1st (AC)³ Science Conference on Arctic Amplification

26 – 28 March 2017 | Bremen | Germany

Conference Booklet

UNIVERSITÄT LEIPZIG

Universität Bremen

TROPOS
Leibniz Institute for Tropospheric Research

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Universität zu Köln

Ladies and Gentlemen,

it is our privilege to welcome you to the 1st International (AC)³ Science Conference on Arctic Amplification, kindly hosted by the University of Bremen, Institute for Environmental Physics (IUP). We are delighted that you have followed our invitation to Bremen to present and discuss the results of the first year of our work within the Transregional Collaborative Research Center (TR 172) on "Arctic Amplification: Climate Relevant Atmospheric and Surface Processes, and Feedback Mechanisms" (AC)³, funded by the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG).

The conference offers five sessions with the following topics: **A**: Fluxes in the Arctic Boundary Layer, **B**: Clouds; Aerosols & Water Vapor, **C**: Surface Atmosphere Interactions: Processing & Trace Constituents, **D**: Atmospheric Circulation & Transport, and **E**: Integration & Synthesis. These five scientific topics represent the five project clusters of (AC)³. The sessions will be introduced by keynote talks given by renowned invited speakers which are experienced, long-standing researchers in the fields of the session topics. Most of the other oral presentations in the sessions are given by PhD students or young Post-Docs working within (AC)³. Furthermore, we have invited several speakers representing German partners of (AC)³. We have also organized respective poster sessions. A particular highlight of the conference will be an invited evening talk. Please have a look at the detailed program given in this booklet.

We will reward both the best oral presentation and the most attractive poster by the "(AC)³ Distinguished Young Investigators Prize", which we plan to award also during each of the upcoming (AC)³ conferences.

We are convinced that we have put together an attractive program and we are very much looking forward to present and discuss the scientific results achieved in the first year of (AC)³, and to outline the next steps of our project. Again, we would like to warmly welcome you to our conference.

Manfred Wendisch & Marlen Brückner,
on behalf of the (AC)³ community

Conference Locations

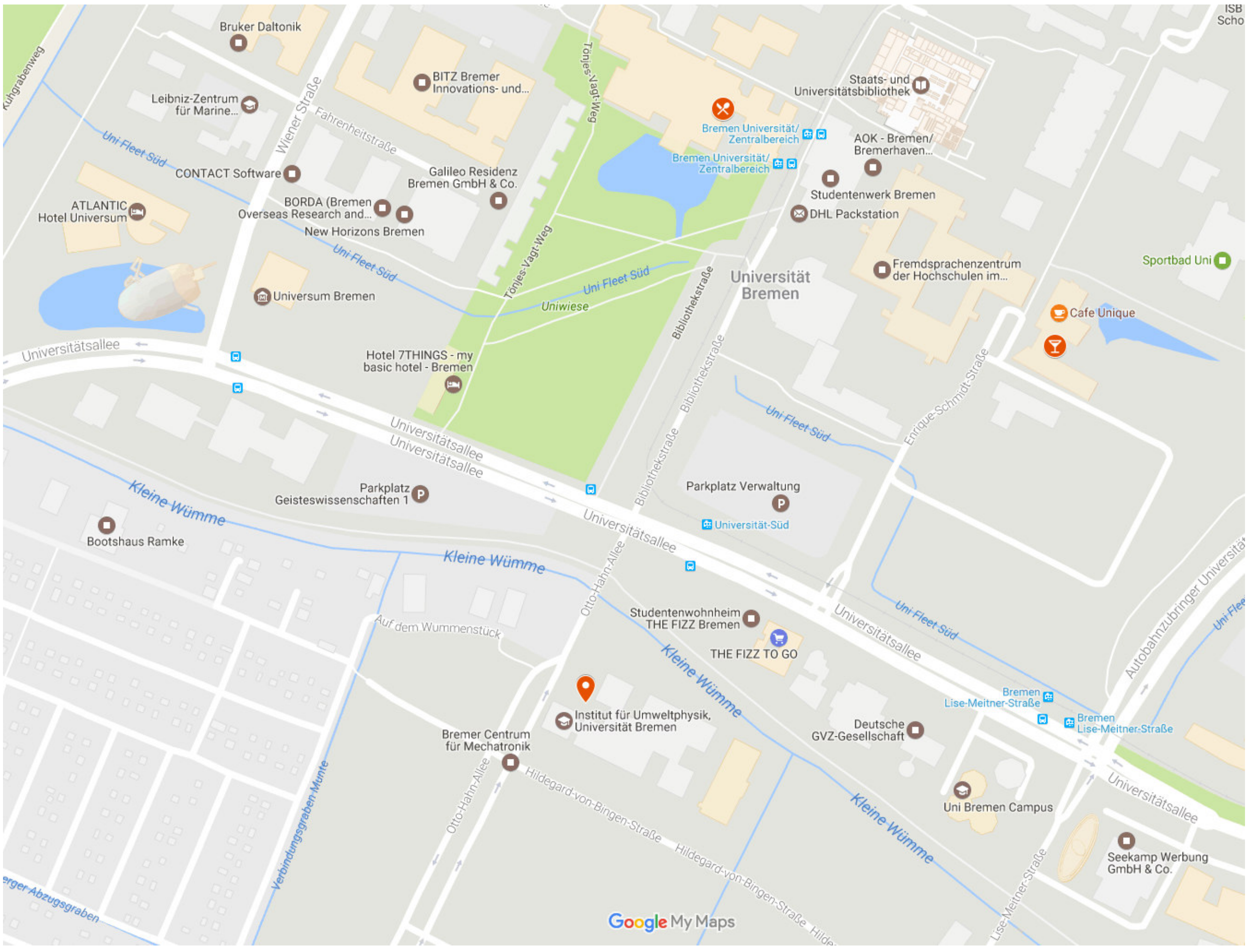
Ice breaker on Sunday, 26 March 2017

Location: Café Unique
Enrique-Schmidt-Straße 7
28329 Bremen
cafe-unique.de

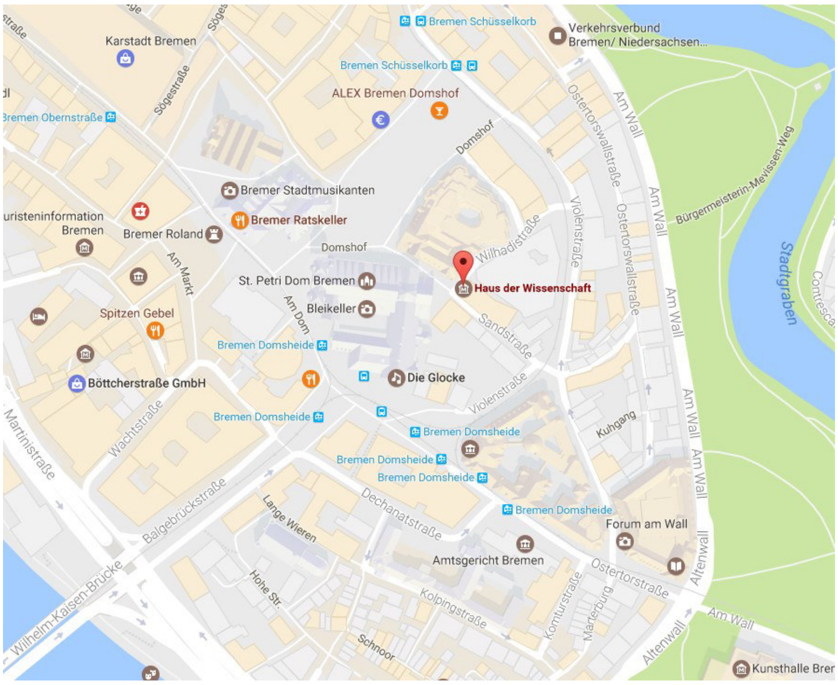
Conference on Monday, Tuesday, (and Wednesday), 27 – 29 March 2017

The 1st (AC)³ Science Conference will take place at the University of Bremen, Institute for Environmental Physics (IUP) (http://www.iup.uni-bremen.de/eng/). All sessions will be in the lecture room HS2 equipped with a digital projector and computer. Wireless internet will be available (for further information please ask the registration desk).

Address: Institute of Environmental Physics
University of Bremen
Otto-Hahn-Allee 1
D-28359 Bremen, Germany



Evening reception on Monday, 27 March 2017
Please note that this is a closed event. A previous registration is required.
Location: Haus der Wissenschaft
Sandstraße 4/5
28195 Bremen
www.hausderwissenschaft.de



Instructions for Participants

Instructions for Speakers

- Rooms will have a digital projector and computer.
- Speakers can bring their own laptop but for the sake of simplicity, we prefer to collect all presentations at one laptop before the session.
- A volunteer will be on hand to help.
- The time allocated to each speaker, including time to set up and time for questions, is:
  - Keynote talks: 30 minutes.
  - 15 minutes (4 talks per session) or 20 minutes (3 talks per session), respectively.

Instructions for Session Chairs

- Please stick to the schedule and moderate questions.

Instructions for Poster Presenters

- There will be two poster sessions on Monday and Tuesday afternoon. Both poster sessions will take place in the "Studierhaus" at IUP.
- Presenters should arrive in advance to set up their posters.
- Each presenter will be provided with a 1m x 1.5m poster board and drawing pins.
- Poster boards will be grouped according to numbering (please see poster list); labels will be provides so you can easily find the poster boards.
- Presenters should remove their poster at the end of the session.

CONFERENCE PROGRAME

SUNDAY, 26 March (Café Unique)

18:00 – 22:00 Ice Breaker

MONDAY, 27 March (IUP Bremen, HS2)

08:00 – 08:45 *Registration desk*

08:45 – 09:00 Opening of the conference (M. Wendisch)

09:00 – 10:30 Session A (Chairs: C. Lüpkes, M. Wendisch)
09:00 – 09:30 Keynote talk by ***Von P. Walden*** *(Washington State University)* "The importance of surface energy fluxes in the Arctic: From sea ice to the top of Greenland"
09:30 – 09:50 ***Dmitry Chechin et al.*** *(AWI-Bremerhaven)* "Atmospheric boundary layer evolution and associated low-level baroclinicity during cold-air outbreaks in the Arctic"
09:50 – 10:10 ***Christof Lüpkes et al.*** *(AWI-Bremerhaven)* "A new bulk parametrization of surface fluxes for stable atmospheric conditions over sea ice"
10:10 – 10:30 ***Felix Lauermann et al.*** *(University of Leipzig)* "Meter-scale horizontal variability of the cloud top radiative cooling derived from airborne spectral imaging over Arctic stratocumulus"

10:30 – 11:00 *Coffee break*

11:00 – 12:30 Session B (Chairs: A. Macke, J. Notholt)
11:00 – 11:30 Keynote talk by ***Jost Heintzenberg*** *(Stockholm University)* "Water vapor, aerosols, and clouds in the Arctic"
11:30 – 11:45 ***Elena Ruiz Donoso et al.*** *(University of Leipzig)* „Cloud thermodynamic phase discrimination over snow surfaces using passive solar remote sensing"
11:45 – 12:00 ***Sebastian Zeppenfeld et al.*** *(TROPOS)* „Method development and first measurements of marine biopolymers and ice nucleating particles for the application in Arctic field samples"
12:00 – 12:15 ***Linlu Mei et al.*** *(University of Bremen)* "Retrieval of aerosol optical thickness from passive remote sensing over the Arctic region"
12:15 – 12:30 ***Ana Radovan et al.*** *(University of Cologne)* "Microwave brightness temperatures simulations at AMSU-B frequencies for a polar low case on 7th of January 2009"

12:30 – 13:30 *Lunch (Cafeteria)*

13:30 – 15:00 Session C (Chairs: J. P. Burrows, A. Bracher)
13:30 – 14:00 Keynote talk by ***Ulrich Platt*** *(Ruprecht-Karls-University Heidelberg)* "Halogen chemistry in the polar boundary layer – The roles of meteorology, surface, and aerosol"

14:00 – 14:20	***Tobias Donth et al.*** *(University of Leipzig)* "Sensitivity of the surface albedo on micro- and macrophysical snow properties including Black Carbon"
14:20 – 14:40	***Sebastian Hellmann et al.*** *(AWI-Bremerhaven)* "Investigating variability and trend of three major phytoplankton groups during the period of rapid change based on modelling and satellite retrievals"
14:40 – 15:00	***Christine Pohl et al.*** *(University of Bremen)* "Influence of varying opening angle and spectral bandwidth on bidirectional reflectance factors"
15:00 – 15:30	*Coffee break*
15:30 – 18:00	**<u>Poster session A – C</u>** (see table below)
20:00 – 23:00	**Evening talk and reception** (Haus der Wissenschaften, Olberssaal) – Closed event
20:00 – 20:30	Evening talk by ***Sebastian Gerland*** *(Norwegian Polar Institute)* "Changing Arctic sea ice implications for climate, ecosystem and society"
20:30 – 23:00	Reception (drinks and finger food)

<u>TUESDAY, 28 March (IUP Bremen, HS2)</u>

08:30 – 09:00	*Registration desk*
09:00 – 10:30	**<u>Session D</u>** (Chairs: A. Rinke, J. Quaas)
09:00 – 09:30	Keynote talk by ***Dave Bromwich*** *(Ohio State University)* "Arctic system reanalysis of Arctic atmospheric circulation"
09:30 – 09:45	***Ralf Jaiser et al.*** *(AWI-Potsdam)* "The linkage between Arctic sea ice changes and mid-latitude atmospheric circulation in reanalysis data and model simulations-Tropo-stratospheric coupling and barotropic interactions"
09:45 – 10:00	***Philip Rostosky et al.*** *(University of Bremen)* "Snow depth retrieval on Arctic sea ice from satellite radiometers – extension to lower frequencies"
10:00 – 10:15	***Rodrigo Caballero et al.*** *(University of Stockholm)* "Warming the Arctic with moist intrusions"
10:15 – 10:30	***Jacob Schacht et al.*** *(TROPOS)* "Aerosol as a player in the Arctic Amplification – An aerosol-climate model evaluation study"
10:30 – 11:00	*Coffee break*
11:00 – 12:30	**<u>Session E</u>** (Chairs: S. Crewell, M. Maturilli)
11:00 – 11:30	Keynote talk by ***Irina Gorodetskaya*** *(University of Aveiro)* "Clouds and precipitation in the polar regions: Integration and synthesis of observations and regional climate models"
11:30 – 11:45	***Kerstin Ebell et al.*** *(University of Cologne)* „Large Eddy Simulations at Ny-Ålesund with ICON-LEM"

11:45 – 12:00	***Sandro Dahlke et al.*** *(AWI-Potsdam)* „Origin and characteristics of lower-tropospheric air masses above Ny-Ålesund during different flow conditions”
12:00 – 12:15	***Karoline Block et al.*** *(University of Leipzig)* “Analysis of feedback uncertainties contributing to the spread in Arctic warming amplification”
12:15 – 12:30	***Rosa Gierens et al.*** *(University of Cologne)* “Investigating mixed phase clouds using a synergy of ground based remote sensing measurement”
12:30 – 13:30	*Lunch (Cafeteria)*
13:30 – 15:00	**Poster session D – E** (see table below)
15:00 – 15:30	*Coffee break*
15:30 – 17:30	**General Assembly of (AC)³, internal SAB meeting (in parallel)**
15:30 – 16:00	Report of Speaker and Scientific Coordinator
16:00 – 17:00	Introduction of new members, to be elected.
16:00 – 16:15	***Astrid Lampert*** (TU Braunschweig)
16:15 – 16:30	***Emma Järvinen*** (KIT)
16:30 – 16:45	***Johannes Schneider*** (MPIC)
16:45 – 17:00	Awarding of the "(AC)³ Distinguished Young Investigators Prizes"
17:00	End of conference

Additional Arctic related lectures

WEDNESDAY, 29 March (IUP Bremen, HS2)

09:00 – 12:30	**General, introductory lectures** *(mainly for PhD students but interested audience and discussants are also welcome)*
09:00 – 10:00	Lecture by ***Von P. Walden*** *(Washington State University)* “Physical characteristics and basic features of Arctic climate”
10:15 – 11:15	Lecture by ***Dave Bromwich*** *(Ohio State University)* “Contemporary climate change in the Arctic”
11:35 – 12:30	Lecture by ***Irina Gorodetskaya*** *(University of Aveiro)* “Antarctic and Arctic climate systems: Similarities and contrasts”

Monday Poster Session A – C

#1 **Water mass modification processes and water transport into the Arctic,** *R. Gerdes*

#2 **Chemical composition of aerosol particles in the Arctic summer – Anthropogenic and biogenic influences,** *F. Köllner, J. Schneider, H. Bozem, P. Hoor, M. Willis, J. Burkart, W. R. Leaitch, A. Herber, J. Abbatt, S. Borrmann*

#3 **Investigation of the Directional Structure of Horizontal Cloud Inhomogeneities Derived from Ground-Based and Airborne Spectral Imaging and Cloud Resolving Models,** *M. Schäfer, E. Bierwirth, A. Ehrlich, E. Jäkel, K. Loewe, F. Werner, C. Hoose, M. Wendisch*

#4 **Balloon-borne vertical turbulence profiles: Measurement setup and exemplary data,** *U. Egerer, H. Siebert, M. Wendisch*

#5 **Ship-based Studies of AOD in the Norwegian and Greenland Seas between 2007 and 2016 within the NASA-MAN Project,** *T. Zielinski, P. Makuch, T. Petelski, P. Pakszys, P. Markuszewski, A. Smirnov, R. Neuber, Ch. Ritter*

#6 **Quantification of uncertainties on cloud radiative forcing caused by surface heterogeneity,** *E. Jäkel, A. Ehrlich, M. Wendisch, G. Heygster, L. Istomina, C. Pohl*

#7 **In Situ Measurements of Cloud Radiative Cooling and Heating Rates,** *J. Stapf, F. Lauermann, M. Gottschalk, A. Ehrlich, M. Wendisch*

#8 **Microphysical and chemical characterization of cloud particle residues from Arctic mixed-phase clouds sampled during the coming ACLOUD mission,** *S. Mertes, U. Kästner, D. van Pinxteren, A. Macke, O. Eppers, J. Schneider, H.-C. Clemen, F. Köllner, M. Zanatta, D. Kalmbach, A. Herber*

#9 **Changes of Top-of-Atmosphere reflectance over the Arctic from spaceborne measurements,** *T. Stamoulis, M. Vountas, L. Lelli, L. Mei, V.V. Rozanov, J.P. Burrows*

#10 **Investigating variability and trend of three major phytoplankton groups during the period of rapid change based on modeling and satellite retrievals,** *S. N. Losa, S. Hellmann, M. A. Soppa, T. Dinter, J. Oelker, M. Losch, S. Dutkiewicz, A. Richter, V. Rozanov, J. P. Burrows, A. Bracher*

#11 **Cloud masking for aerosol retrieval over the Arctic using AATSR time-series measurements,** *S. Jafariserajehlou, L. Mei, M. Vountas, V.V. Rozanov, J. P. Burrows*

#12 **Balloon-borne measurements of heating and cooling rates in Arctic stratocumulus,** *M. Gottschalk, F. Lauermann, J. Stapf, A. Ehrlich, H. Siebert, M. Wendisch*

#13 **Cloud detection over snow and ice using synergy of MERIS/AATSR (OLCI/SLTSR),** *L. Istomina, H. Marks, G. Heygster*

#14 **Satellite Remote Sensing of Halogens in the Arctic Troposphere,** *I. Bougoudis, A.-M. Blechschmidt, A. Richter, A. Schoenhardt, J. P. Burrows*

#15 **Characterizing the vertical presence of atmospheric black carbon in the Arctic region during spring and summer,** *M. Zanatta, H. Schulz, S. Wöhler, A. Herber*

#16 **IR-Spectroscopy using a FT-Interferometer in emission and absorption mode and preparation for the Polarstern cruises PS106 and PS107,** *P. Richter, M. Palm, J. Notholt*

#17 **Closure of Arctic Cloud Properties and Radiative Fluxes from ground-based observations,** *C. Barrientos V., H. Deneke, A. Macke*

#18 **N-ICE2015: Observational study on drifting Arctic sea ice north of Svalbard from winter to summer,** *A. S. Gerland, B. M. A. Granskog, C. P. Assmy, D. P. Duarte, E. S. R. Hudson, F. N. Hughes, G. L. H. Smedsrud, H. G. Spreen, I. A. Sundfjord, J. H. Stehen*

#19 **Daily lead map of the European Arctic from Sentinel-1 SAR scenes,** *D. Murashkin, G. Spreen, M. Huntemann*

#20 **Experiences with an optimal estimation algorithm for surface and atmospheric parameter retrieval from passive microwave data in the Arctic,** *R. Scarlat, G. Heygster*

#21 **Automatic detection of polar mesocyclones using satellite microwave humidity sounders,** *C. Melsheimer*

#22 **Merged Total Water Vapour product from AMSU-B and AMSR-E data in the Arctic region,** *A. Triana Gómez, G. Heygster, C. Melsheimer*

#23 **Snow on Antarctic Sea Ice: Distribution and Trends,** *T. Frost, S. Kern, G. Heygster*

#24 **Microwave Radar/radiometer for Artic Clouds (MiRAC) for vertical profiling of ice and liquid water,** *M. Mech, L. Dirks, T. Doktorowski, S. Crewell, T. Rose, M. Stoff*

#25 **Thin cloud characteristics over Ny-Ålesund, Spitsbergen and their radiative signatures from recent multi-year observations**, *A. Kautzleben, M. Maturilli, R. Neuber, C. Ritter*

#26 **Characterization of Arctic Mixed Phase Clouds at regional and small scales**, *O. Jourdan, G. Mioche, J. Delanoe, C. Gourbeyre, R. Dupuy, A. Schwarzenboeck*

Tuesday Poster Session D – E

#27 **Influence of tropospheric circulation patterns on the winter middle and high-latitude mesosphere,** *Ch. Jacobi, D. Mewes*

#28 **The Role of Intense Cyclones for Precipitation, Sea Ice and Snow Cover Distribution in the Nordic Seas,** *E.M. Knudsen, S. Crewell, K.I. Hodges, A. Rinke*

#29 **A comparison of the two Arctic atmospheric winter states observed during N-ICE2015 and SHEBA,** *R. M. Graham, A. Rinke, L. Cohen, S. R. Hudson, V. P. Walden, M. A. Granskog, W. Dorn, M. Kayser, M. Maturilli*

#30 Sea ice concentrations at 1 km resolution from combined optical and passive microwave data, *V. Ludwig, L. Istomina, G. Spreen*

#31 Meridional temperature flux in the vicinity of the Arctic, *D. Mewes, Ch. Jacobi*

#32 Characterization of the cloud conditions at Ny-Ålesund using sensor synergy and representativeness of the observed clouds across Arctic sites, *T. Nomokonova, K. Ebell, U. Löhnert, M. Maturilli*

#33 Evaluating Svalbard's exceptional geographical location from an Arctic surface temperature budget perspective, *S. Dahlke, M. Maturilli*

#34 Thin sea ice thickness retrieval using L-band satellite sensors, *C. Patilea, G. Heygster, M. Huntemann, G. Spreen*

#35 Multiyear sea ice concentration estimates using ASCAT and AMSR2 data, *Y. Ye, G. Spreen, M. Shokr, G. Heygster*

#36 SWIFT: Fast stratospheric ozone chemistry for global climate models, *D. Kreyling, I. Wohltmann, R. Lehmann, W. Dorn, M. Rex*

#37 Measurements of atmospheric properties using solar absorption spectroscopy and emission spectroscopy using FTIR spectroscopy, *R. Basu, M. Palm, J. Notholt*

#38 Changes in Arctic sea ice dynamics observed by satellites, *A. Kazlova, G. Spreen*

#39 Recent Progress Towards a Coupled Regional Climate Model System of the Arctic, *W. Dorn, A. Rinke, C. Köberle, H. Matthes, K. Dethloff, R. Gerdes*

#40 Spatiotemporal patterns of snowfall in the Arctic, *B. Segger, A. Rinke, S. Crewell, E. Knudsen, P. Rostosky, G. Spreen*

#41 Microphysical Properties and Radiative Impact of an intense biomass burning event in Ny-Ålesund, *C. Ritter, C. Böckmann, R. Neuber, M. Maturilli*

#42 The effect of mid-latitude air masses on the high Arctic lower troposphere during spring (NETCARE 2015) and summer (NETCARE 2014), *H. Bozem, P. Hoor, D. Kunkel, F. Köllner, J. Schneider, M. Willis, J. Burkart, W. R. Leaitch, A. Herber, J. Thomas, J. Abbatt*

#43 Evaluation of cloud properties in the Arctic in the global aerosol-climate model ECHAM6-HAM2 using the COSP satellite simulator, *J. Kretzschmar, J. Quaas*

#44 Fine Scale Simulations of Arctic Cloud with an Improved Scheme for Mixed-phase Microphysics, *J. Chylik, R. Neggers*

#45 Atmospheric Correction of Sea Ice Concentration Retrieval of 89 GHz AMSR-E Observations, *J. Lu, G. Heygster, G. Spreen, C. Melsheimer*

#46 Ridge detection from different spatial resolution SAR imagery, *T. Zhu, G. Spreen, W. Dierking, G. Heygster, F. Li, Y. Zhang, S. Zhang*

#47 Comparison of meteorological conditions in Svalbard fjords: Hornsund and Kongsfjorden, *M. Cisek, P. Makuch, T. Petelski*

#48 Influences of surface heterogeneities on Arctic low-level cloud entrainment by shear – A motivation and a first test, *R. Rauterkus*

#49 A coupled large-eddy simulation sea ice model for simulating Arctic air mass transformation, *A. Dimitrelos, A. M. L. Ekman, R. Caballero*

#50 Plans for a HALO campaign within (AC)³, *M. Wendisch, M. Brückner, S. Crewell, J. Notholt, J. P. Burrows, K. Dethloff[4] K. Ebell, A. Ehrlich, C. Lüpkes, A. Macke, J. Quaas, A. Rinke, I. Tegen, R. Neggers, A. Herber, M. Rex*

#51 Planned contributions of (AC)³ to MOSAiC, *M. Wendisch, M. Brückner, S. Crewell, J. Notholt, J. P. Burrows, K. Dethloff, K. Ebell, A. Ehrlich, C. Lüpkes, A. Macke, J. Quaas, A. Rinke, I. Tegen, R. Neggers, A. Herber, M. Rex*

Atmospheric boundary layer evolution and associated low-level baroclinicity during cold-air outbreaks in the Arctic

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The evolution of the atmospheric boundary layer (ABL) height, temperature and wind speed downwind the marginal sea ice zone during cold-air outbreaks is studied using aircraft observations in the Arctic and idealized nonhydrostatic modelling. Apart from rapid ABL growth and heating, a significant acceleration/deceleration of the ABL flow over open water relative to wind speed above the ABL is observed. It is shown that the increase of the ABL wind speed resulting in a low-level jet occurs in a certain range of such parameters as: i) surface temperature difference between the sea ice and open water and ii) the orientation of the ice edge relative to the direction of the large-scale flow. It is shown that baroclinicity associated with the ABL heating can explain the sensitivity of the low-level jet strength to external parameters.

To interpret observations and get more insight into the effect of low-level baroclinicity on the ABL wind, a simple dry quasi-analytical mixed-layer model (ML) is presented. A good agreement between the ML model results and observations is demonstrated with respect to the ABL height and temperature. However, ML underestimates the ABL warming by about 10% which might be due to neglect of condensational heating and subsidence. It is concluded that the latter factors play a secondary role for the ABL development compared to the warming due to surface sensible heat flux, at least over the first few hundred kilometers downwind the ice edge. Also, the ML model reproduces well baroclinicity related with the ABL heating. Moreover, it is shown that baroclinicity associated with the sloping of the inversion at the ABL top and baroclinicity above the ABL also have a non-negligible effect on the ABL wind speed. All the three baroclinic terms have to be taken into account in the ML model in order to obtain a good quantitative agreement of its results with those of a 3D nonhydrostatic model. Using the ML analytical solution, an expression for the horizontal length scale of the cold-air mass transformation is obtained. This scale also describes the decay of the low-level baroclinicity downwind the ice edge. This scale is shown to vary from 400 to 1000 km for typical high-latitude CAOs and is found to be almost independent of wind speed.

This work was supported by the SFB/TR172 project “ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes and Feedback Mechanisms” (AC)^3 funded by Deutsche Forschungsgemeinschaft.

Meter-scale horizontal variability of the cloud top radiative cooling derived from airborne spectral imaging over Arctic stratocumulus

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Stratocumulus covers approximately 20 % of the Earth's surface in annual mean, leading to a strong influence on the atmospheric and surface radiative energy budget. A complex system of various processes and feedback mechanisms control the dynamics in stratocumulus. E.g., the cloud top radiative cooling leads to convective instability and drives the circulation within the cloud. In order to improve our understanding of the horizontal variability of relevant radiative processes in Arctic stratocumulus, airborne spectral imaging measurements were performed onboard the Polar 5 research aircraft from the Alfred-Wegener-Institute for Polar and Marine Research (AWI). The flights took place during the VERDI campaign (Vertical Distribution of Ice in Arctic Clouds) in April and May 2012 over the southern Beaufort Sea. Cloud top radiative cooling rates were obtained from the spectral imaging system AISA Eagle, which provides fields of liquid water path (LWP) and effective droplet radius with pixel sizes smaller than 4 m x 4 m [1]. These data were used as input for radiative transfer simulations applying the independent pixel approximation to calculate the cloud top radiative cooling rate for each pixel of a cloud field of approx. 4.5 km x 1.1 km.

The research flights did probe the same area on three consecutive days (15.-17. May 2012). During this period, a strong subsidence was present, leading to a subsidence inversion with increasing inversion strength and decreasing inversion height with time. This enabled to study the cloud top radiative cooling for inversions of different strength and altitude above the same persistent cloud. The simulations showed large differences in the mean cloud top radiative cooling of the three measurement examples, correlating with height and strength of the temperature inversion. The strongest cloud top radiative cooling was found for the highest and weakest inversion in combination with the largest LWP. Horizontal inhomogeneities of the cloud top radiative cooling are visible down to horizontal scales of less than 20 m. The variability of the cloud top radiative cooling was found to be correlated with the inversion parameters, resulting in an overall variability of 12 $\mathrm{K\,h^{-1}}$ for the weakest inversion and 3 $\mathrm{K\,h^{-1}}$ for the strongest inversion. This illustrates the strong impact of the temperature inversion on the cloud top radiative cooling. Furthermore, fields of the downward vertical velocity resulting from the radiative cooling were calculated. Significant differences in the mean vertical velocity were found over the three days as well as an increasing horizontal gradient with decreasing inversion strength.

References

[1] M. Schäfer, E. Bierwirth, A. Ehrlich, E. Jäkel, and M. Wendisch, Airborne observations and simulations of three-dimensional radiative interactions between Arctic boundary layer clouds and ice floes, *Atmos. Chem. Phys.*, **15**, 8147-8163 (2015).

Cloud thermodynamic phase discrimination over snow surfaces using passive solar remote sensing

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Despite mixed-phase clouds constitute the most common cloud type in Arctic regions, their contribution to the Arctic Amplification still remains unclear. The not-well-understood associated processes along with the lack of observations yield to serious uncertainties when estimating the mixed-phase clouds radiative forcing. The ice phase has been found to play an important role in this context, which makes a precise discrimination of the partitioning between ice and liquid water within the clouds crucial for a correct determination of such radiative forcing.

Traditional methods for phase discrimination rely on the different absorption of liquid water and ice in certain spectral regions. These differences imprint into the cloud top reflectivity as observed by airborne or satellite remote sensing. By different mathematical approaches, these spectral signatures between 1500 nm and 1800 nm have been used to extract parameters which serve as phase indices. E.g., the slope of a linear regression, the first component of a principal components analysis and the equivalent water thickness due to liquid water and ice derived by a spectrum fitting algorithm have been presented in literature. However, the performance of these methods has been demonstrated only for clouds over land or ocean, where surface albedo is low. In Arctic regions, snow and ice surfaces have similar spectral features compared to ice clouds and may bias the cloud phase indices. We have assessed the applicability of these phase indices over a series of simulated liquid, ice, and mixed-phase clouds with different microphysical and optical properties. The suitability of the phase indices has been tested not only over water surfaces (dark surfaces) but also over snow surfaces of different snow grain sizes (i.e. bright surfaces of variable albedo). In general, it was found, that all methods are able to discriminate the cloud phase also for clouds over snow surfaces if cloud optical thickness is high and the thresholds are adjusted. For clouds of low optical thickness, the surface reflection may dominate the reflected radiation above the clouds and bias the phase index to values representing ice clouds. This holds especially for snow with small grain sizes which have higher albedo values in the wavelength range of interest. Additionally, the feasibility of a quantitative estimation of the ice and liquid water path using the proposed phase indices is tested.

Method development and first measurements of marine biopolymers and ice nucleating particles for the application in Arctic field samples

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The knowledge about the origin and chemical composition of aerosol particles in the Arctic is sparse. Recently, marine biopolymers, found in both the sea surface microlayer (SML) and the bulk sea water, have been discussed as potential constituents of ice nucleating particles (INPs) [1] and cloud condensation nuclei (CCN) [2].
Transparent exopolymer particles (TEP), a special group of marine biopolymers, are gelatinous, stainable exudates from marine microorganisms in seawater. To date, there are few analytical measurements for TEP available, especially in marine aerosol particles. As a first step for increasing existing data, an analytical method based on staining the TEP and measuring them spectrophotometrically was adopted within this project to detect TEP and their concentrations in marine field samples. In preliminary experiments with samples from the Baltic Sea we could demonstrate that TEP are present in sea water and aerosols as well. Diameters of these particles ranged from 10-200 µm. These findings might suggest a sea-air phase transfer of TEP.
For a more detailed characterization of the chemical composition of marine aerosols and sea water on molecular level, a new procedure for the quantification of carbohydrates is currently being developed. High Performance Anionic Exchange Chromatography with Pulsed Amperometric Detection (HPAEC-PAD) is a highly sensitive and quick method for sugar analysis, but suffers from strong vulnerability to sea salt. Therefore electrodialysis as a desalting preparation step has been tested. We could demonstrate that electrodialysis allows a reduction of sea salt up to 99.4% for small (5 ml) and high (200 ml) quantities, while carbohydrate analytes can be retained.
Existing methods for the quantification of the ice nucleation behavior of INPs on liquid samples [3,4] have been adapted, optimized, and applied to SML samples of different origins.

These newly developed and/or optimized analytical methods will be applied to Arctic sea water and aerosol samples that will be collected during the field campaign PASCAL aboard the German research vessel *Polarstern* from May to July 2017. From our comprehensive measurements we aim to identify relations between chemical information (e.g. the presence of marine biopolymers) and their physical properties (e.g. IN and CCN activity).

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Retrieval of aerosol optical thickness from passive remote sensing over the Arctic region

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Aerosols in the Arctic are more important for the regional energy balance than elsewhere, because their scattering and absorption are enhanced by the large reflectivity from snow and ice surfaces in the solar spectral region. Aerosol optical properties, especially Aerosol Optical Thickness (AOT), over the Arctic are currently sparsely provided by *in-situ* or active remote sensing observations with very limited coverage. Arctic aerosol observations from passive remote sensing are needed to fill the sparseness in order to reduce the uncertainty in the knowledge on the properties of Arctic aerosol during the recent Arctic amplification.

The surface – atmosphere system over the Arctic regions is dominated by the surface contribution in the solar spectral region under cloud-free condition. Thus besides the cloud masking, there are three additional key aspects need to be addressed. The first one is to precisely describe the surface bidirectional reflectance distribution function (BRDF) because small error due to surface contribution can be larger than the aerosol information content. Secondly, the space-time dependent aerosol micro-physical properties like the scattering and absorbing characteristic over the Arctic region are not well-known. Thirdly, radiative transfer modeling for large sun zenith angle needs to be taken into account. In this work, we present a method for AOT retrieval over snow/ice-covered surfaces addressing all three aspects listed above. The assumption is that dual-view measurements are not sensitive to the snow/ice albedo (BRDF "magnitude"), but rather the BRDF shape. For different snow-covered surface types, the surface reflectances are estimated by a mixing model between snow and ice, tuned by the normalized Differential Snow Index (NDSI). The aerosol micro-physical properties are derived using *in-situ* measurements to represent background aerosol and "Arctic haze" event. The AOT is obtained using Look-Up-Table (LUT) method by minimizing the satellite-observed and radiative transfer simulated dual-viewing surface reflectance ratio. The smooth transition of the AOT over snow/ice covered regions and the adjacent Arctic Ocean (from MERIS XBAER product) qualitatively show the promising quality of passive remote sensing derived AOT over the Arctic. Quantitative validation between ground-based measurements and satellite-derived results show good agreement. The above idea has been implemented and reported in Mei et al. (2013a, 2013b). The method can be used for instrument like AATSR and synergy of Terra/Aqua MODIS observations. All analysis illustrates that the proposed method can be used to derive long-term AOT data record to understand "How have the aerosol properties and surface reflectance changed over the Arctic temporally and spatially".

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Microwave brightness temperatures simulations at AMSU-B frequencies for a polar low case on 7th of January 2009

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A polar low is a is a small-scale, short-lived and intense maritime cyclone whose horizontal scale is typically less than 1000 km and surface winds can be above gale force. These small, but very intense cyclones can bring huge amount of precipitations which combined with strong winds can cause severe damage in coastal communities. Here we investigate how well Arctic System Reanalysis (ASR, 30 km) based simulations are able to represent the polar low observed on 7th of January 2009. We choose this case because compared to other cases this one was more intense in terms of temperature difference between sea surface temperature (SST) and temperature at 500 hPa (T_{500}) reaching 52 K and strong winds reaching the magnitude of 25 m/s [1]. Simulations of microwave brightness temperatures (BT) at Advanced Microwave Sounding Unit B (AMSU-B) frequencies (89, 150, 183.31± 7, 183.31± 3, 183.31 ± 1 GHz) were performed using radiative transfer model PAMTRA (Passive and Active Microwave Radiative Transfer Model). It was found that AMSU-B 183 GHz channels reveal strong snowfall around polar low cores that match well with BT difference between core and the cloud band of more than 40 K. Strong depressions that are present in the simulation could be due to the coarse resolution of the ASR that parametrizes precipitation processes. Another reason could be the description of snow hydrometeors in terms of size or density distribution. In general, the simulations show better performance over ocean with degrading agreement over land mostly because of emissivity being more variable over land than over open ocean. The presentation will give an overview on the methodology how reanalysis is related to BT and quantitatively evaluate its performance.

This work was supported by the German Research Foundation DFG Transregional Collaborative Research Centre TR 172

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Sensitivity of the surface albedo on micro- and macrophysical snow properties including Black Carbon

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Black Carbon (BC) is a strong absorbing aerosol. For the Arctic region it represents the second most important anthropogenic emission product which may lead to a radiative forcing of 0.17 to 2.1 W/m² [1]. To analyze the radiative effects of the BC particles also with respect to snow metamorphism more deeply, it is necessary to get the information about the BC amount in the snow. BC has a direct effect on the spectral surface albedo. Exemplarily, 30 ppb BC can reduce the snow albedo by 3 to 6%. This sensitivity of the spectral albedo on BC is used to retrieve its concentration. However, the remote sensing of BC in snow is still challenging, in particular when the retrieval sensitivity is in the range of the measurement uncertainty [2]. Furthermore, the spectral signature of snow albedo depends on further micro- and macrophysical parameters, as grain size and shape, depths and density of the snowpack and the properties of the underlying soil layer.

To reduce the existing BC retrieval issues there is a need to (i) reduce the measurement uncertainties, (ii) to characterize the above-mentioned dependencies. It is planned to use relative instead of absolute spectral changes to minimize the measurement uncertainty. However, to separate the effects of the various parameters other than BC concentration, multispectral sensitivity studies based on TARTES (Two-streAm Radiative TransfEr in Snow) model are performed. TARTES is a snow model and can simulate the spectral albedo and profiles of irradiance in snow [3]. The most important input parameters are the specific surface area, the impurity amount and type, the solar zenith angle and the albedo of the soil layer. Exemplarily, Fig. 1 shows simulations of the spectral albedo with a variable amount of BC and grain size. Each of the two parameters affects the spectral albedo in a different spectral range. The snow grain size influences mainly the near infrared wavelength range, whereas BC shows most signature in the visible. But also the sensitivity on the macrophysical snow properties as on the thickness of the snow layer will be presented. Furthermore, the effect of an underlying ground layer with different albedo values is investigated.

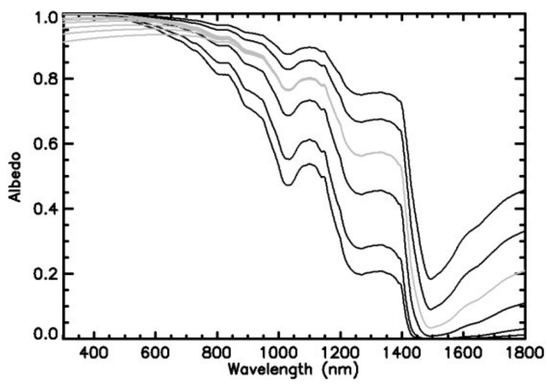

Fig. 1: Spectral snow albedo in dependence of BC (0 - 4 ppm, grey) and grain size (10-800 μm, black).

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Investigating variability and trend of three major phytoplankton groups during the period of rapid change based on modeling and satellite retrievals

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The Laptev Sea around the Lena River delta in northern Siberia is a very remote area where in-situ measurements are only sparsely available. Polar night and long-lasting ice coverage until the end of June makes it difficult to investigate the area all year round. Here satellite investigations of radiances measured e.g. with Envisat-MERIS satellite and derived inherent optical properties (IOP) may help to generate a time series of changing water constituents, phytoplankton pigments (mainly indicated by chlorophyll concentration), coloured dissolved organic matter (CDOM) and suspended particles (SPM). However, large solar zenith angles and cloud coverage in summer after ice break-off limit to investigate this region by remote sensing applications. Therefore modelling approaches are a useful first approximation to identify the feedback to the radiation and the impact on the heat budget in these remote areas. Here, we investigate the influence of CDOM and SPM on the radiative heat transfer into the shelf regions of the Laptev Sea. As a first step we use the coupled atmosphere-ocean radiative transfer model SCIATRAN ([1], [2]) to assess energy input into coastal waters of this region dependent on different concentrations of CDOM varying significantly for different times of the year. The top of atmosphere and surface ocean radiation fluxes are compared to MERIS top of atmosphere and top of ocean data. The later have been corrected with adapting the atmospheric correction scheme developed by Steinmetz et al. [3] to the Arctic Ocean by modifying the underlying ocean optical model following Matsuoka et al. [4]. Low solar elevations and high absorption by water constituents in this area extremely reduces the light penetration depth in the water body. An increased absorption in the surface water leads to higher sea surface temperatures and a high energy release into the atmosphere often occurring in late autumn and consequently influences the ice development process. In the context of climate change and thawing permafrost in Siberia the riverine input of those highly absorbing particles by Lena river may increase in the future. Therefore, a better understanding of these processes is necessary to predict possible future changes for that remote area.

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Influence of varying opening angle and spectral bandwidth on bidirectional reflectance factors

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Changes in optical surface properties in the Arctic are a major driver of the Arctic amplification effect. Particularly, the alteration of the Arctic spectral surface albedo is a crucial key quantity which strongly affects the surface radiative energy budget. To determine the changes in the albedo and hence in the Arctic amplification, directional surface reflectivity measurements, as from satellites or aircraft, are needed over the Arctic. These measurements are converted in spatial distributions of spectral bidirectional reflectance factors (BRFs) to obtain finally the spectral surface albedo.
A direct comparison of the different sensor products from satellite and aircraft observations is difficult due to e.g., different fields of view (FOVs) and spectral bandwidths. The diversity in these sensor specifications introduces an uncertainty in the comparison of ground truth and satellite and airborne BRFs, respectively, and accordingly in the derivation of the albedo.
The influence of different FOVs and different spectral bandwidths on the BRF are analyzed for a variety of snow types. Snow BRF is simulated by the radiative transfer model SCIATRAN in a standard Arctic atmosphere at 75°N under variable solar zenith angles (55° - 80°). The dependence of the BRF on the FOV and spectral bandwidth of the sensor will be presented. This allows an estimation of the uncertainties of the different observation techniques. The uncertainties tend to increase with the solar angle and with the albedo of the surface, which are most common cases in the Arctic.

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The linkage between Arctic sea ice changes and mid-latitude atmospheric circulation in reanalysis data and model simulations-Tropo-stratospheric coupling and barotropic-baroclinic interactions

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Observed global warming trends have their maximum in Arctic regions, a phenomenon referred to as Arctic Amplification. Consequently, Arctic sea ice shows a strong decreasing trend. These changes imprint modifications on atmospheric flow patterns not only in Arctic regions themselves. Changes of teleconnections and planetary scale motions like Rossby waves affect mid-latitude climate as well.

We identified mechanisms that link recent Arctic changes through vertically propagating planetary waves to weakening events of the stratospheric polar vortex. Related anomalies then propagate downward and lead to negative AO-like situations in the troposphere. These results based on ERA-Interim reanalysis data do not allow to entirely dismiss other potential forcing factors leading to observed mid-latitude climate changes. More importantly, properly designed Atmospheric General Circulation Model (AGCM) experiments with AFES and ECHAM6 are able to reproduce observed atmospheric circulation changes if only observed sea ice changes in the Arctic are prescribed. This includes the potential mechanism explaining how Arctic Amplification can lead to a negative AO response via a stratospheric pathway. Furthermore, the impact of sea-ice changes on changes in atmospheric synoptic and planetary waves and its interactions has been studied by analysing the atmospheric kinetic energy spectra and the nonlinear kinetic energy and enstrophy interaction changes.

Snow depth retrieval on Arctic sea ice from satellite radiometers – extension to lower frequencies

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During winter most of the Arctic sea ice is covered by a snow layer. Due to its thermal and optical properties snow plays an important role in the Arctic climate system. Its thermal conductivity is about one order of magnitude less than that of sea ice, i.e. insulates more, and therefore influences the heat exchange between sea ice and atmosphere. Due to its high albedo snow influences the Arctic energy budged. To calculate the sea ice thickness from ice freeboard measurements, which is an important input parameter for global climate models, knowledge about the snow depth on top of the sea ice is crucially needed.

Passive microwave satellite radiometers are a useful tool for retrieving snow depth on Arctic sea ice on a large spatial scale. They are independent of sunlight, only weakly affected by clouds and provide daily coverage of the whole Arctic. In the microwave spectrum, volume scattering within the snow layer influences the emitted radiation and therefore influences the brightness temperature (Tb) measured by the satellites. The current snow depth retrieval [1] uses the gradient ratio (equation 1) of the brightness temperatures at v1 = 37 GHz and v2 = 19 GHz.

$$GR(Tb_{v1}, Tb_{v2}) = \frac{Tb_{v1} - Tb_{v2}}{Tb_{v1} + Tb_{v2}} \qquad (1)$$

However, in the Arctic there are limits for the application of the algorithm. Snow depth cannot be retrieved over multiyear ice (ice that has survived at least one summer melt), which covers a substantial part of the Arctic Ocean. The retrieval is most sensitive to snow depths below 0.5 m. and limited to freezing conditions, i.e. winter. Thaw/refreeze events, which frequently occur in the Arctic strongly influence the retrieved snow depth leading to high daily fluctuations.

With the launch of the satellites Aqua (2002) and GCOM-W (2012) passive microwave measurements from the AMSR-E/2 radiometers at lower frequencies became available. Studies have shown [2] that lower frequencies have a higher penetration depth into the snow and are less influenced by thaw/refreeze events and ice layers within the snow. In a pilot study we derived a new algorithm testing available frequencies to their sensitivity to snow depth. As a training dataset we used Arctic snow depth measurements from an airborne snow radar, which were obtained during the OperationIceBridge (OIB) campaign [3]. The results show that GR(19/7) has the highest correlation with OIB snow depth measurements (R^2 = - 0.62 over firstyear ice). Additionally, we found that GR(19/7) has a reasonable correlation with snow depths over multiyear ice (R^2 = - 0.46), although the uncertainty is high. However, at the current state realistic results over multiyear ice can only be obtained in March and April. Time series of snow depth over first-year ice from 2003 to 2016 show high interannual variability.

The AMSR-E product (V3) and the OIB product (V1) were distributed by the National Snow and Ice Data Center (NSIDC), Boulder USA. The AMSR-2 product was provided by Courtesy of JAXA. This study was supported by the SFB/TR 172 "ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes and Feedback Mechanisms (AC)³ in Project D03 funded by the DFG.

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Warming the Arctic with moist intrusions

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The Arctic is the region where the most dramatic climate change is expected. There is increasing evidence that the Arctic winter climate is strongly controlled by filamentary intrusions of moist, warm air—akin to the atmospheric rivers of lower latitudes—which penetrate deep into central Arctic. I will first discuss our recent observational work [1,2] on how the statistical distribution of these intrusions is affected by large-scale atmospheric circulation, particularly midlatitude storm track activity, blocking events, and possibly by interaction with the stratosphere. A key finding is that most of the climate impact is due to a relatively small subset of the most extreme intrusions. These extreme intrusions occur roughly once per week on average during winter and produce very large positive surface temperature anomalies over the central Arctic pack ice, as well as large reduction of sea ice cover where they cross the marginal ice zone.

Secondly, I will discuss how well the statistics of moist intrusions are represented in historical CMIP5 simulations compared to reanalysis [3]. We find that most models show too little poleward moisture flux in the Atlantic sector but an excess flux in the Pacific sector. At the same time, models exhibit a robust deficit of storm track activity and a cold bias in the northern North Atlantic, and excess eddy activity and a warm bias in the Pacific sector. Using a Lagrangian trajectory algorithm, we also compute climatological intrusion trajectory densities and examine how the bias in these trajectory densities is related to biases in the large-scale atmospheric circulation within the Arctic basin. Finally I will describe ongoing work into how the statistics of moist intrusions are expected to change in future based on CMIP5 scenario simulations.

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Aerosol as a player in the Arctic Amplification – an aerosol-climate model evaluation study

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Climate warming is much more pronounced in the Arctic than in any other region on Earth – a phenomenon referred to as the "Arctic Amplification". This is closely related to a variety of specific feedback mechanisms, which relative importance, however, is not yet sufficiently understood. The local changes in the Arctic climate are far-reaching and affect for example the general atmospheric circulation and global energy transport. Aerosol particles from long-range transport and local sources play an important role in the Arctic system by modulating the energy balance (directly by interaction with solar and thermal infrared radiation and indirectly by changing cloud properties and atmospheric dynamics). The main source regions of anthropogenic aerosol are Europe and East Asia, but also local shipping and oil/gas extraction may contribute significantly. In addition, important sources are widespread, mainly natural boreal forest fires. Most of the European aerosol is transported through the lower atmospheric layers in wintertime. The Asian aerosol is transported through higher altitudes. Because of the usually pristine conditions in the Arctic even small absolute changes in aerosol concentration can have large impacts on the Arctic climate.

Using global and Arctic-focused model simulations, we aim at investigating the sources and transport pathways of natural and anthropogenic aerosol to the Arctic region, as well as their impact on radiation and clouds. Here, we present first results from an aerosol-climate model evaluation study. Simulations were performed with the global aerosol-climate model ECHAM6-HAM2, using three different state-of-the-art emission inventories (ACCMIP, ACCMIP + GFAS emissions for wildfires and ECLIPSE). The runs were performed in nudged mode at T63 horizontal resolution (approximately 1.8°) with 47 vertical levels for the 10-year period 2006-2015.

Black carbon (BC) and sulphate (SO4) are of particular interest. BC is highly absorbing in the solar spectrum, an effect that is enhanced by the contrast between the bright snow/ice surfaces and the dark BC. When deposited on snow and ice, BC also accelerates melting and lowers the surface albedo. SO4 however is more scattering and, therefore, cooling.
The model results are compared among each other and evaluated against ground-based in-situ and remote sensing, as well as active satellite observations. The following questions are addressed in the evaluation: 1) Are the sources and transport pathways of aerosol to the Arctic region captured? 2) Is the annual cycle of aerosol conditions reproduced? 3) What are uncertainties related to the emission database?

After thorough evaluation, the model results will provide a state-of-the-art estimate of the aerosol budget and the effective radiative forcing by anthropogenic aerosols in the Arctic region.

Large Eddy Simulations at Ny-Ålesund with ICON-LEM

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To understand and parameterize cloud processes, information about several quantities (e.g. humidity) and its variability on all spatial- and time scales are essential. Part of these information can be provided by large eddy simulations, but before those can be used as a virtual reality, a detailed evaluation based on observational products is required.

Here, first large eddy simulations have been performed over Ny-Ålesund with the ICON-LEM (Dipankar, et.al. 2015) and are set into context to the extensive observations of the AWIPEV atmospheric observatory. Model simulations have been realized by applying a 4-way nesting with 600 m, 300 m, 150 m and 75 m horizontal resolution, using open boundaries and a realist orography. Initial and hourly forcing data are taken from the ECMWF Integrated Forecasting System. Model results for the location of the AWIPEV observatory are provided as highly temporally resolved, i.e. 9 s, column output and are thus comparable to the temporal scales of the measurements. The measurements encompass, among others, observations from the recently installed 94 GHz cloud radar, from ceilometer, microwave radiometer, radiosondes, and standard meteorological observations.

A first qualitative comparison between model results and observations for one day (16 August 2016) revealed a reasonable model performance: the occurrence and timing of low-level and high ice clouds during that day is well captured. Fig. 1 shows examplarily the time series of observed and modeled liquid water path (LWP) on that day. Except for the clouds around noon, the timing and variability of LWP is well reproduced by ICON-LEM.

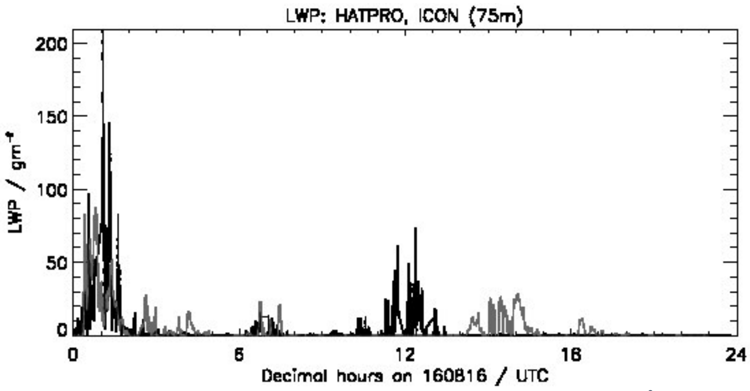

Fig. 1: Time series of LWP on 16 August 2016 at Ny-Ålesund. Black: Observed LWP from microwave radiometer. Grey: LWP from ICON-LEM using 75 m resolution

Here, we will present an extended model evaluation, which will also be based on a longer time series (e.g. 13 – 24 September 2013). In this time period, radiosonde information is available 6 times per day and thus allows for a detailed evaluation of the modeled boundary layer structure.

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Origin and characteristics of lower-tropospheric air masses above Ny-Ålesund during different flow conditions

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During the last two decades, the tropospheric air column above the Arctic site Ny-Ålesund has experienced a strong increase in winter temperature and humidity, together with a higher likeliness for southerly synoptic flow conditions [1]. Here, our attempt is to analyze if the observed changes in advection towards Svalbard also reflect changes in the source region of the air and hence possibly modulate air mass characteristics at Ny-Ålesund. The study is based on the homogenized daily radiosonde data from Ny-Ålesund in 1993 – 2016 to reveal the impact of the synoptic flow direction on local thermodynamic properties of the tropospheric air above Ny-Ålesund.

By combining the daily radiosonde data with FLEXTRA 3D air back trajectories [2] at 1500m height, preferred source regions of the lower–tropospheric air above Ny-Ålesund are identified. Furthermore, the characteristics of air masses from different source regions are contrasted over the annual cycle. Finally, decadal trends for the occurrence probability of air particles originating in a certain source region are evaluated for each season, and the link between source regions and different atmospheric circulation patterns is investigated based on ERA-interim sea level pressure analysis.

This work was supported by the SFB/TR 172 "ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms (AC)³" in Project E02 funded by the Deutsche Forschungsgemeinschaft (DFG).
NILU is acknowledged for providing the FLEXTRA trajectories (www.nilu.no/trajectories) used in this study.

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Analysis of feedback uncertainties contributing to the spread in Arctic warming amplification

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Climate feedbacks associated with changes in sea-ice albedo, water vapor, temperature, and clouds have been found to majorly impact the observed amplified Arctic warming. However, Arctic amplification is modeled with a wide spread which partly arises due to inter-model differences in the various feedbacks.
In order to explain the spread in modeled Arctic warming, we have quantitatively investigated the feedback uncertainties and their origins from 13 CMIP5 models by comparing characteristics of global and Arctic averaged feedbacks.

While the cloud feedback mainly determines the spread of effective climate sensitivity in the global mean, we find that in the Arctic the cloud feedback is not responsible for the spread in Arctic warming as its contribution is too small. Instead, the spread of Arctic warming is rather determined by differing estimates of surface albedo and Planck feedbacks which show the largest inter-model differences. These uncertainties have been found to be related to differences in initial sea ice cover and surface temperatures which are especially large in the Arctic compared to the global mean and directly contribute to the increased spread in estimated warming.

The most striking feature of this analysis is revealed by the total feedback parameter. While all models investigated here simulate a global mean negative total feedback leading the system to a new equilibrium climate state, only half of them also show a negative Arctic feedback. The other half exhibits a positive total Arctic feedback indicating a local runaway system which must be balanced by fundamentally different heat fluxes in these models. Whether or not a model features such a behaviour might depend on the strength of simulated surface albedo feedback – which in turn is uncertain as it depends on initial conditions.

Therefore, we suggest to improve the representation of preindustrial Arctic sea ice and temperature fields to reduce some of the deviations in models' initial conditions. In addition, further investigations of the feedbacks' state dependencies are needed to better assess the relation of initial conditions and projections of a certain climate parameter.

This work was supported by the SFB/TR 172 "ArctiCAmplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms (AC)³" in Project E01 funded by the Deutsche Forschungsgemeinschaft (DFG).

Investigating mixed phase clouds using a synergy of ground based remote sensing measurements

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Clouds have a strong influence on the Earth's radiative budget, and specifically in the Arctic low-level stratiform clouds are a major contributor to cloud radiative forcing at the surface [1]. These occur frequently as mixed phase clouds in the Arctic and can persist from hours to several days [2]. However, the processes that lead to the commonality and persistence of these clouds are not well understood. The aim of our work is to get a more detailed understanding of the dynamics of and the processes in Arctic mixed phase clouds using a combination of instruments operating at the AWIPEV station in Ny-Ålesund, Svalbard. In order to study micro-physical processes, retrievals for micro-physical parameters from Doppler cloud radar will be developed, utilizing data collected during the ACLOUD campaign.

To better describe the micro-physical properties of low-level mixed phase clouds, we investigate the potential of the radar Doppler spectra during a case study of a persistent mixed phase cloud observed above the AWIPEV station. In the frame of the $(AC)^3$ -project, a millimeter wavelength cloud radar was installed at the site in June 2016. The high vertical (4 m in the lowest layer) and temporal (2.5 sec) resolution allows for a detailed description of the structure of the cloud. In addition to radar reflectivity and mean vertical velocity, we utilize the higher moments of the Doppler spectra, such as skewness and kurtosis. To supplement the radar measurements, a ceilometer is used to detect liquid layers inside the cloud. Liquid water path and integrated water vapor are estimated using a microwave radiometer, which together with soundings can also provide temperature and humidity profiles in the lower troposphere. Moreover, profiles of the three-dimensional wind vector are obtained from a Doppler wind lidar. The variability in the vertical wind component can be used to estimate the amount of turbulence, and makes it possible to identify stable and turbulent layers in the boundary layer (wind lidar) and in the cloud (radar).

The Cloudnet scheme (www.cloud-net.org), that combines radar, lidar and microwave radiometer observations with a forecast model to provide a best estimate of cloud properties[3], is used for identifying mixed phase clouds. The continuous measurements carried out at AWIPEV make it possible to characterize the micro-physical properties of mixed-phase clouds on a long-term, statistical basis. Furthermore, the synergy of instruments allows studies of the interaction of dynamics and micro-physical processes in the cloud.

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Water mass modification processes and water transport into the Arctic

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Warm water from the Atlantic and the Pacific affect the Arctic sea ice cover ice free areas of summer heating tend to stay ice free into the freezing season even small spatial shifts in open water positions and sea ice formation areas are shifting as well and the flow of cold and saline water into the Arctic proper is modified. Thus different amounts of Arctic intermediate Water (AIW) form and exit the Arctic Ocean into the Nordic Seas. There Isopycnal surfaces corresponding to overflow waters are rising or sinking resulting outflow into the North Atlantic which occurs as overflow of the of Greenland Scotland Ridge the deep export must by volume be matched by inflowing Atlantic Water, thus closing the feedback loop. Here, I'll summarize the linkages and point out gaps in our current knowledge and understanding of the transport and water mass modification processes.

Chemical composition of aerosol particles in the Arctic summer – Anthropogenic and biogenic influences

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Airborne measurements on board the research aircraft Polar 6 (operated by the Alfred Wegener Institute for Polar and Marine Research) were conducted from Resolute Bay, Nunavut (Canada) during July 4-21, 2014 as part of the "Network on Climate and Aerosols: Addressing Key Uncertainties in Remote Canadian Environment" (NETCARE). The aircraft was equipped with instrumentation for physico-chemical aerosol analysis, several trace gases, and meteorological parameters.

Chemical composition measurements on single aerosol particles (size range ca. 200 to 2000 nm) were performed in different altitudes (between 50 and 3000 m) during the Canadian High Arctic summer by means of the Aircraft-based Laser Ablation Aerosol Mass Spectrometer (ALABAMA [1]).

On basis of the single particle analysis, we could identify two main particle types: trimethylamine (TMA)-containing and levoglucosan-containing particles. Interestingly, these two particle types show different size distributions (Fig. 1) and vertical profiles (Fig. 2). TMA-containing particles are smaller and the associated vertical profile peaks at low levels. Based on the spatial distribution of TMA-containing particles and chlorophyll-a concentration as well as associated wind direction and speed, oceanic phytoplankton biomass could be assigned as a source for gaseous TMA emission in the Arctic boundary layer [2]. Most likely condensation on pre-existing particles and/or dissolution in cloud droplets with subsequent acid-base reaction formed particulate TMA. In contrast to TMA-containing particles, the relative fraction of levoglucosan-containing particles peaks at upper levels. Simultaneous trace gas measurements of CO and CO_2 in combination with the Lagrangian analysis tool FLEXPART indicate a strong influence on levoglucosan-containing particles from biomass burning originating in the Northwest Territories 2-3 days before the measurements above Resolute Bay.

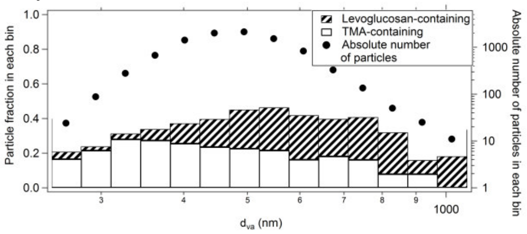

Fig. 1. Size-resolved fraction of levoglucosan- and TMA- cont. particles as well as absolute number of particles.

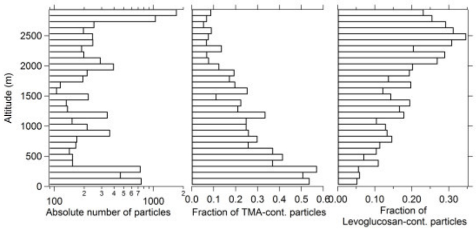

Fig. 2. Vertically resolved profiles of absolute number of particles, TMA- and levoglucosan-cont. particles.

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Investigation of the Directional Structure of Horizontal Cloud Inhomogeneities Derived from Ground-Based and Airborne Spectral Imaging and Cloud Resolving Models

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Clouds exhibit considerable horizontal inhomogeneities of their optical and microphysical properties. This complicates their realistic representation in weather and climate models. In order to investigate cloud inhomogeneities with respect to their horizontal structure, two-dimensional (2D) fields of optical thickness of subtropical cirrus and Arctic stratus are investigated. The applied 2D cloud optical thickness fields with a spatial resolution of less than 10 m are derived from (a) ground-based measured downward (transmitted) solar spectral radiance fields of four subtropical cirrus clouds, and (b) upward (reflected) radiances measured airborne above ten Arctic stratus clouds. The measurements were performed during the two field campaigns: (a) Clouds, Aerosol, Radiation, and tuRbulence in the trade wInd regime over BArbados (CARRIBA), and (b) VERtical Distribution of Ice in Arctic clouds (VERDI). One-dimensional (1D) inhomogeneity parameters and 2D autocorrelation functions are derived from the retrieved fields of cloud optical thickness. For each measurement case, the typical spatial scale of horizontal cloud inhomogeneities is quantified. The results reveal that considerable cloud inhomogeneities with prevailing directional structures are found in most of the investigated cloud cases; the cloud inhomogeneities favour a specific horizontal direction while across this direction the cloud is of homogeneous character. The investigations show that it is not sufficient to quantify horizontal cloud inhomogeneities by 1D inhomogeneity parameters; 2D parameters are strongly required. Additionally, the applied methods are used in conjunction with simulated fields of Arctic stratus obtained from cloud resolving models in order to (I) validate model results against measurements and (II) to increase the number of available cloud fields, which improves the statistics of investigated cloud cases.

Balloon-borne vertical turbulence profiles: Measurement setup and exemplary data

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Turbulent energy fluxes in the Arctic
Quantifying vertical energy fluxes in the Arctic Atmospheric Boundary Layer (ABL) is most important for understanding the exchange of energy between the surface and higher altitudes, and therefore is a key factor to understand the changing atmosphere in a warming Arctic. The structure of the Arctic ABL often differs significantly from the mid-latitudes [1] due to complex stratification. However, vertical profiles of energy fluxes in the central Arctic are still rare due to the challenging conditions in that region. Therefore, we propose to measure tethered-balloon borne profiles of turbulent energy fluxes in the Arctic under different stratification and cloud conditions.

Measuring fluxes with a tethered balloon system
It has been recently shown, that turbulence can be well measured with a tethered balloon system in the mid latitudes [2], as well as under Arctic conditions [3]. Based on that experience, several turbulence probes have been recently developed for a balloon deployment. The measurements will be performed during the Polarstern cruise PASCAL in June 2017.

Fig. 1. TROPOS tethered balloon system in the mid-latitude ABL

The balloon carries two different sensor packages for turbulence measurements: A light-weight hot-wire anemometer package and a more robust three-dimensional ultrasonic anemometer. A standard meteorology package with telemetry link to the ground monitors the mean ABL conditions. The sensors can be attached to the tether in different combinations. Additional radiation packages, developed by the University of Leipzig, will complete the observations. The sampling strategy will include vertical profiling, but also measurements in a fixed height to ensure stable statistics.

Here, we will present first results of balloon-borne turbulence measurements performed during an extensive test campaign under winter conditions in Melpitz close to Leipzig.

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Ship-based Studies of AOD in the Norwegian and Greenland Seas between 2007 and 2016 within the NASA-MAN Project

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Absorption and scattering of radiation by aerosols directly affect the radiation balance of the Arctic, which is thought to be very sensitive to changes in radiative fluxes. This is due to small amount of solar energy normally absorbed in the polar regions. These regions represent sensitive ecosystems, which are susceptible to even small changes in the local climate. Thus, for a given aerosol distribution, the specific optical properties are enhanced in these regions.

Our Arctic studies of aerosol optical properties within the NASA Maritime Aerosol Network program were originated in 2007 during the ARctic EXperiment (AREX) campaigns using the r/v *Oceania*. Every year the vessel cruises for seven weeks (June-August) in the area of the Norwegian and the Greenland seas, typically between 0 and 14°E and 69 and 80°N. The aerosol studies are conducted using an ensemble of instruments, including laser particle counters, sunphotometers and ozonometers.

Arctic aerosols in the Spitsbergen area show significant temporal and vertical variability. The results collected during the campaigns can be divided into two groups, the spring data and the summer data. Each winter, cold dense air settles over the Arctic. In the darkness, the Arctic seems to become more and more polluted by a buildup of mid-latitude emissions from fossil fuel combustion, smelting and other industrial processes. Then, in spring, when the light appears, there is a smog-like haze in the Arctic region. The values of aerosol optical thickness, e.g. at 500 nm, exceed 0.1 and they can be as high as 0.35.

In summer the situation differs from that in spring. The main problem in aerosol optical studies is related to cloud coverage over the region. Also the air mass trajectories can vary significantly which also influences the aerosol optical thickness. The summer values at 500 nm can also be high, up to even 0.3 (land origin of air masses) but majority of data are below 0.1, which indicates very clean air conditions, with very few aerosol particles suspended in it.

For the purpose of this presentation we discuss only Microtops II sunphotometer summer results, which were obtained from board of the vessel between 2007 and 2016. We will also present our research plans in summer 2017, when two vessels, *Oceania* and *Polarstern* will be involved in aerosol studies in the area of the European Arctic.

In general, the increasing values of AOD are related mostly to air masses carrying anthropogenic pollution from mid-latitudes. This is usually caused by Artic Haze, but recently more and more events are related to biomass burning. Such events reach both stations at different times, which depends on the circulation and orography of the surrounding area.

This research has been partly made within the framework of an AREX Project and starting year 2007 the studies were also made within the framework of the Oceanic Aerosol Network: A maritime component of AERONET.

Quantification of uncertainties on cloud radiative forcing caused by surface heterogeneity

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The radiative effects of Arctic clouds not only depend on the macro – and microphysical properties of the cloud itself, but also on the interaction of radiation between the cloud layer and the surface. In particular for surfaces with high reflection as observed in the Arctic, enhanced multi-scattering processes between surface and clouds affect e.g., the magnitude of the solar cloud radiative forcing (CRF). On the other hand, the presence of clouds alters the reflection properties of the surface due to their dependence on the illumination conditions.

Therefore, the characterization of Arctic surface reflectivity properties is a substantial boundary condition for the understanding of radiative transfer in the Arctic. In this region with strong spatial and spectral contrast of surface albedo between highly reflecting snow/ice and mostly absorbing sea surfaces, radiative transfer becomes a complex three-dimensional (3D) problem. However, in many studies cloud radiative effects are approximated by simulations based on 1D assumptions.

This contribution will specifically present a quantification of 3D radiative effects due to surface heterogeneity on the solar CRF. For this purpose, radiative transfer calculations in full 3D mode will be compared with simulations based on Independent Pixel Approximation (IPA) which represent 1D assumptions neglecting horizontal photon transport. As input for the simulations, surface property maps are derived from measurements gained during two previous field campaigns in the Arctic [ARCTAS (Arctic Research of the Composition of the Troposphere from Aircraft and Satellites) and MELTEX (Impact of sea ice thickness, sea ice topography and MELT ponds on the energy and momentum EXchange between atmosphere and sea ice)]. Since there are local differences of the CRF derived from 1D and 3D simulations, it will be shown if these differences are still relevant for area-averaging of the CRF over different scales.

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In Situ Measurements of Cloud Radiative Cooling and Heating Rates

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Terrestrial radiative cooling at cloud top is a major driver of convection in Arctic stratocumulus. It balances the cloud dynamics and can therefore contribute to the persistence and strong radiative impact of Arctic boundary-layer clouds [1]. Contrarily, the solar cloud heating, which counteracts the terrestrial radiative cooling, is in average comparable small in the Arctic due to low solar zenith angles. However due to a strong seasonal cycle the solar heating may contribute to the stabilization of clouds in Arctic summer.

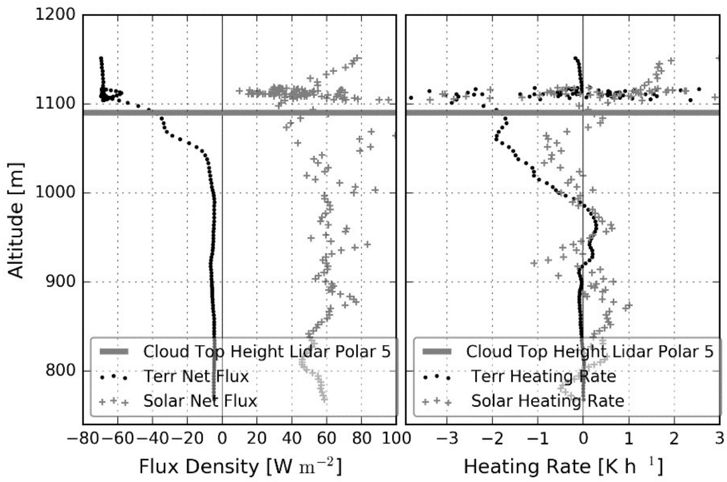

Fig. 1: Cloud profiles retrieved during RACEPAC on the 3. May 2014. a) Terrestrial/solar net flux density profile during ascent. b) Derived heating rates from smoothed flux densities.

To derive the radiative cooling and heating rates by in situ observations different strategies can be applied. Using measurements on a single platform, vertical profiles of the radiative flux densities have to be measured (Approach I). This approach can hardly account for cloud inhomogeneities. Using two collocated measurement platforms (Approach II) the cooling and heating rates can be continuously derived for the layer between both platforms but has a limited vertical resolution. Both strategies will be discussed by analyzing airborne measurements of the Radiation-Aerosol-Cloud Experiment in the Arctic Circle (RACEPAC). Fig. 1 shows net flux density profiles and the calculated cooling rates derived for airborne measurements (Approach I) during RACEPAC. Although the data was smoothed, the prevailing inhomogeneities during this single ascent impede exact interpretations. Averaging of a series of measured profiles or fitting to analytic functions is necessary to obtain reliably results.
Typically, slow response pyranometer and pyrgeometer are used to measure broadband radiation on airborne platforms like aircrafts, helicopters or tethered balloons. The slow response time of these sensors will affect the derived cooling and heating rates especially for sharp cloud top inversions common in Arctic stratocumulus by delaying and smoothing the fast changes of the radiative flux densities. As shown by [2] a reconstruction of high resolution time series can be achieved by correcting the pyranometer and pyrgeometer signal. The improvement of derived cooling and heating rates by application of this method is studied by artificial (based on radiative transfer simulations) and real measurements. It is discussed for which measurement platform (aircraft, helicopter, balloon) and strategy this correction is essential or negligible.

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Microphysical and chemical characterization of cloud particle residues from Arctic mixed-phase clouds sampled during the coming ACLOUD mission

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The contribution of Arctic mixed–phase clouds for the observed strong temperature increase and sea ice decline in the Arctic region (Arctic amplification) is hardly known. This is mainly due to our lack of understanding the diversity of interaction and feedback processes connected to mixed–phase clouds. Especially, the ice phase is found to be a key parameter for the cloud life cycle and their energy budget but observational process studies on ice formation, growth, and sedimentation, are still rare. The micro-structure, phase and persistence of Arctic mixed-phase clouds might depend on meteorological conditions but also on the abundance of aerosol particles acting as cloud condensation nuclei (CCN) or ice nucleating particles (INP) nucleating supercooled drops and ice particles.
One approach to study the aerosol cloud interaction is to sample cloud particles from these mixed-phase clouds and to analyze their cloud droplet and ice particle residuals (CDR and IPR) which can be related to the original CCN and INP for microphysical and chemical properties. In this way it can be at first concluded whether the cloud forming aerosol particles are transported from mid-latitudes or originate from local Arctic sources. For the latter, it will also be possible to differentiate between natural, biogenic and anthropogenic sources. These observations will be related to the ambient aerosol population too, which will sampled when the Polar 6 is flying outside cloud.
This kind of investigation is intended during the airborne ACLOUD (Arctic Cloud Observations Using airborne measurements during polar Day) campaign, which will be conducted in early summer 2017 from Svalbard within the collaborative research center (AC)^3 of the German Research Foundation DFG (SFB/TR 172). During ACLOUD the Polar 5 and 6 aircraft will be operated combining airborne remote sensing with in situ microphysical measurements of cloud and aerosol properties. The Polar 6 will carry the in-situ instrumentation, in particular a counterflow virtual impactor (CVI) inlet system [1, 2]. Due to the construction of the CVI, it is possible to sample cloud particles above a certain minimum size and simultaneously reject smaller non-activated interstitial particles. After collection the cloud particles are still airborne in the sample flow and their condensed water phase is completely evaporated in order to release their residual particle for analysis.
Inside the cabin of the Polar 6 the dry residual particles are guided to several aerosol sensors. The number concentration, size distribution, chemical composition (especially black carbon) and mixing state of cloud particle residuals and ambient air aerosol will be determined in-situ.
More details of the cloud particle sampling, the aerosol instrumentation, but also of the intended combination with other ACLOUD measurements and of the preferred Polar 6 flight pattern will be presented.

This work is supported by the DFG (SFB/TR 172, project B03)

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Changes of Top-of-Atmosphere reflectance over the Arctic from spaceborne measurements

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The amount of solar radiation backscattered and reflected to space is primarily governed by cloud and surface properties and, to a less extent, by molecular scattering, aerosols and various absorbing gases (e.g., O_3, NO_2, H_2O, among others) [1]. Especially over bright surfaces, as is the case in the Arctic region, the analysis of Top-of-Atmosphere reflectance (R_{TOA}) has the potential to provide insights into the dominant mechanisms of the recent warming of the high latitudes, the so-called Arctic Amplification [2]. $R_{TOA,}$ defined as the solar zenith angle-normalized ratio of upwelling radiance to the extraterrestrial solar irradiance, is derived from measurements of the spaceborne spectrometer SCIAMACHY onboard the ENVISAT satellite in the period 2002-2012. The spectral coverage extends from the ultraviolet throughout the shortwave infrared part of the solar electromagnetic spectrum at a varying resolution of 0.2 – 0.4 nm. Selected channels have been used to identify the annual and seasonal cycle of different surface and atmospheric constituents in the Arctic. These long-term datasets not only form the observational basis for the identification of trends, but can also serve as input for the assessment of radiation budgets and as constraints for climate models.

This work was supported by the German Science Foundation (DFG) via the Transregional Collaborative Project TR 172 (AC)[3] (ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms).

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Investigating variability and trend of three major phytoplankton groups during the period of rapid change based on modeling and satellite retrievals

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In our study we focus on improving our understanding of possible interactions between the open water and sea ice and the surface ocean biogeochemistry under the recently observed sea ice decline in the Arctic. In particular, the analysis of changes in phytoplankton functional types (PFTs) over 2002 to 2012 based on long-term time series of satellite retrievals and supported by a modelling study is presented. The phytoplankton dynamics as well as phytoplankton diversity in response to Arctic Amplification is simulated with the DARWIN biogeochemical model [1], [2] coupled to the Massachusetts Institute of Technology General Circulation Model [3]. This combined model and satellite-derived information will later be used for investigating existing relationships and feedbacks between the Arctic climate change, the ocean biogeochemistry and atmospheric oxidative capacity.

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Cloud masking for aerosol retrieval over the Arctic using AATSR time-series measurements

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The lack of satellite-based Aerosol Optical Thickness (AOT) retrievals over the Arctic contributes to uncertainties in the evaluation of aerosol effects on climate change. A crucial prerequisite for an accurate aerosol retrieval algorithm is cloud masking. The accuracy of cloud-masking significantly affects the quality of the AOT retrievals. However, cloud masking over the Arctic is a challenging task since all so far developed methods are affected by the unique atmosphere and surface conditions.

In this study, we initially applied the cloud masking method proposed by Istomina et al. [1]. The main idea of this approach is to analyze the wavelength-dependent spectral shape of each ground pixel measurement to separate snow and cloud using Advanced Along-Track Scanning Radiometer (AATSR) dual-viewing measurements. The results show mixed success. Clouds can be misclassified as snow, which contributes to a positive bias in the aerosol retrieval. This problem is not remarkable in regions covered mostly by snow whereas it is more highlighted in case of cloudy conditions.

A time-series approach by deriving a priori knowledge of surface information from subsequently acquired images of the same geolocation [2] instead of using the spectral shape of snow and tuned thresholds was further proposed and tested. The main concept of this method is that cloud free surface exhibits unchanged or a little changed patterns within a given time period whereas cloudy or partly cloudy pixels show much higher variability in space and time. In this method, the covariance, illustrating the 'stability' of the atmosphere-surface system observed by satellites, is selected to be the key parameter. The cloud free surface is created as a "reference image" by analyzing the covariance value between various images since cloud-free pixels exhibit higher covariance compared to cloudy conditions. The main challenge is to select an optimal time period in order to produce a 'reference image' with minimal cloud contamination and maximal surface information. Some first results including radiative transfer simulations and case studies using the time-series approach based on AATSR measurements will be presented.

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Balloon-borne measurements of heating and cooling rates in Arctic stratocumulus

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Stratocumulus covers approximately 20 % (annually averaged) of the Earth's surface and thus strongly influences the atmospheric and surface radiative budget resulting in radiative cooling and heating effects. [1] Globally, the solar cooling effect of stratocumulus dominates. However, in the Arctic the solar cloud albedo effect (cooling) is often smaller than the thermal-infrared greenhouse effect (warming), which results from the lower incoming solar radiation and the low cloud base height. Therefore, Arctic stratocumulus mostly warms the atmosphere and surface below the cloud. In Addition, [2] identified four cloudy boundary-layer types, which occur mainly over the Arctic Ocean throughout the year. Each type is characterized by different micro- and macrophysical cloud properties and thus may change the radiative budget in the boundary layer.

Balloon-borne measurements of solar and terrestrial radiative flux densities will be used to quantify profiles of the radiative budget in the Arctic boundary layer. In June 2017, the balloon will be launched from a sea ice camp north of the archipelago Svalbard during the Arctic Balloon-borne profiling Experiment (ABEX). Broadband pyranometer and pyrgeometers will be applied to measure heating and cooling rate profiles in and above stratocumulus. Together with temperature and humidity measurements, these profiles will be used to characterize the cloudy boundary layer with respect to the four suggested types. The applied tethered balloon is a slow moving platform and can provide profile measurements with high vertical resolutions. The slow climbing rates partly compensate for the long response time of both broadband radiation sensors and allow to investigate sharp gradients expected at the cloud top inversion. New instrument packages for the balloon have been developed and tested in the laboratory and during test flights of the balloon. The results of these test flights will be reported showing the capability of the measurement setup.

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Cloud detection over snow and ice using synergy of MERIS/AATSR (OLCI/SLTSR)

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An accurate cloud screening over snow/ice is important for many remote sensing applications such as satellite retrievals concerning atmospheric parameters in the Arctic or surface properties of land snow and sea ice properties. As optical properties of sea ice/snow and clouds are alike, an accurate cloud screening in the Arctic is a challenging task. A variety of cloud masks delivered with the operational satellite products exists, however, they are often focused on ocean and land covers rather than on bright snow and sea ice cover.
Some satellite sensors are better equipped for this task, e.g. with a set of thermal infrared bands. However, they may be not suited for certain retrieval methods due to other limitations. That is why it is important to develop quality cloud masks also for sensors which are not specifically designed for the task.
In this work, we present a cloud mask developed specifically for retrievals over bright snow and sea ice surfaces from MERIS and OLCI data.
The presented dataset consists of pixel wise cloud probability for each available MERIS/OLCI swath. The newly developed cloud screening procedure utilizes data from the MERIS/OLCI oxygen A band as well as synergy with SLTSR/AATSR in order to benefit from their infrared bands. The method is able to correctly classify over 90% of the sea ice observations from MERIS during the period May to September if compared to a high-quality cloud mask derived from AATSR.
Case studies over various snow types and examples on how the wrong cloud detection may influence resulting remote sensing products, e.g. surface albedo and melt pond fraction (Fig. 1), are presented and discussed as well as a concept on how to restore surface reflectances under semi-transparent clouds using NIR TOA reflectances from AATSR/SLTSR.

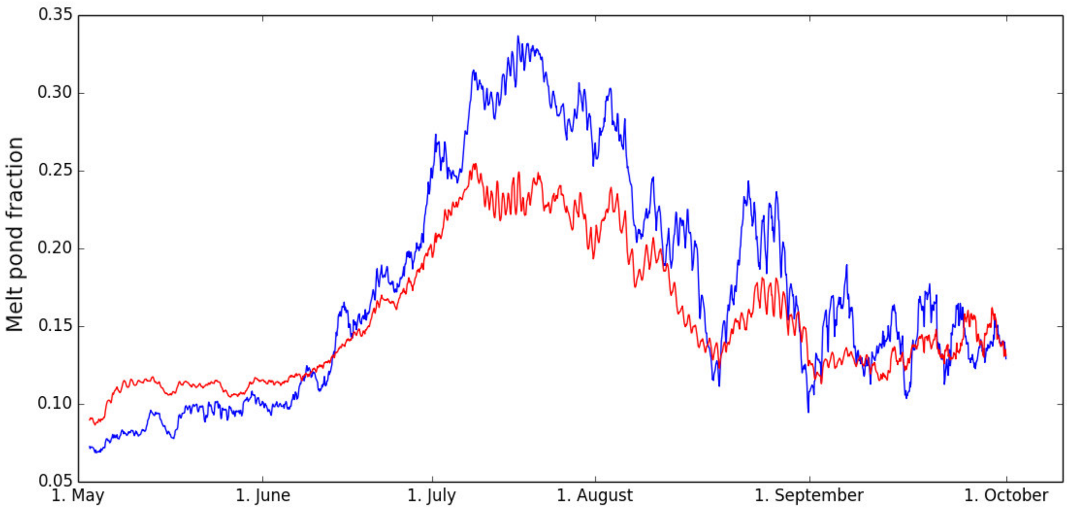

Fig. 1. The smoothing effect of unscreened clouds on the melt pond fraction on the Arctic sea ice retrieved from MERIS for each available swath of May- September 2009. Red curve represents imperfect cloud screening on MERIS data as compared to better cloud screening with the help of AATSR (blue curve).

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Satellite Remote Sensing of Halogens in the Arctic Troposphere

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Halogens play a key role for atmospheric chemistry of the Arctic troposphere, especially as they can cause severe ozone depletion over sea ice covered areas during polar spring. Ozone is a major greenhouse gas and a precursor of OH. As a result, tropospheric concentrations of halogens potentially change radiative properties and temperature, as well as the oxidizing capacity of the Arctic atmosphere. Previous studies have shown that the recent temperature increase due to climate change is more pronounced in the Arctic compared to other parts of the globe, a phenomenon known as Arctic Amplification.
Our primary goal is to investigate if Arctic Amplification affected tropospheric concentrations of halogens in the Arctic during more recent years, and to understand how these changes are related to changes in halogen sources (e.g. sea ice cover and type, oceanic phytoplankton) as well as meteorological parameters regarded as crucial for the release of halogens into the troposphere (e.g. temperature and wind speed).
To assess this goal, a consistent long-term halogen data set based on retrievals from different UV-VIS satellite remote sensors will be developed. Here, we will present preliminary results focusing on comparisons of already existing satellite retrievals of BrO from GOME-2 and SCIAMACHY, which indicate a need to improve the retrievals in order to study the evolution of halogens in the Arctic in time under Arctic Amplification.

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Characterizing the vertical presence of atmospheric black carbon in the Arctic region during spring and summer

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Although the role of black carbon (BC) as Arctic climate forcer is well recognized, the uncertainty of its climatic impact is still considerable [1]. This is caused, among other reasons, by the limited characterization of the vertical distribution and seasonality of BC concentration and its properties. In order to better understand the spring and summer climatic impact of BC, the vertical distribution of refractory black carbon (rBC) concentration and particle diameter was quantified during spring 2014 and summer 2015 within two aircraft campaigns, as part of the NETCARE (Network on Climate and Aerosols: Addressing Key Uncertainties in Remote Canadian Environments) project. A single particle soot photometer was deployed on the research aircraft POLAR 5 and POLAR 6 during several flights conducted over the Canadian High and Sub Arctic.
During spring the averaged rBC concentration ranged between 20 ng/m^3 and 30 ng/m^3, almost one order of magnitude higher compared to summer, when mean concentration hardly exceeded 5 ng/m^3. A linear decrease of rBC concentration with altitude was observed in spring, while rather constant rBC vertical presence was captured during summer. Furthermore, the rBC particle diameter undergo a dramatic shift from spring to summer, decreasing from 210 nm to 130 nm respectively. However pollution events have been detected in the High Arctic (Alert, Northwest Territories) and Sub-Arctic (Inuvik, Nunavut) during spring, its absolute rBC load and size distribution and altitude position were different. Sub-Arctic plumes were detected at higher altitudes and were characterized by wider vertical extend, higher rBC concentration and larger mean diameter compared to High Arctic spring. The marked seasonality and spatial variability of the aforementioned BC properties might lead to a different impact of BC on the Arctic energy budget. Our work provides vertical, spatial and seasonal information of black carbon presence and characteristics in the Arctic, which will contribute to decrease the high uncertainty of radiative forcing and atmospheric warming estimations in the Arctic region.

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IR-Spectroscopy using a FT-Interferometer in emission and absorption mode and preparation for the Polarstern cruises PS106 and PS107

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Using a Fourier Transform Interferometer, water vapour, aerosols and optically thin clouds are measured during the cruises PS106 and PS107 of the RV Polarstern from end of May 2017 to end of August 2017 in the arctic.
In the arctic, aerosols have an impact on the radiative forcing [1]. These aerosols are emitting in the infrared, so they can be measured using IR-Fourier Transform Spectroscopy. For this purpose, the interferometer is operated in the emission mode, in contrast to solar absorption mode where the sun is used as light source.
The FT-Interferometer is calibrated using the so called total power calibration [2]. In this calibration, the spectra of a cold blackbody and a hot blackbody is measured. Using this spectra the effects of the measuring device will be removed.

A 10” container will be prepared for operating on the ship and equipped with two FT-Interferometer by the manufacturer Bruker. Also an air condition will be installed. A solar tracker on top of the container can follow the sun automatically an is necessary for the solar absorption measurements.
The Polarstern cruise PS106 starts in Bremerhaven and will transit to 82.5°N, 15°W and stay there for two weeks as an ice station. After the ice station, there is a transit to Longyearbyen on Ny-Ålesund to change expedition participants. After this there is a transit to 81°N, 28°E for further measurements. The cruise PS107 takes place in the Fram Strait between Svalbard and Greenland.

This presentation will show the first results of emission measurements and the state of the preparation for the ship campaign.

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Closure of Arctic Cloud Properties and Radiative Fluxes from ground-based observations

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Ground-based observations of Arctic clouds and aerosols properties will be carried out within the framework of the OCEANET project on board the Research Vessel Polarstern during its cruise PS106.1-2 next summer (May – July 2017). Joint measurements of the radiative fluxes including the spatio-temporal variability of the surface shortwave radiative flux will be obtained from a network of pyranometers that will be installed as part of the ice station. This will be done with the aim to analyze the sensitivity of the radiative forcing at the surface due to aerosols and cloud properties. Together with changes in ice cover, clouds and their interaction with radiation are considered as one of the important feedback mechanism in the climate system [4].

The synchronized aerosol and cloud remote sensing observations and measurements of the corresponding radiation budget will be utilized for radiative closure studies in order to provide important insights in our ability to realistically represent Arctic clouds and their resulting radiative forcing. For this purpose, the rapid radiative transfer model (RRTM) and Monte-Carlo radiative transfer simulations will be applied to test radiative effects in particular for low sun and highly reflective surface conditions.

As an introductory overview, we will present an analysis of the horizontal, vertical and temporal variability of the tropospheric cloud distribution and aerosol characteristics over the Arctic during summer seasons using the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) lidar and CloudSat radar products, which have been previously used to determine pronounced aerosol layers [1, 2] and macro-physical characteristics of clouds [3] over the Arctic. This analysis will be used afterwards as a background scenario and context for judging the meteorological conditions during the PS106.1-2 campaign.

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N-ICE2015: Observational study on drifting Arctic sea ice north of Svalbard from winter to summer

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Between January and June 2015 the Norwegian Polar Institute's research vessel Lance served as a research station in the drifting sea ice in the Arctic Ocean north of Svalbard during the international Norwegian young sea ICE (N-ICE2015) expedition [1]. The main objective of the project was to understand the effects of the shift to a younger and thinner sea ice regime in the Arctic on energy flux, ice dynamics and the ice-associated ecosystem, and local and global climate. To improve our capacity to model the future, more direct observations in the Arctic are needed to understand key processes in the thinner ice world. The expedition consisted of drifts with RV Lance moored to in total four ice floes. Here we report on the layout of the study, the main work conducted during the campaign and some initial results. Data show that the behavior of the thinner sea ice regime is quite different from what we have learned from earlier work conducted on thicker sea ice prior to N-ICE2015. The data and results are also used in other related projects and initiatives, such as the project ID Arctic for increasing collaboration between Norway and the USA and Canada, and the Centre for Integrated Remote Sensing and Forecasting for Arctic Operations in Tromsø, Norway.

We are indebted to the captains and crew of RV Lance and Airlift AS. This study was supported by the Centre for Ice, Climate and Ecosystems (ICE) at the Norwegian Polar Institute, the Ministry of Climate and Environment, Norway, the Research Council of Norway (several projects, among them CIRFA SFI #237906, and CORESAT #222681), the Ministry of Foreign Affairs, Norway (project ID Arctic), and the ICE-ARC program of the European Union 7th Framework Program (grant number 603887).

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Daily lead map of the European Arctic from Sentinel-1 SAR scenes

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Leads are linear-like areas with open water within sea ice cover. They are of interest for environmental science, weather forecasting and ship navigation in polar regions. Here, an algorithm that provides an automatic binary classification of leads is proposed. Synthetic Aperture Radar (SAR) satellites provide all-weather and season observations and the necessary high resolution to identify leads. Previously often a single co-polarized band was used for ice-water classification which can result in misclassification of leads under windy conditions. The presented algorithm benefits from the use of Sentinel-1 SAR dual channel products which include measurements in co- and cross-polarized modes. Exploiting information from both, the algorithm is capable to identify leads which can not be identified using single co-polarized measurements. The Sentinel-1 extra wide swath mode with 400 km swath width and 40 m pixel size is used. The algorithm is based on Haralick texture features and a supervised classification algorithm. Its stability and high parallelization makes Random Forest Classifier a perfect tool for SAR image feature recognition. It allows per-pixel processing of images with speckle noise. Leads are identified in single SAR scenes, which are then compiled to maps covering a larger region from a set of individual products. Maps of lead distributions for the European Arctic with a resolution of 200 meters are presented.

Experiences with an optimal estimation algorithm for surface and atmospheric parameter retrieval from passive microwave data in the Arctic

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In this study we present experiences in using an integrated retrieval method for atmospheric and surface parameters in the Arctic using passive microwave data [1]. The instrument used is the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) on board NASA's Aqua satellite. The core of the method is a forward model which can ingest bulk data for seven geophysical parameters to reproduce the brightness temperatures observed by a passive microwave radiometer. The retrieval method inverts the forward model and produces ensembles of the seven parameters. These are wind speed, integrated water vapor, liquid water path, sea and ice surface temperature, sea ice concentration and multi-year ice fraction. The forward model uses empirically determined sea ice surface emissivities for simulating brightness temperatures in ice covered areas. In order to constrain the retrieval, a covariance matrix is used together with a set of background values for each parameter. A cost function balances the penalty of the retrieved values moving away from the background value with the penalty of moving away from the observed brightness temperatures. An iterative method is used for minimizing the cost function and finding the optimal ensemble of state vector elements that best match the observed brightness temperatures. Three distinct versions of the retrieval method were implemented using the lower eight (8c), ten (10c) and all twelve frequency channels (12c) of AMSR-E respectively.

Results from an inter-comparison with established retrieval methods are presented. Collocated sets of water vapor, liquid water path, wind speed and sea surface temperature from the Remote Sensing Systems (RSS) AMSR-E Environmental Suite [2] were used for the atmospheric parameters over open water. For validating the atmospheric parameters over sea ice, collocated fields of water vapor, liquid water path, wind speed and skin temperatures from the Arctic System Reanalysis data product were used. For the sea ice concentration retrieval, the ARTIST sea ice product (ASI) [3] was used.

The 8c version shows good performance for sea surface temperature retrieval. Water vapor retrieval using the 10c version provides similar performance to the RSS product while for wind speed retrieval the 10c and 12c versions show similarly good results. Out of the three versions, the 12c version offers the best results for liquid water path retrieval. The 12c also offers the best results in sea ice concentration retrieval when compared to the ASI product.

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Automatic detection of polar mesocyclones using satellite microwave humidity sounders

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Polar mesocyclones are small intense cyclones in polar and subpolar areas. They are challenging to observe, model and predict because of their small size, rapid development and short lifetime. Therefore polar mesocyclones and polar lows (Pls, i.e., particularly strong PMCs over the sea) are poorly monitored -- yet they have significant influence on atmosphere, ocean and sea ice.
Here we present first results of an automatic detection algorithm, based on a simple threshold-based method using data from microwave humidity sounders (AMSU-B and MHS) on several operational meteorological satellites: On maps of the difference between the channels at 183±1 GHz and 183±7 GHz, PMCs over open ocean are visible as small patches of reversed sign [1]. Such PMC signatures can be found by a classification algorithm that determines the size and shape of the patches and joins clusters of them if they are close enough to be considered belonging to the same cyclone. Such an algorithm must be trained, i.e., the distinguishing features of a PMC signature (size, shape, distance to similar signatures) have to be determined. This algorithm training is done by analysing signatures of about 100 known PMCs and PLs cases over the Norwegian Sea between 2000 and 2010. An automatic PMC and PL detection algorithm will allow to compile inventories of PMCs during the whole period of AMSU-B/MHS data (1999 to date). Until now, all such inventories had to be compiled by a human observer.

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Merged Total Water Vapour product from AMSU-B and AMSR-E data in the Arctic region

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Water vapour plays a key role in the global climate system, as it is the most abundant and radiatively relevant greenhouse gas and influences the atmosphere dynamics by transporting moisture and latent heat. Therefore, its global continuous knowledge is required for numerical weather prediction and climate models. Microwave imagers like SSM/I or AMSR-E have routinely provided daily vertically integrated water vapour content (total water vapour, TWV) over open ocean for more than 30 years, but not over the vast areas of the polar sea and land ice. Over those surfaces, a newer method - developed by Miao et al. [1] and improved by Melsheimer et al. [2] - based on data of the microwave humidity sounders AMSU-B and MHS, on the NOAA and METOP satellites, gives the TWV if the values are below 14 kg/m². However, some discrepancies have been observed at the edges of the coverage of both methods, as seen in Figure 1 for a summer day. The first steps towards understanding the discrepancies between these two complementary datasets and requirements to be fulfilled before constructing a combined dataset will be presented. This will eventually provide an Arctic-wide daily dataset of 50 km resolution with seamless coverage from the high Arctic to mid-latitudes from 2002 until now. With that, an assessment of water vapour distribution and temporal variations is possible.

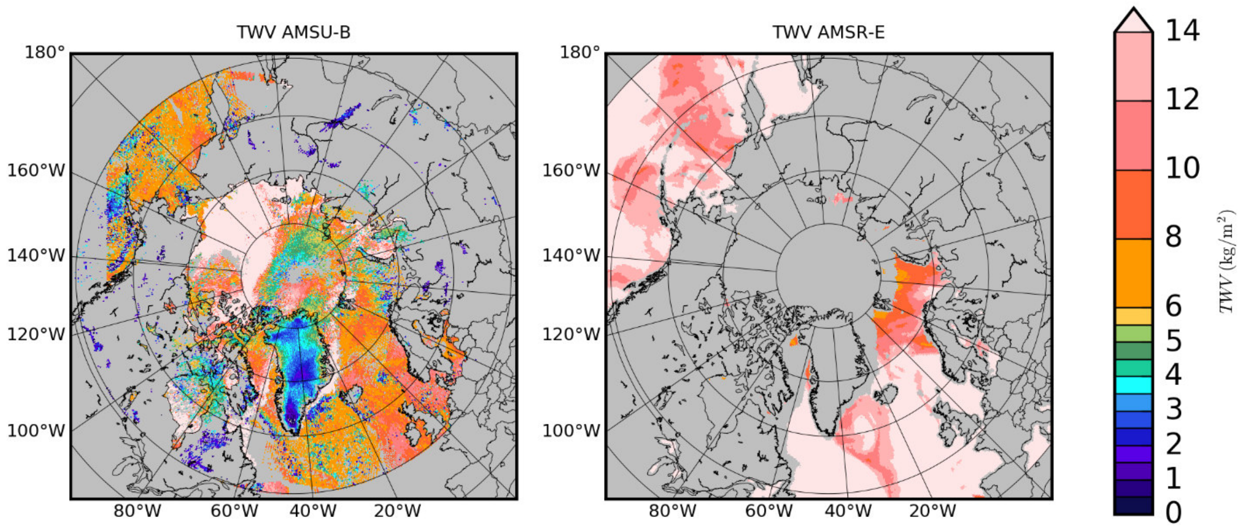

Fig. 1. AMSU-B and AMSR-E TWV for 06.06.2007

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Snow on Antarctic Sea Ice: Distribution and Trends

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Snow on sea ice is an important cryospheric parameter. It is needed to determine the energy flux between ocean, sea ice and atmosphere, the sea ice thickness from altimeter observations, the solar radiation at and underneath sea ice. In addition, the high snow load on Antarctic sea ice frequently leads to flooding and formation of superimposed ice when the water on top of the ice freezes. Moreover, snow depth is needed operationally because the ship friction of snow is similarly high as that of sea ice. Because in-situ measurements are only sparsely available and clouds and missing daylight limit usage of optical or infrared satellite sensors, satellites carrying passive microwave sensors offer the only possibility to continuously retrieve snow depth on Antarctic scale.

Currently the only operationally used algorithm for snow depth retrieval from satellite observations is the one introduced by Markus and Cavalieri [1]. It was originally developed for the passive microwave sensor SSM/I and uses for more recent AMSR-E data a linear regression between the brightness temperatures of the two sensors [2, 3]. However, in the Antarctic several processes (flooding, melting and refreezing) cause snow properties to vary and these together with ice ridges make snow depth retrieval particularly difficult. Often the retrieved snow depth is biased and its accuracy is not known.

Within the framework of the Antarctic Option of the ESA Sea Ice Climate Initiative project, the above mentioned empirical algorithm has been re-derived for AMSR-E data from ASPeCt protocol ship-based snow depth estimates of the years 2002 through 2011. Based on the new snow depth algorithm we will present monthly snow depth mean as well as snow depth trend and trend uncertainty maps for the AMSR-E and AMSR2 observation period 2002-2016. Monthly regions of positive, negative and uncertain trends are identified. We find highest snow depths in West Antarctica, and low snow depth in East Antarctica. Large regions with negative snow depth trends are detected in the inner ice pack of the Bellingshausen-Amundsen and Ross Sea Sectors from June to December, and smaller regions with positive snow depth trends are detected in the outer parts of the same sectors from July to November. This means, we find significant trends in regions where more calibration data pairs are available. At least in East Antarctica more in situ observations are required to better evaluate the snow depth algorithm and obtaining more significant snow depth trends.

This work was supported by the ESA Climate Change Initiative project on Sea Ice.

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Microwave Radar/radiometer for Artic Clouds (MiRAC) for vertical profiling of ice and liquid water

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The contribution of arctic mixed-phase clouds to the Arctic Amplification is still not clear as there are major deficits in their representation in regional and climate models is poor. The subproject "Characterization of Arctic mixed–phase clouds by airborne in–situ measurements and remote sensing" (B03) within the Transregional Collaborative Research Center (TR 172) "Arctic Amplification: Climate Relevant Atmospheric and Surface Processes, and Feedback Mechanisms $(AC)^3$" tries to increase the understanding of these clouds by conducting aircraft based remote sensing and in-situ measurements during a campaign based in Longyearbyen, Svalbard. A key component of the remote sensing instrumentation is the Microwave Radar/radiometer for Arctic Clouds (MiRAC). It consists of a 94 GHz frequency modulated continuous wave (FMCW) radar and passive radiometer with frequencies in the sub-millimeter range between 183 and 340 GHz similar to future satellites. The frequencies implemented in MiRAC are sensitive to humidity, liquid water and ice. Together with the other remote sensing instruments onboard of Polar 5 and the in situ measurements on Polar 6 profiles of liquid and ice water in arctic mixed-phase clouds and, through the scattering signal found in the microwave measurements, information on ice particle properties can be derived.

Within this presentation we will introduce the concept of MiRAC, its integration into the Polar 5 aircraft and preliminary results from measurements taken in ground based mode and obtained during the certification and test flights. Furthermore, we will show what can be expected when observing arctic mixed-phased clouds based on a theoretical study and radiative transfer simulations.

Thin cloud characteristics over Ny-Ålesund, Spitsbergen and their radiative signatures from recent multi-year observations

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This contribution presents cloud climatological characteristics obtained from different optical instruments located at the AWIPEV atmospheric observatory in Ny-Ålesund, Spitsbergen.

Data and Instruments

Cloud base height (CBH) is continuously recorded since 2011 by a ceilometer of type CL51 (Vaisala Oy) four times per minute all year round. It is part of the suite of instruments of the Baseline Surface Radiation Network (BSRN) station, which provides downward and upward short and long wave radiation measurements. Profiles of air temperature, relative humidity, wind speed, wind direction are measured at least daily at noon by balloon borne radiosondes. Tropospheric profiles of temperature and moisture are recorded by a microwave radiometer (HATPRO) as well as liquid and ice water path (LWP and IWP). The Koldewey Aerosol multiwavelength Raman Lidar (KARL) provides backscatter and extinction profiles of aerosol and thin clouds. A sun photometer automatically measures the atmosphere optical depth when the sun is visible during polar day.

Methods

By combining the information from the ceilometer about whether a cloud base was detected and whether the observational range is affected, four cases are discriminated: clear sky (full range, no cloud base), optically thin cloud (full range, cloud base detected), optically thick cloud (reduced range, cloud base detected) and a fourth case of reduced range but without cloud base due to enhanced extinction without a detectable cloud base. This is similar to the approach used by [1].

A second approach used to distinguish between thick and thin clouds is to calculate cloud optical thickness (COT) from extinction, measured with the sun photometer and with the lidar KARL.

Results

The presentation will highlight the annual course of observed cloudiness over Ny-Ålesund of the last 5 years and compares the differences of this land based station next to the North Atlantic with earlier studies from the Arctic Ocean (e.g. [2]) and from Spitsbergen [3]. Cloudiness is analysed with respect to the monthly mean CBH and with respect to the cloud cases as defined above. The radiative signatures of the different cloud types are shown, and are related to the ratio LWP/IWC as a function of temperature and height for summer and winter seasons. Some dependencies of cloud type on the atmospheric state (in terms of temperature profile and water vapour content) as well as the synoptic situation will be analysed and their annual course presented.

CBH statistics show that CBH peaks well below 1000 m altitude, which is within the orographically influenced height range (as shown e.g. by wind shear, as observed with a wind lidar or radio sonde profiles, see [4]). CBHs peak within the height range of highest rel. humidity and well below the altitudes of main temperature inversions. Accordingly, CBH statistics are influenced by orography as well as synoptic influences, which is important for the representativeness studies (see project E02) as well as the latitudinal analyses planned for this project (B06).

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Characterization of Arctic Mixed Phase Clouds at regional and small scales

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Previous observations suggest that Mixed Phase Clouds (MPC) occur frequently in the Arctic and often persist for many days due to a combination of local processes (microphysical and radiative for instance) and larger scale meteorological conditions. These low-level liquid containing clouds exert a large influence on the surface radiative fluxes and feedbacks on Arctic climate. However, understanding the spatial phase distribution within MPC remains a challenge.

In this study, the MPC macrophysical and microphysical properties are investigated at a regional scale using CloudSat and CALIPSO observations (2007-2010) and at smaller scale with airborne in situ measurements performed in the Svalbard region.

Results show that MPCs have a mean frequency of occurrence ranging from 30% (end of winter) to 55% (in autumn) in the Arctic. In the Svalbard region, the frequencies of occurrence are significantly higher with values ranging from 45% to 60%. MPCs are especially located at low altitudes, below 3000m, where their occurrence reaches 90%, particularly in winter, spring and autumn. Moreover, results highlight that MPCs are statistically more frequent over open sea than sea ice or land. These observations also allow us to assess how already performed small scale airborne measurements are representative of the variety of clouds encountered in the Arctic. *In situ* measurements (44 vertical profiles obtained during ASTAR, POLARCAT, SORPIC) are statistically analyzed to derive representative profiles of MPC microphysical and optical properties (optical depth, liquid/water fraction, ice crystals habit). These analyses should contribute to a better understanding of processes occurring in arctic MPC.

Influence of tropospheric circulation patterns on the winter middle and high-latitude mesosphere

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It is widely accepted that the winter polar stratosphere is strongly influenced by tropospheric circulation patterns like NAO and ENSO. On an average, the stratospheric polar vortex is stronger and deeper during winters of positive NAO and during ENSO cold events. We also note from observations that the upper middle atmosphere, i.e. in the mesosphere and lower thermosphere is connected with the troposphere. An example is given in Fig. 1, showing Collm, Germany, radar observations of the zonal wind near the mesopause together with the Niño3 index. High indices, i.e. moderate to strong El Niño events, are followed by stronger zonal winds above ~95 km. It has also been observed that the mesosphere/lower thermosphere circulation is connected with the NAO [1] or NAM [2].

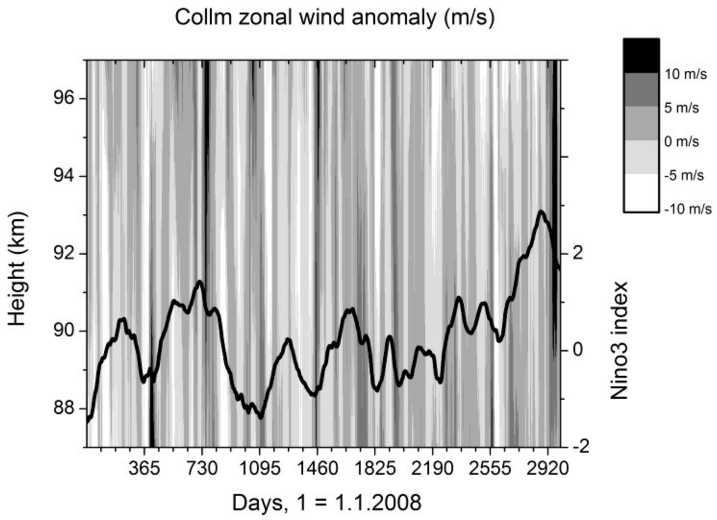

Fig. 1. Zonal wind anomalies over Collm (greyscaling) and Niño3 index (black line).

We present results from radar observations and simulate the response of the mesosphere and lower thermosphere to tropospheric circulation anomalies using the MUAM mechanistic circulation model [3]. We find that the model results agree with the observations. However, since the vertical and latitudinal coupling is mainly through planetary waves, the circulation during single winters may differ from the climatological mean.

This work was supported by SFB/TR 172 in Project D01 funded by the Deutsche Forschungsgemeinschaft (DFG).

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The Role of Intense Cyclones for Precipitation, Sea Ice and Snow Cover Distribution in the Nordic Seas

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The Arctic is warming twice as fast as the global average [1]. This feature, referred to as the Arctic amplification, is a result of and results in substantial changes in the regional cryosphere, heat and moisture transport [1,2]. Here we present a study that investigates the impact cyclones in the Nordic Seas has on the regional precipitation, sea ice and snow cover distribution.

Compositing late fall (October through December; OND) months of high and low cyclone-associated precipitation compared to its climatology 1979-2016, we identify the role these cyclones have on the regional precipitation amount and phase, sea ice, snow cover and sea surface temperature. Data for these time periods are from the reanalysis ERA-Interim[3] and regional climate model HIRHAM5[4], while a short-term case study also includes weather station and satellite data for comparison and a more detailed analysis of the physical interactions.

The results of this study are contributing to the understanding of the anomalous temperature, moisture and sea ice trends of the Barents Sea region compared to the Arctic-wide trends [5,6]. Outcomes are also of substantial interest to actors following the opening up of the region. In this talk, the latest results of this ongoing study will be presented.

This work was supported by the German Research Foundation DFG Transregional Collaborative Research Centre TR 172.

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A comparison of the two Arctic atmospheric winter states observed during N-ICE2015 and SHEBA

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Winter-time atmospheric observations from the 2015 Norwegian young sea-ICE campaign (N-ICE2015) are compared with data from the 1997-1998 Surface Heat Budget of the Arctic (SHEBA) campaign. Both datasets have a bimodal distribution of the net longwave radiative flux for January-February, with modal values of -40 W m^{-2} and 0 W m^{-2}. These values correspond to the radiatively clear and opaquely cloudy states, respectively, and are likely to be representative of the wider Arctic. The new N-ICE2015 observations demonstrate that the two winter states operate in the Atlantic sector of the Arctic and regions of thin sea ice.

We compare the N-ICE2015 and SHEBA data with ERA-Interim and output from the coupled Arctic regional climate model HIRHAM-NAOSIM. ERA-Interim simulates two Arctic winter states well and captures the timing of transitions from one state to the other, despite underestimating the cloud liquid water path. HIRHAM-NAOSIM has more cloud liquid water compared with ERA-Interim, but simulates the two states poorly. Our results demonstrate that models must simulate realistic synoptic forcing and temperature profiles to accurately capture the two Arctic winter states, and not only the presence of mixed-phase clouds.

Using ERA-Interim, we find a positive trend in the number of opaquely cloudy days in the western Atlantic sector of the Arctic, and a strong correlation with the mean winter temperature over much of the Arctic Basin. Hence, the two Arctic winter states are important for understanding inter-annual variability in the Arctic. The N-ICE2015 dataset will help improve our understanding of these relationships.

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Sea ice concentrations at 1 km resolution from combined optical and passive microwave data

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Although it covers only about 1.5% of the Earth's surface, Arctic sea ice is a key element of the climate system with far-reaching impacts, e.g. on mid-latitude weather conditions in Europe and Northern America. Furthermore, various feedback loops make it a sensitive indicator of long-term climatic changes. The percentage of ice within a given area (sea ice concentration) is of special importance as it regulates the ocean/atmosphere exchange, determines primary production rates, is a main input variable for numerical models and provides valuable information about the safety of shipping routes. For more than 40 years, passive microwave measurements from space have been used for monitoring sea ice in general and sea ice concentration in particular. Their capability to provide year-round daily measurements almost independently of the state of the atmosphere along with their good spatial coverage make them a powerful tool for sea ice concentration retrieval. However, they suffer from a coarse spatial resolution of typical 25 km and 5 km today at maximum. Optical measurements provide higher spatial resolution and complementary error characteristics: while depending on daylight in the visible spectrum and cloud-free conditions in the whole optical spectrum, they come with spatial resolutions of up to 30 m for local coverage and 250 m to 4 km for daily Arctic-wide coverage. We present sea ice concentrations from optical data at a resolution of 1 km and their evaluation against a higher-resolution dataset. The so-derived uncertainty estimates are used to merge optical and passive microwave sea ice concentrations in a weighted mean procedure. A multi-year time series is analysed to assess the algorithm's performance throughout the year.

Meridional temperature flux in the vicinity of the Arctic

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It is known that the Arctic is warming more rapidly compared to the rest of the globe, and the meridional temperature gradient has become weaker. This affects the circulation patterns which results from shifts in the jet stream. The jet tends to meander more during a warmer Arctic [1], which by itself might decrease even further the meridional temperature gradient. Furthermore model results show that the jet stream shifts more poleward for models with weaker Arctic surface warming [2]. This is also affecting the circulation and transport in the whole troposphere.

We investigate the meridional temperature flux component using CMIP5 historical model runs, focusing on the vicinity of the Arctic (70° N) to understand the importance of specific regions and heights for the tropospheric heat transport into the Arctic. Analyzing the multi-model means of net meridional temperature flux at 70° N shows a decrease in the end of the 20^{th} century when integrating over the troposphere (1000 hPa to 100 hPa), see Fig. 1. Additionally we investigate the influence of circulation indices on temperature fluxes.

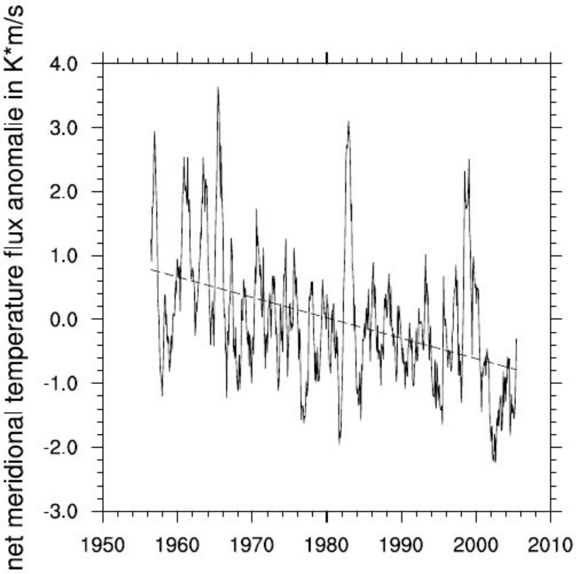

Figure 1: Anomaly of net meridional temperature flux (solid line) of a multi-model mean and trend line (dashed line)

This work was supported by SFB/TR 172 in Project D01 funded by the Deutsche Forschungsgemeinschaft (DFG).

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Characterization of the cloud conditions at Ny-Ålesund using sensor synergy and representativeness of the observed clouds across Arctic sites

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Clouds are one of the crucial components of the hydrological and energy cycles and thus affecting the global climate. Their special role in Arctic regions is linked to their influence on the radiation budget. Arctic clouds usually occur at low altitudes and often contain highly concentrated tiny liquid drops. During winter, spring, and autumn periods such clouds tend to conserve the long-wave radiation in the atmosphere which results in a warming of the Arctic climate. In summer though clouds efficiently scatter the solar radiation back to space and, therefore, induce a cooling effect. An accurate characterization of the net effect of clouds on the Arctic climate requires long-term and precise observations. However, only a few measurement sites exist which perform continuous, vertically resolved observations of clouds in the Arctic, e.g. in Alaska, Canada, and Greenland. These sites typically make use of a combination of different ground-based remote sensing instruments, e.g. cloud radar, ceilometer and microwave radiometer in order to characterize clouds.

Within the $(AC)^3$ project comprehensive observations of the atmospheric column are performed at the German-French Research Station AWIPEV at Ny-Ålesund, Svalbard. Ny-Ålesund is located in the warmest part of the Arctic where climate is significantly influenced by diabatic heating from the warm ocean [1]. Thus, measurements at Ny-Ålesund will complement our understanding of cloud formation and development in the Arctic.

This particular study is devoted to the characterization of the cloud macro- and microphysical properties at Ny-Ålesund and of the atmospheric conditions, under which these clouds form and develop. To this end, the information of the various instrumentation at the AWIPEV observatory is synergistically analysed: information about the thermodynamic structure of the atmosphere is obtained from long-term radiosonde launches. In addition, continuous vertical profiles of temperature and humidity are provided by the microwave radiometer HATPRO. A set of active remote sensing instruments performs cloud observations at Ny-Ålesund: a ceilometer and a Doppler lidar operating since 2011 and 2013, respectively, are now complemented with a novel 94 GHz FMCW cloud radar. As a first step, the CLOUDNET algorithms, including a target categorization and classification, are applied to the observations [2].

In this study, we will present a first analysis of cloud properties at Ny-Ålesund including for example cloud occurrence, cloud geometry (cloud base, cloud top, and thickness) and cloud type (liquid, ice, mixed-phase). The different types of clouds are set into context to the environmental conditions such as temperature, amount of water vapour, and liquid water. We also expect that the cloud properties strongly depend on the wind direction. The first results of this analysis will be also shown.

This work was supported by the (Deutsche Forschungsgemeinschaft) within the Transregional Collaborative Research Center (TR 172) "Arctic Amplification: Climate Relevant Atmospheric and Surface Processes, and Feedback Mechanisms $(AC)^3$".

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Evaluating Svalbard's exceptional geographical location from an Arctic surface temperature budget perspective

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As baseline for the 'Arctic Amplification', there is strong observational evidence that Arctic surface temperatures have been rising over the last decades. The contribution of atmospheric processes to the rate of change of the near surface temperatures in the NCEP/NCAR reanalysis product until 2009 has been systematically analyzed by [1]. Building on this analysis, we present an updated picture of how horizontal advection, diabatic heating and vertical motion terms contribute to Arctic surface warming with more recent data. In particular, decadal changes in the warming contribution of the above individual terms are investigated, based on the ERA-Interim reanalysis product [2] from 1979 – 2015. In contrast to NCEP/NCAR, ERA-Interim directly assimilates surface measurements, uses a sophisticated 4D-Var assimilation method, has a smaller rms-error in Arctic winter temperatures below 700 hPa, and has been found to better reproduce Arctic temperature trends [3].
In particular, decadal changes in the warming contribution of the above individual terms are investigated. A special focus is put on the Svalbard/Barents Sea region, where in agreement with [1] the strongest winter warming is identified to go along with pronounced signals in horizontal advection and diabatic heating. Our results suggest putting a spotlight on the Svalbard/Barents Sea region in studies on Arctic-wide warming, because of its distinct pattern of winter warming and the dynamics of the underlying processes. . The study will help to determine the representativeness of the Ny-Ålesund observations across the Arctic within (AC)^3 subproject E02.

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Thin sea ice thickness retrieval using L-band satellite sensors

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Sea ice thickness is an important parameter necessary in climate modeling, e.g., determining the ocean to atmosphere heat flux, but it is difficult to observe it on hemispheric scales regularly. Satellite altimeters like CryoSat-2 allows retrieving sea ice thickness. For thicknesses smaller than 1 m, i.e. thin sea ice, uncertainties are high. Thin sea ice retrieval has been developed for the L-band radiometer Soil Moisture Ocean Salinity (SMOS). SMOS observations cover the complete polar regions on a daily basis under varying incidence angles. For the purpose of thin sea ice thickness retrieval we used daily means of high incidence angle (40-50°). The algorithm developed is semi-empirical and uses the correlation between brightness temperature intensity and polarization difference to sea ice thickness up to 0.5 m [1].

The new SMOS L1C data version 6.20, has introduced a warm bias in the brightness temperatures compared to the older data version 5.05 the original retrieval algorithm was trained with. The algorithm has been retrained, compensating for the warm bias.

A fit function for the horizontal and vertical brightness temperatures as function of incidence angle has been used for each grid cell of SMOS for each day. From the fit function, brightness temperature at a given fixed incidence angle can be extracted. This avoids shifts in the mean incidence angle which may appear for the ensemble of observations between 40° and 50° within one grid cell. Moreover, this technique may replace the Radio Frequency Interference (RFI) filter used until now which removes the whole snapshot if it contains one or more data point over 300 K thus removing more than the affected data.

The Soil Moisture Active Passive (SMAP) satellite launched in 2015 also carries a L-band radiometer. It is a conically scanning satellite at a fixed incidence angle of 40°. Due to its improved RFI filtering and smaller footprint of the observations much less data is affected by RFI thus making it a good candidate for complementing the SMOS sea ice thickness retrieval. We calibrate the SMAP brightness temperatures to the SMOS ones by a linear regression between the fitted SMOS brightness temperatures at 40° incidence angle and the SMAP brightness temperatures. A merged SMOS/SMAP sea ice thickness dataset is produced using brightness temperatures from both sensors.

A timeseries of thin sea ice thickness for the period 2010 to 2016 will be presented.

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Multiyear sea ice concentration estimates using ASCAT and AMSR2 data

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Arctic sea ice cover is an important component of the global climate system and at the same time a sensitive climate indicator. Its area has decreased dramatically in the Arctic over the past three decades. The decrease is most pronounced in September when the annual sea ice minimum occurs, and particularly so for the area of multiyear ice (MYI), i.e. ice which has survived at least one summer. MYI concentration can be retrieved from passive or active microwave satellite observations. One of the algorithms that combine both types of observations is the Environmental Canada Ice Concentration Extractor (ECICE) [1].

In this study, data from the Advanced Scatterometer (ASCAT) and the Advanced Microwave Remote Sensing Radiometer 2 (AMSR2) are employed to retrieve MYI concentration. Combined active and passive microwave data can help to identify MYI, however, the retrieval shows flaw under specific weather conditions. Here, two corrections are applied to the MYI concentration retrievals from ECICE using ASCAT and AMSR2 data. One correction utilizes air temperature records to restore the underestimated MYI concentrations under warm conditions [2], the other mainly uses sea ice drift to correct the overestimated MYI concentrations [3]. The results are compared with the Canadian Ice Service (CIS) charts and the Equal-Area Scalable Earth Grid (EASE-Grid) Sea Ice Age dataset available from the National Snow and Ice Data Center (NSIDC). The MYI concentration from ASCAT/AMSR2 agrees well with that in the CIS charts. Compared to the ice classified as two years or older in the EASE-Grid Sea Ice Age dataset, the MYI concentration from ASCAT/AMSR2 is approximately 50% or greater.

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SWIFT: Fast stratospheric ozone chemistry for global climate models

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The importance of interactions between climate change and the ozone layer has long been recognized (e.g. [1] Thompson and Solomon, 2002, [2] Rex et al., 2006, [3] Nowack et al., 2015). Hence, it is desirable to account for these interactions in climate models. Since coupling a full stratospheric chemistry module to a GCM is computationally very expensive, ozone is usually prescribed in the type of climate models that are used in the IPCC reports.
The SWIFT model is a fast stratospheric ozone chemistry scheme developed to enable interactions between climate and the ozone layer in climate models. The model consists of two parts: A model that simulates the chemistry of stratospheric ozone depletion in polar winter and a model for extrapolar ozone chemistry.
The polar model is based on a set of coupled differential equations, which simulate the polar vortex averaged mixing ratios of the key species involved in polar ozone depletion. The model is driven by only two input parameters: the fraction of the polar vortex in sunlight and the fraction of the polar vortex below the temperatures necessary for the formation of polar stratospheric clouds. We present the implementation of the model and validate the model by comparison with Aura-MLS and the full chemistry scheme of the ATLAS Chemistry and Transport Model. We show promising results for the seasonal and interannual variability of ozone. In addition, we show first results from SWIFT implemented into the climate model ECHAM6.
The extrapolar model is based on evaluating a polynomial approximated to the rate of change of ozone obtained from runs of the ATLAS Chemistry and Transport Model. The polynomial is a function of nine variables, which include latitude, altitude, temperature, overhead ozone column, and the mixing ratios of ozone depleting chemical families NOx, HOx, ClOx and BrOx. The extrapolar model has been successfully validated against the ATLAS model and observational data. As an ongoing effort the extrapolar model is coupled to the ECHAM6 GCM in order to perform long time prognostic simulations.

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Measurements of atmospheric properties using solar absorption spectroscopy and emission spectroscopy using FTIR spectroscopy

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The Arctic remains one of the most inaccessible areas on Earth. Yet, this region draws considerable attention in the research community because it plays an important role in the Earth's climate system by triggering feedback processes involving the ocean, atmosphere and continental land masses. It serves as an energy sink and could also provide early signals of climate change owing to the feedbacks associated with high albedo and insulation effects of the snow and ice that covers much of the region. For a better understanding of the Arctic climate, the hydrological cycle needs to be better understood. Complex interactions due to cloud formation, impacting convection and land-atmosphere interactions adds uncertainties in weather and climate predictions. Despite the well recognised role of these atmospheric constituents in governing and affecting Arctic climate, observation capabilities of their microphysical quantities are limited and they are not adequately represented in climate models. FTIR spectroscopy allows for retrieval of atmospheric concentrations of water vapour [2] and other gases, and cloud and aerosol properties can be inferred from FTIR emission spectroscopy [3].
In this project measurements of H2O/HDO ratios will be used to study moisture pathways in the atmosphere [1]. Additionally, in cooperation with the subproject B06: "Latitudinal variability of water vapour, aerosols, and optically thin clouds", the representativity of the Ny Ålesund site will be assessed. In this poster, the contribution of the University of Bremen to the subproject E02 will be outlined and the first preliminary results would be shown.

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Changes in Arctic sea ice dynamics observed by satellites

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From buoy and satellite observations it is known that Arctic sea ice speed and deformation has increased during recent decades by 10–15% per decade. Buoys, however, do not cover the complete Arctic Basin and the number and location of observations changes with time. Satellite observations were not yet fully analysed for long-term ice deformation changes, which is the topic of this study. How much the different elements in the sea ice force balance have contributed to the observed changes in sea ice dynamics is not fully understood. Here, different satellite remote sensing datasets of sea ice drift and deformation are analyzed for changes in space and time (e.g., trend patterns).
Synthetic Aperture Radar (SAR) satellite observations deliver high resolution, all weather and season observations of the Arctic sea ice cover since the 1990s. Recently, with the launches of Sentinel-1a & b this dataset got much more extensive. Available SAR datasets of sea ice drift and deformation are analyzed for changes in space and time (e.g., trend patterns). Findings will contribute to better quantify the changes in Arctic sea ice dynamics and help evaluate sea-ice models.

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Recent Progress Towards a Coupled Regional Climate Model System of the Arctic

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The regional climate model system consists of the atmosphere model HIRHAM, the ocean-sea-ice model NAOSIM, and the land surface model CLM. The model system succeeds an earlier version of HIRHAM-NAOSIM [1] but utilizes upgraded components and higher resolution. To allow for identical component model versions in uncoupled and coupled setups, the model system has recently been redesigned in a modular approach. In addition, NAOSIM has been re-parallelized to enable its efficient operation on modern high-performance computer systems. For the same reason, the relatively new and flexible coupling software YAC 1.2.0 that allows for parallelized interpolation and communication of coupling fields [2] has been chosen for the coupling of HIRHAM and NAOSIM. The coupling software has been integrated via separate interface modules in order to simplify further model upgrades intended in the future.

The upgraded version of HIRHAM-NAOSIM will be deployed in $(AC)^3$ for investigating interactions between atmosphere and sea ice in the Arctic with the aim to identify and quantify the individual external and internal drivers and regional feedback mechanisms responsible for sea-ice changes and expected to be crucial for the Arctic Amplification. Improved parameterization schemes for the atmospheric boundary layer and cloud processes, as being developed in $(AC)^3$, will be implemented in the model and evaluated in terms of their potential contribution to reducing model biases. Due to the constrained lateral boundary conditions of a regional model, both the stand-alone and the coupled models can serve as testbeds for improved parameterization schemes before being carried over to global Earth System Models.

Since the upgraded version of HIRHAM-NAOSIM is still under development and not ready for operational use, scientific production runs cannot yet be presented. Instead, structure and setup of the coupled regional model system for the proposed Arctic climate simulations will be presented together with first performance tests.

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Spatiotemporal patterns of snowfall in the Arctic

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Studies based on observations and reanalyses show consistent changes in the Arctic towards a warmer and wetter atmosphere. However, it needs to be examined how the changes in the availability of water vapor translate to changes in total precipitation and snowfall. Changes in snowfall can have important impacts on sea ice by affecting the sea-ice growth in winter (snow insulation effect) and the sea-ice melt in spring and summer (surface albedo effect). Such related feedback mechanisms are hardly investigated.

Our study examines the spatiotemporal patterns of snowfall and snowfall-to-precipitation (S/P) ratio in the circum-Arctic domain based on different reanalysis datasets (ERA-Interim, JRA-55, MERRA-2, ASR) and regional climate model simulations (HIRHAM) for the period 1979-2014, and CloudSat observations for the period 2007-2010. The annual and seasonal long-term spatial patterns, interannual variability and regional trends of snowfall and S/P ratio are presented. The annual S/P ratio decreases in most of the Arctic regions. The model simulates a higher S/P ratio and a less strong decrease, compared to ERA-Interim. The regional and seasonal differences among the different data sets are assessed and the spread across the data is quantified. In addition, the spatial pattern and interannual variability of snowfall over the Arctic Ocean can be put in context to those of the retrieved snow depth on sea ice from satellite radiometers. The work will be extended in future by comparing the results with available station-based snowfall and S/P ratio data. Our study further gives initial interpretation of the calculated S/P patterns and trends by linking them to different environmental conditions such as e.g. temperature and total water vapor.

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Microphysical Properties and Radiative Impact of an intense biomass burning event in Ny-Ålesund

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An event of severe biomass burning aerosol, originating from boreal North America reached Ny-Ålesund in the afternoon of 9 July, 2015 and led to an extremely high Aerosol Optical Depth (AOD) > 1 at 500nm at the next day [1]. In this work data from a Raman-lidar and a contemporary radiosonde have been used to analyse hygroscopic growth of the aerosol, as an almost neutral stratified layer in 2.1km to 3.4km altitude has been found in which the relative humidity rose from about 50% to 90%. Only above 80% relative humidity a growth of the particles is seen in the color ratio and by an inversion of the microphysical aerosol properties. Such an inversion of the aerosol microphysics for different altitudes will be presented.

Further, data from a sun-photometer and radiation values from a BSRN station have been employed to estimate the direct radiative forcing of this event. A strong negative short-wave forcing (blocking of sun light) as well as a weak positive forcing in the infrared (increased backscatter from the aerosol layer) have been found. The dependence of this forcing as a function of AOD is discussed. A close to linear forcing with AOD has been found which is explained by a combination of Lambert's extinction with a term describing multiple scattering, which is captured by the hemispheric radiation sensors, but not by the sun-photometer.

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The effect of mid-latitude air masses on the high Arctic lower troposphere during spring (NETCARE 2015) and summer (NETCARE 2014)

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We present aircraft based trace gas measurements in the Arctic during NETCARE (2014 and 2015) with the Polar 6 aircraft of Alfred Wegener Institute (AWI) covering an area from Spitsbergen to Alaska (134°W to 17°W and 68°N to 83°N). We focus on clouds, aerosol and tracer transport processes of air masses into the high Arctic. For the spring (NETCARE 2015) and summer (NETCARE 2014) season we analyze the transport regimes of mid-latitude air masses traveling to the high Arctic based on CO and CO2 measurements as well as kinematic 10-day back trajectories.

During summer two different meteorological regimes over the course of the measurements in July are observed. The first part of the campaign named as the “Arctic Air Mass Period” (4.-12.7.2014) was dominated by a high pressure area over Resolute Bay with weak northerly flow whereas a cyclonic regime was prevalent during the second phase (“Southern Air Mass Period”, 17.-21.7.2014). Only 15% of trajectory origins were located south of the Arctic circle (66.5°N) during the “Arctic Air Mass Period”. This fraction increases to 55% during the second period with the North American continent being the dominant source region of the air masses. Especially the influence of active biomass burning in the Northwestern Territories alters the composition of the lower Arctic troposphere resulting in an increase of mean CO mixing ratios from 78 ppbv for the first period to 95.0 ppbv for the second period. In spring 2015 the origin of air masses shows a strong dependence on the measurement region. Alert (35% of trajectories originate south of the Arctic circle) and Eureka (35%) are more isolated from mid-latitudinal influence compared to Longyearbyen (70%) and Inuvik (96%).

Isentropic surfaces that slope from the surface to higher altitudes in the high Arctic form the polar dome that represents a transport barrier for mid-latitude air masses to enter the lower troposphere in the high Arctic as shown by the results for the air mass origin during spring and summer. The transition between the mostly isolated high Arctic and more southern Arctic regions indicated by tracer gradients is remarkably sharp. This allows for a chemical definition of the Polar dome based on the variability of CO and CO2 as a marker. Synoptic-scale weather systems frequently disturb this transport barrier and foster the exchange between air masses from the mid-latitudes and polar regions. The distribution of CO and CO2 and the back trajectories further allow for quantifying the effect of those synoptic scale disturbances on the dome boundary and thus the composition of the high Arctic lower troposphere.

Evaluation of cloud properties in the Arctic in the global aerosol-climate model ECHAM6-HAM2 using the COSP satellite simulator

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Among the many different feedback mechanisms contributing to the Arctic Amplification, clouds play a very important role in the Arctic climate systems through their cloud radiative effect. While globally having a cooling effect, clouds in the Arctic are thought to cause a warming at the surface [1] and can enhance the Arctic Amplification in case of an increase in cloud cover. To properly assess the cloud radiative effect from climate models, it is therefore important that those models simulate basic cloud properties like cloud cover and cloud distribution correctly.
We compare results from the global aerosol-climate model ECHAM6-HAM2 to observations from the active satellites CloudSat and CALIPSO, which are more reliable in the Arctic for cloud retrievals than passive instruments, using the COSP satellite simulator [2]. Our results show that the model is able to reproduce the distribution and cloud cover in the Arctic to some extent, but the cloud cover has a positive bias in regions where the surface is covered by snow or sea ice. In those regions, the model simulates too much liquid containing clouds close to the surface. A comparison of temperature and humidity profiles of the model to profiles measured by atmospheric soundings shows that the model is not able to reproduce the strength of the low level inversions as well as the relative humidity close to the surface, which is too high. The same features are visible in the ERA-Interim reanalysis, which is also reported to have too much clouds in the Arctic [3]. Further research is necessary to improve the representation of low level temperature and humidity profiles and thereby the simulation of cloud cover in the Arctic in the climate model.

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Fine Scale Simulations of Arctic Cloud with an Improved Scheme for Mixed-phase Microphysics

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Arctic climate features an abundance of low-level mixed-phase clouds. These clouds affect significantly the surface radiative budget [1]. Therefore, they are expected to play an important role in Arctic Amplification [2]. Unfortunately, these clouds are still not properly represented in climate models and weather forecast models [3]. Therefore, this study aims to improve the descriptions of mixed-phase clouds with the help of fine large eddy simulation (LES).

With the goal to provide an enhanced LES of low-level Arctic clouds, we have implemented the cloud microphysics scheme of Seifert & Beheng [4] into the Dutch Atmospheric Large-Eddy Simulation (DALES) [5]. The full implementation of this two-moment scheme for 3-phase microphysics allows to model the development within the mixed-phase clouds. The performance of this implementation has been tested on chosen semi-idealised cold outbreak cases, including M-PACE [6] and ARM [7]. However, it is intended to be employed also for the fine simulation of Arctic spring stratocumulus. With the aim to properly represent avarying concentration of aerosols in Arctic, this implementation also allows to define vertical profiles of CCN.

The next step in this model study will be preparing the model toolbox for modeling cases observed during the upcoming ACLOUD field campaign. The simulations based on the numerical weather forecast will be compared against the airborne data. We intend to further modify model set-up by inserting the aerosol and surface description based on the suggestions from other projects within $(AC)^3$. This would allow to investigate the effect of aerosol and surface forcing on properties of mixed-phase clouds and the impact on the resulting radiative budget.

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Atmospheric Correction of Sea Ice Concentration Retrieval of 89 GHz AMSR-E Observations

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The longest time series and most reliable information of global sea ice area is derived from satellite-borne microwave radiometers. The AMSR-E radiometer and its successor AMSR2 on the Aqua and GCOM-W satellites, respectively, offer today's highest spatial resolution observations in the 7 to 89 GHz microwave range. An improved sea ice concentration (SIC) retrieval algorithm named ASI2 that uses weather-corrected polarisation difference (PD) of brightness temperatures (TBs) at 89 GHz measured by AMSR-E is developed. Effects of wind, total water vapour, liquid water path and surface temperature on the measured TBs are evaluated through a fast radiative transfer model [1]. Due to its low emissivity, over open ocean the sensitivity to the atmospheric impact is larger than for sea ice, where the emissivity is more influenced by the surface conditions such as temperature and ice type. Atmospheric impacts generally increase the retrieved SIC and cause detection of spurious ice. In this study, we apply a detailed atmospheric correction by simulating changes in TBs caused by the atmospheric water absorption/emission and wind roughened ocean surface scattering using reanalysis data fields as atmospheric profiles. Cloud liquid water is excluded from the correction due to its poor representation in the reanalysis data at the exact satellite footprint and overflight times.

ASI2 is tested on two datasets: the Round Robin Data Package (RRDP) consisting of AMSR-E TBs over open water (SIC0) and consolidated ice (SIC1) [2], and all 2008 AMSR-E swath data over the whole Arctic. Over open water and 100% sea ice, the standard deviation of the retrieved SIC is induced by atmospheric influence, and is expected to decrease after the correction. The correction on the RRDP SIC0 dataset reduces the standard deviation of SIC from over 30% to about 20%, and lowers its bias from over 10% to within 3% throughout the year. Over the RRDP SIC1 dataset, ASI2 SIC shows little difference in winter, yet has much stronger negative bias (up to -6.3%) and standard deviation (up to 8.8%) in summer after the correction. The higher standard deviation can have two possible causes: (i) the variability of ice emissivity during melting season can be up to five times higher than in winter at near 90 GHz [3], and (ii) the removal of atmospheric influence reveals such natural variability. The lower ASI2 SIC reflects the area of melt ponds. Moreover, a new weather filter based on corrected TBs at 19V, 19H and 37V is applied on the 2008 dataset to screen out the residual cloud impacts over open water. A qualitative comparison with MODIS images shows that ASI2 using the 2008 dataset resolves a more realistic ice gradient across the ice edge than the original ASI algorithm. In March 2008, the ASI2 SIC is about 10% to 35% higher than ASI along the ice edges, and around 5% lower over the ice pack. The different performance of ASI2 over low and high SIC regions is reflected by the daily ice extent (defined as the total area covered by at least 15% SIC). ASI2 yields approximately 0.5 million km² higher ice extent than that of ASI and NASA Team 2 in winter, and up to 0.8 million km² higher ice extent during melting season. Yet the corresponding ice area of ASI2 is similar to that of ASI, indicating much lower SIC over regions of high ice concentration.

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Ridge detection from different spatial resolution SAR imagery

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Ridge is one typical form of sea ice surface deformation by the internal stress or the wind stress. Pressure ridge can be observed from high spatial resolution remote sensing imagery. In order to discuss the spatial resolution effect on ridge detection, airborne E-SAR data sets have been used to simulate different spatial resolution imagery from fine spatial resolution to coarse spatial resolution. We follow the simulation procedures presented in ICESAR report [1] for E-SAR simulation. Then, a structure tensor algorithm [2] is developed for ridge detection at the different spatial resolution SAR imagery. The ridge extraction algorithm is based on the hypothesis that the bright pixels are ridges and ridge has curvilinear shapes. With respect to structure tensor, the bright pixels are enhanced and the surrounding pixels are depressed using Log Gabor filter. Tensor structure algorithm has also considered the speckle noise in SAR imagery using the gradient distance to describe the tensor. In order to consider the spatial contextual information in remote sensing imagery, the convolution filter has been utilized in the constructed structure tensor. Direct threshold may work in L-band SAR imagery [3]. However, the contrast between the ridge and level ice in C-band SAR imagery is inferior to L-band SAR imagery. Thus, the ridge detection results using structure tensor algorithm in L-band and C-band SAR imagery are compared in this study. We conclude that the structure tensor algorithm performs well in ridge detection from SAR imagery compared to the direct threshold algorithm.

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Comparison of meteorological conditions in Svalbard fjords: Hornsund and Kongsfjorden

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We aim to present the results of a comparison of basic meteorological parameters in two Arctic fjords: Hornsund and Kongsfjorden situated on the west coast of Spitsbergen, the main island of the Svalbard archipelago. Air temperature, wind speed and direction, relative humidity and cloud cover from the period 2005-2016 are described and compared with previous (from 1975) analyses of meteorological conditions in the investigated region. Such a choice of dates coincides with the time the GAME project measurements were carried out. Even though Hornsund is located more southward than Kongsfjorden, the water in this fjord is colder. Warm Atlantic Water reaches Kongsfjorden directly from the West Spitsbergen Current, whereas Hornsund is strongly influenced by the cold Sørkapp Current. Such a system impacts the meteorological conditions in both fjords. As a result, mean temperature values in the Hornsund stations are well correlated with the temperature of the Atlantic Water carried by the West Spitsbergen, Current [1].

The outcomes are collated with results of studies maintained for many years and available in literature (e.g. [2-5]). We discovered that in the investigated period the climate of the Hornsund region is more oceanic than in Kongsfjorden. The stable level of the difference is manifested and is evident mainly through greater amplitudes in air temperatures in Kongsfjorden, and in stronger winds in Hornsund.

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Influences of surface heterogeneities on Arctic low-level cloud entrainment by shear – A motivation and a first test

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The Arctic amplification has many reasons: global heat transport to the lower latitudes, a lower Tropopause, and the Arctic feedback. Clouds contribute to the Arctic amplification by not only affecting the surface net energy balance. If this contribution is positive or negative, is unclear [1]. Also, they affect by precipitation. The surface can influence cloud development as well. For example, surface heterogeneities can enhance convective development [2].

The importance of correct representation of Arctic low-level clouds is outlined by a study of Shupe (2011): more than 50% yearly cloud over with a maximum in lower altitudes show that low-level clouds are a common phenomenon in the Arctic [3]. Due to their small spatial scales, clouds and their processes are parameterized in climate models and may be a source of uncertainty [4]. To improve their prediction, this study carries out large-eddy simulations of two low-level cloud regimes: persistent stratiform clouds (CR1) and shallow convective clouds (CR2).

Whilst CR2 has been subject to several studies on cold air outbreaks, there are only a few studies on CR1 [5]. One main reason is that CR1 is usually connected to stable atmospheric boundary layers. Therefore, the turbulence is smaller than in convective cases and requires resolutions in the order of meters and more computational resources [5]. Due to the lack of investigations this study mainly focuses on CR1 and the changes in the clouds physics as well as their effect on the surface and vice versa. Special interest is given to the effects of surface heterogeneities.

A recent review by Mellado (2017) summarizes the main reasons for cloud-top entrainment in stratocumulus clouds, one of them is shear [6]. It is probable that most of them exist as well on the cloud bottom but with different magnitudes. A first non-representative test has been run to investigate the effects of surface heterogeneities on shear of horizontal wind. Therefore, two different surface patterns (chess pattern and two halves) have been implemented in WRF-LES. The surface types differed only in the temperatures with a ΔT of 2K. The results can be seen in the figure 1. The figure shows an average increase of 15% in shear using the heterogeneous pattern.

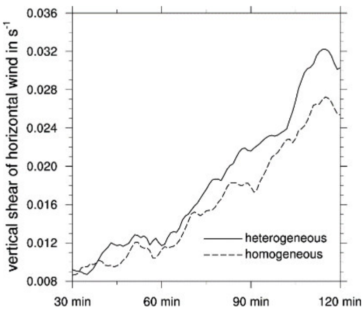

Fig. 1. Spatially averaged shear of the horizontal wind close to the inversion layer. On the x-axis the simulation time is printed. The heterogeneous pattern show an increase of the shear of roughly 15% for the second hour of the simulation

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A coupled large-eddy simulation sea ice model for simulating Arctic air mass transformation

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As warm, moist, maritime air masses are advected north over the high Arctic pack ice, the air mass is transformed with fog and low-level mixed-phase clouds typically forming below the surface temperature inversion. The moist air, and the clouds forming, influence strongly the surface energy fluxes and consequently the formation and melting of sea ice. Further cooling and drying of the air eventually result in cloud dissipation, and the boundary layer transforms into a clear state with strong surface radiative cooling. The processes of air mass transformation, cloud formation and cloud dissipation are challenging to represent in large-scale models, affecting our understanding of their sensitivity and contribution to climate warming. In order to obtain a more detailed understanding of these processes, and their influence on the surface energy balance, we employ atmospheric large-eddy simulation (LES) coupled to a simple sea ice model. In this presentation, we will show results from idealized simulations of winter Arctic air mass transformation for a range of different initial temperature and moisture profiles and discuss the potential impact on sea ice formation.

Plans for a HALO campaign within (AC)³

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The Transregional Collaborative Research Center (TR 172) "Arctic Amplification: Climate Relevant Atmospheric and Surface Processes, and Feedback Mechanisms (AC)³" ([1], see also , http://ac3-tr.de/) plans to deploy HALO (High Altitude and Long-Range Research Aircraft) within (AC)³. We suggest observations of air mass transformations during meridional transports, which are important to understand the teleconnections between the Arctic and Mid-Latitudes. The collected data will be used to test the ability of numerical atmospheric models to reproduce the measurements, which then can be applied to investigate the linkages between Arctic warming and mid-latitude weather.

In particular, vertical profile observations of meteorological, aerosol, cloud, and radiative energy budget parameters and their transformations along meridional air mass transports over sea ice and open water of the Arctic Ocean are suggested. HALO will follow the meridional transformation of air masses in an almost Lagrangian way. HALO is the only aircraft available in Germany, which has sufficient endurance for the planned Lagrange air mass observations. HALO is capable to lift a state-of-the-art set of meteorological and remote sensing instruments high enough to observe the complete vertical tropospheric air mass column, including aerosol particles and clouds. Furthermore, the long endurance and high ceiling of HALO allows observations in "poor weather conditions" (e.g., low cloud base, low visibility, icing in clouds etc.), which have often prevented measurement flights out of Longyearbyen using the Polar aircraft in the past.

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Planned contributions of (AC)³ to MOSAiC

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The Transregional Collaborative Research Center (TR 172) "Arctic Amplification: Climate Relevant Atmospheric and Surface Processes, and Feedback Mechanisms (AC)³" ([1], see also , http://ac3-tr.de/) plans to provide a significant German contribution to MOSAiC.

During the polar ice drift, RV Polarstern will be equipped with the OCEANET container (regular on board Polarstern during the Atlantic transects since 2009) for active/passive remote sensing of the vertical structure of aerosols, clouds, temperature and humidity, together with surface radiation as well as sensible and latent heat budget. The combined remote sensing and energy budget observations will be used to test our current understanding of atmospheric forcing above the sea ice, for the first time also during winter conditions in the Central Arctic.

During MOSAIC it is intended to carry out two airborne campaigns with the AWI aircraft POLAR 5 & 6. The first campaign is scheduled for spring 2020, the second one for early summer 2020. One aircraft will be equipped with instrumentation to characterize the sea ice and the snow surface properties and the interaction with the atmosphere. The second aircraft will be instrumented with trace gas, aerosol, and cloud sensors to obtain information on the vertical and horizontal distribution of atmospheric parameters. It is planned to deploy the German High Altitude and Long Range Research Aircraft (HALO) to extend the point measurements of RV Polarstern.

The modeling groups involved in (AC)³ plan to accompany the measurement campaigns by high-resolved (~1 km horizontally or better) simulations in weather forecast mode, using the ICOsahedral Non-hydrostatic (ICON) model. Furthermore, a series of simulation experiments will be run using a hierarchy of models (LES, RCM, GCM) with the main aim to evaluate and test key parameterizations (e.g., sea-ice properties, mixed-phase clouds). It is planned to run the RCM nudged and un-nudged such that the impact and interaction with the large-scale dynamics can be studied. Additionally, LES model intercomparisons are planned at various observatories (Oliktok point, Ny Ålesund).

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