Integrated Arctic Observation System

Research and Innovation Action under EC Horizon2020
Grant Agreement no. 727890

Project coordinator:
Nansen Environmental and Remote Sensing Center, Norway

Deliverable 2.5

Report on exploitation of existing data: Atmosphere

Start date of project:	01 December 2016	Duration:	60 months
Due date of deliverable:	31 May 2018	Actual submission date:	20 May 2018
Lead beneficiary for preparing the deliverable:		FMI	
Person-months used to produce deliverable:		6.5 pm	

Authors: Eija Asmi, Roberta Pirazzini, Ewan O'Connor, Georg Heygster

Version	DATE	CHANGE RECORDS	LEAD AUTHOR
1.0	30/04/2017	Template	Roberta Pirazzini
1.1	14/12/2017	1st Draft	Roberta Pirazzini
1.2	1/04/2018	2nd Draft (Sect. 2 completed)	Eija Asmi
1.3	20/05/2018	Final version	Eija Asmi
1.4	29.05.2018	Minor edits on the lay-out	K. Lygre

Approval	Date:	Sign.
X	30.05.2018	Stein Sandven Coordinator

USED PERSON-MONTHS FOR THIS DELIVERABLE					
No	***Beneficiary***	***PM***	***No***	***Beneficiary***	***PM***
1	NERSC		**24**	Terradue	
2	UiB		**25**	GINR	
3	IMR		**26**	UNEXE	
4	MISU		**27**	NIVA	
5	AWI		**28**	CNRS	
6	IOPAN		**29**	U Helsinki	
7	DTU		**30**	GFZ	
8	AU		**31**	ARMINE	
9	GEUS		**32**	IGPAN	
10	FMI	*4.5*	**33**	U SLASKI	
11	UNIS		**34**	BSC	
12	NORDECO		**35**	DNV GL	
13	SMHI		**36**	RIHMI-WDC	
14	USFD		**37**	NIERSC	
15	NUIM		**38**	WHOI	
16	IFREMER		**39**	SIO	
17	MPG		**40**	UAF	
18	EUROGOOS		**41**	U Laval	
19	EUROCEAN		**42**	ONC	
20	UPM		**43**	NMEFC	
21	UB	*2*	**44**	RADI	
22	UHAM		**45**	KOPRI	
23	NORUT		**46**	NIPR	
			47	PRIC	

DISSEMINATION LEVEL		
PU	Public, fully open	X
CO	Confidential, restricted under conditions set out in Model Grant Agreement	
CI	Classified, information as referred to in Commission Decision 2001/844/EC	

EXECUTIVE SUMMARY

This document describes the atmospheric data sets exploited in INTAROS WP2. These include in-situ particulate absorption, remote-sensing cloud products and total integrated water vapor from satellites. This document is intended to describe solely the datasets upgraded and the methodologies used. The requirements for the data collections and the assessment of the upgraded products are presented in D2.4 Sections 3—5 jointly with the assessment of existing data sets presented in D2.4 Section 2.

Table of Contents

1. Introduction

This report presents higher-level products from existing atmospheric measurements developed and derived within INTAROS WP2 by applying new methodologies for data processing and derivation of new quantities. The report will present both satellite derived atmospheric products as well as products from in situ observing systems.

To avoid unnecessary repetition and to facilitate comparison and co-evaluation with un-exploited datasets and products, the exploited higher-level products described in this report are evaluated with respect to requirements, capacities and gaps in Sect 4 of the companion report D2.4. Conclusions and final recommendations on the exploited data are proved in Sect 5 of D2.4.

This report thus only provides the descriptions of the higher-level products, while the properties of these are presented in D2.4.

This deliverable (D2.5) covers the data exploitation done on atmospheric data. Corresponding work on ocean/sea ice data and terrestrial/cryospheric data is presented in deliverables D2.2 and D2.8, respectively.

2. Data exploitation

This section includes the description of the work done on data exploitation, as well as the work to format and characterize the data (determining coverage, resolution, uncertainty, etc.) in order to allow their thorough assessment.

2.1 Unified measurements of black carbon in the Arctic as part of WMO-GAW/IASOA/ACTRIS networks (FMI)

The Arctic climate is very susceptible to aerosols. One of the most crucial aerosol quantity in the Arctic is the aerosol absorbing fraction, or Black Carbon (BC). Shindell and Faluvegi (2009) suggested that over two thirds of the Arctic surface temperature increase experienced during the last decades is attributed to changes in the atmospheric concentrations of sulphate and black carbon (BC) aerosols. Contrary to most of the planet, on snow and ice -covered Arctic the overlying clouds can cause a positive forcing and thus increasing the aerosols can in fact enhance the warming (Walsh and Chapman, 1998; Mauritsen et al., 2010). Of particular importance in the Arctic is also the snow and ice albedo reduction by BC and organics containing particles, which can influence the snow coverage by warming the atmosphere, reducing surface-incident solar energy, and reducing snow reflectance after deposition (Flanner et al., 2009). The overall trend of BC in the Arctic during the past decades shows to be decreasing (AMAP, 2015). This, however, is based on a very view long-term measurements in the Arctic BC. The latest report of the Arctic Monitoring and Assessment Programme on Short-Lived Climate Forcers such as BC in the Arctic (AMAP, 2015) specifically highlights the importance of consistent, harmonized observations of the Arctic absorbing aerosols and the need for their integration in the existing networks and monitoring programs.

Indeed, when BC is considered the methodology and the terminology are not well-defined concepts that makes comparison between modelling studies or other measurement locations complicated (e.g. Petzold et al., 2013). The most commonly used instrument to measure aerosol BC in the Arctic is an aethalometer (Backman et al., 2017). With the benefit of being an easy-to-operate and maintain, this instrument suffers from various artefacts. Until the last years, in the lack of full consensus on how to correct for these artefacts, only the level 0 (ie. raw data) were submitted to the WMO aerosol database in NILU. However, in the recent WMO/GAW recommendation for aerosols, a correction scheme along with a unified C0-factor to correct for aethalometer data to levels 1 and 2, is proposed (WMO, 2016). This factor is 3.5.

Our question in INTAROS is: How representative such a global correction scheme may be for the Arctic? To answer this question, aethalometer data from the stations being part of IASOA/GAW/ACTRIS programmes and networks were analysed for the same time period of 2012-2014 and using the same methods (Backman et al., 2017). By comparing with the reference methods a unified C0-factor for the Arctic was determined. This factor was found as 3.45, being thus in good agreement with the WMO/GAW global recommendation. In addition, a new method of data analyses aiming at reducing the noise in data was proposed.

Consequently, using this new harmonized data series of Arctic BC, seasonal and spatial variability were analysed and published (Schmeisser et al., 2018). One important lesson learned was the vast variability in concentrations and seasonal behavior between different locations in the Arctic, calling for a need of a harmonized and sufficiently dense network of Arctic BC measurements.

2.2 Cloud products from ceilometers (FMI)

Clouds are integral to the Arctic climate, and the modelling of many other feedbacks in the Arctic system depends on the correct representation of clouds in numerical models, including their radiative impact (e.g. Curry et al., 1996), and how they respond to changes in sea ice (e.g. Taylor et al., 2016).

Direct long-term observations of clouds are required to evaluate the model representation, but with insufficient observations, meteorological reanalysis is poorly constrained in the Arctic. Forbes and Ahlgrimm (2014) showed that the operational NWP model at ECMWF had temperature biases at the surface (2-m temperature) in excess of 10 K relative to surface SYNOP observations (Fig. 1). Depending on the choice of cloud scheme, these biases were displayed in either direction, with the original scheme having too much supercooled liquid distributed in a thick layer producing a warm bias, and the initial new prognostic scheme producing ice-only layers leading to a cold bias. The bias was much reduced once the prognostic cloud scheme was updated to produce ‘realistic’ supercooled cloud layers. Identifying the cause of this bias would have been difficult without direct ceilometer observations at Sodankylä, Finland, immediately highlighting the supercooled liquid cloud layer issue.

Forbes and Ahlgrimm (2014) shows the importance of having separate liquid and ice prognostic variables in a GCM for the representation of mixed-phase cloud, but also that introducing more degrees of freedom to represent the variability of the real atmosphere can lead to an increase in model errors in certain regimes. They highlighted other potential aspects to address such as boundary-layer turbulence, cloud radiative properties, and whether the model cloud layer is decoupled from the surface as often as observed.

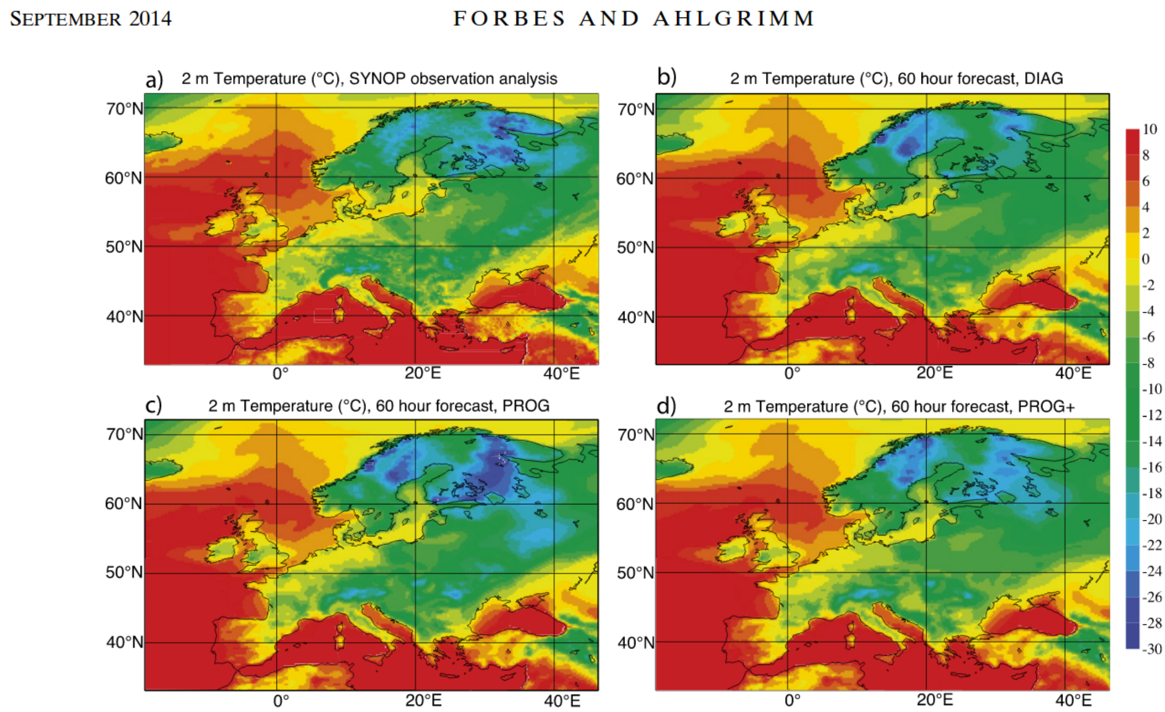

Figure 1. 2-m temperature (°C) over Northern Europe at 0000 UTC 4 Jan 2011 for (a) SYNOP observation analysis, and 60-h forecasts for (b) DIAG simulation, (c) PROG simulation, and (d) PROG+ simulation. Figure reproduced from Forbes and Ahlgrimm (2014), Fig. 10, courtesy of Monthly Weather Review

This highlights that not only is cloud phase important, but so is the vertical cloud structure. For most of the troposphere, the combination of the cloud radar and lidar onboard the satellites Cloudsat and CALIPSO provide an excellent means of extracting the vertical cloud structure, and cloud occurrence at each height. Fig. 2 (from Liu et al., 2012) shows low cloud frequency of occurrence from a combined Cloudsat/CALIPSO product for the Arctic region, however, there are some limitations for this product, which are particularly relevant to the Arctic. Data is limited to below 82.2 degrees North, and detection of clouds below about 1 km is severely hampered due to the surface return (Chan and Comiso, 2013). In addition, Cloudsat does not detect non-precipitating liquid clouds (Stephens et al., 2002) and CALIPSO suffers from intervening layers and multiple scattering close to the surface.

Ground-based measurements of cloud occurrence suggest the frequency-of-occurrence of cloud below 1 km is also significant, an altitude range which is not present in the climatology given in Fig. 2. With passive satellite instruments also struggling with robust detection of low cloud in the Arctic, a means of verifying low-cloud satellite climatologies is necessary, especially when these particular clouds may have a large role in certain feedbacks in the Arctic system.

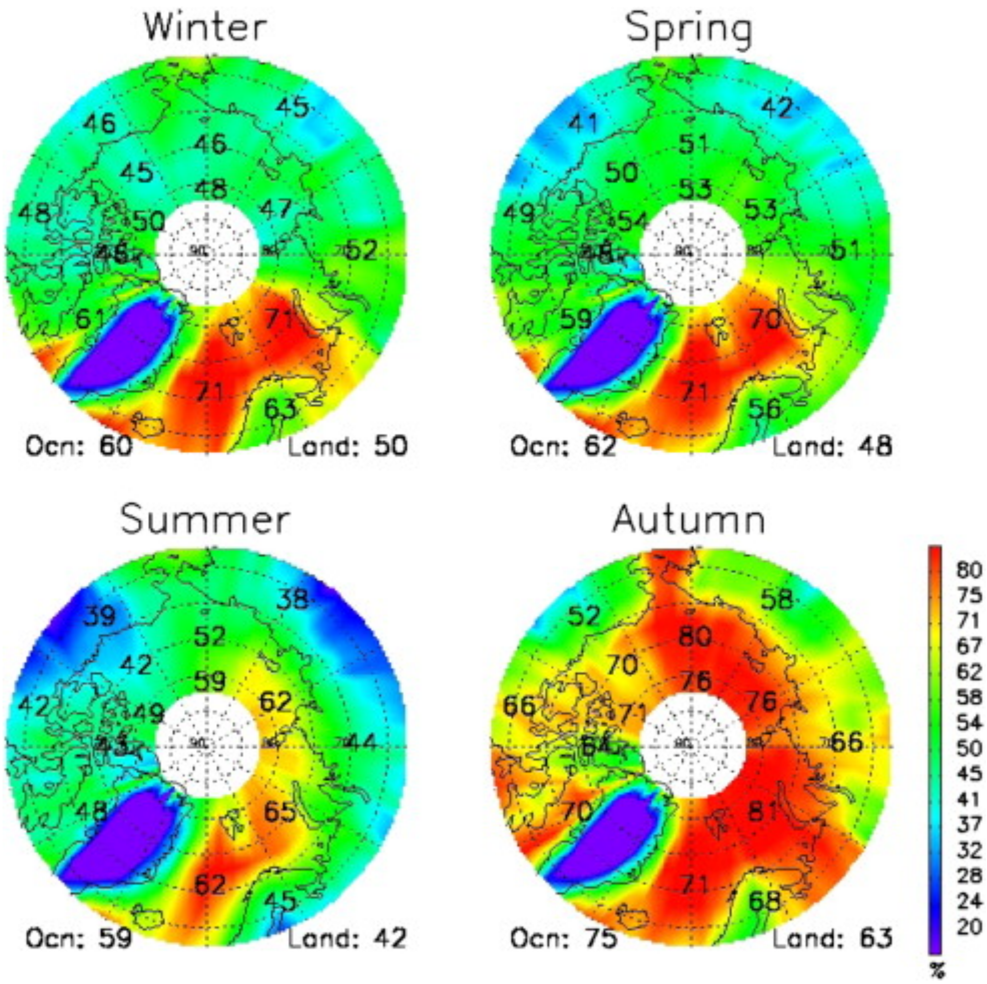

Figure 2. Low-level cloud frequencies in winter, spring, summer, and autumn from RL-GEOPROF from 2006 to 2011. Figure reproduced from Liu et al. (2012), Fig. 8, courtesy of Remote Sensing of Environment.

Another important issue for the Arctic is whether precipitation (whether in the form of drizzle, rain, or snow) evaporates before reaching the surface. Cloudsat is the only satellite instrument capable of monitoring light precipitation (Stephens et al., 2018), but due to the aforementioned 'blind zone' within 1 km of the surface, it does not inform whether this precipitation reaches the surface or not.

To tackle these issues with low cloud, INTAROS can utilize ground-based active remote sensing of cloud profiles by ceilometers. Major advances in solid state laser technology have enabled manufacturing of ceilometers (low-cost automated lidars) with sufficient sensitivity and robustness to provide much more than the cloud base height. These instruments provide reliable liquid cloud base detection from 30 m in altitude up to 7 km or more with vertical and temporal resolution better than 15 m and 30 s. They also provide the attenuated backscatter profile with the same resolution, which can be exploited to deliver new atmospheric products.

Reliable calibration methods for ceilometers are available (O'Connor et al., 2004; Wiegner et al., 2014), which, together with harmonized post-processing (Kotthaus et al., 2016), means that operational data delivery and quality control at the network level is now possible. This has been demonstrated in the E-PROFILE program (http://eumetnet.eu/activities/observations-programme/current-activities/e-profile/alc-network/) coordinated by EUMETNET.

A new classification scheme is under development at FMI to enable full exploitation of the ceilometer attenuated backscatter profile (Fig. 3). The scheme incorporates an improved liquid cloud base detection algorithm suitable for detecting thin layers (e.g. Van Tricht et al., 2014), together with phase discrimination between liquid and ice to enable robust identification of supercooled liquid water layers. New developments have extended the classification scheme to include the diagnosis of warm and cold precipitation, where cold precipitation covers the continuum between ice and snow. This scheme has already demonstrated robust operation for icing applications.

Fig. 3 highlights that that there are often cloud layers within 500 m of the surface, and that cold precipitation often evaporates before reaching the surface. The precipitation diagnosis immediately provides the capability to determine whether precipitation reaches the surface or not, and ongoing developments include the potential for determining precipitation rates in drizzle, rain and snow.

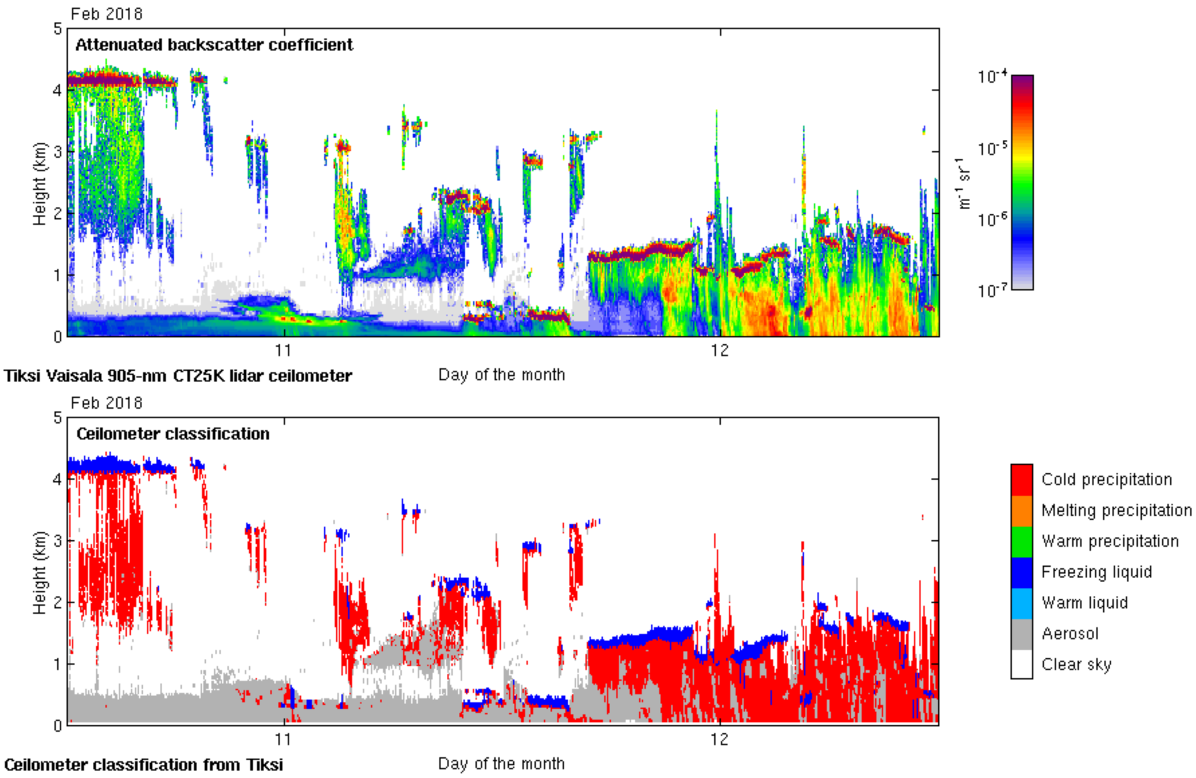

Figure 3. Time-height plots of attenuated backscatter (upper panel) and the hydrometeor classification derived from it (lower panel) for 48 hours of data, 10-12 February 2018, from a Vaisala CT25K ceilometer operated by FMI in Tiksi, Russia. This example contains supercooled liquid layers with ice precipitating below, a characteristic feature of mixed-phase clouds in the Arctic.

With forward operators for attenuated backscatter profiles now being developed by NWP centres (Geisinger et al., 2017; Warren et al., 2018), both weather forecasting and chemical transport models will benefit from data assimilation of the vertical profiles of attenuated backscatter from the ceilometers currently operating in the Arctic. To address data gaps, it has recently been demonstrated that current automated lidar systems meet the low power and environmental constraints necessary to operate in the Arctic and are robust enough to be deployed remotely on the ice, or even on floating buoys (Mariage et al., 2017).

In addition, there are ceilometers deployed for non-research reasons. For pilots to land in poor visibility, airports typically operate an instrument landing system, with Category 3 providing the most support. The WMO and International Civil Aviation Organisation (ICAO) specify that automated systems capable of producing cloud coverage in oktas and cloud base altitude are required for Category 2 and 3 landing systems, and recommended for Category 1 (ICAO, 2010). This cloud information is provided by ceilometer, hence ceilometers are a requirement at most airports and integrated into the Automated Weather Observing System (AWOS), specifically AWOS level III and above. This means that there is an additional 'network' that could be exploited. Note, however, that current usage is limited to the provision of cloud coverage and cloud base height only, with no profile information available, and that changes would require stringent testing to ensure that aviation safety is not compromised.

2.3 Atmospheric Integrated Water Vapor over Arctic sea ice and open water (UB)

Atmospheric water vapor is an important constituent of the global hydrological cycle; it transports humidity and heat and it is the most important greenhouse gas. While over open ocean total precipitable water vapor (PW) is routinely surveyed with satellite microwave imagers like SSMI(S) and AMSR-E/2, large-scale observations in polar regions with low water vapor burden are much more difficult because of the low water vapor signal and, over sea ice and land ice, the high and highly varying surface emissivity. However, a procedure has been suggested exploiting the data of the satellite humidity sounders SSM/T2, AMSU-B and MHS aboard the DMSP, Aqua and Metop satellites or satellite series, respectively (Miao et al., 2001, Melsheimer et al., 2008).

The basic idea is to use three channels of neighbouring frequencies. The surface contribution in the observed brightness temperatures is excluded by considering the ratio of brightness temperature differences. The resulting quotient is closely related to the atmospheric opacity from which in turn the PW can be inferred. The original version [Miao et al., 2001] used the three dual-band channels centred around the water vapor absorption line near 183 GHz (183 ± 3, ± 5, and ± 7 GHz) plus the 150 GHz channels in two different 3-channel combinations for the ranges 0 to 1.5 kg/m2 and 1 to 7 kg/m2, resp.. Later, the procedure has been adapted to the microwave humidity sounders AMSU-B and MHS with channels at 183 ± 1, ± 3, and ± 7 GHz [Melsheimer et al., 2008]. Moreover, the method has been extended to also use the 89 GHz channel by introducing knowledge about the emissivity of Arctic sea ice. This allows for retrieval up to 14 kg/m2 (Scarlat et al., 2017).

A procedure to combine the two data sets is currently being prepared, and based on this a seamless PW data set will be produced covering seamless the Arctic open ocean, sea ice and land ice. Fig. 4 shows a demonstration example with data of 1 Jan 2006. Note that this is the first example of PWV data covering simultaneously the open ocean, sea ice and land ice daily and also during polar night. While the microwave imager based method is well established and validated, more validation work is required for the microwave sounder based product. It is currently being validated, adjusted and made coherent with the microwave imager based retrievals prior to combine both retrievals into a common product. After producing a data set of several years the procedure will be implemented for near real time production.

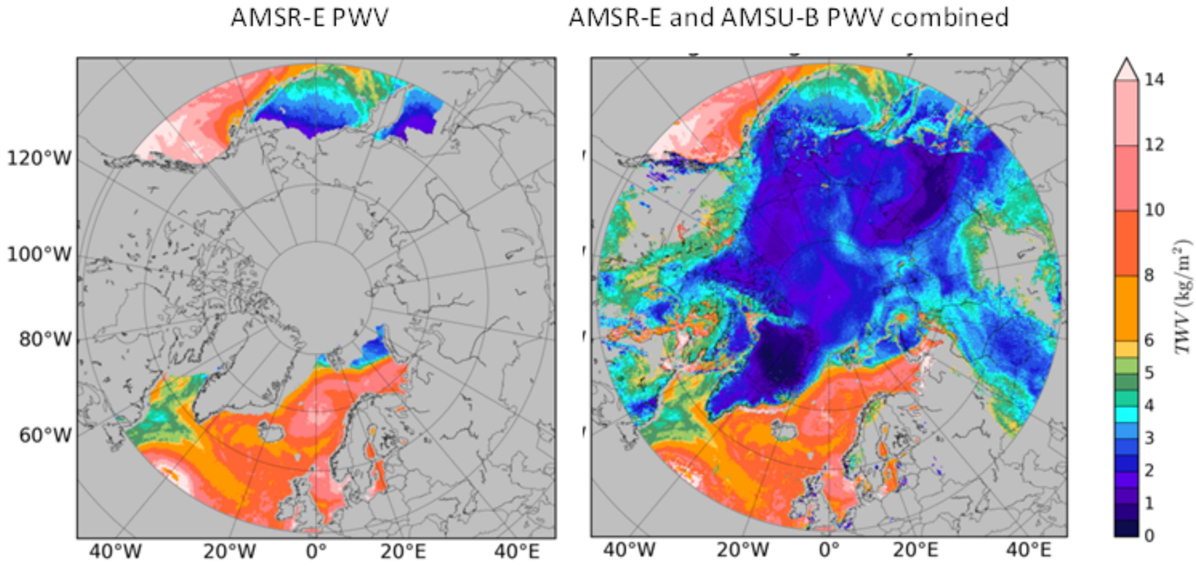

Figure 4. AMSR-E precipitable water vapour (left) and merged precipitable water vapour from AMSR-E and AMSU-B (right) as of 1 Jan 2007.

Literature

AMAP, 2015. AMAP Assessment 2015, Black carbon and ozone as Arctic climate forcers. AMAP, Oslo. 2015.

Backman, J., Schmeisser, L., Virkkula, A., Ogren, J. A., Asmi, E., Starkweather, S., Sharma, S., Eleftheriadis, K., Uttal, T., Jefferson, A., Bergin, M., Makshtas, A., Tunved, P., and Fiebig, M.: On Aethalometer measurement uncertainties and an instrument correction factor for the Arctic, Atmos. Meas. Tech., 10, 5039–5062, 2017. https://doi.org/10.5194/amt-10-5039-2017

Chan, M.A. and J.C. Comiso, Arctic Cloud Characteristics as Derived from MODIS, CALIPSO, and CloudSat. J. Climate, 26, 3285–3306, 2013. https://doi.org/10.1175/JCLI-D-12-00204.1

Curry, J. A., W. B. Rossow, D. Randall, and J. L. Schramm, Overview of Arctic cloud and radiation characteristics, J. Clim., 9, 1731–1762, 1996.

Flanner, M.G. et al. Springtime warming and reduced snow cover from carbonaceous particles. Atmos. Chem. Phys. 9: 2481–2497, 2009.

Forbes, R.M. and M. Ahlgrimm, On the Representation of High-Latitude Boundary Layer Mixed-Phase Cloud in the ECMWF Global Model. Mon. Wea. Rev., 142, 3425–3445, 2014. https://doi.org/10.1175/MWR-D-13-00325.1

Geisinger, A., Behrendt, A., Wulfmeyer, V., Strohbach, J., Förstner, J., and Potthast, R., Development and application of a backscatter lidar forward operator for quantitative validation of aerosol dispersion models and future data assimilation, Atmos. Meas. Tech., 10, 2017. 4705–4726, https://doi.org/10.5194/amt-10-4705-2017

ICAO, 2010, Meteorological Service for International Air Navigation, Annex 3, 17th edition, Montréal, Canada, July 2010.

Illingworth, A.J., R.J. Hogan, E. O'Connor, D. Bouniol, M.E. Brooks, J. Delanoé, D.P. Donovan, J.D. Eastment, N. Gaussiat, J.W. Goddard, M. Haeffelin, H.K. Baltink, O.A. Krasnov, J. Pelon, J. Piriou, A. Protat, H.W. Russchenberg, A. Seifert, A.M. Tompkins, G. van Zadelhoff, F. Vinit, U. Willén, D.R. Wilson, and C.L. Wrench, Cloudnet. Bull. Amer. Meteor. Soc., 88, 883–898, 2007. https://doi.org/10.1175/BAMS-88-6-883

Kotthaus, S., O'Connor, E., Münkel, C., Charlton-Perez, C., Haeffelin, M., Gabey, A. M., and Grimmond, C. S. B., Recommendations for processing atmospheric attenuated backscatter profiles from Vaisala CL31 ceilometers, Atmos. Meas. Tech., 9, 3769–3791, 2016. https://doi.org/10.5194/amt-9-3769-2016

Liu, Y., J. R. Key, S. A. Ackerman, G. G. Mace, Q. Zhang, Arctic cloud macrophysical characteristics from CloudSat and CALIPSO, Remote Sensing of Environment, 124, 159–173, 2012. https://doi.org/10.1016/j.rse.2012.05.006

Mariage, V., et al., IAOOS microlidar-on-buoy development and first atmospheric observations obtained during 2014 and 2015 arctic drifts, Opt. Express., 119, 4 pp, 2016.

Mariage, V., J. Pelon, F. Blouzon, S. Victori, N. Geyskens, N. Amarouche, C. Drezen, A. Guillot, M. Calzas, M. Garracio, N. Wegmuller, N. Sennéchael, and C. Provost, IAOOS microlidar-on-buoy development and first atmospheric observations obtained during 2014 and 2015 arctic drifts, Opt. Express, 25, A73–A84, 2017.

Mauritsen, T. et al., Aerosols indirectly warm the Arctic, Atmos. Chem. Phys. Discuss., 10, 16775–16796, 2010.

C. Melsheimer and G. Heygster, Improved retrieval of total water vapor over polar regions from AMSU-B microwave radiometer data. IEEE Trans. Geosci. Remote Sens. 46(8), p. 2307–2322, 2008. doi:10.1109/TGRS.2008.918013

Miao, J., K. Kunzi, G. Heygster, T. A. Lachlan-Cope, J. Turner, Atmospheric water vapor over Antarctica derived from SSM/T2 data. J. Geophys. Res., 106, D10 (May 27), 10187–10203, 2001.

Morcrette, C. J., O'Connor, E. J. and Petch, J. C., Evaluation of two cloud parametrization schemes using ARM and Cloud-Net observations. Q.J.R. Meteorol. Soc., 138: 964–979, 2012. doi:10.1002/qj.969

O'Connor, E.J., A.J. Illingworth, and R.J. Hogan, A Technique for Autocalibration of Cloud Lidar. J. Atmos. Oceanic Technol., 21, 777–786, 2004.

Petzold, A., Ogren, J. A., Fiebig, M., Laj, P., Li, S.-M., Baltensperger, U., Holzer-Popp, T., Kinne, S., Pappalardo, G., Sugimoto, N., Wehrli, C., Wiedensohler, A., and Zhang, X.-Y.: Recommendations for reporting "black carbon" measurements, Atmos. Chem. Phys., 13, 8365–8379, 2013. https://doi.org/10.5194/acp-13-8365-2013.

Polar View, 2016. Polaris: Next Generation Observing Systems for the Polar Regions. Gaps and Impact Analysis Report, ESA, pp 180.

Scarlat, R. C., Melsheimer, C., and Heygster, G.: Retrieval of Total Water Vapour in the Arctic Using Microwave Humidity Sounders, Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2017-219, in review, 2017.

Schmeisser, L., Backman, J., Ogren, J. A., Andrews, E., Asmi, E., Starkweather, S., Uttal, T., Fiebig, M., Sharma, S., Eleftheriadis, K., Vratolis, S., Bergin, M., Tunved, P., and Jefferson, A.: Seasonality of aerosol optical properties in the Arctic, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2017-1117, in review, 2018.

Shindell, D. and Faluvegi, G: Climate response to regional radiative forcing during the twentieth century. Nature Geoscience 2, 294–300, 2009.

Shupe, M.D., V.P. Walden, E. Eloranta, T. Uttal, J.R. Campbell, S.M. Starkweather, and M. Shiobara. Clouds at Arctic Atmospheric Observatories. Part I: Occurrence and Macrophysical Properties. J. Appl. Meteor. Climatol., 50, 626–644, 2011. https://doi.org/10.1175/2010JAMC2467.1

Sotiropoulou, G., J. Sedlar, R. Forbes, and M. Tjernström, Summer Arctic clouds in the ECMWF forecast model: an evaluation of cloud parametrization schemes. Quarterly Journal of the Royal Meteorological Society 142:694, 387–400, 2016.

Stephens, G.L., D.G. Vane, R.J. Boain, G.G. Mace, K. Sassen, Z. Wang, A.J. Illingworth, E.J. O'connor, W.B. Rossow, S.L. Durden, S.D. Miller, R.T. Austin, A. Benedetti, C. Mitrescu, et al. THE CLOUDSAT MISSION AND THE A-TRAIN. Bull. Amer. Meteor. Soc., 83, 1771–1790, 2002. https://doi.org/10.1175/BAMS-83-12-1771.

Stephens, G., D. Winker, J. Pelon, C. Trepte, D. Vane, C. Yuhas, T. L'Ecuyer, and M. Lebsock. CloudSat and CALIPSO within the A-Train: Ten Years of Actively Observing the Earth System. Bull. Amer. Meteor. Soc., 99, 569–581, 2018. https://doi.org/10.1175/BAMS-D-16-0324.1

Taylor, P. C., S. Kato, K.-M. Xu, and M. Cai. Covariance between Arctic sea ice and clouds within atmospheric state regimes at the satellite footprint level, J. Geophys. Res. Atmos., 120, 12656–12678, 2015. doi: 10.1002/2015JD023520.

Van Tricht, K., Gorodetskaya, I. V., Lhermitte, S., Turner, D. D., Schween, J. H., and Van Lipzig, N. P. M. An improved algorithm for polar cloud-base detection by ceilometer over the ice sheets, Atmos. Meas. Tech., 7, 1153–1167, 2014. https://doi.org/10.5194/amt-7-1153-2014.

Warren, E., C. Charlton-Perez, S. Kotthaus, H. Lean, S. Ballard, E. Hopkin, S. Grimmond, Evaluation of forward-modelled attenuated backscatter using an urban ceilometer network in London under clear-sky conditions, Atmospheric Environment, 2018. https://doi.org/10.1016/j.atmosenv.2018.04.045.

Wiegner, M., Madonna, F., Binietoglou, I., Forkel, R., Gasteiger, J., Geiß, A., Pappalardo, G., Schäfer, K., and Thomas, W., What is the benefit of ceilometers for aerosol remote sensing? An answer from EARLINET, Atmos. Meas. Tech., 7, 1979–1997, 2014. https://doi.org/10.5194/amt-7-1979-2014.

Walsh, J.E. and Chapman, W.L., Arctic cloud-radiation-temperature associations in observational data and atmospheric reanalysis, J. Climate, 11, 3030–3045, 1998.

WMO/GAW Aerosol Measurement Procedures, Guidelines and Recommendations, 2nd Edition, 103 pp. August 2016 (WMO-No. 1177), 2016.

--- END of DOCUMENT---

This report is made under the project
Integrated Arctic Observation System (INTAROS)
funded by the European Commission Horizon 2020 program
Grant Agreement no. 727890.

Project partners: