Short range weather forecasts in the European Arctic; recent work and experiences with AROME Arctic

Morten Køltzow, Malte Müller, Teresa Valkonen, Yurii Batrak, Eivind Støylen, Jørn Kristiansen
MET Norway

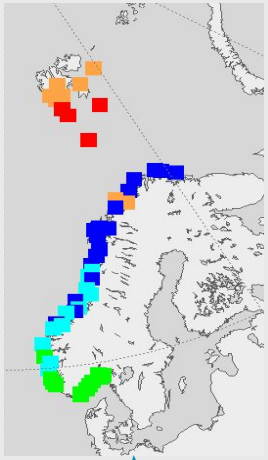
Over the past decades the Arctic warmed more than any other region in the world with profound socio-economic consequences. Thus, our current weather forecasting systems are challenged by increasing interest in accurate forecasting products. There are many challenges for Arctic weather prediction, e.g. the sparse observation network, atmospheric data assimilation, the representation of sea-ice, and the high-latitude representation of many sub-grid scale parameterizations.

The limited area model Arome Arctic, employed in the European Arctic, is a particular MET Norway configuration of the HARMONIE system. Arome Arctic has been in operational use since autumn 2015. It provides four daily forecasts up to +66 hr lead time on a 2,5 km horizontal grid and with 65 vertical levels. The full model output is openly available to the public. It is the source of the forecasts on Yr.no in the European Arctic, and is used actively by the on-duty meteorologists, researchers and downstream users.

The Arctic forecast and research activities at MET Norway focus on use and further development of this particular system. In addition to the core activities at MET Norway, Arome Arctic is a part of a variety of research projects (i.e. APPLICATE, CARRA, Nansen Legacy, NORDNWP PGD)

In this presentation we will give and overview of current developments and recent results of Arome Arctic. Topics we will touch on are: added value of limited area models compared to global coarser resolution models, challenges in Arctic verification with high observational uncertainty, the importance of surface forcings like sea ice description and glacier masks at Svalbard.

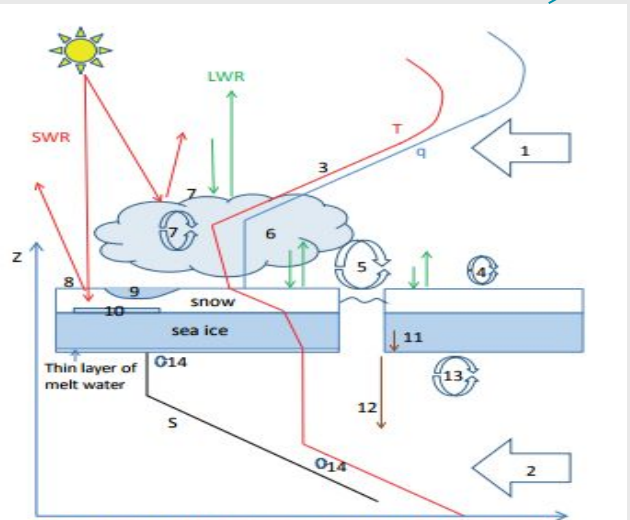
Arctic forecast challenges



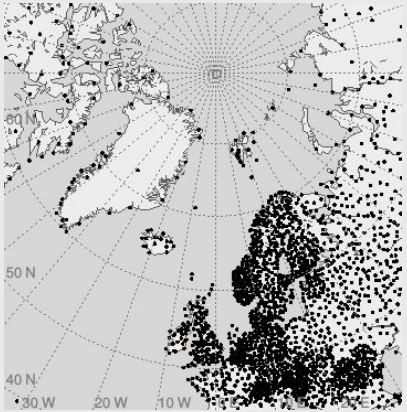
RMSE MSLP DJF 16/17
MET Norway forecasts
vs SYNOP
increases northward

< 1.25
1.25-1.50
1.50-1.75
1.75-2.00
> 2.00

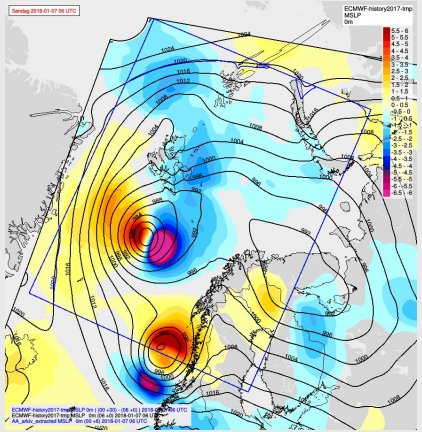
Arctic subgrid-scale processes
Vihma et al. 2014



Less (conventional) observations assimilation techniques



MSLP LBC errors +30hr
(advected from mid-latitudes)



AROME-Arctic

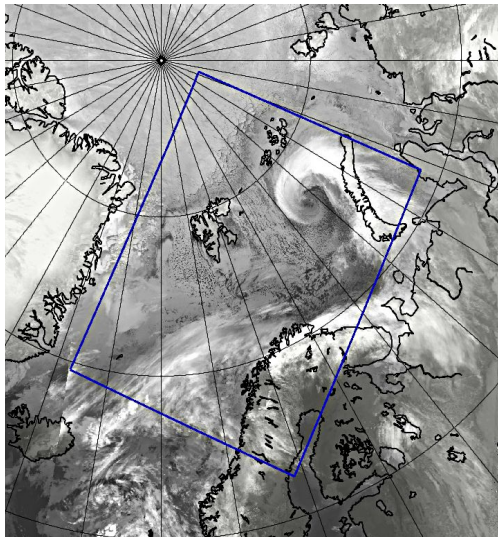
Operational high resolution short range weather forecasts for the European Arctic

- Limited Area Model
- HARMONIE cycle 40h1.1 (European cooperation)
- 4 times daily (00, 06, 12, 18 UTC) +66 hr lead time.
- 2,5 km horizontal res / 65 vertical levels

- Assimilation: 3D-var + surface analysis, 3 hr cycling;
  conventional observations, scatterometer data, satellite radiances

- Lateral and surface boundary conditions; IFS HRES (OSTIA / OSI-SAF).

- Operational since autumn 2015
- Basis for warning considerations
- Model output freely available on thredds.met.no (NetCDF)
- Forecasts published on Yr.no for Svalbard region (post-processed spot data)
- Product generation for Barentswatch https://www.barentswatch.no/en/polar-low/



- Muller et al. (2017): http://journals.ametsoc.org/doi/full/10.1175/MWR-D-17-0194.1
- Home page AROME Arctic: https://www.met.no/en/projects/The-weather-model-AROME-Arctic

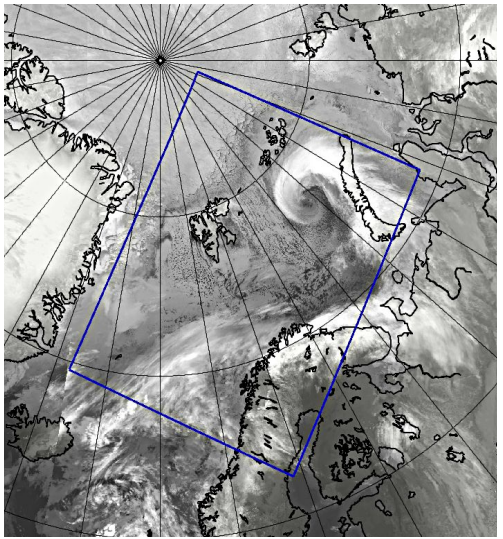
AROME-Arctic

Operational high resolution short range weather forecasts for the European Arctic

- Limited Area Model
- HARMONIE cycle 40h1.1 (European cooperation)
- 4 times daily (00, 06, 12, 18 UTC) +66 hr lead time.
- 2,5 km horizontal res / 65 vertical levels

- Assimilation: 3D-var + surface analysis, 3 hr cycling;
  conventional observations, scatterometer data, satellite radiances

- Lateral and surface boundary conditions; IFS HRES (OSTIA / OSI-SAF).



- Operational since autumn 2015
- Basis for warning considerations
- Model output freely available on thredds.met.no (NetCDF)
- Forecasts published on Yr.no for Svalbard region (post-processed spot data)
- Product generation for Barentswatch https://www.barentswatch.no/en/polar-low/

- Muller et al. (2017): http://journals.ametsoc.org/doi/full/10.1175/MWR-D-17-0194.1
- Home page AROME Arctic: https://www.met.no/en/projects/The-weather-model-AROME-Arctic

AROME-Arctic

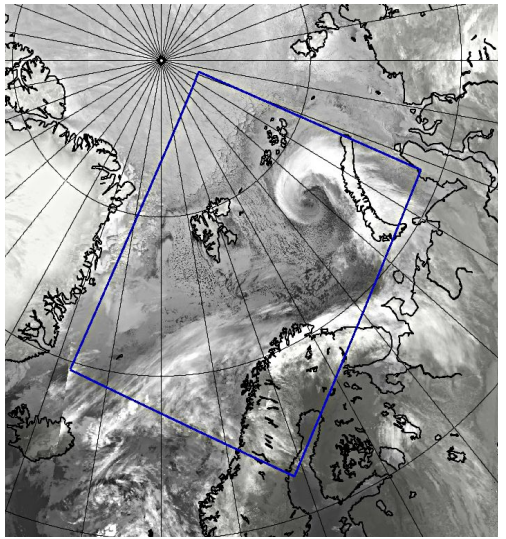
Operational high resolution short range weather forecasts for the European Arctic

- Limited Area Model
- HARMONIE cycle 40h1.1 (European cooperation)
- 4 times daily (00, 06, 12, 18 UTC) +66 hr lead time.
- 2,5 km horizontal res / 65 vertical levels

- Assimilation: 3D-var + surface analysis, 3 hr cycling;
  conventional observations, scatterometer data, satellite radiances

- Lateral and surface boundary conditions; IFS HRES (OSTIA / OSI-SAF).

- Operational since autumn 2015
- Basis for warning considerations
- Model output freely available on thredds.met.no (NetCDF)
- Forecasts published on Yr.no for Svalbard region (post-processed spot data)
- Product generation for Barentswatch https://www.barentswatch.no/en/polar-low/



- Muller et al. (2017): http://journals.ametsoc.org/doi/full/10.1175/MWR-D-17-0194.1
- Home page AROME Arctic: https://www.met.no/en/projects/The-weather-model-AROME-Arctic

AROME-Arctic

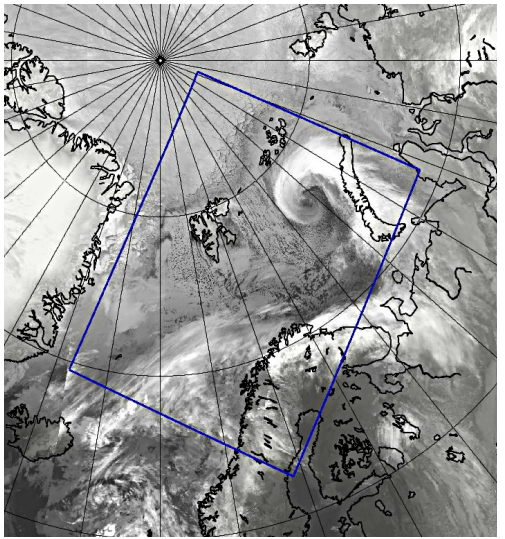
Operational high resolution short range weather forecasts for the European Arctic

- Limited Area Model
- HARMONIE cycle 40h1.1 (European cooperation)
- 4 times daily (00, 06, 12, 18 UTC) +66 hr lead time.
- 2,5 km horizontal res / 65 vertical levels

- Assimilation: 3D-var + surface analysis, 3 hr cycling;
  conventional observations, scatterometer data, satellite radiances

- Lateral and surface boundary conditions; IFS HRES (OSTIA / OSI-SAF).

- Operational since autumn 2015
- Basis for warning considerations
- Model output freely available on thredds.met.no (NetCDF)
- Forecasts published on Yr.no for Svalbard region (post-processed spot data)
- Product generation for Barentswatch https://www.barentswatch.no/en/polar-low/



- Muller et al. (2017): http://journals.ametsoc.org/doi/full/10.1175/MWR-D-17-0194.1
- Home page AROME Arctic: https://www.met.no/en/projects/The-weather-model-AROME-Arctic

AROME-Arctic

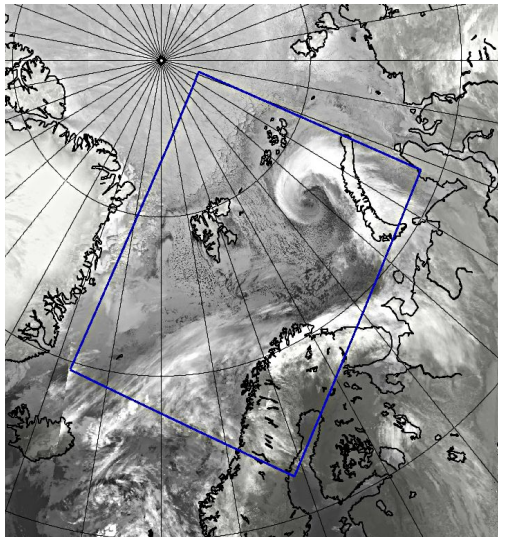
Operational high resolution short range weather forecasts for the European Arctic

- Limited Area Model
- HARMONIE cycle 40h1.1 (European cooperation)
- 4 times daily (00, 06, 12, 18 UTC) +66 hr lead time.
- 2,5 km horizontal res / 65 vertical levels

- Assimilation: 3D-var + surface analysis, 3 hr cycling;
  conventional observations, scatterometer data, satellite radiances

- Lateral and surface boundary conditions; IFS HRES (OSTIA / OSI-SAF).

- Operational since autumn 2015
- Basis for warning considerations
- Model output freely available on thredds.met.no (NetCDF)
- Forecasts published on Yr.no for Svalbard region (post-processed spot data)
- Product generation for Barentswatch https://www.barentswatch.no/en/polar-low/



- Muller et al. (2017): http://journals.ametsoc.org/doi/full/10.1175/MWR-D-17-0194.1
- Home page AROME Arctic: https://www.met.no/en/projects/The-weather-model-AROME-Arctic

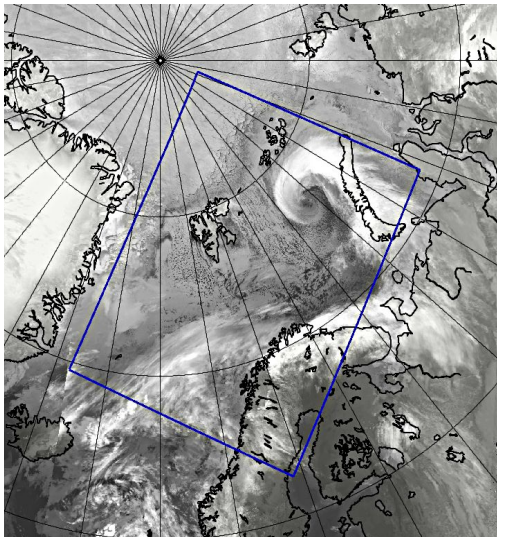
AROME-Arctic

Operational high resolution short range weather forecasts for the European Arctic

- Limited Area Model
- HARMONIE cycle 40h1.1 (European cooperation)
- 4 times daily (00, 06, 12, 18 UTC) +66 hr lead time.
- 2,5 km horizontal res / 65 vertical levels

- Assimilation: 3D-var + surface analysis, 3 hr cycling;
  conventional observations, scatterometer data, satellite radiances

- Lateral and surface boundary conditions; IFS HRES (OSTIA / OSI-SAF).

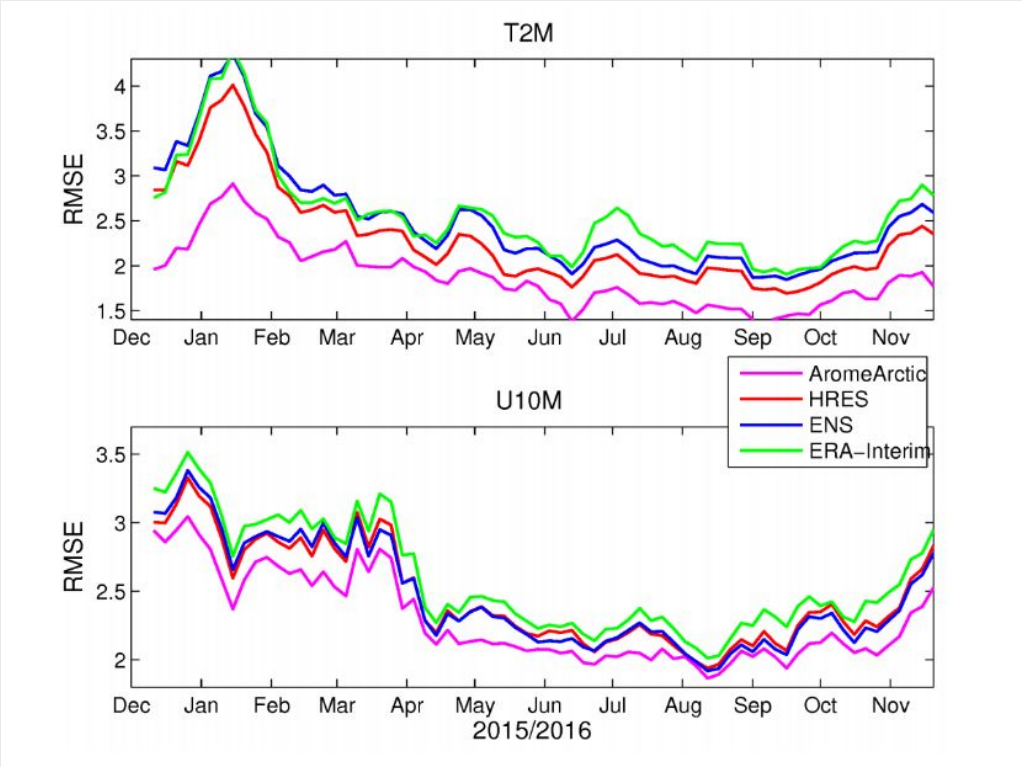


- Operational since autumn 2015
- Basis for warning considerations
- Model output freely available on thredds.met.no (NetCDF)
- Forecasts published on Yr.no for Svalbard region (post-processed spot data)
- Product generation for Barentswatch https://www.barentswatch.no/en/polar-low/

- Muller et al. (2017): http://journals.ametsoc.org/doi/full/10.1175/MWR-D-17-0194.1
- Home page AROME Arctic: https://www.met.no/en/projects/The-weather-model-AROME-Arctic

AROME Arctic performance

Compared against IFS systems (global models)



2m air temperature
(against to SYNOP)

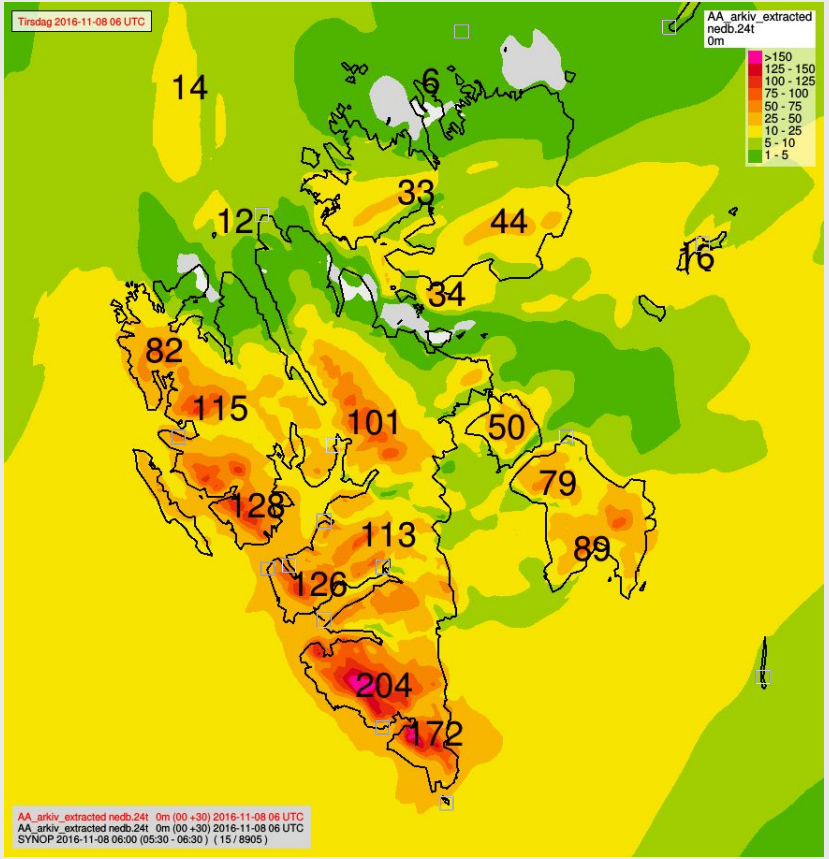
10m wind speed
(against SYNOP)

Müller et al. (2017) Mon Wea Rev.

Norwegian Meteorological Institute

“Atmospheric river” Svalbard Nov. 2016

On 7 and 8 November 2016 a high pressure system over Scandinavia resulted in a long-lasting, strong and mild southwesterly flow towards Svalbard, and resulted in an extreme precipitation event (most of the precipitation as rain)

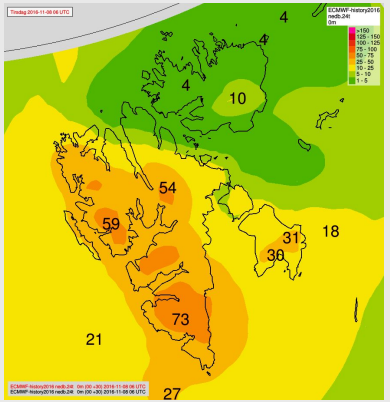


AROME Arctic forecast 24hr acc precipitation

Observations/model [mm/24hr]

Hopen	2.3 / 9.3
Hornsund	36.8 / 38.0
Isfjord Radio	47.2 / 34.5
Svalbard Lufthavn	41.7 / 54.6
Ny-Ålesund	86.8 / 59.8

IFS HRES forecast



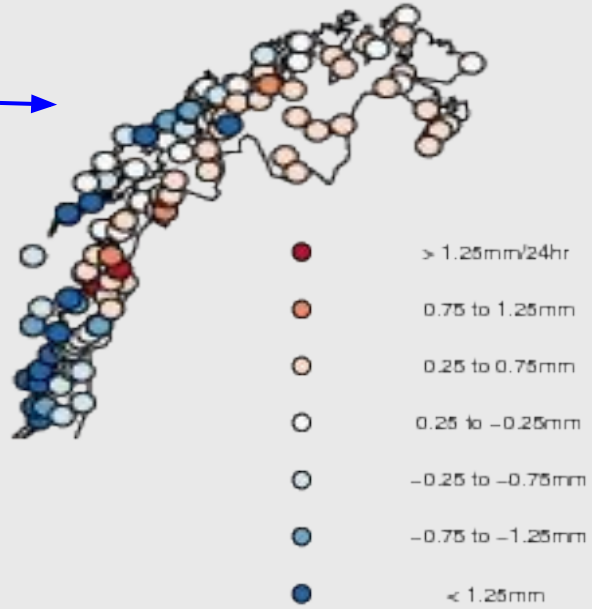
Norwegian Meteorological Institute

AROME Arctic performance

Systematic errors daily precipitation
autumn 2017

Missing shallow convection
over ocean

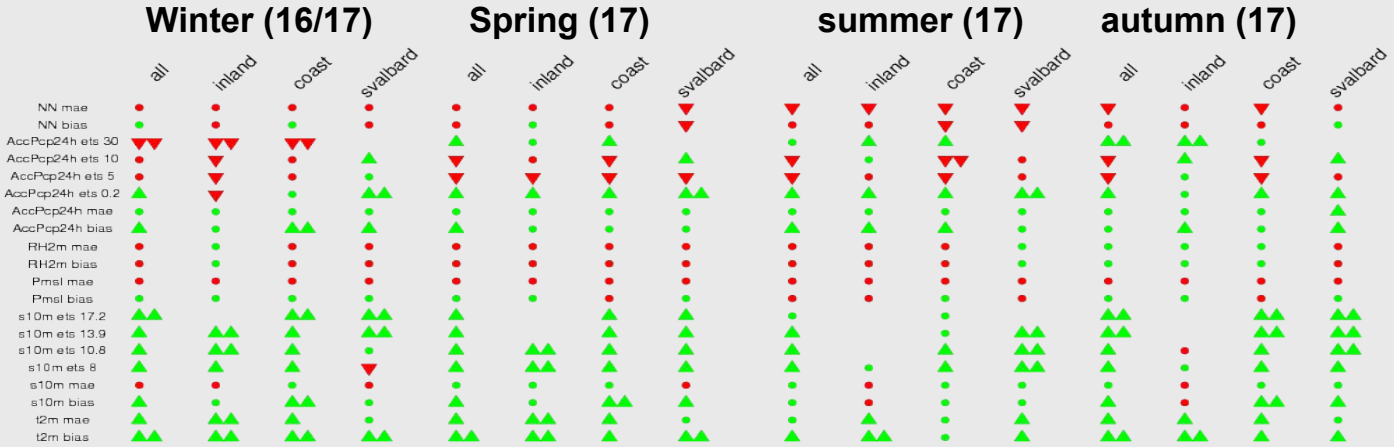
Spin-up distance of humidity /
precipitation from
southern lateral boundary



Norwegian
Meteorological
Institute

AROME Arctic is very competitive compared with global models

Scorecard AROME Arctic vs IFS HRES



Clouds
Precipitation
Near surface humidity
Mean Sea level pressure
10m wind speed
2m air temperature

Green AROME Arctic performs better than IFS HRES
Red AROME Arctic performs worse than IFS HRES
(circle small differences, triangles bigger differences)

Norwegian Meteorological Institute

Are we certain about the forecast skill? Arctic Verification challenges

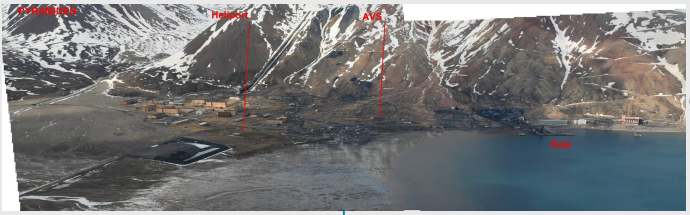
$$\langle \mathrm{F}^{\mathrm{M}}(\mathbf{x}_{\mathrm{obs}}) - \mathrm{F}^{\mathrm{O}}(\mathbf{x}_{\mathrm{obs}}) \rangle = [\varepsilon_{\mathrm{M}}] + [\varepsilon_{\mathrm{R}}] + \varepsilon_{\mathrm{I}} + \varepsilon_{\mathrm{obs}}$$

Kanamitsu & DeHaan (2011)

Model error
initial state error
inadequate model description
(boundary conditions)

Interpolation method
grid to point

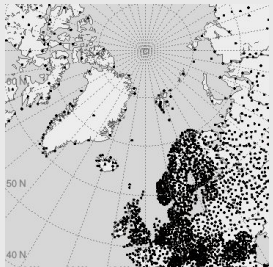
observational errors
e.g. icing on equipment
under catchment precipitation
weaknesses in gridded products



Representativeness
(spatial / temporal)
grid vs point

Reasons to believe that component 1,2 and 4 all are bigger in the Arctic than at lower latitudes (Casati et al. 2017):
"Verification of Environmental Prediction in Polar Regions: recommendations for the Year of Polar Prediction"

In addition, few observations over ocean and sea ice.

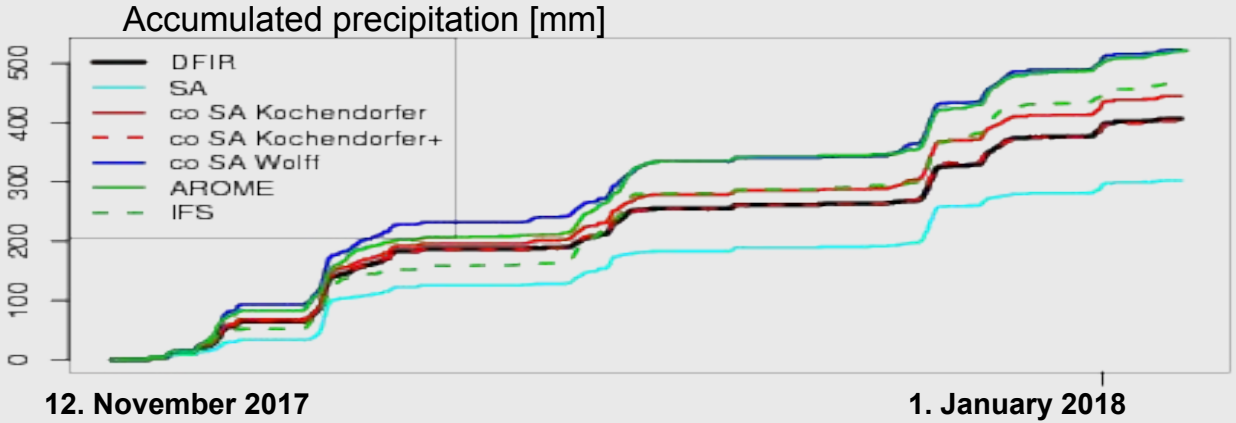


Norwegian Meteorological Institute

Arctic Verification challenges

Under-catchment of snow

Observation errors: Observed and forecasted precipitation Haukeli, Norway (~950 masl)
(Under-catchment of solid precipitation in windy conditions)



Forecasts AROME (solid) and IFS-HRES (dashed)

Red and **blue** corrected observations based on **SA**

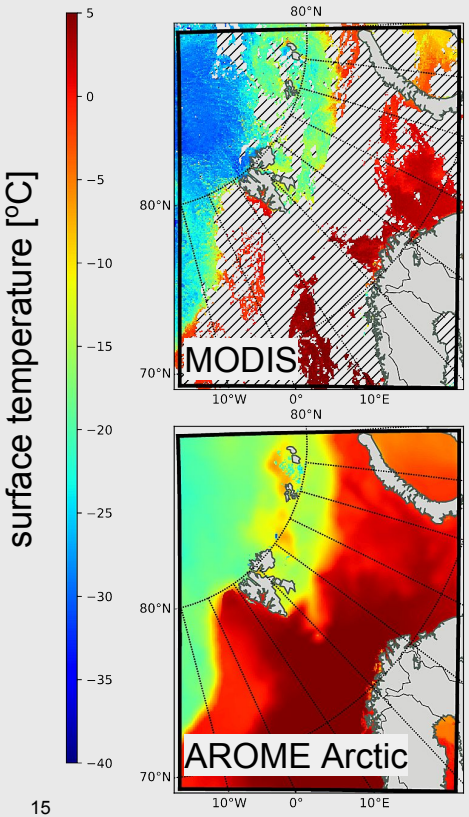
DFIR observation

Single Alter (SA) observation (most common equipment in use)

Norwegian Meteorological Institute

Sea ice in AROME Arctic

21 MAR 2017



- Ice concentration is provided by the IFS model and updated once per cycle
- Ice thickness is uniform and fixed
- Sea ice temperature in AROME Arctic is modelled by the simple prognostic ice scheme SICE
- Operational SICE configuration uses 4 layers within sea ice and treat ice surface as a snow-free one.

Current developments and plans:

- Introduce the prognostic ice thickness to overcome the limitations of the prescribed thickness
- Add snow cover on top of the ice
- Develop the analysis procedure for sea ice variables

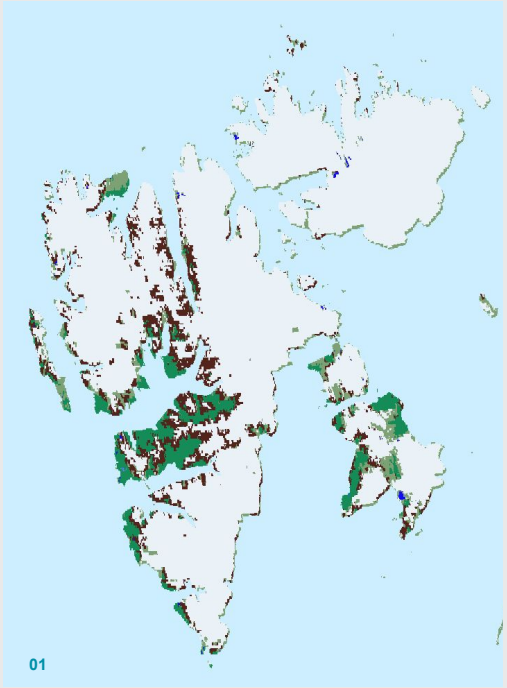
Norwegian Meteorological Institute

Glacier mask update for Svalbard

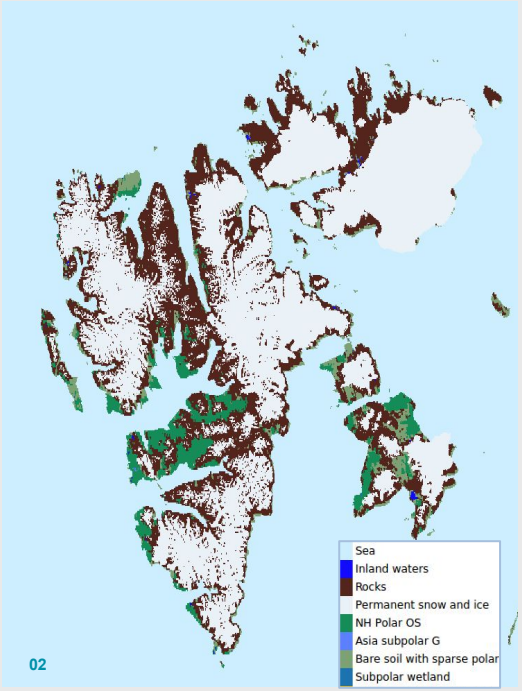
The goal of NORDNWP physiographic database sub project: ”*To identify and use the best physiographic databases in order to get the best forecast.*”

- Implementation of glacier information from the Norwegian Polar Institute into the currently used database
- The sensitivity of the physiographic input data to the 2 m temperature forecasts are locally several degrees
- Meteorological station locations are not heavily affected by cover type changes

ORIGINAL COVER TYPES



UPDATED COVER TYPES



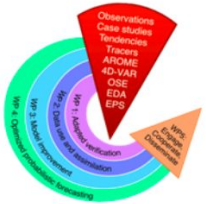
Future work with AROME Arctic

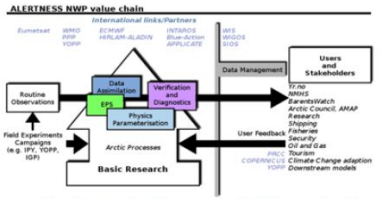
ALERTNESS - (Advanced models and weather prediction in the Arctic: Enhanced capacity from observations and polar process representations)

MET Norway, UiB, UNI, UiT, KNMI, NERSC, UNIS
Project lead: Jørn Kristiansen (MET Norway), Project co-lead: Marius O. Jonassen (UNIS)

The ambition and primary objective of ALERTNESS is to develop world leading capacity for the delivery of reliable and accurate Arctic weather forecasts and warnings for the benefit of maritime operations, business and society.

The scientific hypotheses: (i) improved observations and improved use of observations enable advances in Arctic forecasting, (ii) new ways to identify error compensation will create a pathway to sustained model improvement, and (iii) embracing forecast uncertainty will result in more robust forecasts of Arctic weather.





The ALERTNESS value chain for NWP shows how ALERTNESS adds to the existing, tested and operational value chain for joining mature research results, operational forecasts and user and stakeholder interests.

Funded by Norwegian Research Council, kick-off in February

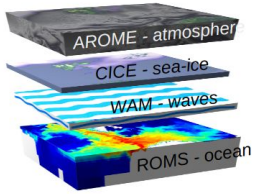
YOPP YEAR OF POLAR PREDICTION

Nansen Legacy RF-4.1

Towards a coupled Arctic prediction system

Goals:

- Coupled Atmosphere, wave, ocean, sea-ice forecasting system for the European Arctic
- Test and optimize the coupling framework with OASIS-MCT
- Collaborations with consortium partners (e.g. UiB, NPI, UNIS, NERSC) to improve the model system.



Methods:

- AROME Arctic, ROMS-CICE, and WAM models
- OASIS-MCT coupler

People involved from MET Norway:
Malte Müller, Yurii Batrak, Jørn Kristiansen, Ana Carrasco, Øyvind Sætra, NN1, NN2

Nansen Legacy - RF-4.1
Tailor an ensemble atmosphere-wave–ice–ocean forecast model system for the Barents Sea and Polar region
Funded by NFR and KD 2017-2023

APPLICATE
www.applicate.eu
Advanced prediction in Polar regions and beyond

CARRA - Copernicus Arctic Regional Reanalysis
Generation of regional reanalysis products for the Arctic

Climate Change

- Warming in the Arctic (observational records and future scenarios) roughly twice as high as global average
- Need for understanding and management of change processes
- Increased economic activity in the region

(Animated gif: NASA)

- Coverage in two domains, main areas of interest in the European sector of the Arctic
- High resolution (2,5 km) adds value to global products
- Extensive use of satellite data
- Use of local surface observation datasets available in the partner countries
- Special emphasis on NWP schemes and observations for the handling of "*cold surfaces*": Snow, sea ice, glaciers

- Led by Met Norway. Partners: The Nordic countries and Météo-France.
- Project started September 2017, 4 years duration
- Will run production at ECMWF HPC facility, giving opportunities for sharing and synergies with the European regional reanalysis and also with the ERA team at ECMWF
- Reanalysis period July 1997 – June 2021 (24 years)

Project leader: Harald Schyberg, MET Norway

Summary

1. **AROME Arctic,**
   an operational high resolution weather forecast model for the European Arctic
   available in real time at thredds.met.no, Yr.no
   used for day-to-day forecasting at MET Norway.

2. **AROME Arctic,**
   the forecast skill is very competitive compared with other weather forecasting models, but deficiencies exist.

3. **AROME Arctic,**
   the predictive capacity of the model system will be enhanced in the coming years due to coordinated research efforts.