OF THE PREVENIR PROJECT IN ARGENTINA

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PREVENIR (Forecast and Warning of Flash Flood Events) is a collaborative effort between Japan and Argentina, supported by the Japan International Cooperation Agency and the Japan Science and Technology Agency. The primary objective of this initiative is to develop an impact-based early warning system specifically tailored to urban flooding events. The initiative focuses on two particularly vulnerable urban basins in central Argentina, where C-band Doppler dual polarization ground radars provide surveillance.

This work focuses on estimating and validating precipitation using dual polarization data for a case of extreme precipitation in the province of Cordoba. The recorded rainfall rates exceeded 110 mm/h causing an urban flooding event and affecting one of the most populated cities in Argentina. The purpose of the present paper is to initiate the development of a regionally calibrated radar quantitative precipitation estimation product to support the early warning system.

To achieve this, we propose using the specific differential phase (KDP), a fundamental variable for rainfall estimation due to its robustness to miscalibration, beam blocking, and attenuation in heavy precipitation. This last aspect is characteristic of C-band radars and can significantly affect reflectivity-based estimates, particularly in cases of extreme precipitation. KDP approximation was estimated from the differential propagation phase by fitting it with a monotonically increasing spline function (Kitahara et al., 2023). The relationship between rainfall rate and KDP was determined by analyzing measurements from disdrometers deployed over the radar range. The analysis revealed a relationship that produced improved results over relationships found in the literature from other regions of the world.

Validation was conducted by comparing the estimate with hourly accumulations obtained from 49 stations distributed over a range of up to 150 km from the radar. A strong correlation was found between the estimates and surface observations, with low mean and mean square error. However, errors associated with total beam extinction due to wet radome attenuation were also observed and are difficult to correct for at this stage of development. This product will undergo further evaluation in other convective and stratiform precipitation conditions, as well as in the other regions of interest. This will enhance the accuracy and reliability of precipitation estimation in these critical urban basins.

COMPARISON OF THE DIFFERENT RADAR-RAIN GAUGE ADJUSTED PRODUCTS OF GERMANY

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The National Meteorological Service of Germany (Deutscher Wetterdienst, DWD) operates a radar-based precipitation analysis in real-time combining radar data every five minutes and hourly surface precipitation observations (RADOLAN) for the last 19 years. German flood forecasting centers use these data for real-time hydrological applications, while the weather warning management of DWD derives severe precipitation warnings from the RADOLAN products.

The main gauge-adjusted RADOLAN product (RW) uses the weighted mean of two different adjustment methods: a multiplicative-factor and an additive correction factor. A second product (RL) uses ordinary kriging for the gauges and merges these with the quantitative precipitation estimate of the radar network, while the third product is a combination of all three adjustment types.

These three products and new developments are compared against an independent dataset of daily rain gauges across Germany. The analysis will focus on seasons and different precipitation thresholds.

ID: 344, Oral presentation

USING RADAR PRECIPITATION FOR IMPACT-BASED SITE-SPECIFIC EARLY WARNINGS

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Early Warning Systems (EWS) have become a crucial instrument for Disaster Risk Management. Now promoted by the United Nations (UN) through the "Early Warnings for All initiative", EWS can be especially critical during weather emergencies, specially under the sensitive effects of climate change. However, to be effective, they must be able to trigger the intended actions for damage reduction to be undertaken by authorities, first and second responders and even citizens.

To that end, Impact-based EWS (IEWS) (WMO, 2021), and particularly Multi-Hazard Impact-based EWS (MH-IEWS) for weather emergencies have been promoted by the WMO and the Sendai Framework (Target G) as the next step to translate forecasts into information supporting actionable decisions during emergencies and triggering site-specific actions based on early risk forecasts (Sempere and Berenguer, 2024).

A MH-IEWS system for emergencies induced by heavy precipitation based on the intensive use of NWP and radar-based QPFs has been deployed in Catalunya (Spain) with a particular focus on the city of Terrassa. The system integrates high-resolution local information, from predefined priority or most vulnerable points to convert the radar-based impact-based early warnings into site-specific warnings (SSWs, Melendez-Landaverde, *et al*. 2020; Melendez- Landaverde & Sempere-Torres, 2022, 2024). Thus, the information contained in the warnings is not only translated into the expected impacts on citizens, but can add enriched information beyond text or voice messages, including images simulating the impacts using augmented reality (e.g. how a specific road passing under a railway track will be affected); providing the best way to evacuate the place you are located; or connecting with pre-defined actions of the self-protection plan of a given location, building or community, even if the concerned people are just passing by.

An example of the use of these SSWs in the city of Terrassa is provided.

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ID: 345, Poster presentation

ANALYSIS OF TRAJECTORY AND INTENSITY OF EXTREME RAINFALL IN THE TROPICAL ANDES BY USING AN X-BAND RADAR

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Economic and human losses are related to the occurrence of extreme events. Extreme events such as floods and rainstorms are linked. This is due to the fact that extreme rainfall events are considered to be one of the main triggers of flooding. Hence the importance of knowing about the characteristics of rainstorms, particularly those related to their core. Rainstorms are a challenge to analyze because of the lack of data and their limited space and time resolution. Especially, monitoring and analyzing the storm core is a problem in areas like the tropical Andes, where topography influences the installation and maintenance of automatic weather stations. For this reason, instruments like weather radars allow to record data with a higher temporal and spatial resolution. The aim of this study is to analyze the trajectory of the rainfall core of three extreme events, which are representative of three storm types identified in the Tropical Andes using data from an X-Band radar. The radar is located at 4450 m a.s.l. in the south of Ecuador and provides data with a resolution of 500 m and 5 min. Three extreme rainfall events were identified and selected according to their duration and intensity. Applying the Space-Time cube method, the trajectory of the maximum rainfall values and maximum intensity in each of the events was analyzed. In the first, the core of the event remained within an area of 250 km^2. In 2nd event, the core of the storm remained within an area of 46 km^2.

Furthermore, in 3rd event, the core of the storm moves within an area of 2500 km^2, showing chaotic behavior. The results of the third event suggest the presence of several storm cores in the study area. It seems that the classification in these types of storms has not properly worked. Finally, the method provided a visualization of tracking individual storms by the position of its maximum. These extreme rainfall events have enabled us to better understand the behavior of extreme rainfall and will be helpful for understanding and forecasting flood generation.

ID: 348, Oral presentation

ASSESSING THE ACCURACY OF RADAR RAINFALL AT CATCHMENT SCALE ACROSS GREAT BRITAIN

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Weather radar networks can provide countrywide rainfall measurements with high spatial and temporal resolutions for meteorological and hydrological applications. However, it is well-known that radar rainfall measurements can be affected by several error sources. National meteorological services routinely apply different correction algorithms to the radar data to minimise these errors. There are several studies in the literature assessing the accuracy of radar rainfall for hydrological applications. However, most of these studies focus on a specific region or a small number of catchments and it is difficult to extrapolate the results to other regions/catchments. In this study, we analyse the accuracy of radar rainfall measurements for hundreds of catchments across Great Britain (GB). To achieve this, we produced a continuous radar rainfall product in space and time across GB for the period 2006-2015. This radar rainfall product is then used to calibrate and validate hydrological models for each study catchment. We will show how the accuracy of radar rainfall changes in space and time and how the performance of the hydrological models is related to different catchment attributes (e.g. catchment area, catchment altitude, distance between the catchment and the nearest radar, etc).

ID: 354, Poster presentation

SCALE-DEPENDENT EVALUATION OF DWD'S SEAMLESS SHORT-TERM FORECASTS OF CONVECTIVE PRECIPITATION

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Short-term forecasts up to 12h ahead are essential for precise and consistent warnings that help to increase the lead time for decision makers in emergency services. These warnings are typically based on nowcasting techniques and numerical weather prediction (NWP). In order to condense information from both forecast systems and to provide an improved basis for warnings, an integrated short-term ensemble forecasting system on the convective scale was developed in the ongoing DWD project SINFONY (Seamless INtegrated FOrecastiNg sYstem).

One key component is the seamless combination technique INTENSE (Integration of NWP Ensembles and Extrapolations). It adapts the Bayesian approach according to Nerini et al., 2019 by utilizing the ensemble Kalman filter in a dimension-reduced space. INTENSE seamlessly combines DWD's implementation of STEPS with the new pre-operational rapid update cycle of ICON-D2. It provides precipitation forecasts up to 12h ahead with a spatial and temporal resolution of 5min and 1x1km^2, respectively.

In terms of domain-wide and time-averaged verification metrics, the forecasts generated by INTENSE ideally seamlessly combine nowcasting and NWP. However, the accurate and consistent forecasting of small-scale structures like convective cells is important in meteorological and hydrological warning management. This may be affected by inconsistencies in the transition period from nowcasting to NWP due to spatial mismatches between them. Further, the forecast skill with respect to the typical size of small river catchments may be low for these phenomena.

In this contribution, we will present the results of a scale-dependent evaluation of INTENSE using days with convective situations in summer 2023 to quantify the spatial scale on which it provides useful information. Further, geometric object properties of contiguous precipitation structures are assessed statistically to quantify inconsistencies within the transition period.

ID: 357, Oral presentation

MACHINE LEARNING APPLICATION ON TUSCANY FOR RADAR-BASED QPE

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Although QPE is the most recurrent application of weather radar, it is still essentially an open issue. Several methods for estimating precipitation exist, some of them only using raingauges with spatialization approaches, some others converting weather radar reflectivity data to precipitation by use of relationship calibrated with historical data; the absolute best rainfall estimation results can be obtained with radar data combined with real-time raingauges. However, raingauges measurements are not always available in real time and some problems remain in the extrapolation of measurements to areas where raingauges are few or missing. A number of algorithms that use machine learning techniques are recently expanding the possibilities of radar meteorologists.

Based on this premises, in this study a QPE method is shown using both raingauge data and radar reflectivity observations, over the territory of Tuscany Region, through machine learning technologies. Reflectivity at three different heights (2000 m, 3000 m, 5000 m) as obtained from the Italian national weather radar network, together with the relative geographical position are the set of predictors and the co-located raingauges measurement is the target quantity.

A dataset spanning a three-year period (2020-2022) are used, randomly divided into 70% and 30% for the training and testing phases, respectively. Some supervised learning approaches applied to this dataset are compared, including Linear Regression, Support Vector Machine, Decision Threes and Random Forest. The preliminary results, on significant case studies selected from a dataset of one year (2023), show encouraging prospects in the use of this type of techniques.

At the moment the method is based on a single pixel single time selection, and it is expected to be improved in the near future by including the ability to regress on 2D or 3D data, thus exploiting the ability of weather radar imagery in reconstructing the dynamics of precipitating systems.

There are also prospects for a real-time application and for the operational estimation of precipitation, as the algorithm can be applied to any available set of three CAPPI reflectivity geolocated images.

ID: 358, Poster presentation

RAIN, SNOW OR FREEZING RAIN? – RADAR-BASED SURFACE PRECIPITATION TYPE ANALYSIS AND VERIFICATION AT DWD

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Several years ago, the scope of operational radar-derived precipitation analysis was broadened from precipitation amount by the type of precipitation. Nowadays, areal information on winterly precipitation type and amount are available in near real-time. In addition to providing these data to the general public (e.g. via App), specialized clients like winter road maintenance services benefit from it for optimized operations planning.

The Deutscher Wetterdienst (DWD) utilizes a C-Band weather radar network that provides terrain-following low-elevation scans every five minutes. We apply a common hydrometeor classification scheme using dual-polarimetric radar data and snowline information from NWP. The vertical extrapolation of hydrometeor type from radar beam height to ground level includes the transition from solid to mixed to liquid precipitation phase. These transitions are estimated from empirical thresholds considering wetbulb temperature profiles. In addition to utilizing NWP profiles, station measurements of temperature and humidity are incorporated for optimization within the boundary layer. Recently, we further developed the algorithm to account for supercooling of liquid hydrometeors that reach the ground. The new surface precipitation types "freezing drizzle" and "freezing rain" are operationally used since winter season 2023/2024.

We conduct objective verification of the analyzed precipitation type using measurements of automatic weather stations in Germany. These disdrometer measurements offer continuous data at a high temporal resolution. With approximately 180 stations, the spatial density is adequate to capture the type of stratiform precipitation over flat terrain in many cases. However, in regions with complex topography, the spatial variability in surface precipitation type is not well represented. Additionally, in some cases, technical limitations pose challenges in accurately discriminating between drizzle, light snow and freezing drizzle. In recent years, crowd-soured reports about in situ precipitation type submitted via DWD's WarnWetter-App became increasingly important. Despite user subjectivity, these reports are well-recognized for supporting DWD's warning decision process, particularly during freezing rain events.

This contribution will explain the algorithm using a case study of a complex weather situation in January 2024. Also, recent verification results and challenges in treating various reference data will be discussed.

ID: 359, Poster presentation

FIRST YEAR OF RADAR AND PRECIPITATION OBSERVATIONS AT THE ENEA STATION FOR CLIMATE OBSERVATION OF LAMPEDUSA

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The ENEA Station for Climate Observation of Lampedusa (35.52°N, 12.63°E, 45 m a.s.l) is in the process to become a National Facility of the Aerosol, Clouds and Trace gasses Research Infrastructure taking part in the components of clouds and aerosols remote sensing measurements. As part of the clouds remote sensing activity, between September 2022 and April 2023, a disdrometer (Thies, Clima), a rain gauge (OTT, Pluvio2) and a doppler cloud radar (Metek, Mira 35C) have been installed at the Station of Lampedusa, where many instruments have been in operation since the early 2000s (https://www.lampedusa.enea.it). This work presents and discusses the first year of combined observations of these new instruments focusing on the rain observations from June 2023 to June 2024. Taking into account the small size and reduced orography of the island as well as its distance from the mainland (e.g. about 130 and 210 km from the African and Sicilian coast respectively) the rainfall observations from the Lampedusa station are particularly significant as they are representative of the rainfall in the open Mediterranean Sea. The observations will be analyzed and presented both in terms of monthly variability than in terms of significant episodes.

ID: 364, Poster presentation

WIND FIELD RECONSTRUCTION BY DOPPLER X-BAND RADARS IN MILAN METROPOLITAN AREA.

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The Po Valley is one of the most populated and urbanized areas in Europe, but due to its location between Central Europe and Mediterranean Sea it is also a *hot spot* for severe convective events, such as the Mesoscale Convective Systems, that are often associated with large hail events, destructive wind gusts such as downbursts or tornadoes, and heavy rainfall. In order to improve the nowcasting and the monitoring activity of such extreme events at regional-scale, the regional Agency for Environmental Protection, ARPA Lombardia, set a three X-band dual-polarization radars forming a high resolution regional network. This work presents the preliminary results of the reconstruction of three-dimensional wind fields derived from the Doppler radar data. The severe events occurred in the Milan district at the end of July 2023 and, more recently, during Spring 2024, are considered. Raw Doppler radar data were processed using open-source software, such as the different tools available with LROSE suite. Estimated three-dimensional wind data were compared to the surface wind data from the ARPA network and to the vertical profiles from the Eumetnet network (program E-Profile). Results and issues related to this approach in obtain high-resolution wind fields, suitable for early warnings in activity of civil protection are illustrated and discussed.

ID: 375, Poster presentation

EXAMINING MACHINE LEARNING BASED QUANTITATIVE PRECIPITATION ESTIMATION OVER COMPLEX TERRAIN

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Weather radar has been widely used to study meteorology and hydrology. One of the important applications of weather radar is quantitative precipitation estimation (QPE). The accurate QPE helps prevent and warn of flash floods and droughts. Rain gauges are used as in-situ instruments for measuring precipitation. However, variability in space and time of rain poses a challenge for accurate QPE. To address this challenge, QPE using radar has been widely studied. The conventional radar based QPE has been studied using a nonlinear empirical Z-R relationship. However, the empirical Z-R relationship has struggled with estimating extreme rainfall. In the past years, the machine learning approach has been emerging as another technique for radar based QPE [1]. The rain gauges are used as a ground truth to train the machine learning based QPE. Weather radar typically scans every 5 minutes while the rain gauge measures the precipitation every 1 minute, 15 minutes, or sometimes 1 hour. The temporal resolution of rain gauges varies depending on the rain gauge type and the spatial resolution of rain gauges depends on the gauge network deployed. The variability in space and time of rain gauge measurements is a fundamental problem to train the machine learning model. Furthermore, radar observation in complex terrain contains different environmental characteristics, and most of the QPE for machine learning is trained from well-defined dataset over flat terrain and no clutter etc. This paper examines the challenges encountered in training adequate machine learning models for QPE in complex terrain. This paper examines the performance of machine learning based QPE using KMLB Next Generation Radar (NEXRAD) in the Florida region and radar deployed in the San Francisco Bay area. Florida has dense gauge networks while the San Francisco Bay area is a complex region where the gauge networks are deployed sparsely both in time and space. Due to the complex terrain, the radar observations have blockage, the physics of rainfall within the domain changes due to orographic lifting, among other challenges. The performance of machine learning based QPE in different terrain and gauge network environments is examined and presented.

Reference

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ID: 380, Oral presentation

NOWCASTING EXTREME PRECIPITATION EVENTS: EVALUATING THE EFFECTIVENESS OF GENERATIVE DEEP LEARNING APPROACHES

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Radar-based nowcasting represents a pivotal application of deep learning technologies in meteorological forecasting, especially in predicting extreme precipitation events. These events pose a considerable challenge due to their intricate dynamics and limited data availability. Our work studies the application of generative artificial intelligence methods for radar-based nowcasting, with a specific focus on forecasting severe weather events. We explore three principal generative modeling techniques: Generative Adversarial Networks (DGMR model), Latent Diffusion (LDCast), and our innovative Transformer-based architecture (GPTCast). These models have been trained using an extensive radar precipitation dataset, scaling 1 km and updating every 5 minutes, incorporating data from multiple radars across the US, Germany, the UK, and France. We emphasize the robust assessment of these models through their application to a set of exceptional precipitation events observed in Italy over the past five years, thereby examining their generalization capabilities. Our analysis includes various performance metrics such as Mean Squared Error (MSE), Mean Absolute Error (MAE), Critical Success Index (CSI), Probability of Detection (POD), and False Alarm Rate (FAR), along with ensemble reliability, uncertainty quantification, and advance warning times. Additionally, we discuss the computational demands and potential limitations when considering the operational deployment of these methodologies.

Radar and society

ID: 22, Oral presentation

THE ROLE OF WEATHER RADAR APPLICATIONS IN ENVIRONMENTAL IMPACT ASSESSMENTS

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Weather radars have been long known to register biological targets, especially birds and insects. Polarimetric moments facilitate the recognition of a broad set of targets even in complex atmospheric conditions. In recent years, various algorithms have been developed to extract biological information from measurements of single- or dual-polarisation weather radars. These algorithms expand the range of applications in the realms of biology. One field with a growing need for aerial monitoring in both preoperational and operational stages is the wind energy sector. The planning of wind parks requires environmental impact assessments, which need to evaluate the effect of the turbines on local and migratory fauna, amongst other birds. While onshore sites can often be easily studied by dedicated bird radars and field surveys at small scales, regional to mid-scale dynamics shaped by weather i.e. the big picture of animal movements and offshore sites pose methodological, technical, and logistic challenges.

The Finnish Meteorological Institute has developed a range bin-based Naïve Bayesian classifier which identifies 19 echo classes, including birds and insects. Here we present a case study of the biological services based on the echo classifier and on visual data inspection to help inform impact assessments in need of local to large-scale bird migration monitoring. Analyses can be focused either on the specific wind park development area or on mid- to large-scale bird fluxes both on land and sea. Radar observations are a valuable complement to field observations as they offer a wider detection range compared to the human eye in both vertical and horizontal direction. Furthermore, long series of continuous nocturnal observations are impossible to obtain by means other than radar. Additionally, radar archives enable the analyses of several seasons backwards to level out annual fluctuations and exceptional migratory events resulting from weather factors.

Biological applications derived from weather radars offer a great potential to broaden the use of weather radars to support green transition. As weather radars typically involve major investments in infrastructure, biological services can help leveraging the full portfolio of possible weather radar-based services.

ID: 58, Oral presentation

OBSERVATION AND SIMULATION OF ECHOES FROM FLYING ORGANISMS USING METEOROLOGICAL RADARS

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The nature of radar echoes is well understood for liquid precipitation, which exhibits spherical characteristics and conforms to the Rayleigh regime. The characterization of echoes becomes considerably more intricate when examining solid precipitation. These solid forms can assume complex shapes, leading to depolarization effects and potentially reaching sizes bordering the Mie regime. Nonetheless, this challenge has been thoroughly investigated over the past three decades. Conversely, the understanding of echoes originating from living organisms such as insects and birds remains relatively obscure. These targets are distinguished by even more complex forms than solid precipitation, non-uniform compositions, and electromagnetic responses within the Mie regime. This complexity entails a significant dependence on the inclination, size, and composition of the object concerning the characteristics of the returned signal. Furthermore, given the non-uniform spatial distribution, it becomes imperative to reevaluate the volumetric philosophy inherent in meteorological radar.

Within the SEMAFOR and MIGRATLANE projects, we are developing a real-time observation tool to monitor bird and insect migrations utilizing the French meteorological radar network. This study involves multiple interdependent research topics: radar echoes classification to segregate volumes characterized by living echoes, estimation of the dominant attributes of the scatterers within the isolated radar volumes, and interpolating/extrapolating measured spatial segments to construct a volumetric product across the territory.

In this presentation, our focus will be on modeling the electromagnetic characteristics of individuals and the moments measured by a simulated radar with the objective to provide clues on the variability of radar moments encountered across different groups of individuals, or under differing radar characteristics. Initially, we will compare various methodologies for modeling object echoes within the Mie regime (Tmatrix vs. WIPL) and assess the influence of inclination, size and composition on echo variability. Subsequently, we will apply our radar echo simulation framework to real meteorological radar data, comparing it against ornithological radar data (BirdScan profiler). Following a forward operator approach, we simulate the objects detected by the ornithological radar and evaluate the radar moments to compare them with actual measurements.

ID: 69, Oral presentation

ADVANCES IN PRECIPITATION ESTIMATION USING THE SOPHY WEATHER RADAR

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The SOPHy (Scanning-system for Observation of Peruvian Hydrometeorological) is the first mobile X-band Doppler dual-polarization weather radar built in Peru by the IGP (Geophysical Institute of Peru). Dual polarization radars bring with them a series of advantages such as observables that are less sensitive to radar calibration and attenuation, leading to improved estimates of precipitation. One of the main challenges of SOPHy is to generate an accurate quantitative precipitation estimation (QPE) product that can be used for research, monitoring or disaster prevention. For this reason, a series of pre- and post-processing algorithms are being implemented and applied to volumetric measurements to generate the first SOPHy precipitation radar product.

During February 2024, two major precipitation events occurred in northern Peru, causing great economic losses for the city of Piura and affecting more than 1000 people due to flooding as reported by National Civil Defense Institute of Perú (INDECI). In this work, we will use these events to i) analyze the quality of the pre-processing algorithms, which include clutter elimination and attenuation correction, and ii) determine which parameters of the empirical Z-R relation as well as the relation between the specific attenuation and rainfall rate are best for the observed events. The first results showed correlation values larger than 0.6 between SOPHy and disdrometer measurements of reflectivity. Additionally, rainfall rates estimated by the SOPHy and the meteorological stations were in agreement, finding a correlation larger than 0.6 with an error smaller than 1 mm/h.

ID: 73, Oral presentation

CONVECTION IN THE VICINITY OF THE BLACK FOREST

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At least one thunderstorm can be observed in southern Germany on 50% of days during the summer months. Locally, a maximum of hailstorm days is observed in the upper Neckar valley. The thunderstorms can cause severe damage and forecasting remains challenging. To better understand the formation and development of thunderstorms in southwest Germany, thunderstorms are tracked using TRACE3D based on measurements from 5 radars and lightning data for the summer months of 2017 to 2023. Most of the thunderstorms were triggered in the vicinity of the southern Black Forest and the Swabian Jura around midday, showing a clear relation to orography. An increased density of thunderstorm tracks is detectable in the upper Neckar valley, which aligns with the increased number of hail storms in the region. Based on the tracking dataset, we analyze the severity and possible trigger mechanisms of the thunderstorms using fuzzy logic membership functions of radar parameters and ERA5 reanalysis data.

To gain insight into the evolution of individual thunderstorms, a supercell storm on 23 June 2021 is analyzed using a combination of radar, lightning and wind lidar measurements from the Swabian MOSES campaign (www.swabianmoses.de). We present a 2-step median filter based multi-Doppler algorithm, which utilizes measurements by 6 different radars. Advanced corrected radial velocities from the German Weather Service radar network form a background as they feature a high Nyquist velocity. Based on the background, less reliable measurements (e.g. due to velocity folding and other artifacts) by the other radars are quality controlled. The additional measurements increase data availability, especially at altitudes below 3 km. The multi-Doppler results facilitate detailed insight into storm initiation and dynamics. For example, the cell-relative wind field and convergence are traceable. Results show a strong co-location agreement between convergence and lightning. The outcomes of this study help to better understand the triggering and dynamics of thunderstorms, which is of importance to improve the forecast of severe thunderstorms.

ID: 96, Oral presentation

ENHANCING WILDFIRE HAZARD INTELLIGENCE FOR EMERGENCY MANAGEMENT THROUGH OPERATIONAL AND PORTABLE WEATHER RADAR OBSERVATIONS

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In the past decade, global wildfire activity has reached unprecedented levels, with megafires wreaking havoc on ecosystems and communities worldwide. California, Canada, Australia, and Europe have been particularly affected, suffering devastating losses to populations, wildlife, infrastructure, and economies. The prolonged presence of smoke has also led to widespread health issues in urban areas, compounding the direct impacts of wildfires.

This study highlights recent applications of ground-based remote sensing technologies for the real-time monitoring of wildfire hazards. By leveraging capabilities of operational and portable weather radars, we can track critical physical processes such as wind changes, downbursts and updrafts, plume dynamics, spot fires triggered by airborne embers, and the presence of high smoke concentrations. Drawing from real-case events from Australia, we demonstrate how these insights empower emergency management authorities with vital intelligence.

We also show how operational weather radar data can complement geostationary satellite observations. Together, these technologies enable comprehensive monitoring of fire-induced smoke plumes and clouds, including the most extreme manifestations like pyrocumulonimbus events, enhancing our ability to respond swiftly and effectively to wildfire emergencies.

ID: 108, Oral presentation

MONITORING FLYING INSECTS WITH DOPPLER CLOUD RADAR

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The abundance of flying insects in the air is an important indicator for the biodiversity, but their biomass declined by 76 % from 1989-2016 in case studies in Germany (Hallmann et al., 2017). However, insects are vital to food security and functioning ecosystems, indicating the need for a reliable method for the monitoring of insects. In the atmosphere, flying insects are continuously observed by cloud and weather radars, albeit usually as unwanted clutter. Techniques to filter out insects in radar data can in turn be used to extract the insect signal for further examination. In this study, we investigate data from a 94 GHz FMCW Doppler cloud radar. The supervised machine learning model VOODOO (Schimmel et al., 2022), developed to detect cloud liquid beyond lidar attenuation by its characteristic signatures in the Doppler spectra, is modified and used to detect flying insects based on their characteristic spectral signatures. Afterwards, the insect radar spectra are investigated further with the radar Doppler spectra peak finding algorithm PEAKO (Kalesse et al., 2019) to derive the number concentration of flying insects at each range gate. So far, most studies on insect abundance are performed with insect traps close to the ground. This work will enable new insights into the insect's flight behaviour in different synoptic conditions and during the diurnal cycle, as studies of insect concentration aloft with high temporal (approx. 5 s) and vertical (approx. 30 m) resolution are extremely rare so far.

The main cloud radar data set contains 15 months of continuous observations in Leipzig, Germany (Dec 2020 to Mar 2022). In addition, multiple months of field experiment data from Punta Arenas, Chile (2018), Lindenberg, Germany (2020), and the SAIL campaign in Colorado, USA (2022/23), are available for investigation.

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ID: 211, Poster presentation

WSR-88D OBSERVATION OF BIRDS LEAVING ROOSTS BECAUSE OF EARTHQUAKES

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S-band WSR-88D (KTLX) observed an abrupt increase of non-meteorological returns at lowest three elevation angles after an earthquake occurred near Prague, OK at 05:24 UTC (in the middle of the night CST) on February 3, 2024. The maximum reflectivity reaches about 20 dBZ with low cross-correlation coefficient ρ_{hv}, and highly variable differential reflectivity Z_{DR} and differential phase Φ_{DP}. By checking the location of most non-meteorological returns near ground, it is found that these are associated with woods around Shawnee Reservoir. Rapid increases of non-meteorological returns above the wooded area just after sunrise also confirms the nesting birds roost in that area. At sunrise birds fly out of nests in search of food. Presented is the number of range locations with significant returns at the lowest elevation scans just after the earthquake. The numbers suddenly jump right after the earthquake and gradually decrease to similar values as the ones within the same periods of the days before and after the earthquake. Examined are polarimetric variables from these roosting birds with the aim to separate them from returns of smaller birds. Large birds like waterfowl are hazardous to aviation and hence it is desirable to recognize these in the fields of polarimetric variables. Also analyzed is the aspect dependence of polarimetric variables of large birds by using circularly symmetric signatures caused by birds leaving the roost. Few cases of similar analysis will be presented.

OUR STATIC, THEIR SIGNAL: CHALLENGES USING THE EUROPEAN RADAR NETWORK FOR AEROECOLOGY

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Birds, bats, insects and plants use the atmosphere to move around, presenting both great opportunities for ecologists and challenges for meteorologists. Biological scatterers are often removed in radar data processing pipelines to improve the quality of meteorological products. However, weather radar data are increasingly important to study the aerial movements of animals. Besides purely ecological uses, these data are, e.g. used for bird strike prevention in aviation, and spatial planning and curtailment of wind farms during bird migration.

We illustrate how biological information is extracted from European weather radars using a standardized process converting radar measurements to vertical profiles of flying birds. In collaboration with OPERA and BALTRAD, these profiles are continuously generated and stored in a public data archive (Aloft). This process is highly dependent on the availability of Doppler-filtered reflectivity and radial velocity moments that are not cleaned using dual-polarization or other quality control algorithms, as these tend to remove biological signals. In addition, the use of spatially-explicit radar analyses (e.g. through PPIs) has increased, requiring polarimetric moments for fine-scale classification of biology.

We show how extracting biological products from the OPERA data pipeline depends on the availability of uncleaned polar volume data. Using standard cleaning procedures for meteorological outputs, estimated biological activity extracted from this data can be reduced by an order of magnitude or more, rendering them near-useless for biological purposes. However, acquiring uncleaned polar volume data from individual meteorological institutes is impractical given the continental scale of animal movements. In addition, this hampers our ability to use data assimilation techniques incorporating recent movements in operational monitoring and forecasting systems.

We address how recent changes in data sharing practices for biologically meaningful data both enable novel avenues of weather radar uses as well as threaten ongoing and operational work on conservation and mitigation of human-wildlife conflicts. Furthermore, central availability of all uncleaned polarimetric radar variables would enable making more homogeneous high- quality continental-scale precipitation products. Therefore, we advocate for broader access to these uncleaned weather radar moments both for better biological information and better meteorological products.

ID: 216, Oral presentation

YOUR NOISE, OUR DATA: CURRENT AND FUTURE OPPORTUNITIES OF WEATHER RADAR FOR AEROECOLOGY

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In a time of unprecedented global change, major changes to life are happening in terrestrial, aquatic and aerial environments. Aeroecology aims to study biological processes in the lower troposphere, encompassing the aerial movements of birds, bats and insects. With their unprecedented ability for continuous monitoring of vast stretches of airspace, radars are an important tool to study these processes.

Here, we present the current state-of-the-art and future uses of aeroecological research using weather radars. Continent-scale networks of weather radars have helped quantify the migratory movements of birds in Europe and North America as well as identify drastic declines of migratory populations over the past few decades. On national levels, measurements of weather radars enable the development and operationalization of bird migration forecast models to conserve migratory birds through wind energy curtailment and lights-off campaigns to avoid collisions of birds with man-made structures. Forecast models also continue to be used for aviation safety, informing where and when military aircraft can fly safely through the lower atmosphere, avoiding unnecessary and costly collisions with birds.

On a local level, the availability of dual-polarization moments enables improved discrimination of birds from weather, insects and other sources of clutter. Aided by machine learning and computer vision approaches, we can extract and study increasingly fine-scale movements of animals through the airspace. Making the assumption that vertical distributions of birds are homogeneous in space, we can now correct for radar range-bias, creating vertically integrated PPIs and spatially explicit maps of birds aloft. Such maps can be used to inform policy-makers where migratory birds might encounter existing and/or planned wind parks, where risks of poultry contracting avian influenza are elevated due to flight ‘paths’ of waterfowl and what the impacts are of large-scale disturbances such as New Year’s Eve’s fireworks. Finally, contributing to pandemic preparedness, we envision a future in which the weather radar network is an integral part of avian-bourne disease monitoring and operationally used in risk mapping and mitigation efforts across continental and local scales.

ID: 249, Poster presentation

OPPORTUNISTIC BIRD MIGRATION DETECTION USING OPERATIONAL WEATHER RADAR NETWORK

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In times of climate change, the pressure on biodiversity is high, there is a larger variability observed in seasonal biomass behaviour, especially in bird migration. As part of mitigation, better anticipation of migration becomes key to preserving and understanding our ecosystem. At the same time, human activity has increased due to the installation of a larger number of wind farms and higher air traffic (according to [1] 80% of flight incidents were caused by collisions with birds), this makes it an essential component of citizen science to be able to detect, predict and adapt to evolving bird migration paths.

Radars dedicated to bird detection are scarce, few, and limited in resolution volume. It therefore becomes interesting to try and detect bird migration using existing networks of operational weather radars. However, sampling strategy and design are not necessarily well suited for such tasks. There are not enough standardized measures to compare the performance of an existing system.

In the poster, we will present a bird detection algorithm developed for the MeteoFrance NIMES radar where strong bird migration can be observed in the Rhone valley in the south of France and its validation using dedicated bird radars. This bird detection algorithm is based on the work of [2] and relies on a rather classical approach to distinguish meteorological echoes from biomass echoes. The results of this algorithm will be used to label radar PPI images with enough accuracy to build a training database consisting of radar polarization products. The labeled images are used during semi-supervised training of a U-net, the same as [3].

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ID: 264, Oral presentation

RADAR NETWORK DEPLOYMENT IN COMPLEX TERRAIN

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Radar network optimization over a flat region is generally treated as a two-dimensional geometric problem. In this scenario, leaving aside practical considerations on the availability of the installation sites, the only factor to consider is the desired network overlap ratio, with the radar nodes equally distributed along a circumference whose radius represents the range of the network's cell. In complex terrains the optimization challenge inherently expands into three dimensions, introducing additional factors to be addressed. Analysis of individual radar beam blockages for candidate installation sites is the primary step in the study of the network deployment. In complex terrain the problem transforms itself from a physics problem to an economic problem, where it may be cheaper to deploy radars in specific locations, due to infrastructure and blockage considerations.

Visibility maps are indispensable tools for selecting the optimal installation area, tailored to the specific objectives of the network observations. For instance, in rainfall applications, understanding the climatology of the melting layer's height is pivotal in order to avoid sites with low blockage but placed at too high altitudes to helpfully observe through the rain layer. Furthermore, employing visibility simulations is essential for determining crucial technological parameters of the systems, such as operating frequency, transmitter type, and power. This consideration directly influences the sensitivity of individual radars, although the overall network's sensitivity will be the result of the final combination of the radar nodes in the network.

This work elucidates the comprehensive process of deploying a radar network within the intricate local topography of the Bay Area in San Francisco. It encompasses all aspects, from selection of the installation sites to choosing the most suitable radar technology, and demonstrates the practical application of dual-polarization observations for rainfall estimation in complex terrain.

ID: 268, Poster presentation

AN OPERATIONAL X-BAND RADAR FOR QPE AND SUPPORT TO WEATHER MONITORING IN THE COASTAL AREA OF THE STATE OF SAO PAULO

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Operational radar coverage of the coastal zone in the state of Sao Paulo is provided by a long range S-band radar positioned in the highland. Due to the Serra do Mar mountain range which extends along the coastal zone, the lowest atmospheric levels over the land strip adjacent to the coastline are not observed by the S-band. An X-band radar operationalized by IEAMar/Unesp together with IPMet/FC/Unesp was very recently deployed in the Ilhabela island, near the coast line at longitude -45.46° and latitude -23.89°, in an altitude of 32 m amsl. It features a solid-state technology transmitter with 500 W per channel and a 1.3° half-power beamwidth antenna. It is in an operational test phase, collecting data at 12 elevations (from 0.6° to 18.8°) and at a scanning speed of 13.3°/sec up to the 2.4° elevation and 24°/sec above. During the data verification process, several reflectivity patterns were observed, showing apparent compatibility with the orographic rainfall enhancement mechanisms identified in prior studies in the region. Specially for the event of 03/17/2024, indications suggest the actuation of at least a mixed seeder-feeder/triggered convection - like mechanism. Observations from nearby rain-gages are compatible with the corresponding reflectivity product. For this case, a brief comparison with the S-band radar suggests that the X-band fill the gap in the observations from of the lower atmosphere. Works in initial phase include verification of auto consistency of the polarimetric variables, areal integration of KDP, MDZ impacts, ZH and KDP rainfall relationships, and identification of orographic rainfall mechanisms. In particular, results from the project with the XSCW X-band gap filling radar deployed in the region of the San Francisco bay area will be considered. Additionally, the application of CRMN to a reflectivity dataset from the X-band to retrieve a super-resolution image (see abstract by Santos, D.F.S. et al. submitted to ERAD 2024) is planned.

ID: 298, Oral presentation

COMPARING RADAR DATA AND PRECIPITATION GROUND TRUTH: WHERE CAN IOT SENSORS HELP?

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Radar is measuring precipitation aloft, and there are different reasons why the measured values differ from what is reaching the ground at the supposed location directly underneath a radar pixel. These reasons comprise drift, evaporation and rainfall enhancement underneath the radar beam, just to name the most prominent ones.

Low-cost IoT (Internet of Things) sensors are frequently being installed by citizens and by organisations - but can these sensors help to identify ground truth, i.e. the rainfall which reaches the ground?

In the framework of a research project on severe precipitation named heavyRAIN (duration: 2022 - 2025), 50 optical IoT-sensors have been installed within the city of Lübeck. The density is variable and represents partly more than one sensor per radar pixel. Thus, the following items should be investigated:

- variability within a radar pixel
- time and location of rainfall (arrival) indicating fall speed and possible drift effects.

Such a detailed analysis requires

- precise knowledge about the sensor data quality
- knowledge about the radar beam height and associated fall speed / data lapse time
- knowledge about the exact radar data time stamp

The IoT-sensors installed are optical IR-based sensors which record precipitation several times per minute, scaling the values between 0 and 7. The measured values are then transferred through a LoRaWAN network to the SmartCity hub of the city of Lübeck and made available for further use.

The sensor data quality has been investigated

- in laboratory in detail, for different drop sizes and drop impact points
- in the field, comparing to co-located radar data of the DWD Boostedt radar which have been adjusted through the procedure described in Strehz & Einfalt (2021).

The sensor test in the laboratory revealed that the sensor is recording differently for different impact locations of drops on the sensor surface, and therefore has less useable rainfall classes than advertised.

The sensor test in the field provided a good range of values which can be used for further work, sensor information being classified as no rain, little rain and heavy rain.

Further analyses were performed on two rainfall events in 2023, the 24th July convective event causing flooding and the 20th october widespread event causing nearly no flooding from rain, but from Baltic Sea storm surge.

Results show that the available IoT-sensors

- help to identify the rainfall start time at the ground and give hints to drift effects
- are in line with firebrigade interventions for flooding: fire brigades start being notified of damage approximately 15 minutes after storm onset
- need to be used with care because of their non-uniform sensing behaviour

More results will be produced in the summer seasons of the years 2024 and 2025.

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RADAR-NEWS: A RADAR-BASED ALGORITHM ON SUPPORT OF THE NATIONAL EARLY WARNING SYSTEM

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The Mediterranean region is generally considered a climate change hotspot, meaning that it is one of the areas of the globe likely to suffer pronounced climate changes. Recent reports on Italian climatology have shown, on the one hand, an increase in periods of drought and, on the other hand, an increase of the intensity of phenomena during short weather phases characterized by precipitation. Regionally, the northeast is the area of the country with the highest frequency of very intense thunderstorm phenomena accompanied by exceptionally large hail precipitation.

Although numerical weather forecasting models reached very high skills, the forecast of severe weather events spanning from the local to the mesoscale is still very uncertain. The Italian Early Warning System operates in the short-term forecasting range issuing weather warnings to the civil protection system with a lead-time of up to 72 h. The outcomes of the monitoring and nowcasting activities are uniquely addressed to the operational community, whereas the generic public plays the role of a passive recipient of the EWS activity. To cope with the so-called last mile gap, especially in case of rapidly evolving phenomena (few hours), civil protection warnings should reach the broadest possible community as quickly as possible to let the public adopt self-protection measures.

In this perspective, a radar-based algorithm named RADAR-NEWS, which integrates radar, rain gauge and lightning measurements was conceived to identify, rank, track, and nowcast severe precipitation with the scope to operationally broadcast warnings to the population.

This work describes the characteristics of the algorithms and their performance in terms of capability of detection and nowcasting.

ID: 346, Oral presentation

OPEN RADAR SCIENCE

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The last decade has seen an unprecedented growth of the open radar science software stack. In addition to software advances, a number of weather services have made radar data openly available including on cloud infrastructure (ex. United States National Weather Service). In parallel to this growth, two key projects have created some enabling technologies for education and analysis of radar datasets at scale: Project Pythia and Pangeo. Beyond open radar science software and data, a dedicated community of practices around open-source large-scale data analysis has emerged, sparking the development of the open radar community. As the open radar community has grown, its mission has expanded to include radar scientific literacy and open methods through the open radar discourse website (https://openradar.discourse.group/).

In addition to motivating open radar science, this presentation will provide a “state of the open radar stack” and introduce several projects that apply open radar science to develop a data science equipped workforce who will leverage operational and research radars in everything from nowcasting to model improvement. This includes workforce efforts in:

• The Atmospheric Radiation Measurement User Facility

• The Community Research on Climate and Urban Science project

•A free, asynchronous, college-level radar meteorology course through COMET

• The LROSE Science Gateway

• The Radar Cookbook

• Fieldwork data collection and analysis institutes.

The presentation will showcase new technologies and opportunities to engage in open radar science and invite the audience to join this growing and vibrant community.

RADAR PRODUCTS AT THE ESSL TESTBED AND THE TIM FIELD CAMPAIGN

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Since 2012, the European Severe Storms Laboratory has annually carried out a series of "Testbeds" that consisting of several week-long sessions with weather forecasters, researchers and developers, and severe weather experts, during which new products to support forecasting and nowcasting are put to the test. Over the years, a number of radar products, primarily from the German Weather Services (DWD) have subject to testbed evaluations. The development of these products, such as the mesocyclone detection algorithm or cell-based nowcasting systems, has substantially benefitted from the evaluations at the ESSL Testbed. ESSL, an organization whose mission it is to improve the resilience of society against severe storms and their impacts, is planning to intensify its work with radar products in collaboration with its institutional full members, a large number of European weather services. The wider availability of radar volume data, available either as open data or made available within OPERA, is crucial for these activities.

Aside from training activities, ESSL collects severe weather reports with the help of volunteers, which is stores in the European Severe Weather Database (ESWD). This database, which currently contains approximately 400,000 single reports of severe weather at the ground is a frequently used resource for the validation of radar algorithms or derived nowcast products, having been cited in almost 400 peer-reviewed articles. Interestingly, the ESWD shows a strong increase in the number of reports of very large hail, especially during the last 10 years. Although a substantial portion of this increase is caused by intensifying collaborations with voluntary reporters of severe weather, reanalysis-based studies, and several other indications hint that the true occurrence of severe storms is on the rise, especially in regions surrounding the mountain ranges of Central Europe.

This is one of several motivations that has prompted ESSL to initiate an effort to organize a large multi-year field campaign to collect data to increase our understanding of severe convective storms and their relation to mountains, called TIM, which stands for "Thunderstorm Intensification from Mountains to plains". A large number of questions will be addressed, such as how environmental characteristics of storms affect their likelihood of producing severe weather, how the interactions of the tropospheric flow with mountains across a range of scales can lead to storm initiation and invigoration. Furthermore, many questions on the role of storm-internal processes are currently unanswered, such as how the probability of storms producing severe weather depends on storm-internal depending on poorly known quantities, such as the amount of supercooled water within a storm, which idealized studies show to be highly relevant to the production of large hail. Answering questions like these will require both measurements from nearby radars, mobile radars, as well as in-situ measurements to be obtained by novel technologies such as drone-based measurements and sondes that can act as pseudo-Lagrangean drifters.

ID: 386, Poster presentation

CALIBRATING THE AZIMUTH POINTING OF WEATHER RADAR USING GROUND CLUTTER CORRELATION

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Weather radars' antenna pointing parameters are important indicators to measure radar detection accuracy and data quality. Mark Curtis et al.(2021) reported that after a period of use, because of the mechanical wear and other reasons, the angle pointing error of a weather radar between different scans could reach statistical 2o. The aim in this study is to devise an algorithm for pointing position adjustment and azimuth calibration, leveraging optimal ground clutter correlation for weather radars. The statistical properties of ground clutter correlation in relation to the clutter noise ratio are elucidated. This method derives the initial azimuth correction value by optimizing the correlation between ground clutter echoes from two continuous scans. The adaptive selection of clutter range bins in the plan position indicator enhances azimuth calibration accuracy while mitigating computational complexity. Adjustments for certain clutter-free azimuths were refined based on physical constraints. Our proposed azimuth pointing calibration algorithm is benchmarked against both with radar readings and without adjustments, in both precipitation and clear conditions. Statistical analysis of over 4 million radial rays data indicates that our algorithm significantly improves the probability of correlation. This novel method is straightforward to implement and has a wide range of applications, offering a promising approach for achieving more precise azimuth angles in operational weather radar systems.

ID: 387, Poster presentation

CALIBRATION TECHNIQUE FOR POLARIMETRIC PHASED ARRAY WEATHER RADAR BASED ON THE METAL BALL CARRIED BY DOUBLE DRONES

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The X-band Dual-polarization Phased Array Radar (X-DpolPAR) was developed in early 2022. Digital beamforming is exclusively employed in X-DpolPAR elevation angles, offering enhanced spatial and temporal resolution. X-DpolPAR azimuth scanning is accomplished through mechanical rotation. Such operating mode is widely utilized in weather radar systems. To meet the accuracy requirements for precipitation estimation, measurement errors in radar echo intensity must be controlled within 1 dBZ, with differential reflectivity errors kept within

1.2 dB. Yin et al. (2019) proposed a scheme utilizing a single drone equipped with a metal sphere. Through a drone waypoint tracking, radar precision calibration is achieved. Toledo et al. (2020) employed a method involving angular reflection from the top of a slender rod for calibrating weather radars. However, these approaches lack flexibility and are susceptible to interference from ground clutter or drones. This study proposes a novel dual-drones suspension ball calibration method for precise calibration of X-DpolPAR. The two drones and one metal ball are arranged in a "V" shape. Constraining the metal spheres with the dual-unmanned aerial vehicles reduces their susceptibility to wind-induced drifting, thereby mitigating the influence of adverse environmental conditions on calibration. Two drones locate at the first null position on either side of the azimuthal beam, and thin, equal-length cords tether metal sphere to the center of each beam. This approach offers advantages including stable calibration and minimal impact on calibration results from the scattered echo energy of the drone itself. By using this method, X-DpolPAR's reflectivity factors, differential reflectivity, differential phase, and directed patterns can be calibrated.

Space borne clouds and precipitation radar

ID: 2, Oral presentation

CLOUD AND PRECIPITATION MICROPHYSICAL RETRIEVALS FROM THE EARTHCARE CLOUD PROFILING RADAR: THE C-CLD PRODUCT

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This presentation discusses the development of the Cloud and Precipitation Microphysics (C-CLD) algorithm, which leverages data from the EarthCARE 94-GHz Doppler Cloud Profiling Radar (CPR) to retrieve microphysical properties of cloud and precipitation systems. The algorithm employs an optimal estimation approach, combining CPR measurements with prior climatological information on clouds and precipitation.

Focusing on stratiform precipitation, the algorithm retrieves vertical profiles of two moments of the particle size distribution: mass content and mean mass-weighted diameter. To constrain the retrievals and establish robust forward models, a large dataset of surface-based observations is utilized. Additionally, a one-dimensional parameterization is introduced to represent the spectrum of ice particle densities.

Tests with simulated EarthCARE CPR observations across various climate regimes have demonstrated accurate rain parameter estimation, aided by the Doppler capability. However, retrieving ice particle information remains a challenge. The presentation addresses challengase associated with generating reliable a-priori properties for precipitation and mitigating ambiguities in ice scattering signals.

In this talk, we present actual EarthCARE radar measurements, algorithm outputs for real scenes, and an assessment of the unprecedented Doppler capabilities' benefits and limitations. Additionally, future enhancements will be discussed, including incorporating two-dimensional radar data, brightness temperatures, refining a-priori assumptions, and potentially extending to convective precipitation retrievals. The overarching goal is continuously improving retrieval accuracy and broadening the algorithm's applicability across precipitation regimes. These refinements will be facilitated by in-situ cloud and precipitation property measurements collected by the FAAM aircraft laboratory during 10 planned underflights in the commissioning phase. We hope to use this data to remove biases in the C-CLD product.

RAINFALL RATE OBSERVATIONS FROM SPACE BORNE W-BAND RADARS - TECHNIQUES AND CHALLENGES

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The best global estimates of light to moderate rain on a global scale are those available from CloudSat's 94GHz nadir pointing radar and rely on the path integrated attenuation (PIA), which is derived from the observed drop in the ocean surface return. This PIA is assumed to be due to attenuation by rain, ice and the cloud water. The component of the PIA due to rain is derived by making the following assumptions:

a) the rainfall rate is constant with height whereas it might be expected that rain rate generally increases as the rain falls through the cloud down to the ground and

b) the attenuation due cloud water is a simple empirical monotonically increasing function of rainfall rate implying that cloud water content is constant with height.

Based on CloudSat's global observations over the sea, Stephens et al (2012) [https://doi.org/10.1038/ngeo1580] proposed changes in the latent heat term of the Earth's radiation budget of 10-17W m^{-2}. In this paper we examine the validity of the two assumptions a) and b) and suggest alternative approaches for estimating surface rainfall rates with space borne W-band radars. Such approaches could be useful for deriving rain rates from;

1) the nadir pointing 94GHz radar of EarthCARE Earth Explorer 6 mission currently scheduled for launch in May 2024, and

2) the scanning Doppler 94GHz radar proposed for the "WIVERN: Earth Explorer 11 mission, one of two candidate missions for selection in 2025 to be launched in 2031.

ID: 64, Poster presentation

THE STATUS AND TESTING RESULTS OF THE FENGYUN-3G PRECIPITATION MEASUREMENT RADAR IN COMMISSION PHASE

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The FengYun-3G (FY-3G) satellite was launched on 16 April 2023. The nominal orbital altitude of the FY-3G satellite is 407 km, and the nominal orbital inclination is 50°. As the core instrument of the FY-3G satellite, Precipitation Measurement Radar (PMR) can provide the three-dimensional structure of typhoon, rainstorm, snowstorm and other precipitation, and retrieve accurate precipitation intensity, precipitation type and other information. Therefore, it can improve the ability of space-based precipitation measurement, deepen the understanding of storm structure, cloud microphysics and dynamics of mesoscale weather system, and improve the accuracy of precipitation and other weather forecasting. PMR is a dual-frequency phased array radar, which is composed of a Ku-band radar and a Ka-band radar. Compared to the Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) and Global Precipitation Measurement (GPM) mission Dual-frequency Precipitation Radar (DPR), PMR has wider observation swath and lower antenna peak sidelobe level. Another difference is that the two frequency-band radars of the PMR always observe same area synchronously.

Calibration of the PMR in orbit consists of internal and external calibrations. The internal calibration is carried out one time every 15 orbits to monitor the in-orbit status of the PMR. The instrument status is very stable ever since it was powered on. Since the internal calibration can't obtain information of the parameter changes of the whole radar, the external calibration is designed to absolutely calibrate the PMR. Twenty-three external calibration experiments were conducted in 2023. During the commission phase, several technical parameters including central frequency, beam width, beam matching accuracy, minimum detectable rain rate, and radiometric accuracy, were tested to determine the in-orbit status and performance of the PMR. All of the results show that the PMR has been working normally since its entry into orbit.

ID: 65, Poster presentation

A FREQUENCY CORRECTION ALGORITHM FOR SPACEBORNE PRECIPITATION MEASUREMENT RADAR AND GROUND-BASED WEATHER RADAR

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By combining the bright band model used in the Global Precipitation Measurement (GPM) retrieval algorithm and Mie scattering calculation, the look-up tables of scattering functions for three types of precipitation are generated which include solid precipitation, liquid precipitation and mixed phase precipitation; The accuracy of the look-up table is verified by comparing with the measured data of GPM, which shows that the maximum deviation of scattering calculation is less than 0.5dB. Based on the look-up table, the frequency correction from spaceborne Ku band radar to S-band radar is completed. The analysis of the scattering function shows that the frequency correction from Ku band to S band depends on the phase and spectral parameter D_m. Among them, the frequency correction of liquid precipitation is mainly negative, and the maximum is not more than -3dB. The frequency correction of mixed phase precipitation varies significantly with the height of the bright band. The frequency correction of solid precipitation is positive without a bright band. When there is a bright band, it changes significantly with temperature. The method proposed here can be used to realize the frequency correction between satellite and ground radars in different bands, and provide effective support for the matching and comparison of satellite and ground radars.

SEA SURFACE AND SNOWFLAKES AS NATURAL TARGETS CONNECTING FY-3G AND GPM-CO DUAL-FREQUENCY RADARS

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The Precipitation Measurement Radar (PMR) onboard FengYun-3G consists of a Ku-/Ka-band radar, which is characterized by similar configurations with the Dual-frequency Precipitation Radar (DPR) carried by Global Precipitation Measurement mission Core Observatory. However, directly comparing observations from two radars is challenging due to a scarcity of their coincidences. In this study, sea surface echoes in their track intersections were employed to cross-calibrate PMR. Then, we show that the dual-frequency ratio (DFR) in snow stably increases with Ku-band reflectivity in statistics, allowing for an assessment of the consistency between PMR and DPR observations. Surprisingly, our results reveal a significant underestimation of DFR in DPR inner swath, while observations from PMR are in good agreement with those from DPR outer swath. This study demonstrates the novel use of natural targets for spaceborne dual-frequency radar calibration, and presents a unique view into the connection between the two spaceborne precipitation radar missions in operation.

ID: 70, Oral presentation

EVALUATION OF ANGLE BIN DEPENDENCY OF PRECIPITATION PRODUCT OF DUAL FREQUENCY PRECIPITATION RADAR (DPR) ONBOARD GLOBAL PRECIPITATION MEASUREMENT (GPM) CORE OBSERVATORY

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The latest version of the GPM/DPR Level 2 product (V07) is the first major upgrade after the change in the DPR scan pattern in May 2018, and for the first time dual-frequency precipitation retrieval at full swath was performed. One of the evaluations of V07 was the angle bin dependence of DPR surface precipitation rate. In the initial report comparing the DPR surface precipitation rate between the original dual-frequency swath (inner swath) and the extended swath (outer swath) shows that the outer swath estimated lower precipitation than inner swath. In this study, integrated attenuation (PIA) that is used as the boundary condition of the precipitation retrieval is examined for all angle bins. The observed PIA and surface precipitation rate is sorted by the Ku-band PIA estimated by the Hitschfeld-Bordan method. The result shows that clear angle bin dependency is found in the Ka-band data that causes the underestimation of PIA at larger incident angles. The incidence angle dependency was especially significant for the case of large estimated PIA of Ku-band. To investigate the cause of the underestimation of PIA in the Ka band at large incident angles, we examined the characteristics of the surface echoes (profiles) used to calculate PIA, and found that the intensity of the surface echoes was contaminated with precipitation echoes. The surface echo profile should reflect the antenna pattern of radar even under attenuated condition if there is no non-uniform beam filling. The actual surface echo profile shows, however, distorted profile. The surface echo profile is corrected by using the precipitation echo strength just above the surface clutter, and it is found that it reproduced profile becomes to be close to the ideal surface echo profile. However, surface echo profile cannot be corrected by the precipitation echo alone. Other mechanism to degrade the surface echo profile should be considered.

ID: 86, Oral presentation

IMPROVEMENT OF LIQUID PARTICLE SIZE DISTRIBUTION RETRIEVAL FROM DUAL-PRECIPITATION RADAR MEASUREMENT USING A DEEP NEURAL NETWORK

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The Dual-frequency Precipitation Radar (DPR) onboard the Global Precipitation Measurement (GPM) core mission, operating at Ka (35.5 GHz) and Ku (13.5 GHz) -bands, provides the opportunity to estimate cloud and rain microphysics parameters globally, including precipitation amount, intensity, and type. These parameters can be estimated either by directly measuring particle size distributions (PSDs) in-situ or by retrieving the PSD parameters from DPR measurements. Traditionally, PSDs have been characterized using a gamma-shaped size distribution described using the shape (μ), mass-weighted mean diameter (Dm), and normalized intercept (Nw) parameters. An analytical solution for estimating the parameters of the PSDs typically requires at least three pieces of observational information to retrieve an equal number of parameters. However, DPR retrieval provides only two observables, Z and Dual Frequency Ratio (ratio between Ku and Ka-band; DFR). As a result, the shape (μ) parameter has been conventionally fixed at three to solve the precipitation retrieval system of equations. In this study, we investigated whether the limited degrees of freedom in the GPM legacy retrievals contribute significantly to uncertainty when estimating rain and cloud microphysical parameters. To address this hypothesis, we utilized microphysical measurements from NASA's Clouds, Aerosol, and Monsoon Processes Philippines Experiment (CAMP2Ex) field campaign. The CAMP2Ex field campaign conducted 19 research flights near the Philippines using two aircraft platforms, the NASA P-3 and SPEC Learjet aircraft, with remote sensing and in situ microphysical probes to characterize cloud and precipitation properties under varying tropical rainfall conditions.

We used in-situ measurements from the Two-Dimensional Spectrometer (2DS) and the High-Volume Precipitation Spectrometer (HVPS) to compute bulk properties, normalized gamma size distribution (NGSD) parameters, and rainfall rates at 1-Hz resolution. These measurements were then compared with those retrieved using the GPM-baseline precipitation retrievals over tropical cumulus (Cu) and cumulus congestus (Cu-con) clouds. The analysis revealed that the mean absolute error (MAE) and root mean square error (RMSE) for rainfall rate (R) were 5.2 mm/hr and 59.2 mm/hr for the GPM analytical retrieval, and 6.1 mm/hr and 15.1 mm/hr for the GPM operational retrieval, respectively. These findings indicate that GPM-baseline retrievals inadequately represent in-situ rain rates for Cu and Cu-con clouds, leading to significant errors in retrieving cloud and rain microphysical parameters. To enhance NGSD parameter estimation, we developed a novel neural network algorithm to retrieve the three parameters of the PSD and compute rainfall rates. The MAE and RMSE yielded values of 1.9 mm/hr and 5.4 mm/hr, respectively, indicating a significant improvement in rainfall rate retrievals compared to the GPM-baseline methods.

ID: 113, Poster presentation

NON UNIFORM BEAM FILLING CORRECTION FOR SCANNING SPACE-BORNE DOPPLER RADARS

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Existing and planned spaceborne radar missions provide a unique three-dimensional view of cloud, precipitation and convection, thus providing new insight in the Earth's water and energy cycle. Doppler and wide swath capabilities are now being considered as additional features to enhance radar capabilities. One of such systems is the ESA WInd VElocity Radar Nephoscope (WIVERN, Illingworth et al., 2018), now in phase A; its payload consists of one conically scanning Doppler W-band radar in low-Earth orbit. This system could measure the profile of the line-of-sight (LOS) component of the horizontal wind in combination with the vertical structure of hydrometeor content, observations which are critical for improving NWP and for evaluating and validating the representation of cloud and precipitation related processes in the next generation of Earth System Models.

An End-to-end simulator is a paramount instrument for preparatory studies on proposed future missions. One simulator has already been developed for WIVERN (Battaglia et al., 2022). The model simulates the radar observables accounting for the satellite orbit, the radar observation geometry and the radar specifics (e.g. antenna pattern, point target response, noise level) and runs from outputs of global Earth storm resolving models, like the System for Atmospheric Modeling (SAM; Stevens et al. 2019).

An important component in the error budget of spaceborne Doppler radar in LEO is the Non-Uniform Beam Filling (NUBF) error of mean Doppler velocities, i.e. a bias introduced when there are inhomogeneities within the backscattering volume of the reflectivity fields, that has been thoroughly studied for nadir-looking radars like EarthCARE (Kollias et al. 2014). The aim of this work is to extend the correction methodology for NUBF to a conically scanning radar, specifically WIVERN, by developing the technique and testing its performance. In order to correct the Doppler velocities for the NUBF errors in conically scanning geometry, reflectivity gradients (along the direction orthogonal to the boresight and lying in the plane generated by the satellite velocity and by the antenna boresight) are needed. But such gradients are not provided by the radar measurements in the actual desired direction and they must be estimated. Results based on a gamut of simulations across different storms will be discussed as a function of the antenna scanning angle.

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ID: 116, Poster presentation

CHARACTERIZATION OF SURFACE CLUTTER SIGNAL FOR A SPACEBORNE CONICALLY SCANNING W-BAND DOPPLER RADAR

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The present work aims at characterizing the ground clutter expected for a conically scanning W-band Doppler radar instrument in Low Earth Orbit, using high resolution digitized elevation and land-cover maps. This study is carried out in the context of the WIVERN mission, one of the remaining two candidates to be the ESA's Earth Explorer 11 mission, which aims at filling some of the observational gaps in the measurements of global horizontal in-cloud winds and of cloud and precipitation micro- and macro-physical quantities.

Surface clutter reflectivity and Doppler profiles for scenarios relevant to the WIVERN mission have already been simulated for homogeneous flat surfaces. The presence of surface orography and of inhomogeneity of the backscattering cross sections within the radar footprint are expected to induce significant deviations. Whilst this has been simulated in the past in the case of ground-based instruments, the aim of this study is to quantify such effects for a conically scanning space-borne radar with Doppler capabilities.

Using a discretized formulation, a surface clutter computation code has been developed, in combination with an orbital simulator. The spacecraft sun-synchronous polar orbit and antenna rotation are propagated, providing a position and line-of-sight axis in 3D space at each instant pulses are sent from the radar instrument. Orographic information is derived from a high-resolution raster Digital Elevation Model (NASA's ASTER GDEM Version 3), which is used to compute most quantities necessary for calculation of the radar profiles in the desired region, such as range, surface slope, incidence angle and visibility of each elementary surface. The backscattering cross sections are derived using a raster land surface classification map combined with look-up tables from literature, which allow for calculation of normalized radar cross sections (NRCS) based on the incidence angle and pixel classification.

A case study for the WIVERN mission is presented, using maps defined over the Piedmont region in northwest Italy. Various scans are simulated across the region, and a statistical analysis over many samples is presented by clustering reflectivity and Doppler profiles according to the standard deviation of the elevation and of the NRCS. Results for flat homogeneous terrain and obtained for a nadir-pointing radar are used as touchstone.

ID: 118, Poster presentation

I AND Q SIMULATIONS FOR A POLARIZATION DIVERSITY PULSE PAIR SPACEBORNE DOPPLER RADAR

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The WIVERN (WInd VElocity Radar Nephoscope) mission, proposed as part of the ESA Earth Explorer 11 missions, aims to achieve global observations, representing a significant advancement by simultaneously acquiring vertical profiles of reflectivity and line-of-sight winds within cloudy and precipitating regions. To overcome the challenge posed by the limited coherence duration between successive radar pulses emitted from low Earth-orbiting satellites equipped with antennas of finite beamwidth, WIVERN utilizes a dual-polarization Doppler radar operating at 94 GHz with conical scanning capabilities. This radar system transmits a single polarization state (either Horizontal or Vertical) while receiving signals in both polarization states. The Polarization Diversity Pulse Pair (PDPP) technique is then employed to derive Doppler velocity measurements. Consequently, at the receiver end, a weak cross-polar signal (ghost signal) is anticipated to interfere with the primary co-polar signal. Thus, simulating I and Q time series signals for a space-borne dual-polarization Doppler radar utilizing the polarization diversity technique is deemed highly valuable for testing the efficacy of the PDPP estimator and analyzing the impacts of various error sources on its performance, chiefly the signal-to-noise ratio and signal-to-ghost ratio.

To this end, two distinct methods for simulating I and Q time series of WIVERN's Doppler spectra in the Horizontal (H) and Vertical (V) channels are proposed. The first “classical” method involves initiating I and Q simulation based on known Doppler spectrum information and employing an inverse discrete Fourier transform technique to generate both correlated (co-polar) and uncorrelated (cross-polar) I and Q sequences. In contrast, the second method generates H- and V- I and Q time series directly from the covariance matrix of the auto-correlation function. While the first method assumes some stationarity of the spectrum over a given number of pulses, the second method considers the generated signal as a realization of a non-stationary stochastic process, thus being more tailored to the PDPP pulse sequence transmitted by a fast-rotating antenna, and is much more computationally efficient.

Furthermore, polarimetric variables such as differential power (Z_{DR}), differential phase (Φ_{DP}), and cross-correlation (ρ_{HV}) have been incorporated into the I and Q simulations. This is particularly useful for assessing the PDPP estimator's performance of these variables in terms of bias and standard deviation. Example of simulations from realistic scenes corresponding to different weather systems will be shown and discussed.

ID: 144, Oral presentation

ASSIMILATION OF DOPPLER FROM SPACE IN WRF MODEL: APPLICATION TO WIVERN RADAR FOR THE MEDICANE IANOS CASE STUDY

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Accurate weather forecasts are important to our daily lives. Wind, cloud and precipitation belong to the fundamental variables in NWP models. The WIVERN (Wind Velocity Radar Nephoscope) mission (Illingworth et al., 2018), for observing global winds, clouds and precipitation, has the opportunity to be the first space-based mission to provide in-cloud winds. It is currently in the phase A of the European Space Agency (ESA) Earth explorer 11 program and, If demonstrated successful, WIVERN data could be beneficial to enhance NWP performance, as long as validate climate statistics. In this work, we present an assimilation experiment of the WIVERN Doppler (HLoS; Horizontal winds along the Line of Sight) data for the outstanding case of the Medicane Ianos, occurred in mid September 2020.

To this end, we use the following approach: we run the Medicane Ianos with WRF at 4km horizontal resolution using the ECMWF-EPS (European Centre for Medium range Weather Forecast – Ensemble Prediction System) analysis/forecast cycle issued at 12 UTC on 16 September 2020 as initial and boundary conditions. Fifty-one occurrences of the Medicane Ianos (members) are forecast, taking into account for the atmospheric predictability of that day. For all members the trajectory of the Medicane is determined by the minimum surface pressure. The trajectories are then compared with the reference trajectory determined by the method of Flaounas et al. (2023) and the best member (i.e., the one whose trajectory has the minimum spatial error compared to the reference trajectory) among the 51 WRF simulations, is determined. The Wivern pseudo-observations are then generated for the best member using the Wivern simulator (Battaglia et al., 2022).

Assimilation of HLoS is performed by WRFDA using 3DVar (Federico 2013). The HLoS is assimilated in WRF. Assimilation is performed with a variable repetition cycle to test different degrees of Wivern overpass frequency. Results show a positive impact of the data assimilation on the simulation of the Ianos trajectory. The distance between the simulations assimilating HLoS and the best trajectory are more than halved compared to the control forecasts. Two sensitivity tests aiming at assessing the impact of the observation error and of the observation revisiting time on the forecast of the Ianos trajectory will be also presented.

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ID: 164, Poster presentation

FY-3G/PMR ON-ORBIT CALIBRATION DESIGN AND CALIBRATION TEST

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As FY-3G/PMR(Precipitation Measurement Radar) is a space-based high-precision atmospheric quantitative remote sensing instrument, the radar needs to be calibrated with high precision. A combined method is adopted for PMR on-orbit calibration: internal calibration and external calibration:

The internal calibration is conducted with a calibration loop, which is configured by a coupler and a calibration network at the load end of the phased array antenna unit, with the radar uplink and downlink. The amplitude/phase of the phased array radar transceiver and receiver link and TR channel branches are monitored with the time-sharing acquisition and processing of coherent signals. The internal calibration is carried out once a day when the radar is in orbit.

With the ground active radar scaler (ARC), the external calibration is used to check and calibrate the transmitting/receiving/transmitting, the antenna pattern, and the matching of the Ka/Ku dual-frequency radar beam of the spaceborne radar. The radar completed the on-orbit active external calibration test in August ~ September 2023.

One year of on-orbit testing and application witnesses that indicators of the radar system can meet the design requirements and the PMR can run stably in orbit, which prove its good application.

This paper will introduce PMR’s on-orbit calibration design and the test results.

ENHANCING SPACE BORNE SNOWFALL ESTIMATES BY COMBINING ACTIVE AND PASSIVE MICROWAVE WIVERN OBSERVATIONS

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At high-latitudes, most precipitation stems from ice containing clouds, which are a crucial component of the Earth's weather and climate systems. Accurate measurements of snowfall are particularly important, because snow provides a vital freshwater source, and impacts glacier mass balances as well as surface albedo. However, ice water content (IWC) in-cloud and snowfall rates (SR) below-cloud are hard to measure due to their high spatial variability and the remoteness of polar regions.

WIVERN (WInd VElocity Radar Nephoscope) is one of the two remaining ESA Earth Explorer 11 candidate missions equipped with a conical scanning 94 GHz radar and a passive 94 GHz radiometer. While the main objective of the mission is to measure global in-cloud winds using the Doppler effect, WIVERN can also quantify IWC and SR. Compared to NASA's CloudSat – which is considered the reference for global snowfall estimates – WIVERN will provide a 70 times better coverage and a significantly reduced radar blind zone near the surface.

This presentation discusses the potential of the WIVERN mission to provide improved estimates of IWC and SR in polar regions. We propose a joint approach to retrieve IWC and SR using WIVERN observations of radar reflectivity as well as brightness temperature over ocean within an Optimal Estimation framework. Including brightness temperatures in the retrieval will result in a better attenuation correction. Furthermore, it allows us to modify the used ice particle mass size relation assuming that the emission of the liquid water layers is related to the presence of riming, which increases ice particle mass.

We demonstrate the potential of this retrieval approach using data based on ground-based in situ SR observations collected in Ny-Ålesund, Svalbard and Hyytiälä, Finland. For IWC, we use airborne in situ measurements collected during multiple campaigns in the Arctic. As forward operators, we use the SWEEP end to end simulator, the Passive and Active Microwave radiative TRAnsfer tool (PAMTRA) and empirical relationships of riming and ice particle properties.

This will highlight the potential of WIVERN to significantly reduce uncertainties of IWC and SR estimations in polar regions, which play key roles in glacier mass-balance, radiative budget, and climate feedbacks.

ID: 184, Oral presentation

AIRCRAFT OBSERVATIONS OF STRATOCUMULUS CLOUDS USING A W-BAND RADAR-RADIOMETER: PRELIMINARY RESULTS FOR THE WIVERN MISSION

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The WInd VElocity Radar Nephoscope (WIVERN) mission is one of the two remaining candidates within the ESA Earth Explorer 11 program. The payload, a conical scanning W-band Doppler radar with polarization diversity, will provide, for the first time globally, measurements of in-cloud winds in addition to cloud and precipitation micro- and macro-physical properties at unprecedented sampling and horizontal resolutions. While the wind observations are expected to significantly improve the accuracy of mid-range weather forecasts, and the latter will shed light on a better understanding of the global cloud and precipitation system and will benefit from the unique capability of the system to measure coincident 94 GHz radar reflectivity slant profiles and brightness temperatures both with ~1km horizontal resolution.

In 2024, the ESA-funded suborbital WIVERNex-CAN project is underway, with the primary objective of enhancing WIVERN cloud and precipitation products, in particular, the in-depth characterization of stratocumulus clouds over water surfaces (lake and ocean). This is achievable through a detailed examination of co-located, coincident radar-radiometer observations at W-band (94.05 GHz). The NRC's W-band airborne radar (NAW) was modified to include a radiometer channel operating in an interleaving mode with the radar, pointing at an incidence angle of 42°, as is envisaged for the WIVERN antenna. The spatial resolution of the measurements is determined by the observational antenna sizes: 30 cm for the radar and 8 cm for the radiometer. The NRC’s Convair-580 research aircraft has the first-ever airborne W- band radar with such capabilities.

This paper presents the preliminary results of the WIVERNex-CAN campaign conducted over Lake Ontario and the Atlantic Ocean at Halifax, NS, Canada, the main foci being:

- Calibrating the radiometer using ground measurements and validating the calibration results using outputs of a Radiative Transfer Model (RTM) and flight data in clear air conditions.
- Retrieving Liquid Water Path (LWP) of non-precipitating stratus/stratocumulus

clouds,from coincident radiometric signals and radar reflectivity. The literature suggests that cloud droplets in such clouds typically have diameters smaller than 50 microns. Consequently, an RTM only accounting for absorption/emission could be sufficient to calculate 94.05 GHz brightness temperature. Nevertheless, the contribution of multiple scattering is assessed by comparing scenarios with and without it. Polarization is incorporated into the RTM to account for the strong contrast between emissivity of the ocean at the different polarization, especially significant at the 42° viewing angle.

ID: 208, Oral presentation

ANALYZE GPM PRECIPITATION DATA WITHOUT GETTING SOAKED - HOW GPM-API HELPS YOU STAY DRY AND WISE

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The Global Precipitation Measurement Mission (GPM) data archive currently includes satellite data records that extend back to 1987.

This extensive archive is the result of contributions from two spaceborne radars and a fleet of 35 passive microwave sensors that form the so-called GPM constellation.

The GPM-API is a Python package designed to drastically increase scientist productivity by simplifying coding tasks associated with the download, reading, manipulation and analysis of the GPM data.

It also aims to serve the scientific community as a platform where collaboratively prototyping and sharing of new retrievals, data processing techniques, features databases and satellite coincidence datasets can take place.

The goal is to foster research reproducibility, accelerate model development and unlock new scientific discoveries.

The presentation will demonstrate GPM-API's capabilities through a visual exploration of the GPM Dual-frequency Precipitation Radar measurements across various processing levels and spatio-temporal scales.

Through this journey, we will showcase various software features including event identification and feature extraction, geographic binning, as well as interactive 2D and 3D radar visualization.

We will also present example applications in the context of ongoing studies aiming to investigate the diversity of storm spatial organization and structure, and create a coincidence dataset between GPM and the new third-generation geostationary VIS/IR imagers to extend the TRMM/VIIRS data records.

In conclusion, the presentation aims to stimulate the attendees' curiosity, who, upon returning to their office and thanks to GPM-API, can start diving into their data or events of interest in a matter of minutes!

The GPM-API software documentation and tutorials are already available at https://gpm-api.readthedocs.io.

ID: 241, Oral presentation

HYDROMETEOR PARTITIONING RATIOS FOR DUAL-FREQUENCY SPACE-BORNE AND POLARIMETRIC GROUND-BASED RADAR OBSERVATIONS

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To date, hydrometeor classification (HMC) algorithms focus primarily on the identification of the dominant hydrometeor class within a resolved radar volume. However, recently methods to also estimate proportions of individual hydrometeor types (hydrometeor partitioning ratios, HPR) within the mixture have been developed. These newer algorithms (HMC-DP) are exploiting dual-polarization (DP) measurements of ground-based weather radars (GR), while similar algorithms for space-borne radar (SR) observations with dual-frequency (DF) capabilities do not exist yet. In general, the evaluation of such algorithms, derived from GR or SR, is challenging. In this study, the combination of DF SR and DP GR is exploited to develop an algorithm for HPR estimation based on satellite DF observations (HMC-DF) by utilizing the DP observation and to evaluate HPR retrievals derived from HMC-DP and HMC-DF. Therefore, measurements of the Dual-frequency Precipitation Radar (DPR) of the Global Precipitation Measurement (GPM) core satellite are matched with the DP observations of NEXRADs WSR-88D GR. Each matched volume, represented by averaged DF or DP measured variables, may contain a few SR but several hundred GR measurement volumes (depending on the distance to the GR). This large difference in observation resolution allows the determination of quasi HPRs per matched volume based on the dominant hydrometeor types classified with GR. Based on the quasi HPRs the matched DF and DP measurements are subdivided into clusters, representing different hydrometeor classes. These serve as the basis for the HMC-DF and HMC-DP algorithms and their HPRs retrievals, which in turn are verified with the quasi HPRs.

Results show a good agreement of the vertical HPR distributions for the different hydrometeors derived with HMC-DF and HMC-DP. HPRs derived with HMC-DP show a higher correlation with the quasi HPRs compared to the HPRs derived with HMC-DF, because DP observations provide additional information e.g. about hydrometeor orientation, shape and their homogeneity in the measurement volume.

However, both HMC-DF and HMC-DP tend to overestimate HPRs of hail and graupel, which often occur with low mixing ratios but have a huge impact on the DF or DP signal. Preliminary analyses show that weighting functions for different hydrometeor classes, depending on their vertical occurrences, can reduce this overestimation for graupel and hail and decrease in general the HPR BIAS of all hydrometeor classes.

ID: 265, Poster presentation

AN EVALUATION OF SATELLITE GPM-DPR PRECIPITATION ESTIMATES WITH GROUND-BASED DISDROMETERS IN A MEDITERRANEAN REGION

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Weather radar spaceborne quantitative precipitation estimates are essential for global measurement of precipitation. This study aims to evaluate the behavior of precipitation intensity, radar reflectivity factor (Z_{Ku} and Z_{Ka}) and Drop Size Distribution (DSD) parameters (weighted mean diameter, D_m; intercept parameter, N_w) of the Dual-frequency Precipitation Radar (DPR) aboard the Core Satellite of the Global Precipitation Measurement (GPM DPR). Observations recorded during 9 years from 7 disdrometers (OTT Parsivels[1,2]) located in different topographic zones with Mediterranean influence are taken as ground reference. In general, the dual-frequency algorithm captures well the variability of the observed DSD at different intensities. However, overestimation of the mean D_m and underestimation of the mean N_w are observed, especially at moderate and high intensities, being much more sensitive to errors in drops larger than 1.5 mm. Different matching techniques between satellite estimates and ground level observations were tested here and best results were found for the so-called optimal comparison approach. Results indicate lowest errors for radar reflectivity factor and D_m, and highest for N_w and precipitation rate. In addition, the GPM DPR provided relatively better estimates for stratiform precipitation compared to convective precipitation.

ID: 282, Oral presentation

THE NASA INCUS MISSION AND OBSERVATIONS OF CONVECTIVE MASS FLUX THROUGH REFLECTIVITY DIFFERENCING

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Observing convective dynamics, especially globally, remains a challenge but one that is important for improving convective-scale models. Several upcoming satellite missions seek to measure vertical velocity with spaceborne radars, including the National Aeronautics and Space Administration (NASA) Investigation of Convective Updrafts (INCUS) mission. INCUS will sample vertical mass transport using the method of time-differencing of reflectivity. Three spacecraft carrying Ka-band radars will fly in a train with a spacing of 30, 90, and 120 s. By viewing the same point on the Earth at such short time intervals, the change in reflectivity can be related to the underlying vertical velocity. INCUS will be the first mission to estimate convective mass flux across the tropics.

This study aims to understand the changes in reflectivity relative to vertical mass transport on short time scales using ground-based radar observations. Reflectivity differences have contributions from the vertical mass flux, microphysical processes, and horizontal and vertical advection. Over short time scales, the effects of advection and microphysical evolution are generally small compared to changes due to the vertical mass flux. Herein, we examine these factors using rapidly scanning polarimetric radar data coupled with high-resolution convective-scale simulations. We calculate each term and compare the relative magnitudes to understand their contributions to observed changes in reflectivity in different convective environments. Additionally, we quantify horizontal advection as a function of temporal scale (30, 90, and 120 s) and spatial resolution (200 m, 1 km, 3 km). We investigate convective evolution using the time-differencing technique from several cases sampled by ground-based C-band radars during the 2022 Department of Energy (DOE) TRACER (Tracking Aerosol Convection Interactions Experiment) and National Science Foundation (NSF) ESCAPE (Experiment of Sea Breeze Convection, Aerosols, Precipitation, and Environment) field campaigns near Houston, TX. These case studies demonstrate the application of the reflectivity time-lapse approach that will be utilized by INCUS for understanding convective evolution and mass flux.

ID: 289, Poster presentation

DEVELOPMENT OF AN ENSEMBLE NOWCASTING SYSTEM BY USING THREE-DIMENSIONAL RADAR ECHO MOTION FIELDS

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In this study, 3-Dimension motion fields are estimated by the entire volume scanned data and applied to MAPLE (McGill Algorithm for Precipitation nowcasting using Lagrangian Extrapolation) nowcasting system. With four different types of weather event, the characteristic of 3D motion fields in space and time are analyzed. Furthermore, based on the analysis of 3D motion field, an ensemble nowcasting scheme was developed by considering the variation of motion field. An evaluation of this ensemble nowcasting method demonstrated its efficacy in accurately predicting precipitation occurrences, with a reliability extending nearly 3 h for four aforementioned weather events. Moreover, The forecast of accumulated rainfall also accurately captures rainfall distribution compared to the observation. Overall, it is feasible to construct the ensemble nowcasting by considering the diversity of motion field from 3D volumn radar data.

ID: 295, Oral presentation

EVALUATION OF THE POTENTIALITIES OF A SYNERGISTIC USE OF SATELLITE RADAR AND RADIOMETER OBSERVATIONS FOR SNOWFALL RETRIEVAL

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Snowfall is a fundamental part of the global hydrological cycle. Both satellite active (AMW) and passive (PMW) satellite microwave observations represent useful tools for snowfall retrieval: satellite radars provide the most accurate space-borne measurements, while radiometers guarantee higher spatial coverage and a lower revisiting time. In recent years, space-borne radar snowfall products have been used as reference truth for the development of PMW snowfall retrieval algorithms. In particular, the CloudSat 94 GHz Cloud Profiling Radar (CPR) snowfall product has proved to be the most accurate spaceborne snowfall product with global coverage. Moreover, the CloudSat brightness temperature (TB) product (2B-TB94), measured by using CPR in passive mode, can be exploited for snowfall retrieval. The upcoming Earth Cloud Aerosol and Radiation Explorer (EarthCARE) mission will be equipped with a 94 GHz CPR that shares many characteristics with that onboard CloudSat.

The presence of supercooled liquid water (SLW) layers represents one important challenge for snowfall retrieval. SLW, being almost always present in snowing clouds at high latitudes, has a strong radiative effect, and plays an important role in the microphysics of snowflake genesis. W-band radar observations are not sensitive to the presence of SLW layers, while combined lidar/radar products allow the SLW detection only close to the cloud top, but fail if the SLW is deeply embedded in the cloud. In this context, the combined use of radar and PMW observations has the potential to fill the observational gap of SLW.

The analysis was carried out using the CloudSat-CPR observational dataset and cloud and precipitation vertical profiles derived from combined CPR/CALIOP observations using the EarthCARE mission CAPTIVATE retrieval algorithm.

First, an extensive comparison between simulated TBs and the 2B-TB94 product has been carried out; then, case studies of snowfall events extracted from the database are analyzed in detail, complemented by coincident PMW observations.

Both analyses show the radar/lidar product limitations in detecting SLW layers and the potentialities of a synergistic use of AMW and PMW observations to detect SLW layers and possibly estimate their mass. In particular, the satellite radar on board the EarthCARE mission and the Arctic Weather Satellite mission, which will carry the Microwave Radiometer - equipped by a unique set of MW high-frequency channels - can be exploited to develop more accurate retrieval of both SLW layers and associated snowfall events.

ID: 312, Oral presentation

CLOUD-PRECIPITATION PARTICLE CATEGORIES OBSERVED FROM SPACE BORNE ACTIVE SENSOR

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Classification of cloud phase, ice cloud particle habits and the treatment of cloud microphysics and radiative properties in numerical simulations, significantly influences the prediction of clouds and radiation fields in future climate. The high-sensitivity 94GHz Cloud Profiling Radar (CPR) with Doppler capability onboard the Earth Cloud, Aerosol and Radiation Explorer (EarthCARE) mission (JAXA-ESA) is expected to be useful for testing hypotheses regarding the formation mechanisms of clouds and precipitation in relation to the differences in the observed environmental conditions. The JAXA EarthCARE L2 algorithms for cloud, precipitation and vertical motion adds several new aspects such as those to further infer the geographical preference of occurrence and seasonal and height-dependent characteristics of different ice-particle habit categories, mixed-phase conditions and the transition of the microphysical properties from cloud to precipitation from CPR and from the synergy with the Atmospheric Lidar (ATLID) and the Multi-Spectral Imager (MSI). Expectations from EarthCARE observations to enhance the understanding of cloud related processes and the linkage to the observed cloud microphysical and radiative properties are discussed with aid of the A-train observations.

ID: 331, Oral presentation

VALIDATION OF EARTHCARE REFLECTIVITY WEIGHTED MEAN DOPPLER VELOCITY IN RAINFALL BY USING DUAL-POLARIZATION WEATHER RADAR OBSERVATIONS

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The ESA / JAXA satellite Cloud, Aerosol and Radiation Explorer (EarthCARE) that is going to be launched in the coming months, May – June 2024, will be the first Doppler cloud radar in space. The Doppler radar observations will allow for better characterization of cloud and precipitation processes, classification of hydrometeor types and investigation of cloud dynamics. The stated sensitivity and Doppler velocity measurement accuracy requirements of the EarthCARE Cloud Profiling RADAR (CPR) are -35 dBZ and 1 m/s respectively. Given that this will be the first observation of Doppler radar velocity from space extensive validation of such observations is needed. Considering that the EarthCARE Cloud Profiling radar 3dB footprint is about 700m, and uncertainties in the satellite orbit (dead band) the direct comparison of CPR and ground-based profiling radar observations will be limited to very few locations, airborne radar observations during dedicated satellite under flights, and mobile radar platforms placed on the EarthCARE ground track.

To extend the available datasets that can be used for validation of EarthCARE observations, we are proposing to use dual-polarization weather radar rainfall measurements. Weather radar scans cover large disk areas centered on radar and with the radius of few hundred kilometers (typically around 250 km in Europe). These observations provide excellent opportunity for direct comparison to CPR measurements. For validation of CPR Doppler velocity observations, however, horizontal observations of dual-polarization radar variables should be converted to W-band reflectivity weighted sedimentation velocities of raindrops. This transformation can be achieved by using dual-polarization radar variables, i.e. Z, Zdr and Kdp that are sensitive to number of raindrops, their sizes and shapes, and relating them to W-band reflectivity weighted sedimentation velocity (V_w). To derive the relations, we have used multi-year disdrometer observations collected in Italy and Finland. The following relations were derived and tested: V_w – Z_{dr}, V_w – Z, V_w- Kdp/Z and V_w-D_0(Z_{dr}). To test the relations, we have used FMI Ikaalinen weather radar and Hyytiälä W-band cloud radar observations collected in July- August 2018 and 2019. Given the wavelength difference between weather radars (typically operating at S, C or X- bands) and CPR there is a significant uncertainty in estimation of V_w from dual-polarization radar variables. However, in the light to moderate rainfall regimes accurate enough estimates of V_w can be achieved for assessment of CPR Doppler measurement quality.

ID: 365, Poster presentation

USING SYNTHETIC CLOUD PROFILING RADAR DATA TO DEVELOP VALIDATION METHODOLOGIES FOR GROUND-BASED CLOUD RADAR SITES

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The value of permanent, multi-sensor surface-based observatories that collect continuous long-term observations for satellite L2 data products has grown significantly the last 10-15 years. Examples of such established surface-based networks include: The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) network, the US Department of Energy Atmospheric Radiation Measurements (ARM) observatories and the recently established 94-GHz Miniature Network for EarthCARE Reference Measurements (FRM4Radar).

Core of the work presented is the application of the developed transformation of suborbital to orbital radar data by orbital-radar.py. This simple L1 transformational operator convert L1 suborbital (surface-based or airborne) measurements to the EarthCARE or CloudSat Cloud Profiling Radar (CPR) L1 observations. The transformational operator ensures that the orbital-suborbital comparison accounting for differences in the sampling geometry, measurement uncertainty, instrument sensitivity and simulates the impact of the surface echo. Furthermore, the operator simulates the characteristic reflectivity and Doppler velocity errors.

Applying such a tool on long-time data sets make it possible to generate the optimal foundation for a statistical analysis of the EarthCARE CPR performance. So, the optimal sampling for CPR and ground base data can be estimated or the CPR detection of clouds and precipitation processes near ground analyzed and evaluated. In addition, it shows how important ground-based networks are, and that they play an important role in the evaluation of satellite measurements and products. Target classification such as ACTRIS cloudnet can also be applied to the synthetical CPR data and increase the possibilities of statistical analysis. Combining all this, tools such as orbital-radar.py and the large amount of suborbital radar data may help to evaluate future CPR satellite missions - expanding the L1 transformational operator to other spaceborne radar systems.

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