

Wissenschaftliche Mitteilungen

aus dem
Institut für Meteorologie der Universität Leipzig



ISBN 978-3-9814401-5-7

**Meteorologische Arbeiten (XXII) und
Jahresbericht 2016 des Instituts für
Meteorologie der Universität Leipzig**

Hrsg.: Armin Raabe, Manfred Wendisch

Leipzig 2017

Band 55

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Introduction of the Transregional Collaborative Research Center TR 172: Arctic Amplification

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Summary: A new German research consortium is investigating the causes and effects of the rapid rise of near-surface air temperatures in the Arctic. Within the last 25 years a remarkable increase of the Arctic near-surface air temperature exceeding the global warming by a factor of two to three has been observed. The phenomenon is commonly referred to as Arctic Amplification. The warming results in rather drastic changes of a variety of climate parameters. For example, the Arctic sea ice has declined significantly. This ice retreat has been well identified by satellite measurements. However, coupled regional and global climate models still fail to reproduce it adequately; they tend to systematically underestimate the observed sea ice decline. This model-observation difference implies that the underlying physical processes and feedback mechanisms are not appropriately represented in Arctic climate models. Thus, the predictions of these models are also likely to be inadequate. It is mandatory to identify the origin of this disagreement.

Zusammenfassung: Ein neu geschaffenes deutsches Forschungskonsortium untersucht die Ursachen und Effekte des rapiden Anstiegs der bodennahen Lufttemperatur in der Arktis. Innerhalb der letzten 25 Jahre wurde ein bemerkenswerter Anstieg der Bodenlufttemperatur in der Arktis beobachtet, welcher die globale Erwärmung um den Faktor 2 bis 3 übersteigt. Dieses Phänomen wird als arktische Verstärkung bezeichnet. Diese Erwärmung resultiert vielmehr in einer drastischen Änderung einer Vielzahl von Klimarparametern. Beispielsweise ist das arktische Meereis deutlich zurückgegangen. Dieser Eisrückgang wurde durch Satellitenbeobachtungen gut beobachtet. Dagegen haben regionale und globale Klimamodelle immer noch Probleme, den Rückgang entsprechend zu reproduzieren. Sie tendieren dazu, den Meereisrückgang systematisch zu unterschätzen. Die Unterschiede zwischen Modell und Beobachtungen legen nahe, dass die grundlegenden physikalischen Prozesse und Rückkopplungsmechanismen nicht

entsprechend in arktischen Klimamodellen repräsentiert werden. Somit sind wahrscheinlich auch die Vorhersagen der Modelle unzureichend. Es ist notwendig, den Ursprung dieser Unstimmigkeit zu identifizieren.

1. Introduction

Parts of this paper were published in *Wendisch et al., 2017*. For meteorologists and climate scientists, the Arctic is one of the most interesting regions on Earth. Here, climate changes currently take place at an unprecedented pace and intensity, and the reported dramatic changes have not been completely anticipated. The Arctic is warming more rapidly than the rest of the world, a process referred to as the Arctic Amplification.

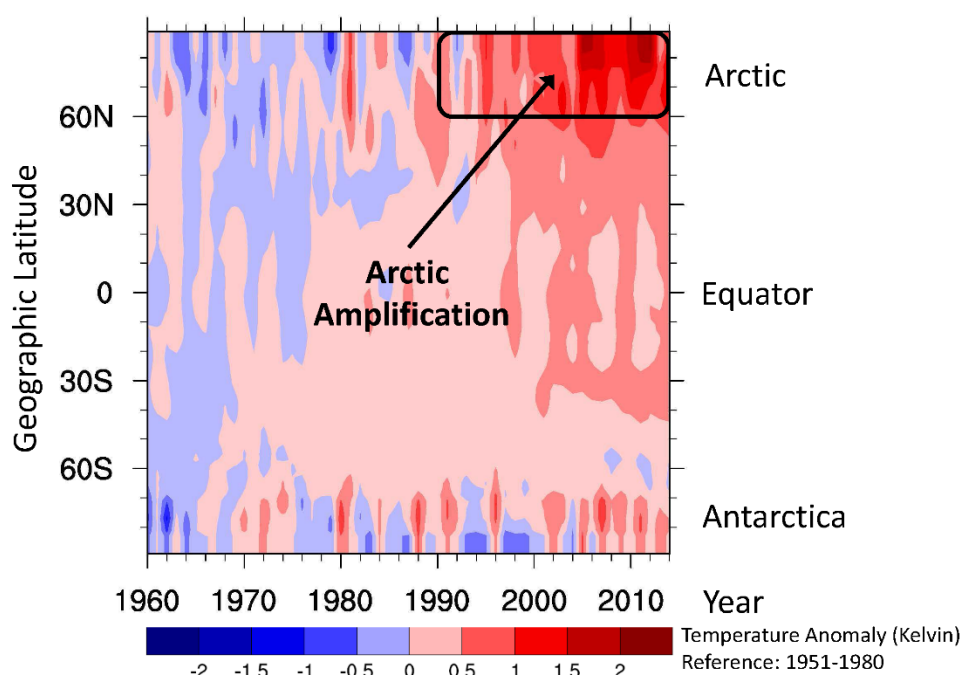


Fig. 1: Mean temperatures (by location and year, measured in Kelvins), shown as deviations from 1951–1980 mean temperatures. The increase in red areas in more recent years indicates global warming. The area inside the black box shows how this warming is amplified in the Arctic. The data have been provided by the NASA Goddard Institute for Space Studies.

Over the past 25 years, scientists have observed a remarkable increase of near-surface air temperatures, which exceeds the global warming by a factor of 2 to 3 (Figure 1). To find out why this is happening, in January 2016 the German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) launched a new Transregional Collaborative Research Center (TR 172) called “Arctic Amplification: Climate Relevant Atmospheric and Surface Processes, and Feedback Mechanisms.”

This effort, known by the abbreviation [\(AC\)³](#), has as its overarching scientific objectives the identification, investigation, and evaluation of key processes involved in Arctic Amplification; improving the understanding of the major feedback mechanisms; and quantifying the relative importance of these mechanisms.

Our current understanding of the rapid changes in the Arctic climate implies that atmospheric processes likely dominate the short-term warming mechanisms involved. Thus, research in (AC)³ has an atmospheric focus during its Phase I, which was approved to obtain funding by DFG from January 2016 to December 2019. In Phases II and III the researchers of TR 172 plan to investigate the interactions between oceanic and atmospheric components more thoroughly.

The project is organized in 5 project Cluster. Project Cluster A characterizes the fluxes of energy in the Arctic boundary layer, while Cluster B investigates clouds, aerosol particles, and water vapour. Cluster C addresses surface-atmosphere interactions and processes. Large-scale atmospheric circulation patterns and transport are investigated in Cluster D. Project Cluster E aims to synthesizing and synergistically combining the observation analyses of Clusters A-D by linking the results of observations and simulations. Altogether, the project consists of 19 individual sub-projects..

2. Recent Arctic Climate Changes

As a consequence of the recent drastic warming in the Arctic, other climate variables will also be affected dramatically [*Serreze and Barry, 2011*]. For example, routine satellite measurements have documented an enormous decline in the extent of the Arctic sea ice, which is even more than models predicted [*Stroeve et al., 2012; Jeffries et al., 2013*]. The past nine years of satellite data have revealed the six smallest annual minima of sea ice extent since appropriate and reliable satellite observations began in 1979. The recent decline is larger than any observed in more than 1400 years [*Kinnard et al., 2011*]. Climate models predict that the summer Arctic sea ice may completely vanish by the end of the 21st century or earlier.

Not only is the Arctic sea ice extent shrinking, but so is its thickness [*Lindsay and Schweiger, 2015*]. The reduced summer sea ice in the Arctic results in larger areas of thinner first-year ice forming during the subsequent winters. The average thinning of the Arctic sea ice causes a higher transmission of solar radiation into the ocean and enhanced heat energy fluxes from the ocean to the atmosphere. It also accelerates transpolar ice drift, a migration of ice from Russia's Siberian coast across the Arctic basin, resulting in an increased export of sea ice into the North Atlantic off the eastern coast of Greenland. The thinner sea ice is also more vulnerable to storms like the major Arctic cyclone in summer 2012.

The extent of the summer snow cover in both Eurasia and North America reached a record low in June 2012 [*Shi et al., 2013*]. In contrast, autumn snow cover over Eurasia has tended to increase in recent years, enhancing the strength of the Siberian high-pressure system during winter. This change in snow cover strongly affected the surface albedo of the Arctic land areas, the length of the growing season, the timing and dynamics of spring river runoff, the thawing of permafrost, and the wildlife population.

A continued amplified warming in the Arctic is also expected to decrease the temperature gradient between the Arctic and midlatitudes, which is supposed to

influence the meandering of the polar jet stream and wind patterns [Walsh, 2014]. Consequently, this might increase the probability of extreme weather events in the midlatitudes, including colder winters and summer heat waves.

3. Models have Room for Improvement

Unfortunately, coupled regional and global climate models do not yet unambiguously reproduce the recent drastic changes of Arctic climate parameters. For example, they systematically underestimate the decline of observed sea ice extent. These significant differences between models and observations imply that the climate models do not adequately describe the underlying physical processes and feedback mechanisms in the Arctic. As a result, the projections from these models are also likely to be inadequate and not yet fit for use.

As human influence on climate increases, more significant and potentially drastic climate changes in the Arctic are likely, although the accuracy of current projections is uncertain. These changes will have perceptible socioeconomic and ecological consequences for marine transportation, fisheries, ecosystems and ecosystem services, and tourism, as well as for oil, gas, and mineral exploration. It is thus a matter of urgency to qualitatively and quantitatively improve our knowledge of the Arctic climate system and the accuracy of its prediction.

4. How the Arctic is Unusual

The Arctic climate exhibits many unique features. For example, the sun does not rise high over the horizon, and seasonal variations in daylight are extreme (polar day and night). Bright ice and snow cover provide a highly reflective surface, low-level mixed-phase (water and ice) clouds are quite frequent, and the prevailing atmospheric boundary layer is specially shallow in the Arctic. These special characteristics profoundly influence physical and biogeochemical processes and atmospheric composition, as well as meteorological and surface parameters in the Arctic.

Several feedback mechanisms are particularly effective in the Arctic, and these generally increase the sensitivity of the Arctic climate system (Figure 2). The most famous and already well-studied feedback mechanism is the surface albedo effect, which reinforces warming over highly reflecting surfaces worldwide but is amplified even more in the Arctic. The increased near-surface air temperature causes a melting of the sea ice and snow cover. This reduced coverage, in turn, exposes less reflective surfaces, including open seawater, bare ground, and vegetated land. The less reflective surfaces absorb more solar radiation, which warm the land surface and the upper oceanic mixing layer, enhancing the energy fluxes from the surface to the atmosphere, which increases the near-surface air temperature even further.

The surface albedo effect amplifies global warming in the Arctic, and other changes might intensify this warming even further. Such changes include meridional (north–south, or vice versa) atmospheric and oceanic mass transport processes and related modifications of vertical turbulent exchange of energy between the ocean and the

atmosphere. A warmer ocean surface could increase the atmospheric water vapor amount and enhance the occurrence of clouds in the atmosphere, which warm the lower atmosphere by radiating heat downward. An increase in the abundance of soot aerosol particles could enhance the absorption of solar radiation both in the atmosphere and on snow or ice surfaces, further intensifying the warming effect. Biological activity changes in the ice-free ocean could increase the amounts of phytoplankton, which would also absorb more solar radiation.

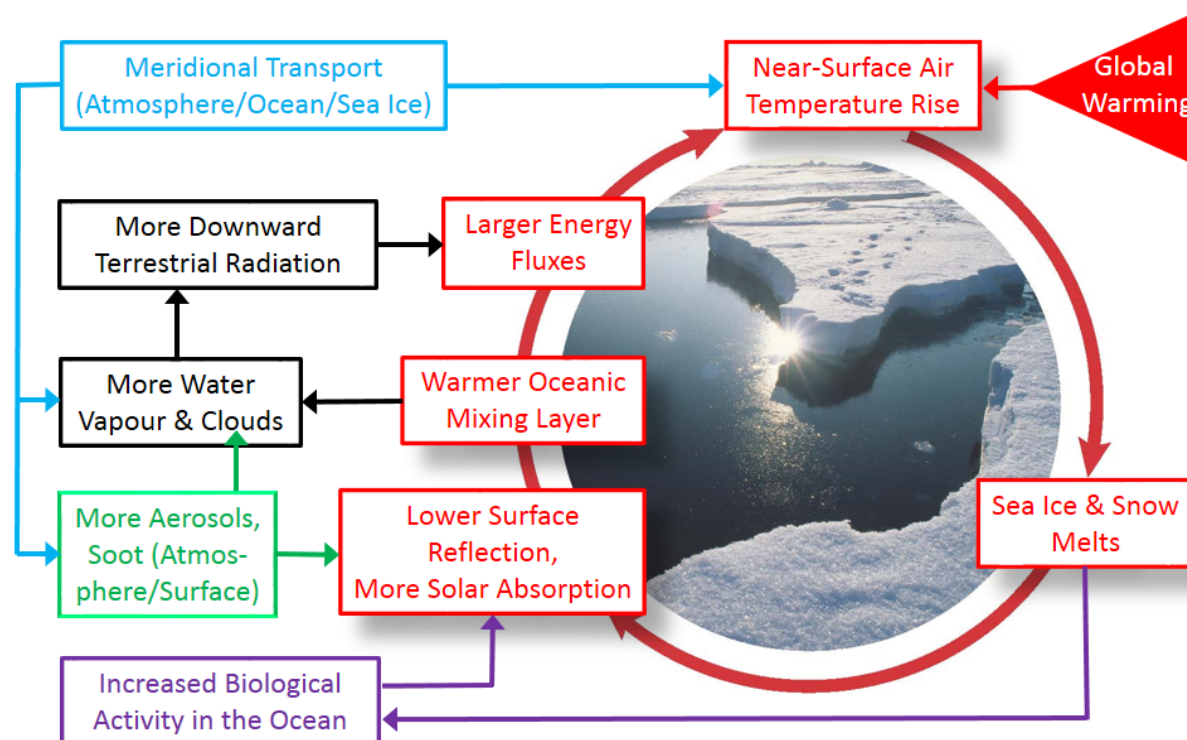


Fig. 2: Examples of feedback processes that amplify an initial near-surface air temperature rise caused by global warming.

These changes will have an impact on the unique atmospheric chemical processes taking place at high latitudes, removing short-lived climate pollutants and toxic heavy metals in the troposphere and controlling the stratospheric ozone layer. In addition, algae and phytoplankton production depend on these processes and their modifications, and the organohalogenes they release into the atmosphere will also change.

Although many individual consequences of changes in these Arctic climate parameters are known, their combined influence and relative importance for Arctic Amplification are complicated to quantify and difficult to disentangle. As a result, there is not yet a consensus in the Arctic research community about the dominant mechanisms leading to the phenomenon of Arctic Amplification.

5. Planned Observations and Modelling Studies

In the framework of (AC)³, we will use campaign-based and continuous observations to establish consistent shorter- and longer-term measurements and data product records. These observations will be collected by instrumentation carried on aircraft,

tethered balloons, research vessels, and satellites and from instruments at a selected set of ground-based sites. We will conduct field studies in different seasons and meteorological conditions, covering a suitably wide range of spatial and temporal scales (Figure 3).

The shorter-term intensive campaigns are embedded in longer-term data sampling programs (i.e., the past 30 years), which aim to identify trends in the spatiotemporal variability of Arctic climate parameters. We will carry out this observational strategy in an international context and in close collaboration with modeling activities.

Modelers will use a hierarchy of process, regional, and global models to bridge the spatiotemporal scales, from local processes to appropriate global and long-term climate indicators (Figure 4). The models will serve several purposes. They will guide the planning and performance of field campaigns, assist in the interpretation of the local measurements, serve as test beds to evaluate process parameterizations, quantify feedback mechanisms, and help researchers determine the origins of observed Arctic climate changes. The observations, in turn, will be used to evaluate the predictive skills of the models.



Fig. 3: Field observations within the framework of (AC)³. *CONCORD*, continuous characterization of the Ny-Ålesund/Spitsbergen column and radiative effects from ground-based remote sensing; *ABEX*, Arctic Balloon-borne profiling Experiment (May–June 2017); *ACLOUD*, Arctic Clouds–Characterization of Ice, aerosol Particles and Energy fluxes (May–June 2017); *PAMARCMiP*, Polar Airborne Measurements and Arctic Regional Climate Model Simulation Project (spring 2018); *AFLUX*, Arctic Amplification: Fluxes in the Cloudy Atmospheric Boundary Layer (spring 2019); *PASCAL*, Physical feedback of Arctic Atmospheric Boundary Layer, Sea ice, Cloud and Aerosol (May–June 2017); *MOSAiC*, Multidisciplinary drifting Observatory for the Study of Arctic Climate (2019–2020).

We will place particular emphasis on evaluating different parameterizations, analyzing and quantifying feedback mechanisms in sensitivity studies, and assessing the

importance of processes for Arctic climate and their interaction with the global dynamics and climate change.

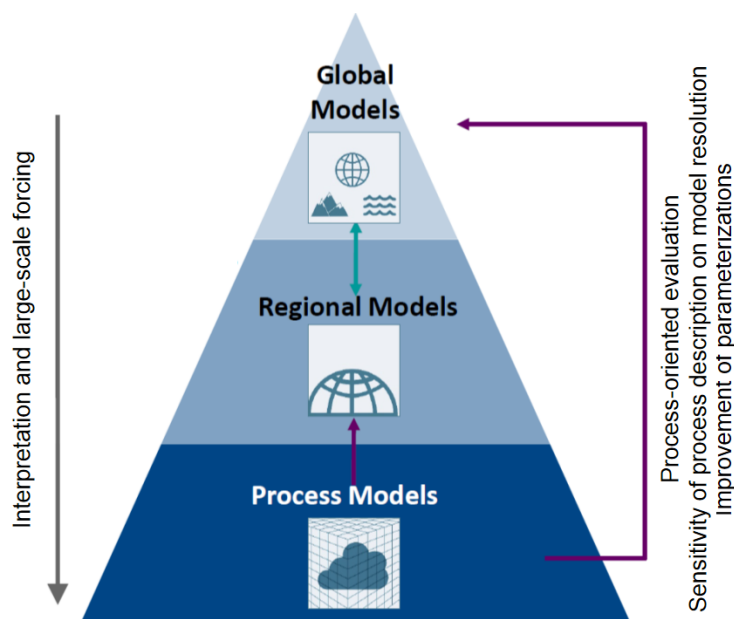


Fig. 4: The (AC)³ consortium will use a hierarchy of models covering a wide range of spatial and temporal scales to study Arctic Amplification.

6. Plans for the Coming Year

We have made preparations for a major observational campaign using the R/V *Polarstern*, tethered balloon measurements from an ice floe camp, and the research aircraft Polar 5 and Polar 6 (based in Longyearbyen, Svalbard) during May and June 2017. In particular, we will investigate the coupling of sea ice, clouds, and aerosol in the transition zone between open ocean and sea ice.

The instrumentation on board R/V *Polarstern* will provide standard observations and additional spectral radiation measurements to determine the surface energy budget and a detailed characterization of surface, cloud, and aerosol properties. A continuous ground-based measurement site at Svalbard, close to the open ocean, will provide similar measurements.

Polar 5 and Polar 6 will operate between Svalbard and the actual location of R/V *Polarstern* along the sea ice edge. The airborne observations will be supplemented by measurements of the boundary layer structure (turbulent and radiative energy fluxes) from a tethered balloon. The campaign will be the basis for extended modeling efforts to improve our understanding of Arctic climate changes.

The Leipzig Institute for Meteorology (LIM) is represented with altogether 8 individual sub-projects and is the coordinating speaker university. The main focus of airborne measurements in sub-projects A02 and A03 is on turbulent fluxes of momentum, sensible and latent heat, and radiation, and their vertical distribution for different meteorological situations, cloud cover, aerosol content, and sea ice coverage. Sub-project B03 investigates the importance of mixed-phase Arctic clouds for the cooling/warming of the near-surface air by means of aircraft-based measurements. Sub-project C01 deals with the radiative warming (or cooling) due to Arctic clouds

and how sensitive it is to the heterogeneity of surface reflection properties like ice/snow and open water, while in sub-project C02 the extent of the darkening of snow/ice surface by soot depositions is investigated and the issue of the near-surface air warming by atmospheric soot is studied. Sub-project D01 hypothesizes that regional Arctic climate change and Arctic Amplification is modulated by large-scale tropospheric and stratospheric circulation patterns. Sub-project D02 will quantify the role of aerosol particles, their impact on clouds, as well as its transport and radiative/dynamical effects on Arctic Amplification from a modelling perspective. Sub-project E01 will quantitatively identify the important physical climate feedback mechanisms in the Arctic using state-of-the-art global circulation models.

7. Acknowledgment

We gratefully acknowledge the support from the German Research Foundation (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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HALO-Based Research Conducted by the LIM: Previous Campaigns and Plans for the Future

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Summary: This article gives an overview about the activities of the Leipzig Institute of Meteorology (LIM) within the HALO (High Altitude and Long Range Aircraft) Scientific Priority Program (SPP 1294 funded by DFG). HALO offers unique possibilities for atmospheric research and Earth observations. It can carry a scientific payload of up to 3 t, cover a range of 10000 km and reach a ceiling of 15 km. The LIM contributes to the instrumentation of HALO with the Spectral Modular Airborne Radiation measurement system (SMART). SMART was deployed during the first HALO mission TECHNO in 2010. During subsequent five HALO campaigns SMART measurements provided valuable insights regarding cloud properties and the Earth's radiative budget. Three further missions, which are scheduled for the coming years, will make use of SMART measurements as well.

Zusammenfassung: Dieser Bericht gibt einen Überblick über die Aktivitäten des Leipziger Instituts für Meteorologie (LIM) im HALO Schwerpunktprogramm (SPP 1294 der DFG). HALO bietet einzigartige Möglichkeiten für die Atmosphärenforschung und Erdbeobachtung. Es kann eine wissenschaftliche Nutzlast von 3 t aufnehmen, eine Reichweite von 10000 km zurücklegen und eine maximale Flughöhe von 15 km erreichen. Das LIM trägt zur Instrumentierung von HALO mit dem Spectral Modular Airborne Radiation measurement system (SMART) bei. SMART wurde 2010 bei der ersten HALO Mission TECHNO eingesetzt. In fünf folgenden HALO Kampagnen verschafften SMART Messungen wertvolle Erkenntnisse bezüglich Wolkeneigenschaften und dem Strahlungsbudget der Erde. Drei weitere HALO Missionen, die für die kommenden Jahre geplant sind, werden ebenfalls SMART nutzen.

1. Introduction

HALO is based on a commercial business jet, a Gulfstream G550. Due to numerous modifications, HALO is capable to accommodate multiple in situ and remote sensing instruments. With a scientific payload of 3 t, a range of 10,000 km and a ceiling of 15 km HALO offers unique possibilities for atmospheric and geophysical research as these features in combination are not met by many other research aircraft in Europe.



Fig. 1: The HALO research aircraft.

HALO was purchased with a joint investment of German Ministry of Science and Education, the Helmholtz Association and the Max-Planck-Gesellschaft. The annual standby costs for HALO are funded by a consortium, currently consisting of the German Research Foundation (DFG), German Aerospace Center (DLR), Max Planck Society (MPG), Karlsruhe Institute of Technology (KIT), Research Center Jülich (FZJ), German Research Center for Geosciences (GFZ), and Leibniz Institute for Tropospheric Research (Tropos). The largest share is covered by the DFG, with almost one third of the total budget.

The participation of universities to the HALO project is funded via a Scientific Priority Program (SPP 1294) by the DFG. This program is coordinated by the universities of Leipzig, Frankfurt and Dresden.

2. The Spectral Modular Airborne Radiation measurement sysTem (SMART)

In the HALO campaigns described below, the Leipzig Institute of Meteorology contributed to the instrumentation of HALO with the Spectral Modular Airborne Radiation measurement sysTem (SMART, Wendisch et al., 2001). It measures upward and downward spectral irradiances and upward radiances in the spectral range from 0.3 to 2.2 μm . The received radiation is transmitted via optical fibers to a set of spectrometers. Between 0.3 to 1.0 μm the spectrometers have a spectral resolution (Full Width at Half Maximum, FWHM) of 2-3 μm . Both, the upper as well as the lower sensor package, are equipped with an active horizontal stabilization unit keeping the sensor head in a strict horizontal position during flight. Thus, irradiances can be measured with high accuracy.

SMART measurements can be used to retrieve cloud optical and microphysical properties such as the cloud particle effective diameter, the cloud optical thickness and thermodynamic phase (Ehrlich et al., 2008). These properties are crucial for accessing the radiative forcing of clouds and thus Earth's energy budget.

Furthermore, the spectral measurement of the irradiance can be used to determine the cloud top and surface albedo.

3. Previous HALO Campaigns

3.1 HALO-TECHNO

SMART was employed on HALO in the frame of the HALO TECHNO mission (HALO Technical Mission) conducted in 2010. TECHNO was the first HALO mission to try the capabilities of the new aircraft. From the data collected during the TECHNO mission the LIM investigated the influence of the surface albedo variability on the retrieval of cirrus optical thickness and particle size (Fricke et al., 2014). For this analysis the SMART measurements were used together with the data of the WALES (Water vapor Lidar Experiment in Space) lidar instrument, which was onboard HALO as well (Groß et al., 2014).



Fig. 2: Sensors for SMART on top (left) and bottom (right) of HALO

3.2 ML-CIRRUS

ML-CIRRUS (Formation, Lifetime, Properties and Radiative Impact of Mid-Latitude Cirrus Clouds) was performed in March and April 2014. The campaign took place over Europe and the North Atlantic. Ice clouds in altitudes between 7 and 13.5 km were analyzed with respect to their formation, lifecycle, and radiative effects (Voigt et al., 2017). A particular emphasis was put on the differences between naturally developing cirrus and contrail cirrus produced by aircraft. This research is

motivated by the importance of the anthropogenic influence of contrail cirrus on Earth's radiative budget.

Remote sensing and radiative energy budget instruments were used in synergy with a set of in situ cloud particle instruments. On the one hand, nine different cloud particle probes were deployed in combination with in situ instruments using aerosol inlets. Thus, the particle size spectrum could be accessed from nucleated aerosol particles to large ice crystals.

Contrail cirrus showed an increased number concentration of small ice particles with diameters of less than $30\ \mu\text{m}$. This leads to a higher optical depths compared to natural cirrus clouds.



Fig. 3: Inlets on top side of HALO (left) and PMS-carriers below the wings (right)

On the other hand, cirrus clouds were probed with remote sensing instruments. SMART measurements were combined with measurements of the mini-DOAS to demonstrate the potential of radiation measurements in limb direction to characterize thin cirrus clouds (Wolf et al., 2017). This study showed that limb observations have a higher sensitivity for cloud optical thickness compared to nadir observations and are less affected by the surface albedo. Therefore, also subvisible cirrus can be detected by such measurements. For a case study, a general agreement between the independent observations by SMART, WALES and mini-DOAS was found. Differences were mainly caused by the different observation geometries.

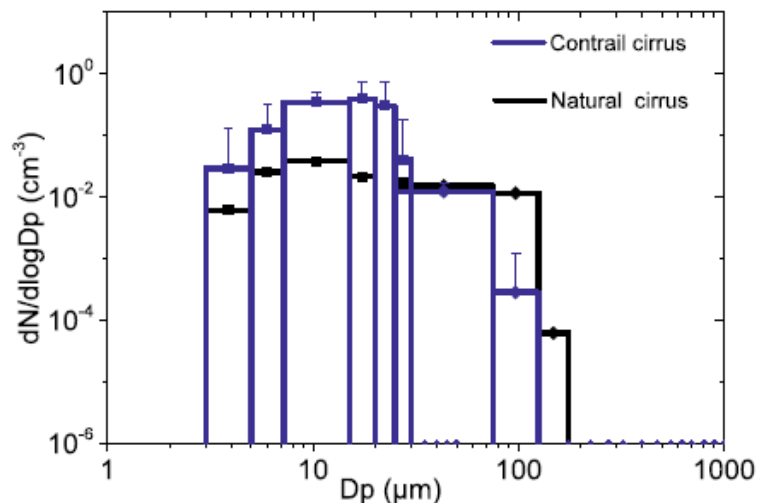


Fig. 4 Particle size distribution of a contrail cirrus (blue) compared with the neighboring natural cirrus (black). Contrail cirrus clouds contain higher number densities of small ice crystals compared to natural cirrus. The figure is taken from Voigt et al. 2017.

3.3 ACRIDICON-CHUVA

The HALO mission ACRIDICON (Aerosol, Cloud, Precipitation and Radiation Interactions and Dynamics of Convective Clouds) took place in Brazil in September and October 2014. It was performed in cooperation with numerous Brazilian partners from the CHUVA (Cloud Processes of the Main Precipitation Systems in Brazil: A Contribution to Cloud Resolving Modeling and to the GPM [Global Precipitation Measurement]) campaign and the US-American and Brazilian measurement campaign GOAmazon (Green Ocean Amazon). Thereby, a combined approach of remote sensing and in situ measurements, onboard HALO as well as from supporting ground-based measurement sites, was conducted.

The aim of the ACRIDICON mission was to investigate the emergence, development and properties of tropical clouds as well as their dynamic and radiative effects. The influence of aerosol particles on clouds and on climate was examined. Cloud measurements over the rainforest were contrasted to measurements over polluted or deforested areas.

It was confirmed that clouds developing in polluted conditions contained rather small and thus a higher number concentration of cloud droplets, which leads to a cooling effect in the Earth's radiative energy budget. Furthermore, these microphysical properties cause a suppression of precipitation (Wendisch et al., 2016).

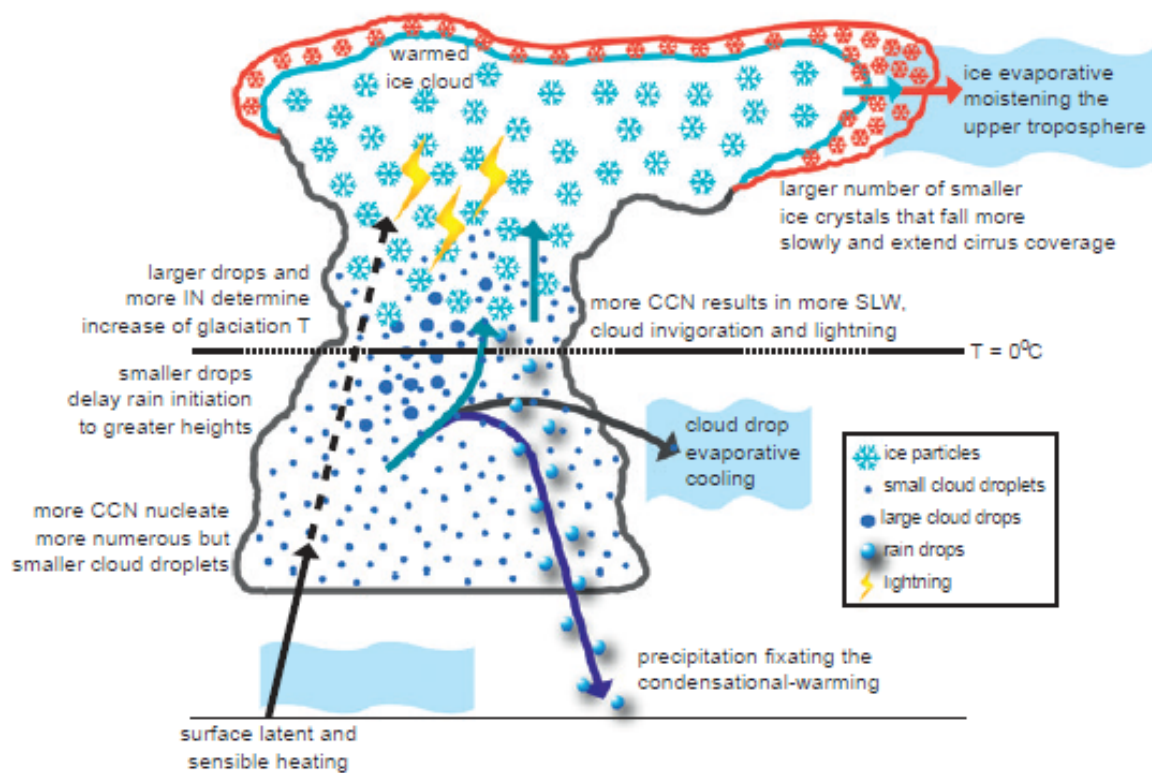


Fig. 5: Illustration of processes in deep convective clouds over Amazonia. The effect of an increased CCN load is shown. (SLW: supercooled liquid water, T : temperature). The figure is taken from Wendisch et al. 2016.

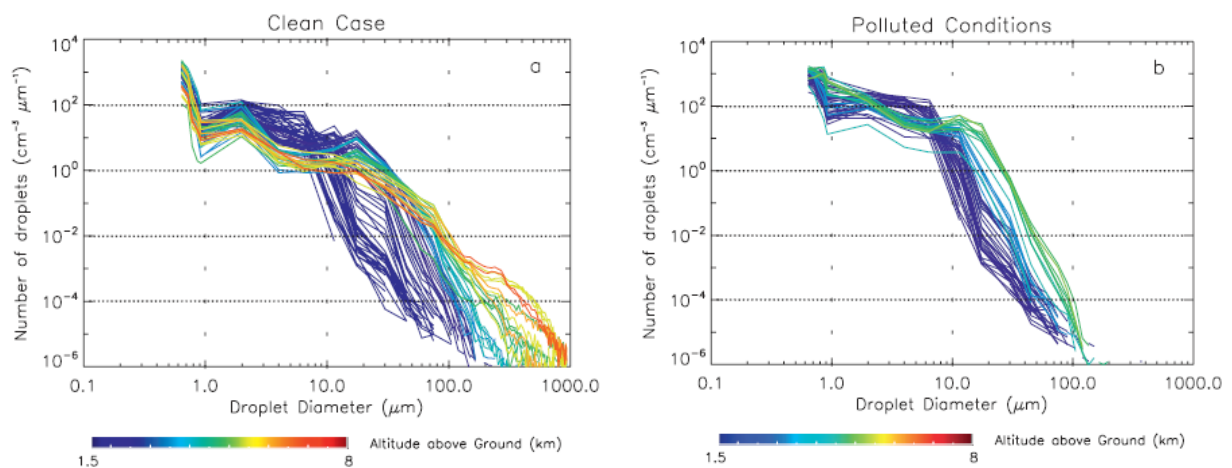


Fig. 6: Measurements of cloud droplet size distribution in warm convective clouds. The plots show a research flight in clean conditions (left) and in polluted conditions, influenced by biomass burning. The figure is taken from Wendisch et al. 2016.

Moreover, increased concentrations of cloud condensation nuclei (CCN) were observed in higher altitudes. Their origin is still under investigation.

To this mission the Leipzig Institute of Meteorology contributed not only with measurements of the SMART instrument. Beyond that, it was responsible for the scientific management of this HALO campaign, together with the Max Planck Institute for Chemistry.

3.4 NARVAL and NARVAL 2

NARVAL (Next Generation Remote Sensing for Validation Studies) consisted of two parts. The first one (NARVAL-South) was performed in December 2013. The observational focus was on shallow convection in the trade wind region East of Barbados. NARVAL-North took place over the extra-tropical North Atlantic in January 2014. There, post-frontal regimes were investigated.

The focus of the NARVAL instrumentation was on remote sensing of trade wind cumuli. A 36 GHz cloud radar and three microwave radiometers were deployed on HALO for cloud measurements. Height-resolved profiles of water vapor were derived with a differential absorption lidar. Furthermore, a mini-DOAS, dropsondes and SMART measured onboard HALO.

This instrumentation was used for the evaluation of satellite retrievals. 11 underpasses of the CloudSat satellite and 22 underpasses of the SSMIS (Special Sensor Microwave Imager / Sounder) were flown.

Cloud retrieval of cloud fraction, cloud size and liquid water path based on SMART measurements were used to analyze Radar observations by HAMP (Schnitt et al. 2017). The different wavelength ranges and physical principles used by the SMART and HAMP, provide different retrieval sensitivities for precipitating and non-precipitating clouds and helped to identify the detection limit of radar observations. The comparison of the retrieval results showed the potential of such synergetic analysis of multiple remote sensing instruments.

The follow-up mission NARVAL 2 was performed in August 2016, also based in Barbados. The instrumentation was similar to NARVAL, with SMART measuring onboard HALO.

Thus, the measurements of NARVAL-South, performed during the dry season were complemented with the NARVAL 2 data from the wet season. Hence, the statistics gained from NARVAL could be extended significantly.

Organized convective systems were probed. The life cycle of some systems was observed with several consecutive flights. Both, the organization of the convection itself as well as the status of the ambient boundary layer was analyzed. Disentangling the relation between convective aggregation and boundary layer evolution is an important key to assess the climate sensitivity of organized convection.

3.5 NAWDEX

The LIM took part with the SMART instrument. Research flights for NAWDEX (North Atlantic Waveguide and Downstream Impact Experiment) were performed in the Northern Atlantic region in September and October 2016. The payload was identical to the NARVAL 2 mission.

NAWDEX was part of an international field experiment – the High Impact Weather (HIW) program, which was performed by an international consortium from the US, Canada, UK, France and Germany under the auspices of the World Meteorological Organization (WMO). Altogether, four research aircrafts were employed.

The scientific aim of NAWDEX is to obtain a comprehensive picture of the thermodynamic structure of the atmosphere close to jet streams. Therefore, the impact of diabatic processes for the weather evolution over Europe will be quantified. For these investigations, midlatitude Rossby waves constitute an important component. Hence, NAWDEX aims at the quantification of errors in their numerical representation.

In the frame of NAWDEX a hurricane was observed in detail on its way from the tropics to the midlatitudes.

4. Outlook: CIRRUS-HL, EUREC4A and HALO-(AC)³

The completed HALO missions illustrated the fascinating possibilities of this research platform. The high request for these measurements is illustrated by the HALO schedule, which shows that HALO is fully booked with scientific missions until mid-2022. Scientists from the LIM are involved in three planned missions.

CIRRUS-HL (Cirrus in High Latitudes) aims at the formation, lifetime, properties and climate impact of Arctic cirrus. Aerosol effects on cirrus will be investigated, which will include the influence of air traffic on cirrus.

The observations will be performed in high northern latitudes. In these regions, observations of cirrus are scarce and the properties in terms of abundance, altitude, microphysics and radiation are expected to differ from cirrus in lower latitudes. Similarly, to ML-CIRRUS, the instrumentation will consist of a combination of state-of-the-art remote sensing and in situ measurement devices.

EUREC4A (Elucidating the Role of Cloud-Circulation Coupling in Climate) builds on the experiences and insights from NARVAL and NARVAL 2. Apart from minor upgrades, HALO will carry the same instrumentation as on the preceding NARVAL missions. The region of interest will be the tropical Atlantic, with HALO being based on Barbados. The measurements aim to understand the interplay between clouds, convection and circulation and their role in climate change.

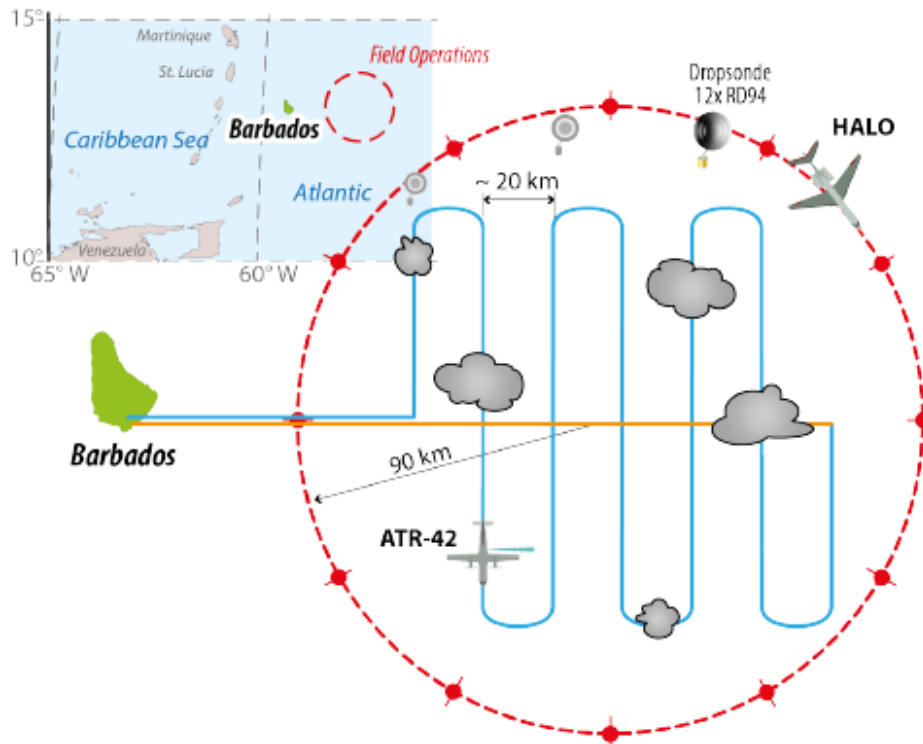


Fig. 7 Planned flight patterns for EUREC4A, HALO with the remote sensing instrumentation will fly in higher altitudes. The French ATR-42 will fly below HALO and perform in situ cloud measurements.

EUREC4A is a German-French initiative. The French aircraft ATR-42 will be deployed to perform in situ measurements below HALO in order to gain more detailed insights about cloud properties. Furthermore, measurements from several research ships are planned.

HALO-(AC)³ (HALO – Arctic Amplification: Climate Relevant Atmospheric and Surface Processes and Feedback Mechanisms) will be coordinated by the LIM. The scientific payload will be identical to that installed on HALO during EUREC4A. This HALO campaign is embedded in the DFG-funded Transregional Collaborative Research Center SFB/TR 172, called (AC)³, which is coordinated by the LIM. The aim of (AC)³ is to achieve a better understanding of the Arctic warming, which currently occurs at an unprecedented pace and intensity.

HALO-(AC)³ will give a significant contribution towards a better understanding of the intensive Arctic warming. Furthermore, effects of the Arctic warming on the weather in the midlatitudes will be examined. For this objective, air mass transformations during meridional transports will be observed. Thereby, meteorological, aerosol, and cloud properties will be measured.

5. Summary

HALO is a state-of-the-art research aircraft with features which are not met by many other research aircraft in Europe. Thus, HALO offers unique possibilities for atmospheric research and Earth observations.

The LIM contributes to the instrumentation of this research platform with the SMART instrument. The LIM took part at five HALO campaigns – three further missions are planned for the coming years. The campaign locations as well as the foci of the missions are manifold. However, the SMART measurements proved to be a state-of-the-art method to derive various cirrus properties.

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Observations of glories above arctic boundary layer clouds to identify cloud phase

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Abstract

The glory is an optical phenomenon observed above liquid water clouds and consists of coloured rings around the anti-solar point. Since the glory is caused by scattering on spherical particles it can be used as a proxy to identify liquid water at the cloud top. Images taken with a CANON digital camera equipped with a fish-eye lens on board the research aircraft Polar 5 during the measurement campaign Radiation-Aerosol-Cloud Experiment in the Arctic Circle (RACEPAC) were analysed for glories. To identify glories an algorithm consisting of five criteria was developed by using simulations of the scattering angle dependent radiance and a test data set of measurements. The algorithm was tested and proved to be able to distinguish between images showing a glory and images not showing any glory.

Zusammenfassung

Die Glorie ist eine optische Erscheinung, die über Flüssigwasserwolken beobachtet werden kann und aus farbigen Ringen um den Gegen Sonnenpunkt besteht. Da die Glorie durch Streuung an sphärischen Partikeln entsteht, kann sie zur Identifikation von Flüssigwasser am Wolkenoberrand genutzt werden. Bilder, die mit einer CANON Digitalkamera, die mit einem Fischaugenobjektiv ausgestattet war, von Bord des Forschungsflugzeugs Polar 5 während der Messkampagne RACEPAC aufgenommen worden, wurden auf das Auftreten von Glorien untersucht. Zur Identifikation wurde ein Algorithmus mit fünf Kriterien entwickelt, die mit Hilfe von Simulationen der streuwinkelabhängigen Radianz und einem Testdatensatz der Messungen erstellt wurden. Der Algorithmus wurde getestet und ist in der Lage zwischen Bildern mit und ohne Glorie zu unterscheiden.

1. Introduction

The radiative energy budget is strongly influenced by clouds. While low altitude clouds in low and mid-latitudes have a cooling effect, low clouds in high latitudes may act both cooling and warming e.g. due to the lower altitude of the sun (Wendisch et al., 2013). Previous research has shown that a relatively large proportion of clouds in the Arctic boundary layer are mixed-phase especially in the boundary layer (Mioche et al., 2015). A typical Arctic mixed-phase cloud has an inhomogeneous horizontal distribution of areas consisting of either pure liquid water or pure ice and areas consisting of both liquid water and ice in between the areas of pure phase cloud particles. The patches of pure phase cloud particles have a size range of 100 to 1000 m (Korolev et al., 2003, Korolev and Isaac, 2008). Unlike the horizontal phase distribution the vertical phase distribution is much more structured. The top of Arctic mixed-phase clouds is typically dominated by liquid water

droplets (Ehrlich et al., 2009).

The thermodynamic phase of a cloud can be distinguished by different types of remote sensing, like active remote sensing using lidar or radar or passive remote sensing using microwave radiometers. The approach used here applies passive remote sensing of solar radiation using the directional information. Directional information relies on optical phenomena hence single scattering gives only information concerning the cloud top. This method was previously used by Ehrlich et al. (2012) and by Bréon and Goloub (1998), who used satellite data. Ehrlich et al. (2012) used a digital camera by Canon to retrieve both optical thickness and effective radius of an arctic boundary layer cloud using the cloud bow. In this study the optical phenomenon of the glory is used as a proxy for the dominating phase at the cloud top. The glory is a backscattering phenomenon which only occurs on spherical particles (Laven, 2005). Since only liquid water droplets are spherical the detection of the glory does allow determining the dominating cloud phase. Basis for the identification was the measured reflected radiance.

2. Instrumentation

With a digital camera (Canon EOS 1D Mark III) with a 180° fish-eye lens (SIGMA 8mm F3.5 EX DG FISHEYE) which was mounted on the Polar 5 research aircraft images displaying the entire half space beneath the aircraft were taken. With the help of a radiometric calibration and an attitude correction each image was converted to scattering angle dependent radiance in different zenith and azimuth direction. In combination with the solar position (θ_0, φ_0) each viewing direction (θ_r, φ_r) can be converted into a scattering angle using the methods and algorithms described by Ehrlich et al. (2012). Assuming both rotation symmetry and single scattering a scattering angle ϑ was assigned to each pixel by:

$$\vartheta = 180^\circ - \arccos(-\sin \theta_0 \cdot \cos \varphi_0 \cdot \sin \theta_r \cos \varphi_r - \sin \theta_0 \cdot \sin \varphi_0 \cdot \sin \theta_r \cdot \sin \varphi_r + \cos \theta_0 \cdot \cos \theta_r) \quad (1)$$

3. Simulation of scattering angle dependent radiance

To analyse the sensitivity of the scattering angle dependent radiance of clouds and to detect glories simulations of radiances of liquid water and ice clouds were produced using the library for radiative transfer libRadtran 2.0.1 (Emde et al., 2016). The radiative transfer calculations were performed with the help of the intensity corrected radiative transfer solver DISORT by Buras et al. (2011). For the ice clouds the ice crystal parametrization for solid columns by Key et al. (2002) was used. The results of the calculations of the radiance $I(\theta, \varphi)$ were then interpolated on a grid representing the whole observed hemisphere. Therefore, the simulated radiances could be converted to scattering angle dependent radiance $I(\vartheta)$ like the images of the digital camera.

Fig. 1 shows the simulated scattering angle dependent radiances of liquid water clouds and an ice cloud. To simulate the radiances of liquid water clouds a monodisperse droplet distribution with an effective radius of 10 μm and 4 μm respectively was used. Additionally the cloud optical thickness was varied. The radiances of the ice cloud were simulated by assuming an effective radius of 50 μm and using said ice crystal parametrization. The differences between the ice cloud's radiances after varying optical thickness and/or effective radius were too small to be distinguished in the plot. The scattering angle dependent

radiances of both liquid water and ice clouds differ from the respective phase functions. Despite this fact a glory is detectable at a scattering angle of 180° within the measurements of the scattering angle dependent radiance. In case of ice clouds no glory is observable. With increasing cloud optical thickness the values of the radiance increase as well. From the results shown in Fig. 1 can be concluded additionally that an increase in the effective radius yields an increase in the local maximum near backscattering direction.

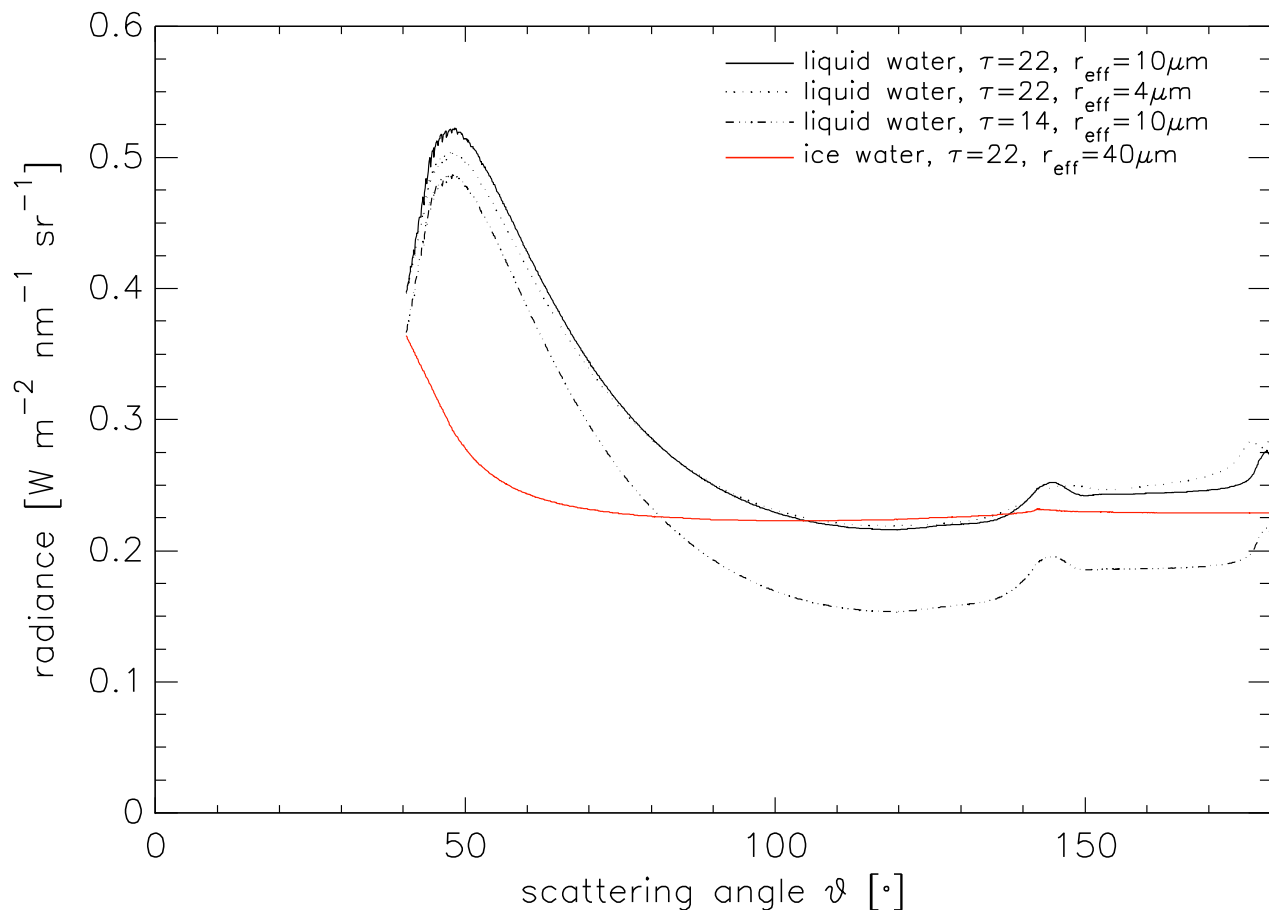


Fig. 1: Simulation results of reflected scattering dependent radiances for liquid water clouds (black) and ice water clouds (red)

4. Definition of Algorithm

As simulations of the scattering angle dependent radiance show the differences between ice and liquid water clouds are especially pronounced in the backscattering direction near 180° . To reduce the potential influence of horizontal inhomogeneities in the phase distribution the range of scattering angles in the development of an identification algorithm was limited to 170° - 180° . Focusing only on the maximum in backscattering direction does not allow identifying the glory. Further tests have shown that a single parameter is not sufficient to identify the glory and correspondingly the cloud phase. Therefore, several criteria were defined. The local maximum of the scattering angle dependent radiance between 173° and 180° has to be within the range of 176° and 180° . During the next step it was checked, if the mean of the radiance values $\pm 0.3^\circ$ around the maximum minus one per cent of its value ($I_{\max} - 0.01 \cdot I_{\max}$) is larger than the mean of the scattering angle dependent radiance between 173° and 180° . The mean of the maximum $\pm 0.3^\circ$ was chosen to smooth possible irregularities in the measured radiance. This criterion serves as a measure of the maximums

and the glories strength. The two discussed criteria can be expressed as:

$$176^\circ \leq \theta_{\max} \leq 180^\circ \quad (2)$$

$$I_{\max} - 0,01 \cdot I_{\max} > \bar{I}_{173^\circ-180^\circ} \quad (3)$$

Fig. 1 shows a comparison of liquid water clouds and ice clouds. The values for the criteria of the liquid water and ice clouds used in the simulations are listed in the following table. Additionally to the radiances depicted in Fig. 1 the values of simulation results for two more ice clouds are shown in Tab 1. Since the radiances of the ice clouds appeared to be indistinguishable by eye those two additional radiances were not shown in Fig. 1.

Tab. 1 Identification criteria from simulation

		θ_{\max}	$I_{\max} - 0.01I_{\max}$ [Wm ⁻² nm ⁻¹ sr ⁻¹]	$\bar{I}_{173^\circ-180^\circ}$ [Wm ⁻² nm ⁻¹ sr ⁻¹]
liquid water cloud	$\tau = 22, r_{\text{eff}} = 4\mu\text{m}$	179.4°	0.280	0.277
	$\tau = 22, r_{\text{eff}} = 10\mu\text{m}$	179.4°	0.272	0.259
	$\tau = 14, r_{\text{eff}} = 10\mu\text{m}$	179.3°	0.215	0.201
ice cloud	$\tau = 22, r_{\text{eff}} = 40\mu\text{m}$	173.8°	0.227	0.229
	$\tau = 22, r_{\text{eff}} = 10\mu\text{m}$	173.8°	0.227	0.229
	$\tau = 14, r_{\text{eff}} = 10\mu\text{m}$	173.8°	0.227	0.229

The values of the identification parameters as presented in Eq. 2 and Eq. 3 for the radiances shown in Fig. 1 are listed in Tab. 1. With the help of the two identification parameters it is possible to distinguish between ice and liquid water clouds. The glory serves as distinction criterion which could be identified in all cases. The position of the local maximum of the liquid water cloud radiances does not change much even when varying effective radius and cloud optical thickness. The strength of the glory, however, does vary. In case of an effective radius of 4 μm the difference between $I_{\max} - 0.01 \cdot I_{\max}$ and $I_{173^\circ-180^\circ}$ equals 0.003 W m⁻² nm⁻¹ sr⁻¹. An effective radius of 10 μm yields a difference between $I_{\max} - 0.01I_{\max}$ and $I_{173^\circ-180^\circ}$ of 0.14 W m⁻² nm⁻¹ sr⁻¹ ($\tau = 14$) and 0.13 W m⁻² nm⁻¹sr⁻¹ ($\tau = 22$) respectively.

On the basis of the values of $I_{\max} - 0.01 \cdot I_{\max}$ and $I_{173^\circ-180^\circ}$ it is possible to state if the optical thickness of boundary layer clouds determines how large the detected radiances are. The parameters do not show any sensitivity regarding changes of cloud optical thickness and effective radius in case of ice clouds.

With the help of a test dataset consisting of 480 images taken by the camera the algorithm was tested. The dataset consisted of images taken on the 6th of May 2014 out of which 300 images showed a closed cloud cover below the aircraft and 180 images showed partly broken clouds or optical thin clouds. For a closed cloud cover of optical thick clouds the two proposed criteria (Eq. 1 and Eq. 2) are sufficient. To identify broken and optical thin liquid water clouds respectively additional criteria have to be defined: the ratio between local minimum and maximum of the scattering angle dependent radiance between 173° and 180°, the ratio between the local minimum and the mean of the radiance between 172° and 174° and the standard deviation between 170° - 173°. The criteria determined from the analyses of the test dataset are:

$$0.015 < 1 - \frac{I_{\min}}{I_{\max}} < 0.11 \quad (4)$$

$$-3 < \left(1 - \frac{I_{\min}}{\bar{I}_{172^\circ-174^\circ}}\right) \cdot 1000 < 20 \quad (5)$$

$$\sigma_{170^\circ-173^\circ} < 4.0 \text{ mW m}^{-2} \text{ nm}^{-1} \text{ sr}^{-1} \quad (6)$$

All five criteria must be fulfilled for a glory to be identified. Analogous to Eq. (3), the ratio between local minimum and local maximum is a measure for the strength of the glory. Despite that, this criterion is not redundant as tests showed. The ratio of I_{\min} to $\bar{I}_{172^\circ-174^\circ}$ is a measure of the variation of the scattering angle dependent radiance between 172° and 180° . The variation is low, if the value of $\left(1 - \frac{I_{\min}}{\bar{I}_{172^\circ-174^\circ}}\right) \cdot 1000$ is close to 0.0. The standard deviation between 170° and 173° allows drawing conclusions about the clouds homogeneity.

Tab. 1 and Tab. 2 show the values of the identification parameters for the simulations of radiances of pure liquid water and pure ice clouds. Again there are only minor differences between the simulated radiances of ice clouds after varying effective radius and cloud optical thickness. Since the differences were only minor, just one example of scattering angle dependent radiance of ice clouds was plotted in Fig. 1. With varying cloud optical thickness and varying effective radius changes in the parameters for liquid water clouds could be observed. Since simulated radiances were analysed the cloud was homogeneous and, therefore, the standard deviation was low in all cases. Similar to Tab. 1 the values show that the difference between local minimum and maximum of radiance is smaller for an effective radius of $4 \mu\text{m}$ ($1 - \frac{I_{\min}}{I_{\max}} \approx 0.07$) than for $10 \mu\text{m}$. For these clouds $1 - \frac{I_{\min}}{I_{\max}}$ is approximately 0.11 ($\tau = 14$) or 0.10 ($\tau = 22$) respectively.

Tab. 2 Values of identification criteria derived from test dataset for simulations

		$1 - \frac{I_{\min}}{I_{\max}}$	$\left(1 - \frac{I_{\min}}{\bar{I}_{172^\circ-174^\circ}}\right) \cdot 10^3$	$\sigma_{170^\circ-173^\circ}$ [mWm ⁻² nm ⁻¹ sr ⁻¹]
liquid water cloud	$\tau = 22, r_{eff} = 4\mu\text{m}$	0.0714	1.3	1.60
	$\tau = 22, r_{eff} = 10\mu\text{m}$	0.0981	0.4	0.56
	$\tau = 14, r_{eff} = 10\mu\text{m}$	0.1079	1.0	0.50
ice cloud	$\tau = 22, r_{eff} = 40\mu\text{m}$	0.0001	0.1	0.20
	$\tau = 22, r_{eff} = 10\mu\text{m}$	0.0001	0.2	0.20
	$\tau = 14, r_{eff} = 10\mu\text{m}$	0.0001	0.2	0.20

In case of the simulated radiances of the ice clouds the local maxima of the radiance are relatively weak compared to the maxima in case of liquid water clouds. The difference between local extrema is almost negligible. This can be seen in Tab. 1 and Tab. 2 and in Fig. 1.

5. Application on measurement examples

During the application of the proposed algorithm on measured data, cloud inhomogeneities

may lead to difficulties. To test the algorithm it was applied to several single images taken by the camera.

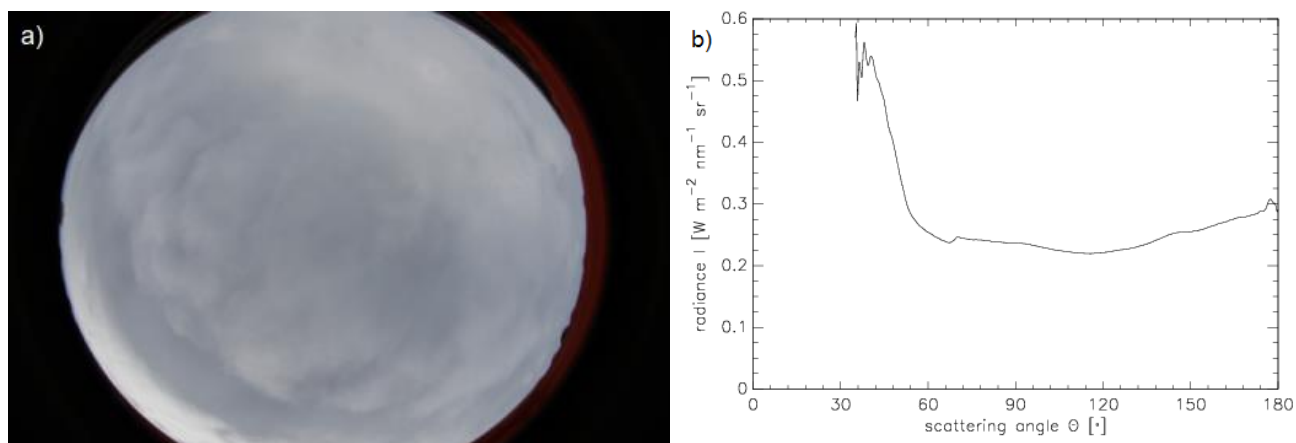


Fig. 2 Image taken by camera (a) and scattering angle dependent radiance (b) at 6 May 2014 at 17:21:16 UTC

An example of a closed boundary cloud layer which appears relatively homogeneously is shown in Fig. 2. This figure shows the image taken by the Canon camera and the corresponding scattering angle dependent radiance of 6 May 2014 at 17:21:16 UTC. The obtained identification parameters are listed in Tab. 3.

The comparison of the parameters with the constraints obtained by analysing simulations and measurements shows that a glory is detected in Fig. 2. In this case the glory could already be identified correctly with the help of the two parameters derived from simulations. Fig. 3 displays both the image and the corresponding scattering angle dependent radiance of 6 May 2014 at 19:49:36 UTC. The image shows clouds with a relatively weak glory but the glory is still detectable in the radiances. The values of the parameters lie within the defined constraints and are shown in Tab. 3.

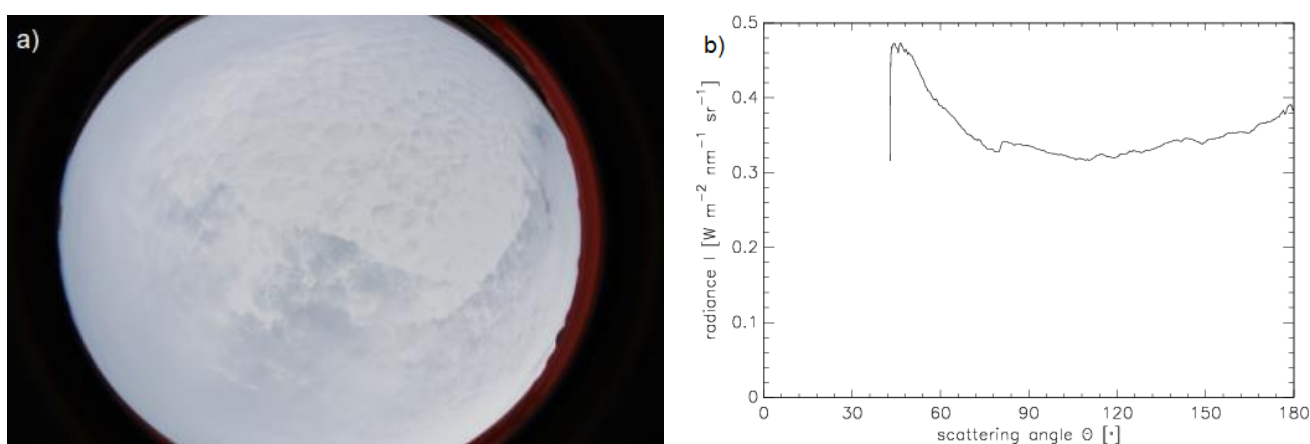


Fig. 3 Image taken by camera (a) and scattering angle dependent radiance (b) at 6 May 2014 at 19:49:36 UTC

An example of a cloud without a glory hence an ice cloud is given in the image of 6 May 2014 at 19:39:52 UTC (Fig. 4). In the image as well as the scattering angle dependent

radiance show no glory whatsoever. Therefore it has to be assumed that at said time the underlying cloud was an ice cloud. The criteria are given in Tab. 3.

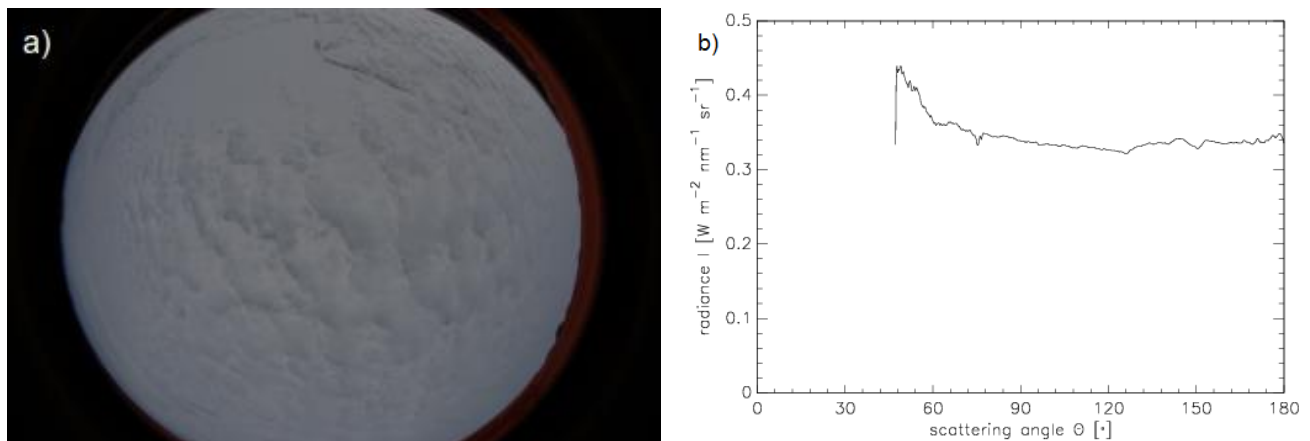


Fig. 4 Image taken by camera (a) and scattering angle dependent radiance (b) at 6 May 2014 at 19:39:52 UTC

This example also gives a handy illustration why the two criteria derived from simulations proved to be insufficient and additional criteria had to be defined. Both the scattering angle of the local maximum and the comparison of the local maximum with the mean of the radiance between 173° and 180° suggest the existence of a glory. Since the ratios of local maximum and minimum and of the local minimum and the mean between 172° and 174° do not correspond to values within the defined constraints, Fig. 4 shows an ice cloud.

On 6 May 2014 at 19:56:16 UTC there was no cloud below the aircraft, as can be seen in Fig. 5. The scattering angle dependent radiance shows a higher variability especially in the section between 170° and 180° . The standard deviation between 170° and 173° of $23.0 \text{ mW m}^{-2} \text{nm}^{-1} \text{sr}^{-1}$ exceeds the threshold of $4.0 \text{ mW m}^{-2} \text{nm}^{-1} \text{sr}^{-1}$.

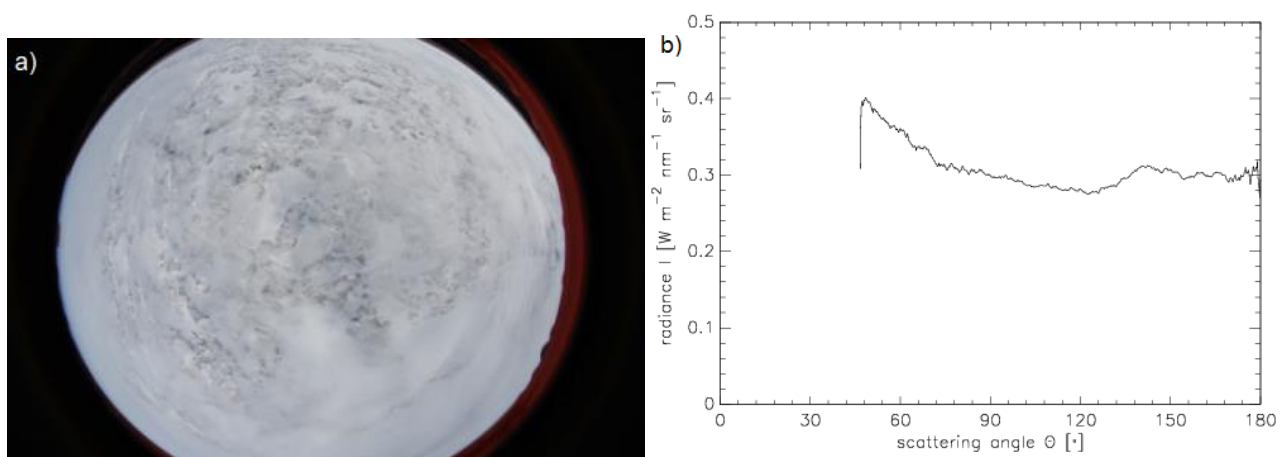


Fig. 5 Image taken by camera (a) and scattering angle dependent radiance (b) at 6 May 2014 at 19:56:16 UTC

Tab. 3 Values of identification criteria for the images shown in Fig. 2-5

Fig.	Time (UTC)	θ_{\max}	$I_{\max} - 0.01I_{\max}$ [Wm ⁻² nm ⁻¹ sr ⁻¹]	$\bar{I}_{173^{\circ}-180^{\circ}}$ [Wm ⁻² nm ⁻¹ sr ⁻¹]	$1 - \frac{I_{\min}}{I_{\max}}$	$\left(1 - \frac{I_{\min}}{I_{172^{\circ}-174^{\circ}}}\right) 10^3$	$\sigma_{170^{\circ}-173^{\circ}}$ [mWm ⁻² nm ⁻¹ sr ⁻¹]
2	17:21:16	177.3°	0.304	0.295	0.0730	2.1	1.24
3	19:49:36	179.1°	0.386	0.381	0.0480	-1.0	1.34
4	19:39:52	178.2°	0.344	0.343	0.0146	-13.8	1.97
5	19:56:16	179.5	0.306	0.300	0.0750	27.1	23.0

6. Conclusion

The glory is an optical phenomenon consisting of concentric, coloured rings around the anti-solar point caused by scattering on spherical particles with a radius between 4 μm and 25 μm (Laven, 2005). The size of the rings is inverse proportional to the size of the droplets.

Images taken on 6 May 2014 during the campaign RACEPAC with a calibrated Canon digital camera equipped with a 180° fish-eye lens were analysed for the occurrence of glories. To identify glories from measurements of scattering angle dependent radiance the following five criteria within tested boundary values were used:

- Position of local maximum between 173°-180°
- Comparison of local maximum with the mean between 173°-180°
- Ratio of local minimum to local maximum (both between 173°-180°)
- Ratio of local minimum to mean between 172°-174°
- Standard deviation between 170°-173°

With the help of the proposed criteria it is possible to identify glories at the top of arctic boundary layer clouds and therefore to identify the dominating phase at the cloud top. The proposed criteria should be applied to further measurements of scattering angle dependent radiance in order to improve the criteria.

Since both mixed-phase clouds and liquid water clouds feature a glory at the cloud top, a distinction between these two cloud types is not possible. To differentiate between mixed-phase and liquid water clouds the use of methods such as spectral reflectivity measurements, which rely on a weighting function which penetrates deeper into the cloud should be considered.

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Effect of El Niño on the mesosphere/lower thermosphere winds over Collm (51.3°N, 13°E)

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Summary: Mesosphere/lower thermosphere (MLT) zonal winds measured by a VHF meteor radar at Collm, Germany (51.3°N, 13.0°E) during late winter 2015/2016 show very strong westerly winds above about 90 km, but not below that height. This anomaly appears during a very strong El Niño event. The comparison of Niño3 equatorial sea surface temperature index and the Collm MLT wind time series starting in 2004 shows that in January and especially in February zonal winds are positively correlated with the Niño3 index. The signal is strong for the upper altitudes (above 90 km) accessible to the radar observations, but weakens with decreasing height. This reflects the fact that during El Niño years the westerly winter middle atmosphere wind jet is weaker on an average, and this is also the case with the easterly lower thermospheric jet. The El Niño effect on the meridional wind is weak. The experimental results can be qualitatively reproduced by numerical experiments using the MUAM mechanistic global circulation model with prescribed tropospheric temperatures and latent heat release for El Niño and La Niña conditions.

Zusammenfassung: Der Zonalwind in der oberen Mesosphäre/unteren Thermosphäre über Collm (51.3°N, 13.0°E) in der zweiten Hälfte des Winter 2015/2016 weist eine besonders starke westliche Komponente oberhalb von etwa 90 km auf. Diese Anomalie erfolgte während eines sehr starken El Niño-Ereignisses. Der Vergleich von Collmer Zonalwinden seit 2004 und dem Niño3-index zeigt im Januar und besonders Februar eine positive Korrelation. Diese ist stark oberhalb von 90 km, nimmt aber nach unten hin ab. Dies spiegelt die Tatsache wider, dass während El Niño-Jahren im Mittel der stratosphärische/mesosphärische Westwindjet schwächer ist. Dieses Signal kehrt aber in der oberen Mesosphäre um, so dass der thermosphärische Ostwindjet ebenfalls schwächer ist. Der Effekt auf den meridionalen Wind ist schwächer. Die Beobachtungen können mit Modellexperimenten qualitativ reproduziert werden.

1. Introduction

Mesosphere/lower thermosphere (MLT) winds and temperatures show considerable variability at time scales of several years, which is at least partly owing to the influence of atmospheric variability below. One of the primary circulation patterns at equatorial latitudes, which also affects climate worldwide is El Niño and its counterpart La Niña. El Niño events are characterised by high central Pacific sea surface temperature (SST), more clouds over the Pacific, and an anomaly of the Walker circulation. They are also connected with a cooling of the equatorial stratosphere and therefore a reduced temperature gradient between lower latitudes and the polar vortex and weakening of the latter. For El Niño years, there is also enhanced probability of sudden stratospheric warmings, which have effect on the North Atlantic and Eurasian troposphere (Camp and Tung, 2007; Polvani et al., 2017). On an average the polar stratospheric vortex is weaker during El Niño years than it is during La Niña years. This means that the high-latitude stratosphere is warmer during El Niño years, however, the mesosphere is colder then, which has been also observed by satellites and could also successfully been modelled (Garcia-Herrera et al., 2006; Fischer et al., 2008; Lu et al., 2011; Li et al., 2013).

There has been considerable interest in a possible coupling of El Niño also with the MLT region. Jacobi and Kürschner (2002) found that the correlation between El Niño and zonal wind at 90 km altitude over Collm, Germany (51.3°N, 13°E), is mainly negative in winter, but weakly positive in summer. They used data from 1979 – 1999. However, Jacobi (2009), using the same dataset extended until 2008 showed that after the 1990s these correlations decrease and even tend to reverse.

Modelling of El Niño influence on the middle atmosphere has mainly been done with focus on the temperature response and wave forcing. From WACCM model runs Li et al. (2013) obtained negative (westward) wave drag in the stratosphere during El Niño, but positive drag in the mesosphere. Consequently this is connected with easterly wind anomalies in the stratosphere, as reported by Taguchi and Hartmann (2006), Fischer et al. (2008) and Lu et al. (2011). The positive wave drag anomaly in the mesosphere reduces this negative wind anomaly. Most models, however, are confined to the stratosphere and mesosphere, or the analyses for the MLT did not focus on the wind.

Here we use observations at Collm made with a VHF meteor radar since 2004, which, in contrast to the earlier analyses by Jacobi and Kürschner (2002) and Jacobi (2009) cover the entire height region between about 80 and 100 km. We also apply the Middle and Upper Atmosphere Model (MUAM), which is a mechanistic circulation model from the ground to the thermosphere to interpret the observations.

2. Collm MLT wind measurements

At Collm Observatory (51.3°N, 13°E), a SKiYMET meteor radar is operated on 36.2 MHz since summer 2004 (Jacobi, 2012). The wind measurement principle is the detection of the Doppler shift of the reflected VHF radio waves from ionised meteor trails, which delivers radial wind velocities at the position of the meteor. An interferometer, consisting of five 2-element Yagi antennas arranged as an asymmetric cross was used to detect azimuth and elevation angle from phase comparisons of individual receiver antenna pairs. Together with range measurements the meteor trail position can be de-

tected. The raw data collected consist of azimuth and elevation angle, wind velocity along the line of sight from the receiving antenna to the meteor, meteor height, and additionally the decay time for each single meteor trail. The data collection procedure is also described in detail by Hocking et al. (2001). Recently, the Collm radar system has been upgraded, and the main modifications are higher power and the use of a 4 element transmitting antenna. This effectively increases the number of observed meteors and consequently the height range of wind measurements. The wind analyses, however, are not affected because they rely only on the Doppler shift of the reflected radio waves, and not on meteor parameters.

The individual meteor trail reflection heights roughly vary between 75 and 110 km, with a maximum around 90 km (e.g. Stober et al., 2008). In the standard configuration used here, the data are binned in 6 different not overlapping height gates centred at 82, 85, 88, 91, 94, and 98 km. Individual winds calculated from the meteors are collected to form half-hourly mean values using a least squares fit of the horizontal wind components to the raw data under the assumption that vertical winds are small (Hocking et al., 2001). An outlier rejection is added. Note that the nominal heights not necessarily correspond to the mean heights within the gates, because the meteors show a vertical distribution with increasing/decreasing count rates with height below/above about 90 km (Stober et al., 2008; Jacobi, 2012). Therefore, below/above 90 km mean heights tend to be higher/lower than nominal heights, and due to the small number of meteors at high altitudes, a substantial difference is visible for 98 km nominal altitude, so that the real mean height is closer to 97 km than 98 km (Jacobi, 2012). For the other height gates, the difference between real and nominal height may be neglected.

Time series of monthly mean wind parameters have been calculated applying a least-squares regression analysis of either zonal or meridional half-hourly horizontal winds collected during one month each on a model wind field including mean wind, diurnal, semidiurnal and terdiurnal oscillation. The results have been attributed to the centre of the respective time interval, and the analysis was repeated for each month. The 2005 – 2015 mean seasonal cycles of the zonal and meridional mean wind at 94 km and 85 km are shown in Fig. 1. The standard deviations of the monthly means are added as error bars, while the single monthly means are shown as small asterisks. The seasonal cycles are similar to those reported earlier e.g. by Jacobi (2012). The zonal winds show the uppermost part of the westerly wind jet in winter. In spring/summer the upper part of the easterly mesospheric wind jet is visible, while at 94 km the lower thermospheric westerly jet can be seen. The wind reversal is connected with the meridional southward jet.

In Fig. 1, the monthly mean winds for December 2015, January 2016 and February 2016 are highlighted. The January and February 2016 zonal winds at 94 km are the strongest that has been observed so far. However, this is not the case at 85 km. The meridional winds do not show a specific behaviour during this winter. The 2015/2016 winter was characterised by a strong El Niño event (Kennedy et al., 2016) which, among others, contributed to the extremely high Arctic temperatures this winter (Cullather et al., 2016). Therefore we assume that the strong MLT winds are connected with El Niño, and analyse this based on the Collm radar observations and numerical modelling in the following.

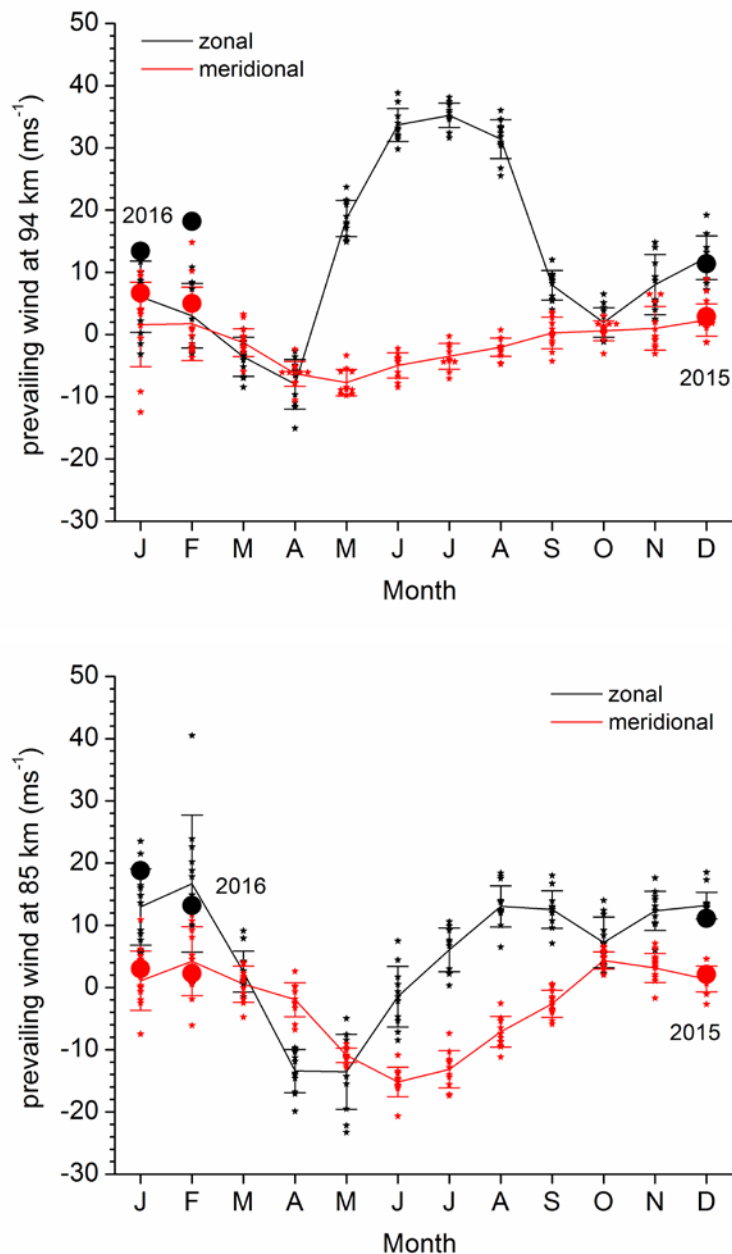


Fig. 1: 08/2004 – 04/2016 mean monthly mean zonal (black) and meridional (red) mean winds over Collm at 94 km (upper panel) and 85 km (lower panel). Error bars show the standard deviation of the monthly means, single months are added as small asterisks. Winter 2015/16 values are highlighted as big circles.

3. Correlation of Collm zonal winds and El Niño

To compare the variability of MLT zonal winds with El Niño, we use the Niño3 index, which represents the normalized area averaged SST in the region from 5°S - 5°N and 150°W - 90°W . We use SST from NOAA Extended Reconstructed Sea Surface Temperature (ERSSTA, Huang et al., 2015), Version 4, normalized to 1981-2010 (KNMI, 2016). There are several indices available that can be used for definition of El Niño (e.g. Trenberth, 1997). The Niño3 index represents the sea surface temperature in the

eastern part of the Pacific. The different indices are strongly correlated and the results should not differ qualitatively if another index would be used.

Correlation coefficients of monthly mean Niño3 index and MLT wind at different altitudes were calculated for each month and each radar altitude gate, and the results are shown in Fig. 2. The strongest El Niño response is seen for the zonal wind in February for the upper height gates. The effect decreases with decreasing altitude and even reverses for the lowest height gates. During the other months of the year the correlation is weaker. The results for winter are in correspondence with literature results. The middle atmosphere zonal winds during El Niño are weakened, but the positive wave drag in the mesosphere reduces this effect with increasing altitude, and eventually will lead to the reversal that can be observed in the Collm measurements. For the meridional wind component (lower panel of Fig. 2) the correlation is weaker and not significant.

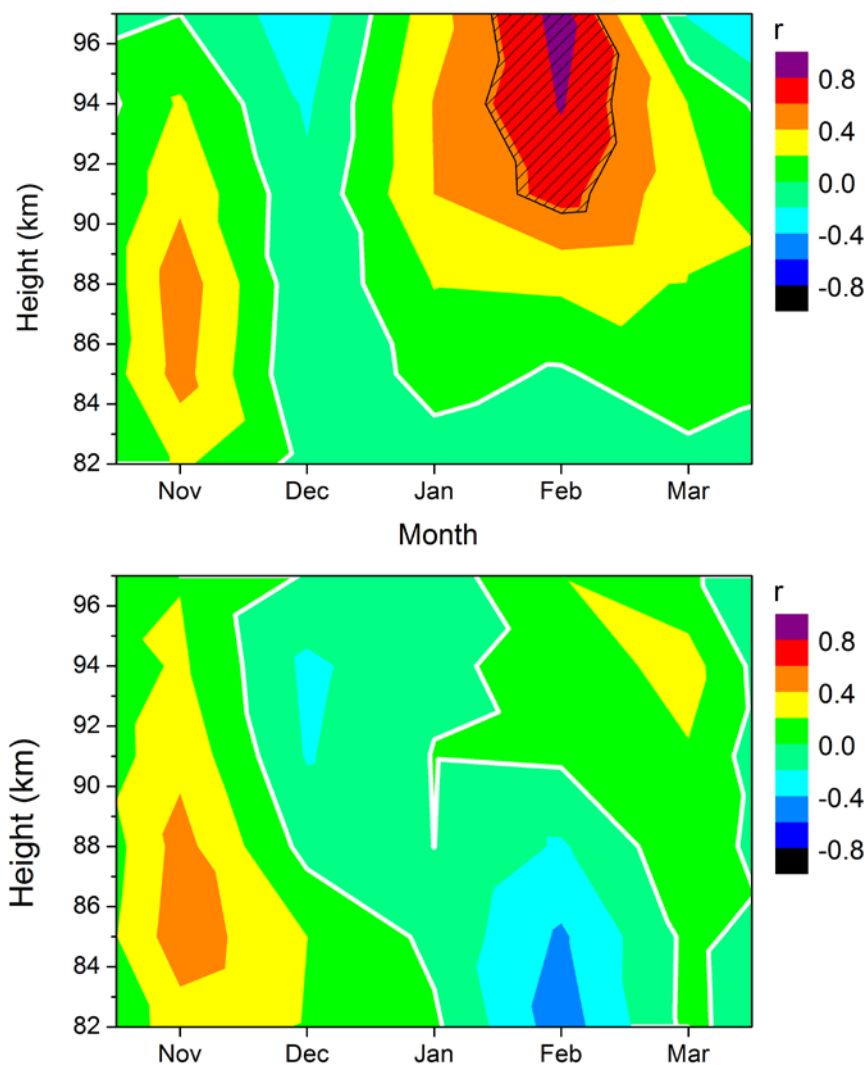


Fig. 2: Correlation coefficients of monthly mean zonal (upper panel) and meridional (lower panel) winds at different heights and Niño3 indices. Data from 08/2004 – 07/2016 have been used. Significant values at the 5% level according to a t-test are hatched.

4. Numerical model results

In order to substantiate the observed correlation of zonal winds with El Niño, we use MUAM model to simulate the MLT response to El Niño. MUAM is a nonlinear primitive equation 3D grid point mechanistic model with a resolution of $5^\circ \times 5.625^\circ$ in the horizontal and 56 vertical layers expressed in log-pressure height $z = -H \cdot \ln(p/p_0)$ with a constant scale height $H = 7$ km and $p_0 = 1000$ hPa. The vertical layers are spaced evenly with a step size $\Delta z = 0.4 \cdot H$. Further details can be obtained from Pogoreltsev et al. (2007).

Heating of the atmosphere due to absorption of solar radiation by water vapor, CO_2 , ozone, oxygen and nitrogen is introduced in the model (Fröhlich et al., 2003). Infrared cooling of CO_2 is parameterized after Fomichev et al. (1998), while ozone infrared cooling in the $9.6 \mu\text{m}$ band is calculated after Fomichev and Shved (1985). Gravity waves in the middle atmosphere are parameterized based on an updated linear scheme (Fröhlich et al., 2003).

To consider the El Niño influence on the dynamical processes in the extra-tropical middle atmosphere, a semi-empirical parameterization of the latent heat release has been included that takes into account diurnal and longitudinal variations. Latent heating composites for Northern Hemisphere January under El Niño and La Niña conditions have been calculated using MERRA (Rienecker et al., 2011) reanalysis precipitation data. The corresponding composites of geopotential height and temperature at the lower boundary have been constructed from JRA-55 (Kobayashi et al., 2015) reanalyses. The El Niño and La Niña composites have been constructed from 9 strong or moderate events each. The January 2010 fields thus were included in the El Niño composite, but not January 2007. The recent 2015/16 El Niño also has not been included so that only one El Niño event was both included in the composite and covered by the observations. Regarding La Niña, January 2008 and January 2011 fields have been included in the composite, and 7 more cases that for earlier years when radar observations were not available. We therefore expect that, while the overall behaviour of zonal winds in our observations might be reproduced by the model, there will be differences in detail. Ensemble runs consisting of 10 members for El-Niño and La-Niña conditions, respectively, have been performed and ensemble means and their standard deviations have been calculated. The following results have been also presented in Jacobi et al. (2017).

We performed model runs for January conditions. Niño3 sea surface temperatures during the El Niño events peaked near the end of the years 2006, 2008, and 2015, while the zonal wind maximises in January or February of the following year, so that there is a delay in MLT response to El Niño. However, with MUAM we are modelling quasi-stationary cases, so that using January conditions represents a compromise between the delayed response and the stationary modelling approach.

January mean zonal mean latitude-log-pressure height cross-sections of temperature and zonal wind as simulated with MUAM for El Niño conditions are shown in Fig. 3. The latitude-height structure reproduces observed features known e.g. from empirical climatologies like URAP (Swinbank and Ortland, 2003,) or the radar based GEWM (Portnyagin et al., 2004). At $50\text{--}55^\circ\text{N}$ there is a wind reversal from the mesospheric

westerly jet to the lower thermosphere easterly jet at about 90 km, which is a little bit lower than observed.

The mean differences between El Niño and La Niña years are shown in Fig. 4. The temperatures on the left panel show the stratospheric warming and mesospheric cooling during El Niño years known from global observations and other models (Garcia-Herrera et al., 2006; Li et al., 2013). The reduced stratospheric wind jet reported in the literature (Taguchi and Hartmann, 2006; Fischer et al., 2008; Lu et al., 2011) is shown in the right panel of Fig. 4, and above that in the MLT an increase of the zonal wind is visible. This qualitatively reproduces the Collm observations.

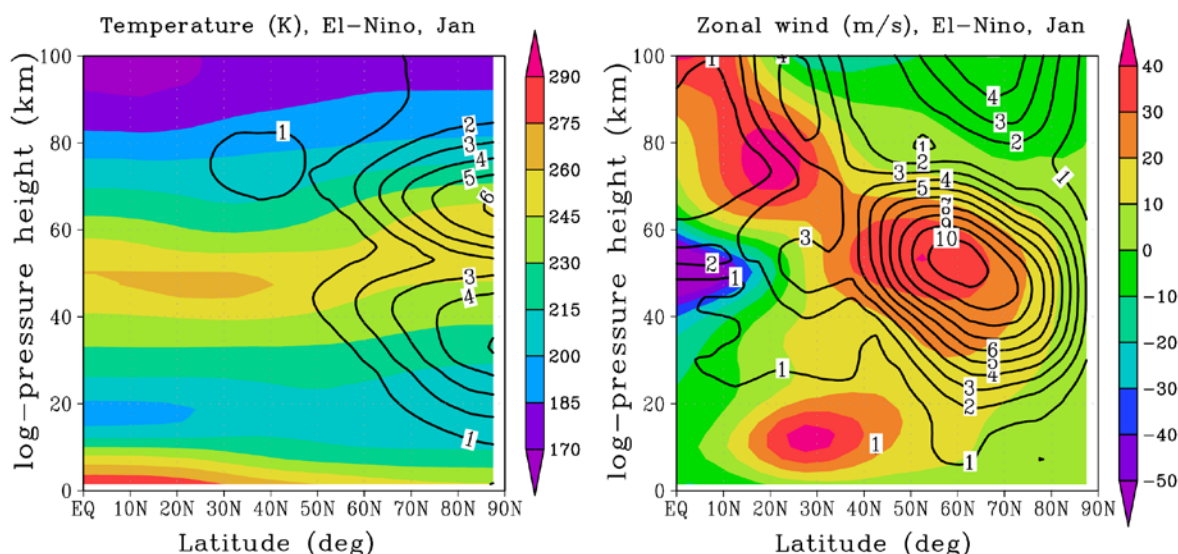


Fig. 3: January mean temperatures (left) and zonal winds (right) as simulated with MUAM for El Niño conditions. Colour coding shows mean values over 10 ensemble runs. Standard deviations of the ensemble members are added as black contour lines.

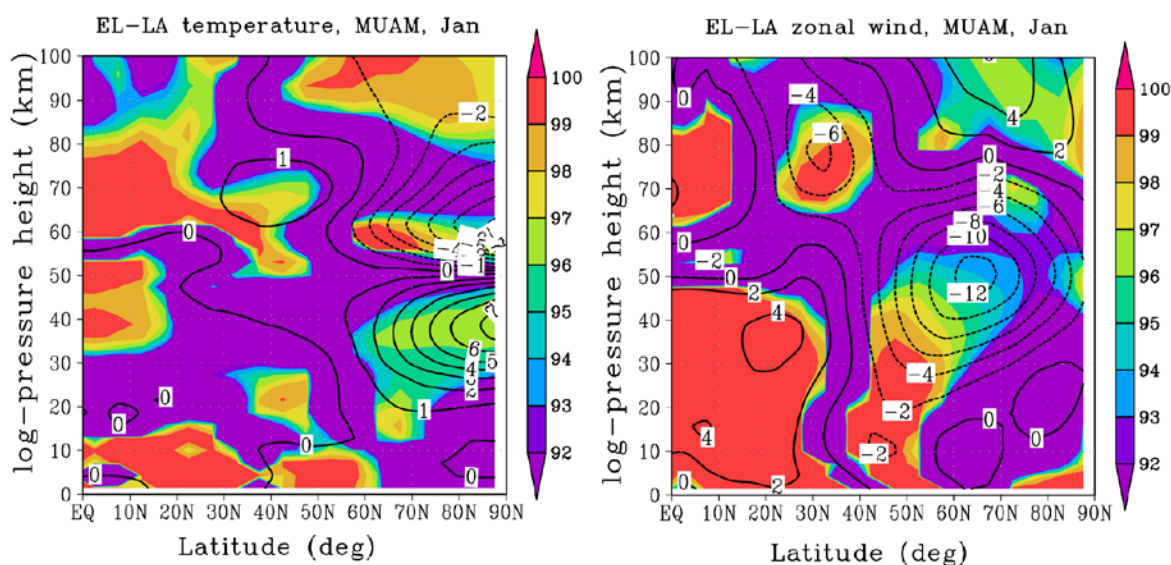


Fig. 4: El Niño – La Niña differences of January mean temperature (left) and zonal wind (right) as simulated with MUAM (contour lines). The colour coding shows the significance of the differences according to a t-test.

5. Conclusions

Radar observations of winds over Collm have shown that the zonal wind in the MLT region in February is correlated with the Eastern Pacific SST. In the upper mesosphere, the effect reduces and there is a tendency that it even reverses, although the effect is not significant at 82 km. Earlier reports on El Niño effects on the MLT often has used observations at about 90 km (e.g. Jacobi, 2009). At this altitude, however, the response of the zonal wind to El Niño is weak (correlation coefficient of about 0.5 in February, see Fig. 2).

The decrease of the correlation in the upper mesosphere is in correspondence with MUAM model analyses that show that the negative zonal wind response in the stratosphere and mesosphere is reversed in the MLT.

Acknowledgements

Niño3 indices based on NOAA ERSST.v4 sea surface temperatures have been kindly provided by KNMI through the KNMI climate explorer, <https://climexp.knmi.nl>. Ch. Jacobi and D. Mewes acknowledge support by the SFB/TR 172 in Project D01 funded by the Deutsche Forschungsgemeinschaft (DFG). MUAM model simulations were supported by the Russian Science Foundation through grant number 14-17-00685.

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Mesospheric wind and temperature trends simulated with MUAM

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Summary: The Middle and Upper Atmosphere Model (MUAM) was used for the period from 1979 to 2015 and for January and July to analyze the interannual and long-term development of the horizontal wind and temperature in the middle atmosphere. Above the troposphere, for each season a long-term temperature decrease was observed, with maxima in the polar stratosphere in winter. In the zonal wind, a weakening and slight northward displacement of the mesospheric westerly wind could be observed in the respective winter hemisphere. On the southern hemisphere in January there was a slight weakening of the wind jets, while in the northern hemisphere a slight increase could be observed in July. For the meridional wind, especially for the mesospheric branch of the meridional wind jet, the southerly wind was intensified in January, while the northerly wind weakened particularly in the southern hemisphere in July. Possible reasons for the long-term trends are discussed.

Zusammenfassung:

Mit dem Modell für die mittlere und obere Atmosphäre MUAM wurden Berechnungen über den Zeitraum von 1979 bis 2015 für Januar und Juli durchgeführt, um die Entwicklung des Zonal- und Meridionalwindes sowie der Temperatur zu analysieren. Dabei zeigte sich ganzjährig ein Temperaturrückgang oberhalb der Troposphäre, mit einem Maximum in der polaren Stratosphäre während des Winters. Beim Zonalwind ließ sich in der jeweiligen Winterhemisphäre eine Abschwächung und leichte Nordverlagerung des mesosphärischen Westwindjets beobachten. Auf der Südhemisphäre im Januar kam es zu einer leichten Abschwächung der Starkwindbänder, während im Juli auf der Nordhemisphäre eine leichte Verstärkung festgestellt werden konnte. Für den Meridionalwind, insbesondere für den meridionalen mesosphärischen Windjet zeigte sich im Januar eine Intensivierung des Südwindes, während sich der Nordwind im Juli besonders auf der Südhemisphäre abschwächte. Gründe für diese Trends werden diskutiert.

1. Introduction:

The anthropogenic climate warming leads to changes not only in the troposphere, but also at upper atmospheric layers. The effects of climate warming in the mesosphere and the lower thermosphere have so far been insufficiently explored. Interactions between increasing CO₂ in the atmosphere and the MTL are known. Lübken et al. (2013) showed

that an increase of CO₂ leads to a cooling in the mesosphere. It is to be investigated, if measurements from the last years and decades can be reproduced using model calculations from a middle and upper atmosphere model. The concentration of CO₂ in the atmosphere has increased in the last century. In 1979, the CO₂ mixing ratio was 335 ppm and it was rising to 408 ppm in 2016. The pre-industrial level of CO₂ was 280 ppm (IPCC, 2001), so that the current year is about 130 ppm above the pre-industrial level. There is an increase of about 15 ppm between 1980 and 1990, but of 20 ppm from 2005 to 2015. An increase in emissions is also expected in the coming years. In Fig. 1 it is shown how the CO₂ concentration has developed in the last 40 years.

Roble and Dickinson (1989) investigated the effects of changes in CO₂ and methane on the structure of the mesosphere and thermosphere with a global circulation model. A doubling of the CO₂ led to a cooling in the mesosphere and a warming in the mesopause. With the “Leibniz-Institute Middle Atmosphere” (LIMA) model, Lübken et al. (2013) considered the effects of the trends of CO₂ and ozone on the MLT region. They found that CO₂ has a larger effect than ozone on the cooling in the middle atmosphere. But the warming effect of ozone was stronger in the mesopause. This also confirmed the simulations of Marsh et al. (2013).

Also important for middle atmospheric variability are changes in ozone concentration, which have a large effect on temperatures in the stratosphere. The time series of global ozone mass as calculated from MERRA reanalyses (Rienecker et al., 2011) is shown in Fig. 2. The ozone mixing ratio has decreased with time, but owing to the to the ban of chlorofluorocarbons, there is a slight increase in the ozone concentration since the 1990s (Solomon, 1999; Bodeker et al., 2001).

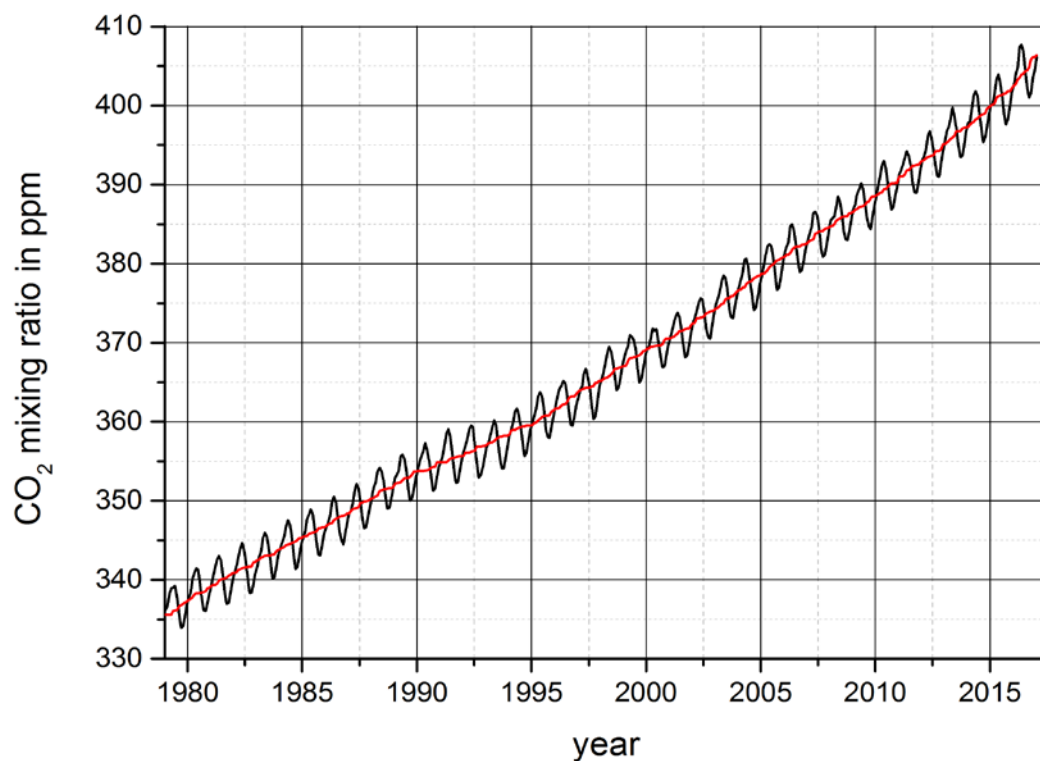


Fig. 1: CO₂ mixing ratio from 1979 to 2016 at Mauna Loa Observatory. The red line corresponds to a sliding five-year mean. Data: NOAA, (Tans and Keeling, 2017).

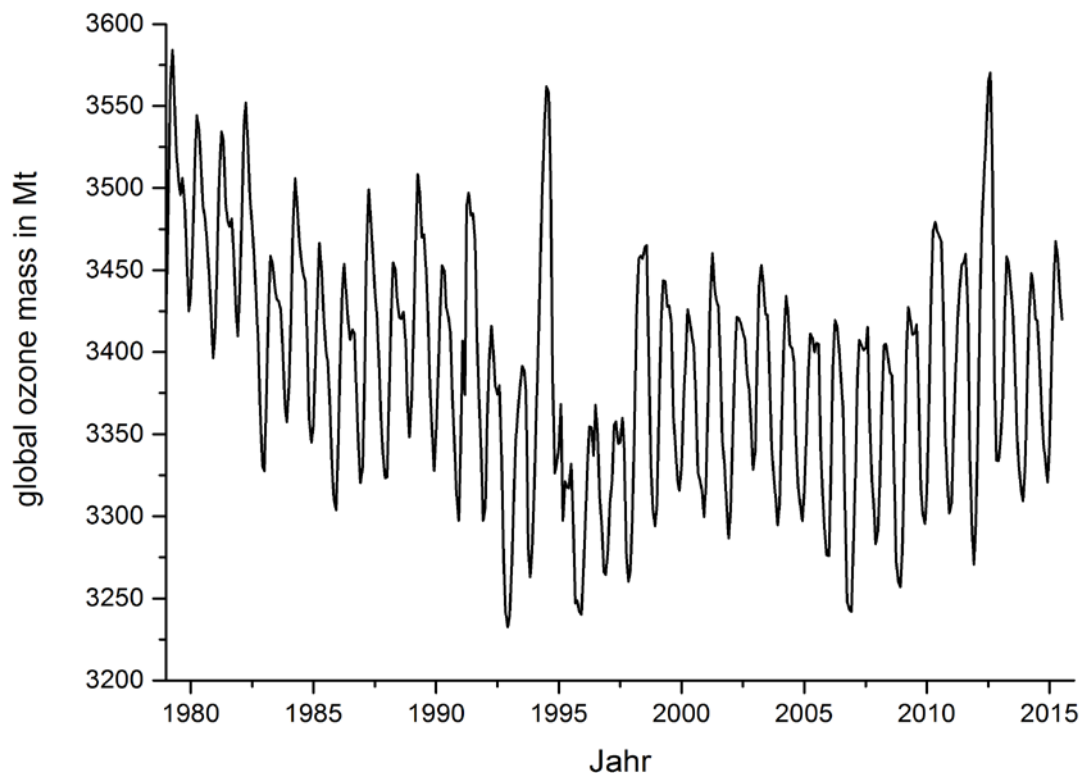


Fig. 2: Global ozone mass in megatons from MERRA (Rienecker et al., 2011) data from 1979 to 2015.

Some model simulations on middle atmosphere wind trends were performed by Jacobi et al. (2015a). An intensification of the westerly wind in January in the mesosphere was observed, as well as a weakening of the wind jet in July. This was also seen by Marsh et al. (2013). The meridional wind in the upper mesosphere increased in both January and July.

Measurements were analyzed by Bremer and Berger (2002) and a review of long-term temperature trends can be found at Beig et al. (2003) and, more recently, Beig (2011). These confirm the model results with regard to the cooling in stratosphere and mesosphere and the weaker cooling or small warming in the mesopause. Satellite measurements were analyzed by Funatsu et al. (2016). These measurements also show the temperature drop in the stratosphere which was stronger in the middle and higher latitudes during winter.

Various wind measurements from the mesosphere were compared in Jacobi et al. (2015a). Measurements in Collm (51°N, 13°E, Germany), Saskatoon (52°N, 107°W, Canada) and Obninsk (55°N, 37°E, Russia) were compared. For the zonal wind in winter there is an increase (more eastward) until 2005, after that year there is a decrease (less eastward) in Collm and Saskatoon. The meridional wind in winter shows a decrease until 2005 (less northward) and an increase (more northward) after that in Collm and Obninsk. In summer the westerly wind intensifies until 2005 and then decreases slightly. The meridional wind in the summer shows a decrease of the northerly wind until 2005. After that time, there is a slight increase in the northerly wind, especially over Obninsk. To summarize, there are obvious long-term trends in the middle and upper atmosphere, but still some details are missing. Therefore we calculated with MUAM time series over 37 years of zonal wind, meridional wind and temperature and examined these for trends.

The remainder of the paper is organized as follows: in section 2 the model will be introduced, section 3 shows the model results and section 4 summarized the results.

2. Model Description and Experimental Setup

The MUAM 3D mechanistic global circulation model of the middle atmosphere was used. It based on the Cologne Model of the Middle Atmosphere-Leipzig Institute for Meteorology (COMMA-LIM, Fröhlich et al., 2003; Jacobi et al., 2006). The model is based on the primitive equations. It has a horizontal resolution of $5 \times 5.625^\circ$ and it reaches to an altitude of 160 km in log-pressure heights $x = \ln(p_s/p)$ with p as pressure, $p_s = 1000$ hPa as a reference pressure. The step size is 2.842 km in log-pressure height $h = x \cdot H$ and $H = 7$ km as the scale height. Pogoreltsev et al. (2007) described the model in detail. The model uses a time step of 225 s in the 56-level version following a Matsuno integration scheme (Matsuno, 1966). Zonal means of temperature and geopotential as well as their stationary planetary waves of zonal wavenumbers 1-3 derived from ERA-Interim reanalyses are used at the lower boundary of the model (1000 hPa). To correct the climatology in the troposphere and lower stratosphere, also zonal mean temperature up to an altitude of 30 km was nudged to the model.

Parameterizations of CO₂ and ozone radiative effects are important for the radiation balance in the model. The CO₂ mixing ratios are assumed to be globally constant, the database is the measurements of the Mauna Loa Observatory on Hawaii. A CO₂ reference profile is created in the model where the volume mixing ratio remains constant up to 85 km and decreases to 0 at 140 km (Lange, 2001). CO₂ absorbs most strongly in the near infrared at 15 μm, thereby overlapping the absorption bands of water vapor (Lange, 2001). The CO₂ cooling rates are larger than heating rates so that the CO₂ has a cooling effect in the middle atmosphere. The model uses ozone fields as monthly and zonal mean based on MERRA (Modern-ERA Retrospective Analysis for Research and Applications) data (Rienecker et al., 2011). Ozone absorbs ultraviolet radiation resulting in heating of the stratosphere. The amount of the ozone infrared cooling rates is smaller than heating rates so that the ozone has a warming effect in the middle atmosphere. The heating (Strobel, 1978) and cooling (Fomichev and Sheved, 1985) rates of CO₂ and ozone are calculated in the model.

Some model experiments were carried out for the period from 1979 to 2015. The lower boundary conditions, ozone and CO₂ data were changed from year to year, resulting in a time series of winter winds from 1979 through 2015.

3. Model results

The results for January are shown in Fig. 3. The colored background represents the 37-year mean of the MUAM simulations from 1979 to 2015 for January as zonal means. Trends can be seen as contour lines in the left panels. Hatched areas indicate positive trends. The standard derivations of the zonal means for temperature (top), zonal wind (middle), and meridional wind (bottom) are shown on the right panels. The climatology of MUAM simulations shows good consistency for zonal mean of temperature and wind jets to other climatologies, such as CIRA (Fleming et al., 1990), UARS Reference Atmospheric Project (Hays et al., 1993, Swinbank and O'Neill, 1994) and the Global Empirical Wind Model (GEWM) of the middle atmosphere by Portnyagin et al (2004) and extended by Jacobi et al. (2009). Compared to climatologies, it can be seen that in

the January the mesospheric wind reversal in the MUAM is near 80 km at midlatitudes, and thus is lower than measurements show.

For the temperature standard derivation (top, right side) high values can be seen at high latitudes of the northern hemisphere from the troposphere up to the mesopause with maxima in the polar tropopause and stratopause. Higher values can also be found at the lower thermosphere. This broadly corresponds with the maxima of trends, which are shown on the top left panel. A maximum of positive trends is located in the troposphere and tropopause with over 0.1 K/y in the northern polar region of tropopause. Large negative trends can be seen in the northern polar stratosphere and stratopause with up to -0.2 K/y. Above 100 km in the thermosphere there is a strong decrease of temperature (-0.1 K/y to -0.4 K/y).

The standard derivation of zonal wind (Fig. 3, middle row, right panel) shows a maximum in the middle at higher latitudes of the northern hemisphere, especially in the midlatitude jets. Positive zonal wind trends, i.e. a decline of the easterly winds or an increase of the westerly wind, are seen in the area of the mesospheric westerly wind jet between 30°N and 50°N (larger than 0.1 ms⁻¹y⁻¹), which means an intensifying of the mesospheric westerly wind jet, because the stronger cooling at high latitudes caused an increase of horizontal temperature gradients. A positive trend of zonal wind in the northern polar (decrease of easterly wind) or southern midlatitude mesopause (increase of westerly wind jet with 0.1 ms⁻¹ y⁻¹), but in the east wind maximum there is an intensification of the east wind up to over 0.12 ms⁻¹ y⁻¹. Positive trends can be observed at middle and high northern latitudes in the stratosphere and mesosphere with up to 0.2 ms⁻¹ y⁻¹, which indicates a southward shift and a strengthening of mesospheric westerly wind jet. Also negative trends can be seen in the mesospheric easterly wind jet (increase of this jet) in northern and in the southern midlatitude mesosphere.

On the bottom right panel, the standard derivations of the meridional wind are shown. The maximum of the standard derivation is in the region of the meridional wind jet in the middle and lower latitudes of the mesosphere and mesopause. Notable positive trends (up to 0.02 ms⁻¹ y⁻¹) can be identified in the range of the meridional wind jet in mesosphere and mesopause. This means an intensification of this circulation from the southern hemisphere to the northern hemisphere during January. Reasons could be that the zonal wind increase implicates larger gravity wave amplitudes and stronger gravity waves divergence in the MLT and this caused a stronger meridional wind through gravity wave forcing.

In Fig. 4 the results for July are presented. The colored background shows the climatology of MUAM simulations from 1979 to 2015 for July as zonal mean. Trends can be seen left, the standard derivations on the right panels as zonal mean for temperature (top), zonal wind (mid), meridional wind (bottom). Hatched areas indicate positive trends.

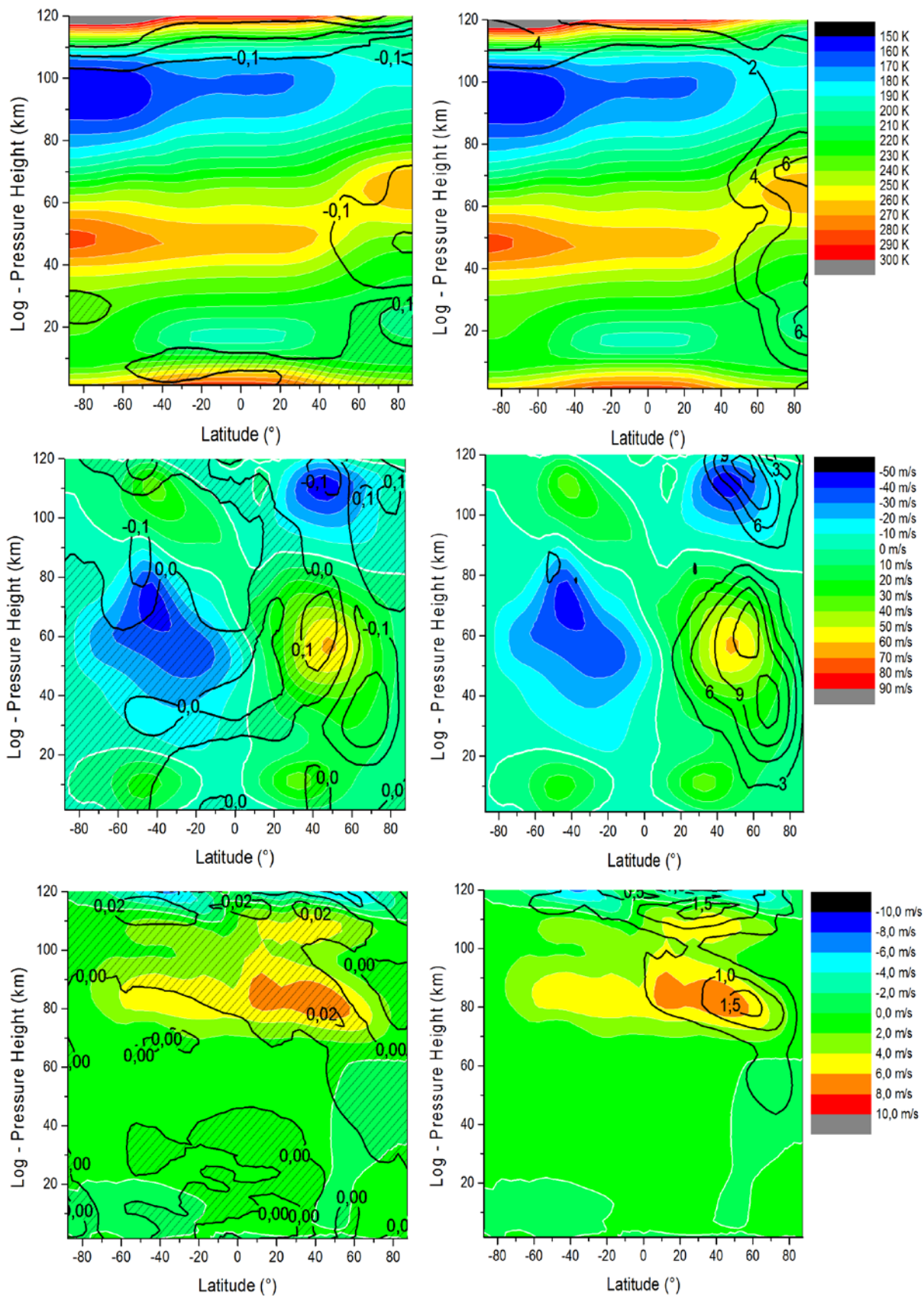


Fig. 3: Climatology of MUAM simulations from 1979 to 2015 for January (background) as zonal mean. Trends (left) as zonal mean per year and standard deviation (right) for temperature (top), zonal wind (mid) and meridional wind (bottom). Hatched for positive trends.

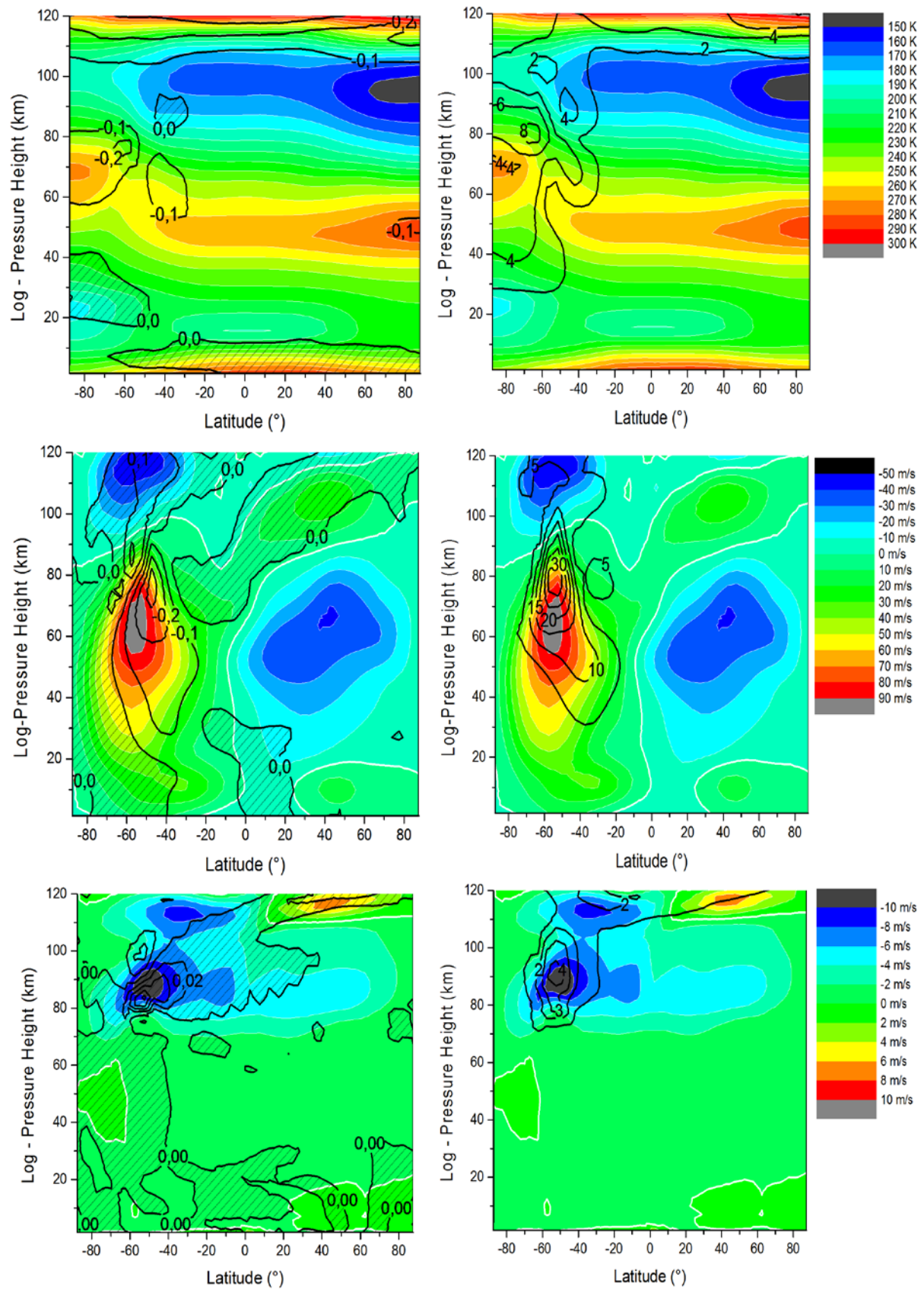


Fig. 4: Climatology of MUAM simulations from 1979 to 2015 for July (background) as zonal mean. Trends (left) as zonal mean per year and standard deviation (right) for temperature (top), zonal wind (mid) and meridional wind (bottom). Hatched for positive trends.

The upper right panel of Fig. 4 shows the standard deviation of the temperature. The highest values are in the range of the middle and high southern latitudes with a maximum in the mesosphere. High standard deviations can be observed in all latitudes above 100 km. The standard deviation of the temperature is therefore greatest in the middle and high latitudes on the winter hemisphere. On the upper left side of Fig. 4 one can see that positive trends occur only in the troposphere and at middle and high southern latitudes in the stratosphere (up to 0.1 K/y). Note that this is not modeled but due to ERA-Interim trend. Larger negative trends are found in the stratopause and mesosphere of middle southern latitudes and in both polar regions with -0.2 K/y. Note that the polar negative trend maximum is found at higher altitudes than in northern hemisphere summer. This must have consequences for the thermal wind, and should be connected with a negative (inserted of positive) trend of the zonal westerly wind jet (middle left panel of Fig. 3). Above 100 km exists a large temperature decrease for all latitudes (up to -0.3 K/y) as was already seen in January.

On the middle right panel of Fig. 4, a maximum of the standard derivation for the zonal wind can be seen in the area of and slightly above the westerly wind jet of the southern middle latitudes in the mesosphere with over 30 ms^{-1} . For the trends of zonal wind in July a decrease of the westerly wind jet (-0.3 ms^{-1}) in the mesosphere of midlatitude of southern hemisphere can be observed. The increase of the westerly wind in the middle and higher latitudes of the stratosphere (up to 0.1 ms^{-1}) and in the high latitudes of the mesosphere indicates a poleward shift of the westerly wind jet in the mesosphere on the southern hemisphere. In addition, a decrease of the westerly wind (up to 0.2 ms^{-1}) in the southern midlatitude mesosphere is found. For the northern hemisphere, a slight increase of the easterly wind jet (up to 0.1 ms^{-1}) in mesosphere of the midlatitudes occurs. In the area of the westerly wind jet in the mesopause of the middle latitudes of the northern hemisphere, there is an increase of the westerly wind (up to 0.1 ms^{-1}).

The bottom panels of Fig. 4 show the standard deviation on the right hand side and the trend for the meridional wind on the left side. High values of standard deviation can be seen in the low und middle latitudes of mesosphere and mesopause. A maximum is located in the north wind maximum in the midlatitudes of southern hemisphere with 4 ms^{-1} . A decrease of the northerly wind (0.08 ms^{-1}) can be observed in the middle latitudes of the mesosphere in the southern hemisphere. On the other hand, there is an increase in the southerly wind (0.02 ms^{-1}) in the mesopause and lower thermosphere in the northern hemisphere.

5. Discussion and Conclusion

The run showed a decrease of the temperature above the troposphere, which was more pronounced above 100 km. For the northern hemisphere in winter there was a positive trend in the troposphere and a negative trend in the high and middle latitudes of the stratosphere. The same can be seen in winter of the southern hemisphere. During summer in the southern hemisphere there was a weak negative trend in strato- and mesosphere and a weak positive trend in high latitudes of tropopause. In summer on the northern hemisphere there is a negative trend with maximum in the polar stratopause. This is in agreement with the general view known, e.g., from reviews by Lastovicka et al. (2008), Ramaswamy et al. (2001) and Qian et al. (2011). The CO_2 has the largest

proportion of the negative temperature trend (Akmaev et al., 2002; Lübken et al., 2013). Also it was found that the temperature decrease in the mesopause was less intense (Lastovicka et al., 2008; Lübken et al., 2013; Marsh et al., 2013). This is also confirmed by measurements by Bremer and Berger (2002) and agrees with reports by Beig et al. (2003). The increased temperature drop in the winter polar stratosphere is also confirmed by satellite measurements (Ramaswamy et al., 2001; Funatsu et al., 2016). The model calculations showed a weakening of the jet in the mesosphere of the northern hemisphere winter hemisphere north of 50°N in January and a strengthening south of it (and actually in the center of the jet). The increase in the region south of 50°N was also seen by Jacobi et al. (2015b). As Jacobi et al. (2015b) showed by comparison of different measurements at about 80-100 km altitude, in the middle latitudes at about 50°N it first came to a strengthening of the westerly wind in winter, from 2005 onwards this turned to a tendency for a drop. Hoffmann et al. (2011), however, could also see an increase of the westerly wind in winter until 2010. Jacobi et al. (2005) could still see a clear trend towards the increase in 2005. This also shows that a change in the trend in the westerly wind jet in winter in northern hemisphere is possible after 2005. An increase of the easterly wind of the southern hemisphere was only calculated at about 80 km altitude in January, also seen by Marsh et al. (2013), as well as a decrease of the westerly wind in the mesopause at 110 km altitude. In July, an increase of the westerly wind south of 80°S could be observed in the winter hemisphere, whereas a decline in wind speeds could be seen for large parts of the westerly wind jet. Also, there was a weakening of the easterly wind in the mesopause and lower thermosphere. The increase of the easterly wind in the mesosphere in the run on the northern hemisphere in July was confirmed by measurements in Juliusruh (Keuer et al., 2007; Hoffmann et al., 2011). Both also showed the increase of the westerly wind in the mesopause. It also became clear that the ozone and CO_2 induced trend is very low. The exception of the westerly wind jet of the southern hemisphere a clearly positive trend could be observed, which is contrary to the run. Another exception for the CO_2 is the area above 100 km altitude, where CO_2 have a large effect of the trend shown in the run. The largest effect is caused by the lower boundary conditions.

For the meridional wind, the run for January provided an intensification of the meridional wind jet, while in July a decline be observed, especially in the middle latitudes of the southern hemisphere. The influence of ozone and CO_2 on the trend of the meridional wind is generally low, at most in the southern hemisphere, in connection with the meridional wind jet, weak trends can be identified. The greatest effect is nevertheless caused by the lower boundary conditions. The evoked developments of ozone and CO_2 are contradictory. For January, Jacobi and Kürschner (2006) and Keuer et al. (2007) also showed an increase of the southerly wind in the meridional wind jet. In July, there was no trend or only a slight decrease of the northerly wind; this confirms result by Jacobi and Kürschner (2006).

Acknowledgements

ERA-Interim reanalyses have been provided by ECMWF through www.ecmwf.int/en/research/climate-reanalysis/era-interim, and have been used in MUAM for assimilation in the troposphere as lower boundary condition. Carbon dioxide data were provided by NOAA: www.esrl.noaa.gov/gmd/ccgg/trends/. Global ozone data

were calculated from MERRA provided by NOAA on disc.sci.gsfc.nasa.gov/daac-bin/FTPSubsreanalyses.et.pl?LOOKUPID_List=MAIMCPASM.

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Variability of horizontal temperature fluxes over the Arctic

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Summary: We used ERA-Interim reanalysis data to perform a pattern analysis of the tropospheric mean meridional temperature flux in the Northern Hemisphere exploiting an artificial neural network called self organizing map (SOM). The basic explanation of the neural network will be given for a better understanding of the presented result. The neural network provides an analyses of the given data in terms of a decomposition into distinct patterns. The results confirms that the strongest fluxes occur over the North Atlantic. Additionally, the SOM showed that in general fluxes over the North Atlantic are most common over all analyzed winters.

Zusammenfassung: Wir verwendeten ERA-Interim Reanalysedaten. Dabei wurde für eine Analyse des über die Troposphäre gemittelten Temperaturflusses ein künstliches neuronales Netzwerks namens Selbstorganisierende Karte (Self Organizing Map, SOM) benutzt. Das neuronale Netzwerk hilft dabei den Datensatz in bestimmte Muster zu unterteilen. Die Ergebnisse bestätigen, dass die größten Flüsse über dem Nordatlantik in die Arktis vordringen. Weiterhin zeigt sich mithilfe der SOM-Methode, dass im Allgemeinen für den analysierten Zeitraum Flüsse über dem Nordatlantik häufiger sind als andere Pfade in Richtung Arktis.

1 Introduction

The Northern Hemisphere high latitudes are a very important region for the Earth's climate system, and acting as a net transmitter of radiation into space. Small changes in the properties of these regions will change the energy budget of the planet by changing the outgoing terrestrial radiation. With regard to climate change especially the Arctic has changed dramatically. During the last decades, the Arctic temperature is increasing approximately twice as fast as compared to the rest of the atmosphere (Stroeve et al., 2012). This effect is called "Arctic Amplification", and results from different feedback mechanisms in the Arctic (Wendisch et al., 2017), which enhance warming. The main positive feedback mechanisms are the surface albedo feedback, water vapor feedback, cloud feedback, and lapse-rate feedback, while the Planck feedback is negative (e.g. Colman, 2003; Klocke et al., 2013)

Another important aspect of Arctic Amplification is the decline of the meridional temperature gradient between the Tropics and the Arctic (Cohen et al., 2014), so that the general circulation is changing. Strong westerlies that are usual for the winter months are getting weaker and are resulting in more meandering winds. This itself results in more meridional

transport, where warmer air masses from lower latitudes are transported into the Arctic. This in turn leads to an increase of the temperature in Arctic regions and is further decreasing the meridional temperature gradient. To analyse Arctic Amplification, it is therefore necessary to quantify the meridional heat transport, and to elucidate its regional and temporal distribution.

To find distinct circulation patterns and to analyze the time variation of those patterns the artificial neural network Self Organizing Map (SOM) (Kohonen, 1998) can be used. SOMs are useful to find patterns within a given dataset, for example to find distinct pressure patterns. SOMs are becoming more and more used in the field of meteorology (Hewitson and Crane, 2002; Cassano et al., 2006; Lynch et al., 2016; McDonald et al., 2016; Ford and Schoof, 2017). The basic advantage of SOMs compared to other pattern analysis techniques (e.g. Principle Component Analysis (PCA), or empirical orthogonal Eigenfunction analysis, EOF) is that SOMs are not constraint to linear assumptions through the orthogonal decomposition of PCA/EOF. SOMs provides a decomposition that is closer to the data and sometimes easier to interpret physically, whereas PCA provides a mathematical orthogonal decomposition, which may sometimes be difficult to explain in physical terms.

The SOM method has been used to discover patterns of moisture transport over Greenland (Mattingly et al., 2016), which showed that from 2010-2015 compared to 1979-1994 intense water vapour transport to Greenland was more common. Furthermore, it was found that intense Greenland ice sheet melt seasons were preceded by moist winter conditions or occurred at summer times with record frequency of moist days. Cassano et al. (2016) analysed extreme temperature winter events for cold and warm days in Alaska. The synoptic conditions were extracted using the SOM method. They found that for either case temperature advection and anomaly in terrestrial downwelling radiation are the main contributors to the temperature extremes.

In the following we will analyse the large-scale meridional temperature flux in the high-latitude troposphere using the SOM-method. In section 2 the basic algorithm of the SOM neural network will be explained; in section 3 information about the used data will be provided. The results are presented in section 4 and discussed in section 5.

2 Self Organizing Map (SOM)

SOM is a neural network introduced by Kohonen (1998). This unsupervised learning method is able to reduce a high-dimensional input space into a two-dimensional map of nodes, which shows specific features of the given input vector $x(t)$. The created SOM consists of a two-dimensional array of patterns which are arranged in columns and rows. This neural network is based on an iterative process to train the map on a given input vector, which can be based on the formula

$$m_i(t+1) = m_i(t) + \alpha(t) h_{ci}(t) [x(t) - m_i(t)]. \quad (1)$$

Here m_i is the current weight vector of node i , $\alpha(t)$ is the learning factor, and $h_{ci}(t)$ is a neighbourhood function, described by a Gaussian neighbourhood function,

$$h_{ci} = \exp\left(-\frac{\|r_c - r_i\|^2}{2\sigma^2(t)}\right) \quad (2)$$

where r_c, r_i are the location vectors of node c and i . σ defines the width of the function and decreases over time.

At each iteration step each input vector is analysed by its Euclidean distance to each node and is then selected to the node according to the smallest distance. These closest input vectors are collected and are called best matching units (BMUs). Furthermore, each node is compared to their neighbours following h_{ci} , which describes the maximum radius of nodes c around node i to compare against. Then, according to $\alpha(t)$ the node changes to a new states. After these steps are performed for each node, the procedure is repeated until a predefined number of iterations has been performed. As a rule of thumb a SOM converges after a number of iterations that equals 50 times the number of nodes. Through the comparison of the node with its neighbours the map organizes itself in such a way that nodes that are close to each other are more similar compared to nodes that are father apart from each other. The amount of nodes within the map can be arbitrarily chosen. Choosing more nodes will provide more detailed patterns of the input data, whereas the training for only few notes is suitable to get a more generalized view of the input field. In general, SOM are an alternative for a PCA or EOF analysis, but with the major advantage of a non-linear approach. Without linear assumptions SOMs can reproduce any pattern from a given dataset, which are dependant on non-linear interactions. Furthermore, the SOM method shows substantial advantages over PCA and (rotated) EOF analysis to find patterns in given data (Reusch et al., 2005; Liu and Weisberg, 2011). Reusch et al. (2005) found that SOMs, which are large enough, are more capable of extracting key features of a artificial generated dataset of pressure fields. Whereas PCA is less suitable to extract the predefined patterns, the SOM was able to reliably reproduce the predefined patterns in the artificial time series with correct attribution of variance. But it was also shown that the size of the SOM has to be big enough to extract the given patterns, and too small choices of SOM were not able to reproduce all patterns.

To create the SOMs, the python package “somoclu” was used (Wittek, 2013). The package is also available for R, MATLAB and for usage within the UNIX command line. Somoclu is computationally highly optimized to enable training of large maps and large datasets. As settings of the somoclu package we used 10000 iterations, $\alpha(t) = 0.5$ decreasing exponentially while iterating to 0.001. A SOM with 20 nodes was created with 4 rows and 5 columns. This means that 20 distinct patterns were produced which are aligned in a 2 dimensional grid of 5 patterns per row and 4 rows in total. The neighbouring maps/nodes starts to compare against a radius of 4 and the comparison was reduced exponentially during the iteration steps to just the closest neighbours. So the map learns/changes much during the very first iterations and then goes into the state of learning more specific from the given vectors.

It is important to look at the whole map and not just single nodes. This is necessary to get a view on how the algorithm has decomposed the field.

3 Data

For this study, synoptic (00, 06, 12, 18 UTC) ERA-Interim (Dee et al., 2011) winds and temperatures during the 1979 through 2016 winter seasons were used. The ERA-Interim data are available at a horizontal resolution of approximately 0.7 degrees, with 37 pressure levels from 1000 hPa up to 1 hPa. For the performed analysis the synoptic values were

daily averaged. For faster computation, the analysis was limited to regions north of 50°N. Daily data of Temperature T and meridional wind v were at first multiplied to obtain the meridional temperature flux in the unit of K m/s at each grid point. Afterwards the tropospheric mean from 1000 hPa to 200 hPa was calculated for each horizontal grid point:

$$F = \frac{1}{N} \sum_{i=p_0}^{p_1} (v_i(t, x, y) T_i(t, x, y)). \quad (3)$$

Here F is the final mean height, daily meridional temperature flux, p_0 is the lower pressure (200 hPa), p_1 is the higher pressure (1000 hPa), N is the number of pressure levels between p_0 and p_1 , v_i and T_i are the meridional wind and temperature at a given pressure level i , and t, x, y represents time, meridional and longitudinal dependency. The unit of F is K m s^{-1} , so large values for F represent a higher temperature that is moved within a strong meridional wind. Lower values correspond to a weaker meridional transport or a lower temperature to begin with. The 2D-field of the mean height, mean daily meridional temperature flux F is then fed into the SOM algorithm.

4 Results

Figure 1 shows a 4x5 SOM after 10000 iterations as explained before. For easier comparison we denote each pattern corresponding to its position within the map with “node (j,k)”. Here j denotes the row and k denotes the column according to the nomenclature for matrix indices. The contours show the tropospheric mean meridional temperature flux with the occurrence frequency during the analysed time period shown on the upper left corner. In general, there are three patterns which can be distinguished: one where the flux is strongest mostly over the Denmark Strait, one where flux is directed via the west coast of Greenland and another one where the flux is focused over the Bering Strait. Patterns that look similar to wedges of a pie near the pole are a result from the definition of the meridional wind which is only positive for northward wind. This results to such wedge shaped contours in polar projection maps.

Additionally, there are some patterns with an increased flux over the Laptev Sea (8 out of 20), or over the Kara Sea (3 out of 20). The strongest meridional temperature fluxes of 3600 K m s^{-1} occur only at about 5.5 % of the time (node (0,2)). The most frequent pattern occurs during 9.7 % of the analysed winters and favours fluxes over a North Atlantic pathway into the Arctic. The second most frequent pattern occurs during 9.4 % of the time and is mainly dominated by fluxes over the Bering Strait. Those major pathways were also found for moist static energy flux based on an analysis of 25 years of the Geophysical Fluid Dynamics Laboratory (GFDL) dataset (Overland et al., 1996). Other patterns are less frequent and only occur at about 2.4 % up to 3.1 % of the analysed time period. This may be a hint that the chosen size of the whole SOM is already too large to get a generalized view on the data, and might already show very specific patterns. Nevertheless, it can be seen that patterns that are close to each other are more similar compared to patterns that are farther apart. But it can also be seen that the difference between neighbouring patterns are not the same. For example, looking at the pattern in node (2,3), the right neighbour is *closer* to this node compared to the left neighbour. In further analysis these different distances have to be visualized in a way that one can easily

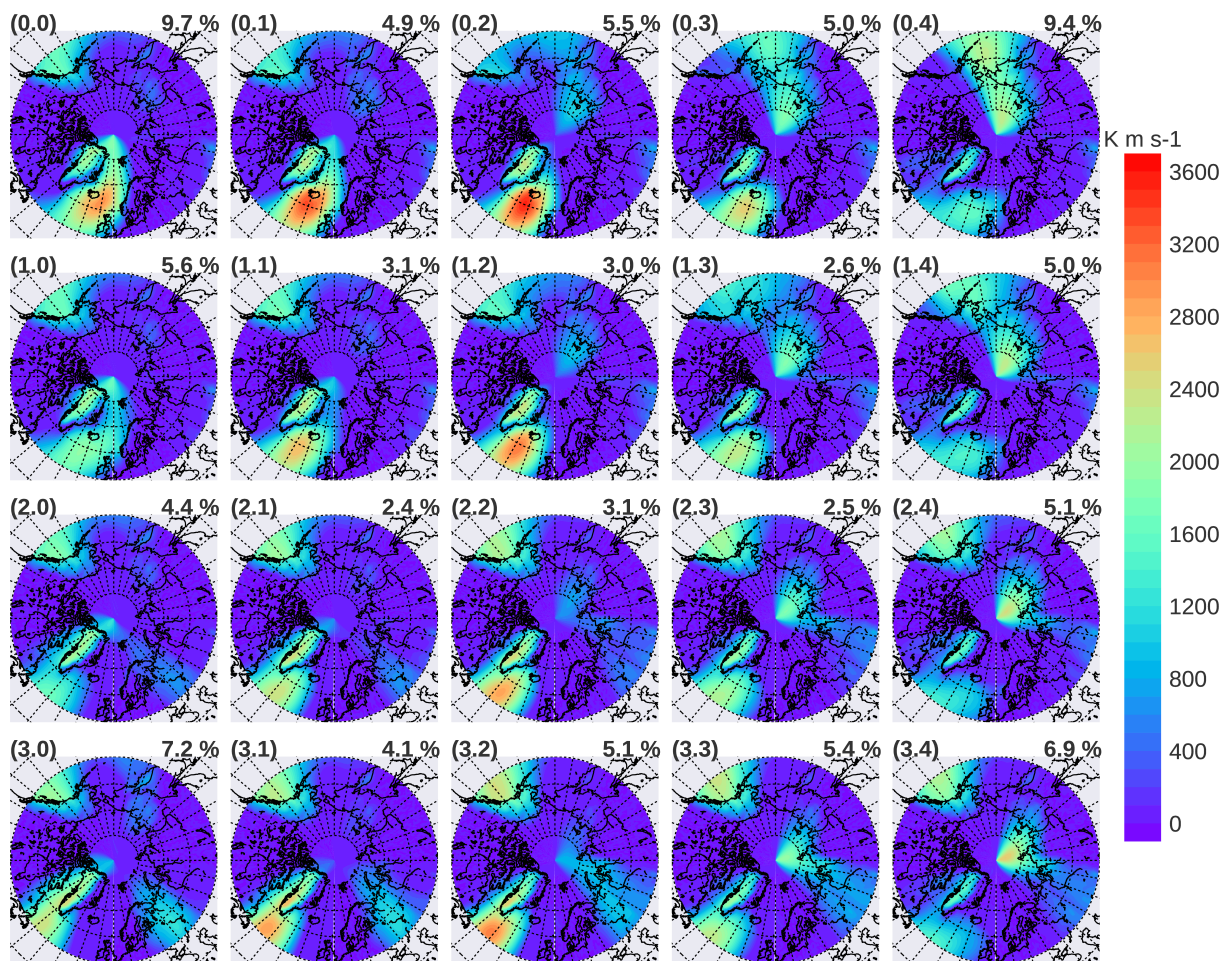


Fig. 1: 4x5 SOM of mean tropospheric (1000 hPa - 200 hPa) meridional temperature flux (vT), of ERA-Interim daily mean data for the winters from 1979/80 to 2015/16; contours show vT in $K m s^{-1}$, numbers in upper right show occurrence frequency in percent. The numbers in the upper left show the number of the node.

distinguish clusters of pattern within the SOM, which can help to find an appropriate size for the SOM. An appropriate size would consist of enough nodes to find patterns that differ substantially enough without showing too many detailed patterns. Of course, it is dependent on the purpose the SOM has to fulfill: for a very rough generalisation a small SOM is sufficient, for a detailed view on the data a very large SOM is necessary. This is one of the drawbacks of using SOM, the decomposition depends on the chosen size of the map.

Figure 2 shows for each pattern (corresponding to the position within the map) the yearly frequency of occurrence together with a 5 year moving average. For the two patterns of node (0,0), and node (0,4) the time series show the strongest variability. In the year 1990 the conditions similar to the pattern shown in node (0,0) occurs at about 30 % of the winter days, while the pattern of node (0,4) is only present during 2 % of the days in this winter. Looking further into the time series of node (0,0) it can be seen that in 2004 the flux over Iceland has almost never occurred, while the temperature flux through the Bering Strait and the East Siberian Sea is most frequent with 15 %.

The frequency of occurrence of the patterns within the center of the map (nodes (1-2,1-3)) rarely exceeds 10 % and they are present mostly during less 5 % of the days of a year.

The correlation of the time series of the patterns among themselves does not show any specific features (not shown). Only the trends of node (2,0) and node (0,3) show significance with p -values smaller than 0.05. The positive trend of node (2,0) corresponds to relatively low fluxes (about 2000 K m s^{-1}) through the west coast of Greenland and south of Alaska. Node (0,3) shows a negative trend for slightly higher fluxes (about 2800 K m s^{-1}) south of Iceland and relatively lower fluxes (about 1600 K m s^{-1}) through the Bering Strait. Just looking at this node might suggest that states will be less common and other states will increase, but no distinct correlation between the nodes was found.

It has to be noted, that the meridional temperature flux itself could be seen as a representation for the meridional heat flux. No direct influence of this flux on the surface can be derived, for that the divergence of the fluxes have to be analyzed. However, the flux itself is useful to find pathways of transport into the desired regions.

5 Summary and Discussion

An analysis of the patterns of tropospheric mean meridional temperature flux from ERA-Interim reanalysis was performed using an artificial neural network called SOM. With this method it is possible to distinguish key patterns of a given dataset, without the limitation of linear assumptions like in an EOF analysis. Moreover, the SOM can be analyzed more easily, because the method recreates states that are already present in the input data, compared to an EOF where the input data is split up into mathematical orthogonal components. The drawback of this method is that one has to find a reasonable size for the SOM to represent key features without showing too many detailed patterns and thereby losing generalization.

From the results of our analysis of meridional temperature fluxes it can be suggested that most of the time the meridional heat flux takes place over the North Atlantic between Greenland and Iceland, offshore west Greenland, and through the Bering Strait. These regions are resulting from the geographic features of the northern hemisphere, where the Arctic region is enclosed by land masses and most of the fluxes are channeled over the

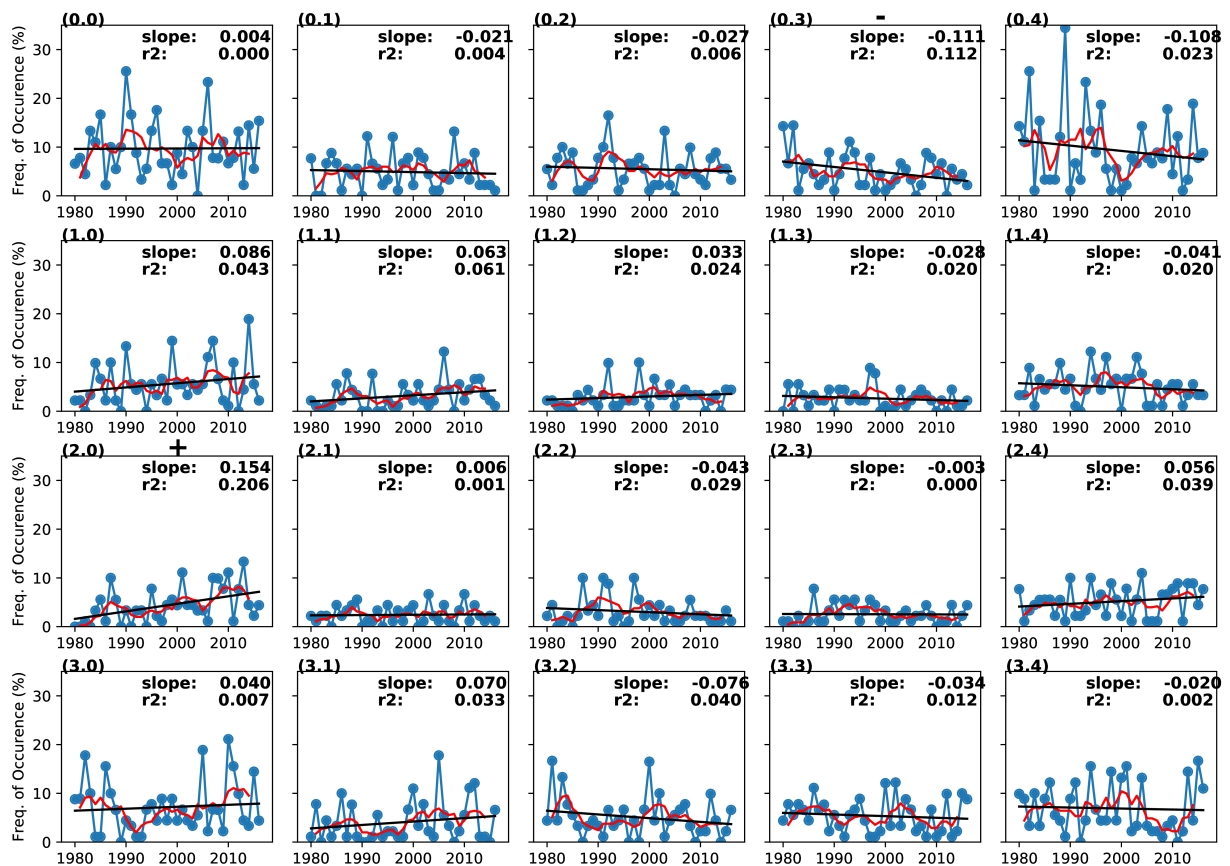


Fig. 2: Time series of the days in each year mapping to the specific state (upper left shows corresponding node/state). Blue lines show percentage of annual days mapping to the specific node, red lines show 5 year moving averages. Black lines show linear fit. In the upper right the slope of the linear fit is shown (in % per year), r^2 , the + and - signs at the top of the plots show if the calculated positiv/negative linear trend is significant or not.

oceans. The time series of the specific patterns show that there are patterns with a large variability and patterns with small variability in the occurrence frequency. The patterns that showed a low frequency of occurrence, which are mostly found in the middle of the map, suggest that the chosen size of the SOM might already be too large to find a more generalized view. Nevertheless, the most frequent pathways that were already found here are consistent with those in the literature (Overland et al., 1996; Adams et al., 2000; Vinogradova, 2007). The strongest fluxes occur over the Denmark Strait and Bering Strait.

Also the pattern looking like wedges of a pie offshore north Siberia might be caused by the choice of daily data. Using daily mean data, synoptic features have to be considered which show these large wedges of temperature flux into the Arctic via Siberia. Those patterns might result from synoptic pressure systems that transport air from northern Siberia into the high-latitude Arctic.

Looking at the frequency of occurrence through time two significant trends were found (see Figure 2). This can be seen by looking at the given p-value which indicates significance above the 95% level for testing the null hypothesis. When this p-value is smaller than 0.05 the trend is considered as significant. In Figure 2 significant trends are indicated by + and – signs depending on the sign of the trend.

Only node (2,0) and node (0,3) contains respectively trend but analysis for different time scales are necessary for further results. This is opposite to the suggestions from Vinogradova (2007), where a negative trend of annual mean meridional heat flux was concluded for January 70°N latitude, which cannot be seen in the trends for the circulation patterns.

For future studies we plan to analyse not only ERA-Interim data but also results from the Coupled Model Intercomparison Project 5 (CMIP5, Taylor et al. (2012)) to see how the models differ from each other and from reanalysis. Further, we will investigate other meteorological variables/fields such as, for example the eddy heat transports and at different time scales, for instance using the method with monthly or yearly mean data. It will also be interesting to look at different patterns of the divergence of heat fluxes. Another possible analysis will be to use the SOM method on 4-dimensional fields (time, level, latitude, longitude) instead of only 3-dimensional fields (time, latitude and longitude) to find patterns/structures that persist within the whole troposphere.

Acknowledgements

ECMWF reanalyses data are provided by apps.ecmwf.int/datasets/data/. We gratefully acknowledge the support from the German Research Foundation (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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Interactions between clouds and sea ice in the Arctic

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Summary: The feedback between clouds and sea ice got more importance in the last years, because of the declining Arctic sea ice extent. Previous observations show the formation of low clouds over newly formed open water. These low clouds are very important for the Arctic Energy Budget, because they warm the surface. This leads to increasing temperatures and stronger sea ice loss.

To assess the relationship between sea ice cover and cloudiness, satellite observations by DARDAR were compared with both global climate reanalyses ERA-Interim and MACC. The analysis focuses on 2007 – 2010 and the relationship between different parameters from the different datasets. It is found that the reanalyses only poorly approximate the cloud cover in the Arctic. Consequently no strong correlation was found for the time period 2007 – 2010.

Zusammenfassung: Das Wolken-Albedo-Feedback in der Arktis gewann in den letzten Jahren immer mehr an Bedeutung aufgrund des Rückganges der Meereisfläche. Vorhergehende Arbeiten zeigten die Bildung von tiefer Bewölkung über kürzlich aufgebrochenen Meereisstellen. Diese tiefen Wolken sind sehr wichtig für das arktische Energiebudget, wegen des Erwärmens der Oberfläche. Daraus folgt ein Anstieg in der bodennahen Temperatur und ein verstärkter Rückgang des Meereises.

Um den Einfluss der Meereiskonzentration auf die Wolkenbildung zu untersuchen, werden in dieser Arbeit Satellitendaten von DARDAR mit den beiden globalen Klimareanalysen Era-interim und MACC verglichen. Analysiert werden Daten aus den Jahren 2007 bis 2010 und für verschiedene Oberflächenbedingungen werden Korrelationen der einzelnen Datensätze erstellt. Es hat sich gezeigt, dass die Darstellung der Wolkenbedeckung in der Arktis durch die Reanalyse Daten nicht geeignet ist. Aus diesem Grund wurden keine signifikanten Korrelationen in der Zeitspanne von 2007 bis 2010 gefunden.

1 Motivation

Clouds play an important role in the energy budget of the Earth and are one factor, which is not well understood and quantified (Wielicki et al., 1995; Boucher et al., 2013; Curry et al., 1993; Quante, 2004). For predicting the future climate it is very important to understand cloud interactions with surface and atmosphere. One of these processes is the feedback between sea ice and cloud properties, which can be best studied in the Arctic.

Due to its stable atmosphere and characteristic surface, the Arctic may show a special feedback between clouds and the surface. As shown by Beesley and Moritz (1999), the Arctic is cloudy 80 % of the year and by contrast to the general cooling effect of clouds, in the Arctic the clouds heat up the atmosphere stronger than they cool the Earth's surface. Only during a short time in polar summer the reflection of incoming radiation is higher, so that the clouds cool the Earth's surface (Shupe and Intrieri, 2004). Additionally because of the variability of the surface and the boundary layer, it is possible to observe the formation and the dispersion of clouds over open water and ice. In this case it is very important to take a closer look on the albedo because at the ice edge there is a big variability of the reflectiveness. This leads to a balancing act between warming and cooling the atmosphere.

Also strongly associated with the warming of the Arctic is the decline of sea ice. Cuzzone and Vavrus (2011) found out, that the years 2007 to 2010 have the lowest sea ice concentration on record over the period from 1979–2010. The record minimum was observed in September 2012 with around 37 % less sea ice than the average over the years 1979 until 2006. Besides, the annual cycle of the sea ice variability is important for the stability of the boundary layer. Furthermore the temperature in the Arctic rises two times faster than in the mid-latitudes. These effects are called Arctic Amplification.

1.1 Satellites and Instruments

The A-Train describes a number of satellites which fly from south to north in 705 km and cross the equator every day at 1.20 pm local time. Here data records of the satellites Aqua, CloudSat and CALIPSO are used. They fly right behind each other, hence with the short time interval between them it is possible to observe the same situation of the atmosphere with various measurements in different perspectives.

From Aqua the data of the *Advanced Microwave Scanning Radiometer* (AMSR-E) were used. It is a passive microwave radiometer with twelve channels and six frequencies (6.9, 10.7, 18.7, 23.8, 36.5 and 89.0 GHz), which combines it to measure the upwelling brightness temperature of the sub-satellite track. The final product taken was the ice concentration, which is derived from the brightness temperature is gridded on an elliptic polar stereographic grid with a cell spacing of 12.5 km.

For the clouds the data record DARDAR was used. This is a assembled product of the *Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation* mission (CALIPSO) and *CloudSat*. CALIPSO provides measurements of all airborne particles, such as cloud and aerosol particles. Therefore an active lidar is used, which contains passive infrared as well as visible imagers. In addition to the lidar measurements CloudSat provides information collected with a radar instrument. Together both instruments give a good overview of the atmospheric conditions, because the lidar can detect thin clouds, and the radar can look through these

clouds and collect data further down in the atmosphere, such as water clouds and precipitation.

1.2 Reanalysis

For comparison two data records of the *European Centre for Medium–Range Weather Forecasts* (ECMWF) are used. The first is ERA–Interim and the other one is *Monitoring Atmospheric Composition and Climate* (MACC). Both are global atmospheric reanalyses. ERA–Interim is based on the IFS (Cy31r2) from 2006. It contains global surface parameters and atmospheric parameters on 60 vertical levels, from the surface up to 0.1 hPa and with a spatial resolution of ~ 80 km. Data are available for the time period 1 January 1979 to present and at the times 0 UTC, 6 UTC, 12 UTC and 18 UTC.

The second data set MACC covers the period 2003 until 2010 and is specialized on chemically reactive gases, as well as aerosols and greenhouse gases. For MACC a newer version of the IFS (Cy36r1) is used. This IFS cycle uses improvements to the cloud algorithms (Inness et al., 2013). The horizontal resolution covers the troposphere and the stratosphere also of ~ 80 km, globally. The difference in the calculated cloud cover between the two reanalyses is relatively small, globally and specified on the Arctic region (north of 60°).

2 Methodology

To get a cloud cover from the satellite record, it was necessary to analyse the satellite track. For that, each time step of the satellite track was assigned to a point on an elliptic polar stereographic map of the ice fraction by AMSR–E with the map projections tool of the *National Snow and Ice Data Center* (Cavalieri and Comiso, 2014) from 1990.

In the database entry, each time step has a longitude and latitude mark and the observation values. These marks were used to transfer to a x, y -grid by converting the geodetic latitude (lat) and longitude (lon) from degree to radians (see Eq. 1). This grid has an extension of 7600 km (x -Axis) and 11 200 km (y -axis). The factor 3850 and 5350 (see Eq. 1) are in kilometre and were added, so that the north pole is in the center of the x, y -grid and ρ is the eccentricity factor.

$$y = \frac{\rho \cdot \cos(lon) + 3850}{12.5} \quad \text{and} \quad x = \frac{-\rho \cdot \sin(lon) + 5350}{12.5} \quad (1)$$

For the cloud cover, the footprint in each grid box over the Arctic were counted for cloud free and cloudy conditions, where the cloudy cases were identified using the *Cloud_Scenario* by Cloudsat and the cloud mask *Calipso_Mask* by CALIPSO. The *Cloud_Scenario* classifies the clouds according to cloud categories from 0 to 8, where 0 says there is no cloud and the values 1 to 8 describe different cloud types. The *Calipso_Mask* is able to give four different values for the detection of clouds, which evaluates the quality of the detected area. Here just cases with the value "good detected" (value=3) were counted. After the addition of both classifications, the value was divided by the sum of all clouds to get a cloud cover (see Eq.2).

$$\text{cloudcover} = \frac{\text{observations of detected clouds}}{\text{sum of all observations}} \quad (2)$$

To evaluate the cloud cover over different sea ice conditions, three cases were defined: Open water with a sea ice condition lower than 15 %, completely ice covered with a sea ice extent over 20 % and the transition region, called edge with a sea ice concentration between 15 % to 20 %. To clarify the transition area, from the grid points which count to the edge conditions, the area was extended for 100 km in each direction of the grid point. With this division it is possible to analyse the relationship of different surface conditions and cloudiness.

3 Results

The comparison of the averaged annual cycle for the years 2007 until 2010, averaged over the region north of 60°, is shown in Figure 1. The reanalysis data of Era-Interim (red) and MACC (blue) are following each other and are converging from August onward. They represent the same annual cycle with a minimum in the cloud cover in June and a maximum in November. However, the annual cycle of the clouds in the satellite data differ from the model cycles. In the satellite record the minimum in the cloud cover is during February (see Fig. 1), as it was described by Intrieri et al. (2002), and two maxima, one in early summer and the other in autumn. The autumn maximum is consistently found in all datasets, the reanalysis data show it in November and the satellite observations a little earlier in October.

To draw a clearer picture the spatial distribution of the cloud cover and the sea ice extent for three selected months of the Era-Interim data is shown in Figure 3 to compare the opposite results of the model and satellite data. Therefore selected were the month November, because of the strong increase in arctic sea ice in the Era-Interim data (not shown) and the month of the minimum averaged cloud cover. The minimum cloud cover differs in between the data. The satellite data of

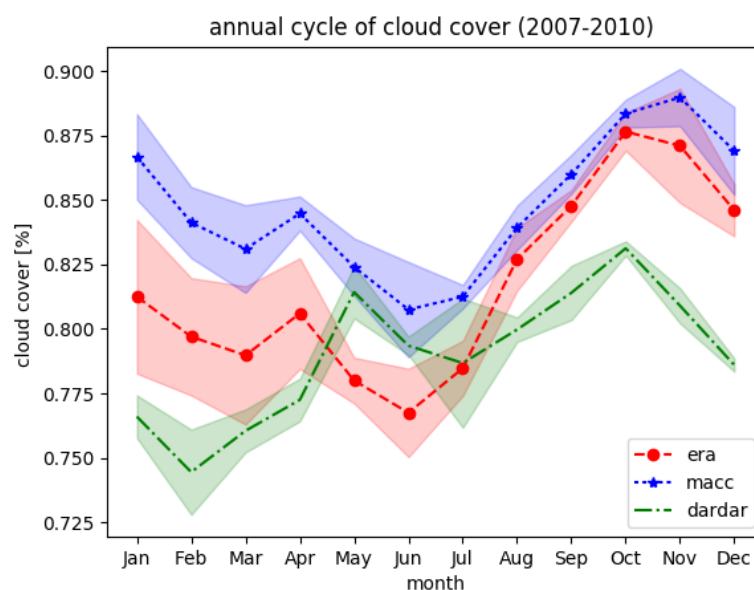


Figure 1: Cloud cover in percent over the Arctic by ERA-Interim (red), MACC (blue) and DARDAR (green) for the years 2007 until 2010. The lines show the averaged cloud cover north of 60 degree for each month and the shading the standard deviation.

DARDAR show the minimum in February and the model data in June. For November the cloud cover of ERA–Interim over the Arctic ocean is over 90%, except of the Beaufort Sea, there the cloud cover is around 70% (comp. Fig. 3). North of Norway, where no sea ice exists the cloud cover reduces and over land the cloud cover is lower than over the ocean or sea ice. During the reanalysis cloud cover minimum in June (see Fig. 3, the middle panel) the cloud cover decreases with the decreasing sea ice. This could imply, that the Arctic cloud cover is not well represented in the models. As Kay and Gettelman (2009) summarized the cloud presence is mostly depending on large scale circulation pattern, but surface conditions, such as snow and ice, influence the cloud as well. The satellite data can catch the Arctic cloud cover better than the models. It can be seen, that during the chosen time interval most of the Arctic is covered with sea ice. In February the sea ice extent is on its maximum, even the Hudson Bay is ice covered. The cloud cover shows in this month a lot more variability than in the others, see Figure 3. Compared to Figure 1 the spatial distribution shows the minimum of the cloud cover in the High Arctic. There the cloud cover is around 20% to 30%.

In the Figure 2 the correlation of the cloud cover between the reanalysis data and the satellite data is shown for the defined surface conditions. The number of analysed data points, in the correlation plot for each time step and each grid point, varies strongly between the surface cases. The transition area contains nearly 23.000 analysed points, but the analyse over the open ocean and ice has around

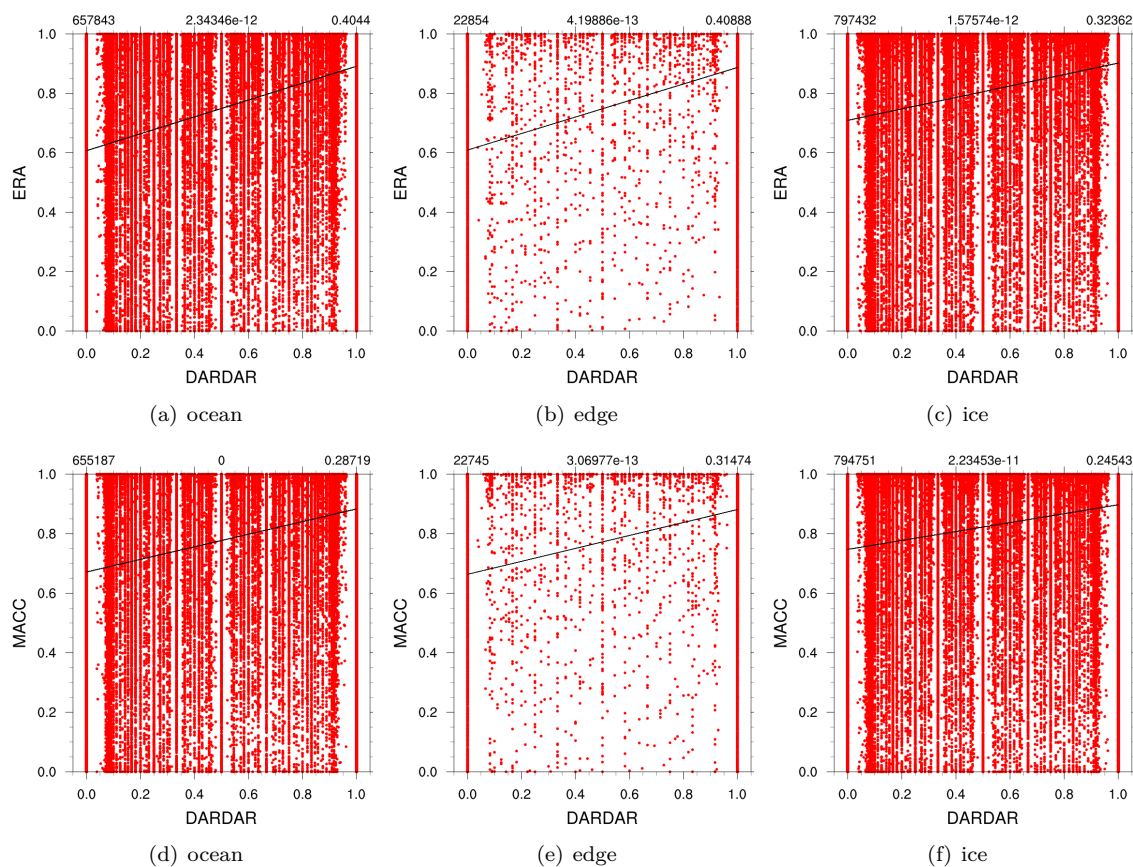


Figure 2: Correlation between the daily averages of the cloud cover of DARDAR and ERA–Interim (upper panel) and MACC (lower panel) over different surface conditions, for the time period 2007 till 2010 with the linear regression. On top in the left corner it shows the number of observed points, in the middle is the p–value of the Pearson's r–test and in the right corner the slope of the regression.

	MACC			ERA-Interim		
	r	r ²	m	r	r ²	m
ocean	0.29	0.08	0.21	0.4	0.16	0.28
ice	0.25	0.06	0.15	0.32	0.10	0.19
edge	0.32	0.01	0.22	0.41	0.17	0.28

Table 1: Correlation (r), explained variance (r^2) and slope (m) of the regression values of the comparison between DARDAR and the reanalysis data MACC and ERA-Interim.

34 times more data points. In all analysed cases it is clear that the produced cloud cover by ERA-Interim and MACC does not depend on the satellite observations, this was shown as well by Zygmuntowska et al. (2012). The corresponding measurements are strongly spread. Even when the satellite detects a cloud free condition, the model data have clouds. In all Figures 2(a) – 2(f) it is found that the cloud cover by ERA-Interim and MACC is noteworthy higher than the satellite data. On average the Era-Interim data are 60 % higher and MACC are 67 %.

The regression lines emphasize this fact by having the point of intersection with the y-axis in all cases above 65 %. Also it is discernible, that a higher DARDAR cloud cover is corresponding with an increased ERA-Interim cloud cover (comp. Fig. 2). The same applies to MACC's cloud cover. In both data records, the correlation coefficient is smallest in the ice case and highest in the ice edge case (comp. Tab. 1). The ERA-Interim correlation values are 0.08 to 0.12 higher than the MACC's correlation coefficients. For the statistical significance of the correlation coefficient the *Pearson's rtest* was used. The proportion to the ERA-Interim data for the variation of the DARDAR data is on average 14.5 % and to the MACC data it is 8.1 %. Comparing the spatial distribution of both reanalyses in the observed time periode (not shown), it is exhibited that neither ERA-Interim nor MACC show the cloud cover minimum in February/March, but in these Figures the annual cloud cycle is approximated. Especially for the central Arctic, it is visible, that the cloud cover rises in the summer months and decreases in the winter. However, for the whole region north of 60° in both cases, the cloud cover is nearly stable and especially for the central Arctic strongly cloudy.

4 Conclusion

In this work, a comparison between the cloud cover of satellite observations and global climate reanalysis data records over different surface conditions in the Arctic was performed. For the satellite data, the DARDAR data set was used, which provides cloud retrievals. First the data were converted to a polar stereographic grid and in a second step the cloud cover was calculated. For the reanalysis data the total cloud cover of ERA–Interim and MACC were used.

The shown annual cycle reveals the distinction between the satellite and reanalysis record. The timing of both, cloud cover yearly maximum and minimum is shifted in the model data. In the spatial distribution it can be seen, that the cloud cover of the model data are nearly homogeneously distributed over the high arctic region. Additionally no connection between the cloud cover and the sea ice can be detected in the reanalysis data. A big change can be only observed over ocean and at the coasts. This is in agreement with the results of Kay and Gettelman (2009), which describe the change in surface as one of the main factors in the observed cloud cover change. The time correlation of daily averages over 4 years for the ERA–Interim and the MACC data showed clearly that the correlation between the data records (comp. Fig. 2) is weak.

In summary it is clearly visible, that neither ERA–Interim’s cloud cover nor MACC’s cloud cover mirror the observed cloud cover by satellites in the Arctic. Also these data are not convincing regarding the feedback between sea ice and cloud properties. The explaining variances for the reanalyses are too small to get a clear answer.

For future research, it will be important to take a closer look of low clouds, because stratus clouds are the most frequent cloud type in the Arctic. Kay and Gettelman (2009) proposed that clouds with a cloud top height lower than 3 km play the largest part in the Arctic energy budget and are also more influenced by the surface conditions than the higher clouds. Here the total cloud cover was used and it is possible that it is not representative. Uncertainties could be produced by cirrus clouds, or in the southern part by nimbostratus clouds. If this is the case, the spread of the correlation will be smaller for low clouds and the variance will be improved. Furthermore a regional comparison between the reanalyses and the satellite data will show if there are regions where the reanalyses data by MACC and ERA–Interim mirror better.

Also it is important to improve the reanalysis data records, to get a connection to the cloud cover measured by satellites. Therefore more measurements over a longer time period in the Arctic are necessary. Such improved datasets might then allow for a more conclusive investigation of the relationship between sea ice and cloudiness.

Appendices

Appendix A Era-Interim 2007-2011

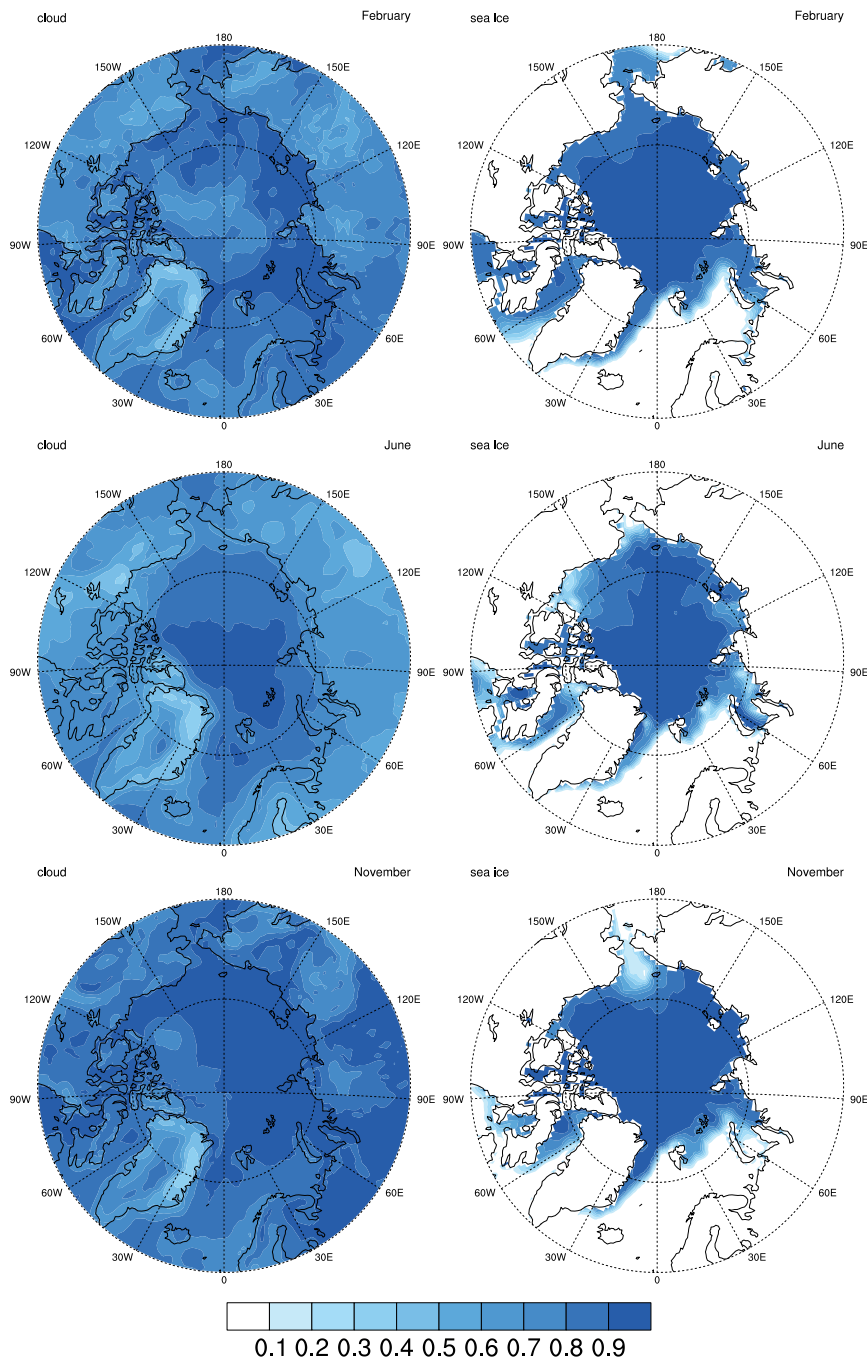


Figure 3: Cloud cover on the left hand side and sea ice concentration on the right hand side, both in percent for the Arctic ocean by ERA-Interim for the month June (upper panel) and November (lower panel) of the years 2007 until 2011.

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Statistische Analyse zur Güte der Niederschlagsprognose für Wassereinzugsgebiete sächsischer Talsperren

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Summary: For the water management the forecast of precipitation is an important input variable for hydrologic models. With a accurate forecast, suitable protection measures, for example dam-predischarges can be initiated on time. However, the precipitation forecast is difficult, because it has a large spatial and temporal variability. This can be seen by the large differences of predicted precipitation height of different forecasts. With a validation of predictions of the COSMO-EU-Model and the radar-based analysis data of RADOLAN a possible optimum warning time shall be found. In addition, different continuous verification methods are applied. Additionally, a possible spatial influence of the orography and different general weather situations were analysed. A total of 57 days, with more than 50 mm precipitation height in 24 h were validated in the years from 2006 to 2014. The data refer to five different catchment areas of Saxony which are managed by the State Reservoir Administration of Saxony (LTV). It has been found that at 62 % of the validated forecasts not enough precipitation was predicted. The closer in time forecast and precipitation event are, the better is the forecast skill. An optimal earlier forecast time cannot be found under the use of the currently available precipitation forecasts.

Zusammenfassung: Für die Wasserwirtschaft ist die Niederschlagsvorhersage eine wichtige Eingangsvariable für hydrologische Modelle. Mit einer guten Vorhersage können die entsprechenden Schutzmaßnahmen wie z.B. Talsperrenvorentlastungen rechtzeitig eingeleitet werden. Jedoch ist die Vorhersage des Niederschlags schwierig, da er eine große räumliche und zeitliche Variabilität hat. Diese zeigt sich auch in der Variabilität der Niederschlagshöhe zu unterschiedlichen Vorhersageterminen. Mit einer Validierung zwischen Vorhersagen des COSMO-EU-Modells und den radargestützten Analysedaten von RADOLAN für Regenmengen in verschiedenen Talsperreneinzugsgebiet Sachsens soll untersucht werden, ob es einen optimalen Warnzeitpunkt gibt, der gekennzeichnet ist durch eine möglichst frühe gebietsgenaue Niederschlagsprognose, so dass für das Durchführen wasserwirtschaftlicher Maßnahmen ausreichend Zeit verbleibt. Um dies einschätzen zu können, werden hier verschiedene kontinuierliche Gütemaße angewandt. Auch ein möglicher räumlicher Einfluss durch die Orographie und der Einfluss verschiedener Großwetterlagen wurde dabei untersucht. Es wurden insgesamt 57 Tage, an welchen mehr als 50 mm Niederschlag in 24 h fiel, in den Jahren 2006 bis 2014 validiert. Die Daten beziehen sich auf fünf Wassereinzugsgebiete Sachsens, die durch die Landes-talsperrenverwaltung des Freistaates Sachsen (LTV) bewirtschaftet werden. Dabei hat sich herausgestellt, dass bei 62 % der untersuchten Vorhersagen zu wenig Niederschlag vorhergesagt wurde. Die unterschiedlichen Gütemaße zeigen das erwartete Verhalten, dass je näher der Vorhersagetermin am Ereignis liegt, desto besser das Gütemaß und somit auch die Vorhersage ist. Ein optimaler früherer Vorhersagezeitpunkt kann unter Verwendung der derzeit verfügbaren Niederschlagsprognosen nicht gefunden werden.

1. Einleitung

Der Niederschlag stellt eine der wichtigsten meteorologischen Größen dar. Leider ist die Vorhersage von Niederschlag schwierig, da Niederschlag eine große räumliche und zeitliche Variabilität hat.

Wie Verifikationen der Wettervorhersagen des DWD (siehe Abb. 1) zeigen, wurde kaum eine Verbesserung der Prognosegüte für den Niederschlag seit 2004 erzielt. Hingegen ist bei der Temperatur, dem Vektorwind und dem Universellen Score, welcher alle Parameter beinhaltet, eine Verbesserung der Wettervorhersagen zu erkennen. Je kürzer die Vorhersage in die Zukunft reicht, desto besser sind die Gütemaße.

Die ungenaue Niederschlagsvorhersage macht deren Verwendung durch potentielle Nutzer, wie z.B. die Hydrologie, sehr schwierig. Der Niederschlag ist eine entscheidende Eingangsvariable für hydrologische Modelle. Ist die Prognose fehlerhaft, wirkt sich dies auf die berechneten Variablen, wie z.B. den Zufluss in eine Talsperre, aus. Ein schönes Beispiel, welches den prognostizierten Niederschlag und Zufluss sowie den tatsächlich gefallenen Niederschlag und den daraus resultierenden Zufluss an der Talsperre Eibenstock im Zeitraum vom 05.08.2006 bis 07.08.2006 darstellt, liefert die Abbildung 2 aus Müller (2010). Der Niederschlag wurde sowohl zeitlich als auch in der Niederschlagshöhe anders prognostiziert. So wurde mit einem Beckeninhalt nahe dem Vollstau gerechnet, aber in der Realität blieb der Beckeninhalt noch unter dem Stauziel. Insbesondere in Gebirgslagen kann eine fehlerhafte räumliche Niederschlagsvorhersage Probleme in benachbarten Einzugsgebieten auslösen. Für die Landestalsperrenverwaltung des Freistaates Sachsen (LTV) ist es eine Herausforderung, auf Grundlage der Progno-

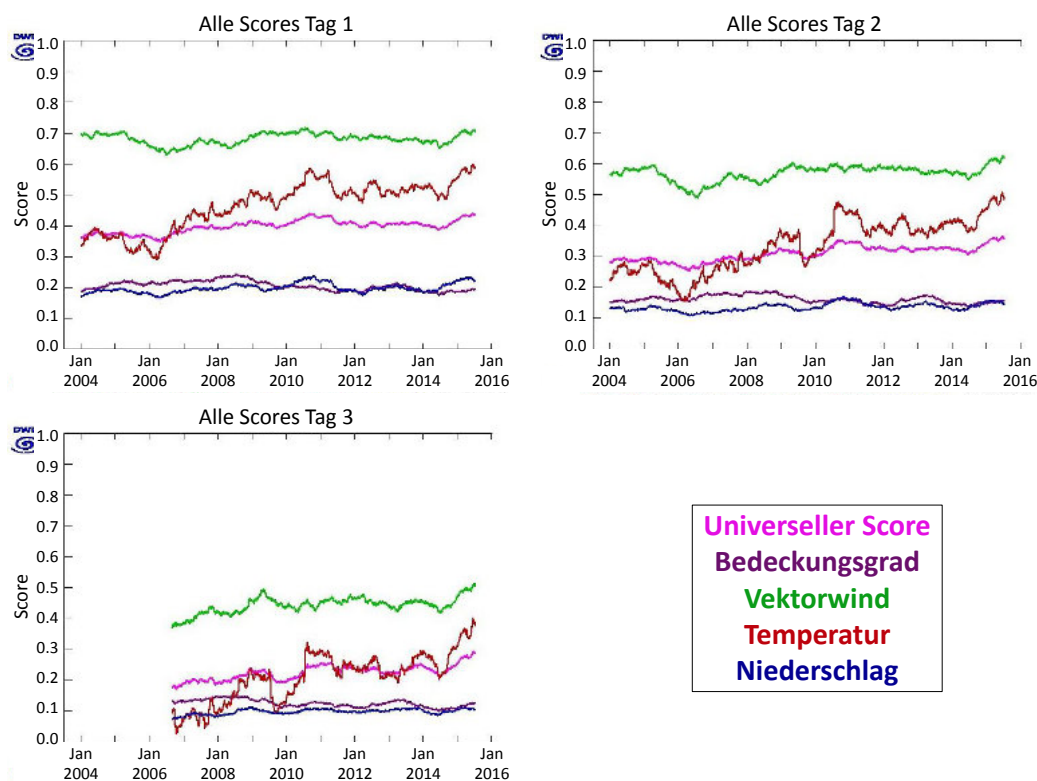


Abbildung 1: Güte (Score) der Wettervorhersage des COSMO-EU-Modells von 2004 bis 2016. Die Güte wurde für verschiedene Wetterparameter, wie z.B. den Niederschlag (blaue Linie) für Vorhersagezeiten von 1 bis 3 Tagen berechnet. Quelle: M. Buchhold, DWD Referat FE15.

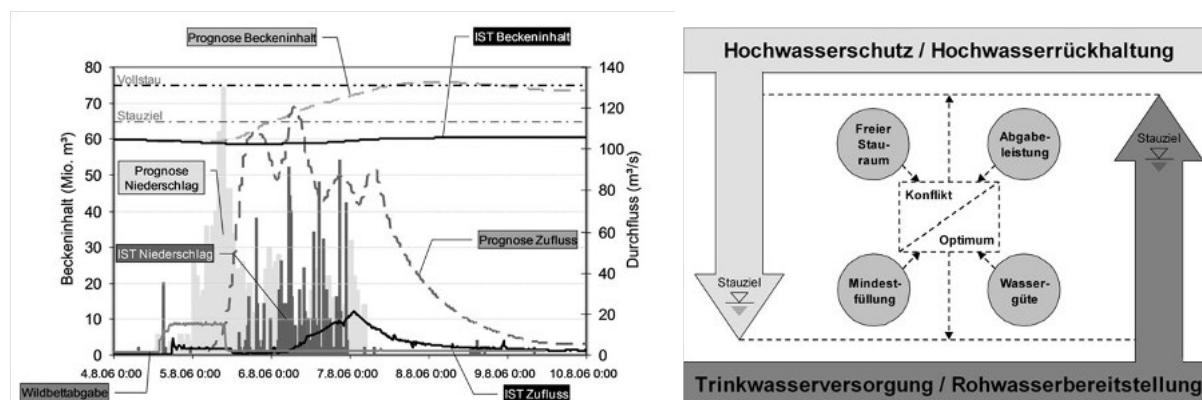


Abbildung 2: Prognose-, IST-Niederschlag und Zufluss an der TS Eibenstock vom 04.08. bis 10.08.2006 (links). Nutzungskonflikt Multifunktionaler Talsperren (rechts) (aus Müller, 2010).

sen des DWD die richtigen Maßnahmen wie z.B. Talsperrenvorentlastungen zu treffen, da sie bei der Betreibung von multifunktionalen Stauanlagen in einem Nutzungskonflikt zwischen Wasserversorgung und Hochwasserschutz stehen (siehe Abb. 2, vgl. Müller (2010)). Eine gute Niederschlagsprognose kann die Bewirtschaftung der Talsperren optimieren.

Nicht nur die räumliche und zeitliche Variabilität der Niederschlagsprognosen stellen ein Problem dar, sondern auch die Variabilität der Niederschlagshöhe zu unterschiedlichen Vorhersageterminen. Es stellt sich die Frage, ob sich durch eine Validierung der Wetterdaten ein optimaler Vorwarnzeitpunkt finden lässt. Dazu werden verschiedene kontinuierliche Gütemaße angewandt. Auch eine mögliche systematische Verschiebung der Niederschlagsgebiete, z.B. durch den Einfluss der Orographie, wird durch das Verschieben von Talsperreneinzugsgebieten untersucht. Möglicherweise spielt auch der Einfluss von unterschiedlichen Großwetterlagen bei der Niederschlagsvorhersage eine Rolle. Die verschiedenen Gütemaße werden auch für verschiedene Großwettertypen berechnet. Die im folgenden vorgestellten Ergebnisse sind das Ergebnis einer Masterarbeit (Redelstein, 2017), die in Zusammenarbeit mit der LTV entstanden ist.

2. Datengrundlage

Niederschlagsdaten

Für die Auswertung werden die Niederschlagsvorhersagen des Regionalmodells COSMO-EU (COSMO-Homepage, 2017) mit den radargestützten Analysedaten von RADOLAN (Weigl, 2016) verifiziert. Die Vorhersagen des COSMO-EU wurden aus dem Online-Archiv Pamore (PARallel MOdel data RETrieve from Oracle databases) des DWD (<http://www.dwd.de/DE/leistungen/pamore/pamore.html>) bezogen. Die RADOLAN-Daten stammen ebenfalls vom DWD und sind unter ftp://ftp-cdc.dwd.de/pub/CDC/grids_germany/daily/radolan/ frei verfügbar.

Zur Auswahl der Analysetage

Die statistische Auswertung wird für 57 Tage in den Jahren 2006 bis 2014 erstellt. Die Auswahl dieser Tage erfolgte durch die LTV. Als Auswahlkriterium wurde eine vom Staumeister gemessene Niederschlagsmenge von mehr als 50 mm innerhalb von 24 h an mindestens einer der Talsperren der LTV (siehe Abb. 3) gewählt.

Ausgewählte Talsperren

Für die statistische Auswertung werden die Niederschlagsmengen in den Einzugsgebieten von fünf Talsperren ermittelt. Zu den ausgewählten Talsperren gehören der Speicher Altenberg, die Talsperren Bautzen, Eibenstock, Neunzehnhain 1 und Sosa. Dabei ist das Einzugsgebiet der Talsperre Bautzen mit 310,47 km² das Größte und das des Speichers Altenberg mit 6,87 km² das Kleinste.

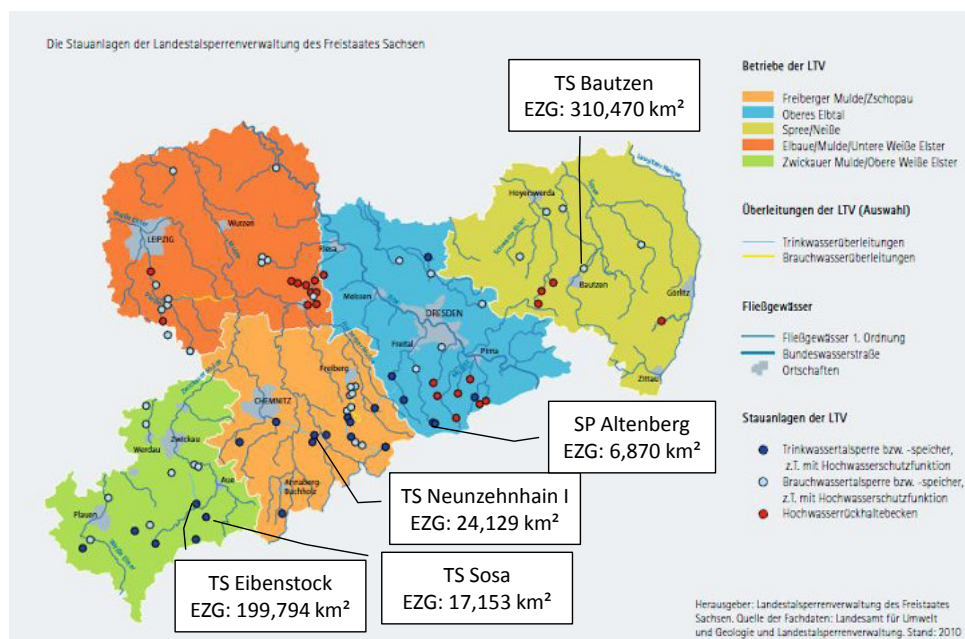


Abbildung 3: Verteilung der Stauanlagen der LTV und ausgewählte Talsperren sowie die Größe der Einzugsgebiete (EZG) (aus LTV, 2013).

3. Verifikation von Wettervorhersagen

Um einen Überblick über die Qualität eines Wettervorhersagemodells zu bekommen, gibt es verschiedene Ansätze aus der Statistik. Die Fehlermaße basieren auf einem Vergleich von Gitterpunktwerten zwischen Beobachtung und Modellprognose. Für die Verifikation von Vorhersagen wird zwischen kontinuierlichen und kategorischen Gütemaßen unterschieden. Kontinuierliche Gütemaße untersuchen ob und um wie viel eine Vorhersage von der tatsächlichen Beobachtung abweicht. Kategorische Gütemaße verifizieren ob und in welcher Häufigkeit bestimmte vorhergesagte Ereignisse eingetroffen sind oder nicht. Kontinuierliche Variablen werden dafür in verschiedene Kategorien eingeteilt. Im folgenden werden die in dieser Arbeit verwendeten Fehlermaße vorgestellt. Dabei dienen als Quellen Wilks (2006) und Jolliffe und Stephenson (2003). Einen guten Überblick liefert auch die Website der WWRP/WGNE Joint Working Group on Forecast Verification Research (http://www.cawcr.gov.au/projects/verification/verif_web_page.html).

Kontinuierliche Gütemaße

Mit den kontinuierlichen Gütemaßen wird die Fähigkeit der Vorhersage von korrekter Lage und Betrag des Niederschlags bestimmt. In den folgenden Gleichungen sind F_i die i -Werte der vorhergesagten Daten und O_i die der beobachteten Daten. Hierbei ist $i = 1, 2, \dots, N$ mit N der Anzahl von Vorhersagen bzw. Beobachtungen.

- Mittlerer Fehler (Mean Error, Bias, ME):

Der mittlere Fehler zeigt die mittlere Richtung der Abweichung von den Vorhersagen und Beobachtungen. Der ME wird wie folgt berechnet:

$$ME = \frac{1}{N} \sum_i^N (F_i - O_i) \quad . \quad (1)$$

Ein positiver ME zeigt, dass die vorhergesagten Werte die beobachteten Werte im Mittel um diesen Betrag überschätzen, wobei ein negativer ME eine Unterschätzung der beobachteten Werte im Mittel bedeutet. Der Nachteil beim ME ist, dass sich Fehler unterschiedlicher Vorzeichen gegenseitig aufheben. Somit kann ein vermeintlich gutes Ergebnis vorgetäuscht werden.

- Mittlerer absoluter Fehler (Mean absolute error, MAE):

Der mittlere absolute Fehler ist ein lineares Maß, welches das Mittel der Beträge aller Fehler wiedergibt. Jedoch wird nicht die Richtung des Fehlers wiedergegeben.

$$MAE = \frac{1}{N} \sum_i^N |F_i - O_i| \quad . \quad (2)$$

- Wurzel aus dem mittleren quadratischen Fehler (Root mean square error, RMSE):

Der RMSE ist ebenfalls ein lineares Maß, welches den mittleren Betrag des Fehlers wiedergibt, aber mit dem Quadrat des Fehlers gewichtet ist:

$$RMSE = \sqrt{\frac{1}{N} \sum_i^N (F_i - O_i)^2} \quad . \quad (3)$$

Wie der MAE gibt der RMSE die Richtung des Fehlers nicht an. Wenn man den RMSE mit dem MAE vergleicht, so bekommen größere Fehler ein größeres Gewicht im quadratischen Mittel. Deswegen ist RMSE ein Maß das große Fehler hervorhebt. Der Vergleich von MAE und RMSE liefert eine Abschätzung für die Fehlervarianz. Dabei gilt:

RMSE > MAE: hohe Fehlervarianz

RMSE ~ MAE: geringe Fehlervarianz

RMSE = MAE: keine Fehlervarianz (alle Fehler haben die gleiche Magnitude)

- Korrelationskoeffizient (Pearson-Korrelation, r):

Der Korrelationskoeffizient gibt eine Auskunft über Stärke und Richtung eines Zusammenhangs zwischen Vorhersage und Beobachtung und kann Werte von -1 bis +1 erreichen. Mit der folgenden Formel wird der Korrelationskoeffizient berechnet:

$$r = \frac{\sum_i^N (F_i - \bar{F})(O_i - \bar{O})}{\sqrt{\sum_i^N (F_i - \bar{F})^2} \sqrt{\sum_i^N (O_i - \bar{O})^2}} \quad , \quad (4)$$

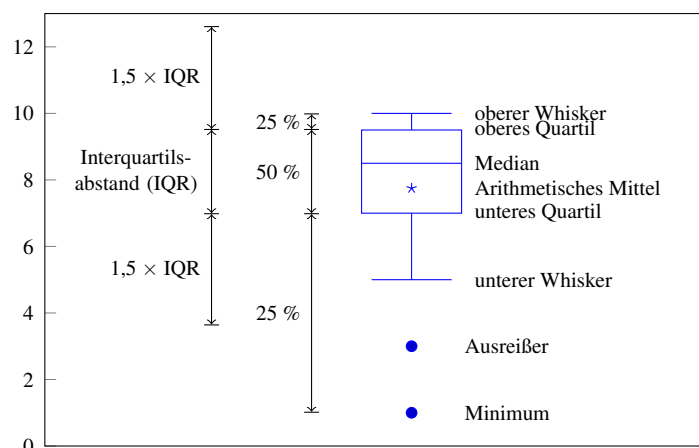


Abbildung 4: Beispiel eines Boxplots (eigene Abb.).

hierbei ist \bar{F} der Mittelwert des vorhergesagten Niederschlags und \bar{O} des beobachteten. Ist $r = 1$, so bedeutet dies, dass die zwei Größen in einem 100 prozentigen linearen Zusammenhang stehen. Der Vorhersagefehler als solcher wird beim Korrelationskoeffizienten nicht berücksichtigt, somit können auch Vorhersagen mit vermeintlich großen Fehlern einen guten Korrelationskoeffizienten vorweisen. Der Korrelationskoeffizient ist sensi-bel gegenüber Ausreißern.

- Boxplots:

Mit einem Boxplot werden die statistischen Größen Quartile, Extrema, Ausreißer, Median und Arithmetische Mittel auf einen Blick deutlich dargestellt (siehe Abb. 4). Es entsteht somit ein Überblick, wie gut die Streuung und auch Spannweite der Daten der Vorhersage mit denen der Beobachtung übereinstimmt. Mit dem oberen und unteren Quartil wird die Box des Boxplots begrenzt, somit befinden sich 50 % der Daten in der Box. Die Länge der Box entspricht dem Interquartilsabstand (IQR), welches ein Maß der Streuung der Daten ist. Im Inneren der Box wird der Median und manchmal auch das Arithmetische Mittel markiert. An beiden Enden der Box schließen sich die sogenannten „Whisker“ an. Diese reichen entweder bis zu den Extrema oder sie haben wie im Beispiel von Abbildung 4 das 1,5-fache des IQR an Länge. Der „Whisker“ reicht dann bis zum letzten Datenpunkt, welcher noch innerhalb von $1,5 \times \text{IQR}$ liegt. Dies kann auch das Maximum oder Minimum sein. Datenpunkte, welche außerhalb von $1,5 \times \text{IQR}$ liegen, werden als Ausreißer bezeichnet.

Räumliche Vorhersagefehler

Bei Modellen mit einer hohen Auflösung ist es schwierig, eine exakte Übereinstimmung zwischen Vorhersage und Beobachtung zu erzielen. Mit den oben beschriebenen Methoden wird eine Niederschlagsvorhersage am falschen Ort, jedoch in Menge, Größe und Zeit richtig als schlecht bewertet. Es kommt zu dem sogenannten „Double-Penalty-Problem“, wenn an der Stelle, wo kein Niederschlag vorhergesagt wird welcher beobachtet wird und an der Stelle, wo welcher vorhergesagt wird keiner beobachtet wird. Die Vorhersage wird somit zweimal bestraft (Michaelides, 2008). Diese Problematik wird mit fünf unterschiedlichen Fällen in Abbildung 5 dargestellt. In Teilbild (a) ist die Vorhersage rein optisch am besten, da nur eine geringe Verschiebung zwischen Beobachtung und Vorhersage besteht. Bei der Bewertung mit den obigen Gütemaßen ist aber

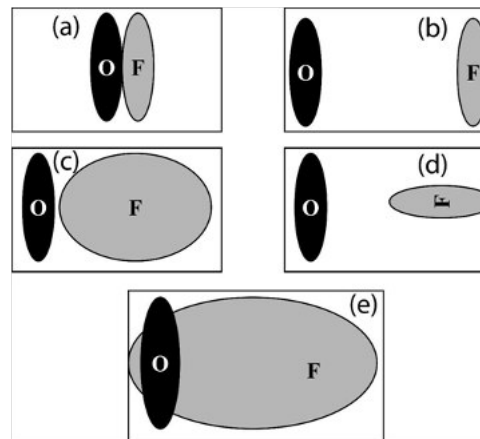


Abbildung 5: Ein schematisches Beispiel verschiedener Kombinationen von Vorhersage- (F) und Beobachtungsfeldern (O) zur Veranschaulichung des Problems der Niederschlagsverifikation mit gitterpunkt-basierten Fehlermaßen (aus Davis et al., 2006).

Teilbild (e) am besten, da hier eine Überschneidung zwischen Vorhersage und Beobachtung besteht.

Für die Wassermengenbewirtschaftung durch die LTV ist entscheidend, wie viel Niederschlag in den jeweiligen Talsperreneinzugsgebieten fällt. Deswegen bezieht sich die Verifikation in Kapitel 4 auf die Niederschlagsmengen in den Einzugsgebieten. Um möglicherweise eine systematische Verschiebung der vorhergesagten Niederschlagsfelder z.B. durch die Orographie zu erkennen, werden auch die Niederschlagsmengen in der benachbarten Umgebung betrachtet. Dazu werden die Einzugsgebiete der Talsperren um die Gitterweite von COSMO-EU (7 km) nach Norden, Osten, Süden und Westen verschoben. Des Weiteren wurden Talsperren mit unterschiedlich großen Einzugsgebieten gewählt. So können Aussagen darüber gemacht werden, ob in einem größeren Vorhersagegebiet die Vorhersage besser mit der Beobachtung übereinstimmt als in einem kleineren.

4. Ergebnisse

Die einzuleitenden Schutzmaßnahmen wie z.B. Talsperrenvorentlastungen, basieren auf den Starkregen- bzw. Niederschlagswarnungen des DWD. Es sollen die vom COSMO-EU berechneten Vorhersagen mit den dafür vorliegenden Niederschlagsbeobachtungen des RADOLAN validiert werden. Ziel ist es aus den meteorologischen Informationen die Güte der Warnungen zu bestimmen sowie einen optimalen Warnzeitpunkt zu finden, auf den dann mit einer effektiven Maßnahme reagiert werden kann. Um einen optimalen Warnzeitpunkt zu bestimmen, sollen für jeden Warnzeitpunkt die in Kapitel 3 beschriebenen Gütemaße berechnet werden. Somit kann die Güte der unterschiedlichen Vorhersagezeitpunkte miteinander verglichen werden. Es werden Vorhersagen für 24, 36, 48, 60 und 72 Stunden Vorhersagedauer ausgewertet. Die Vorhersagedauer endet um 24 UTC des Analysetages.

Zur Auswertung werden die mittleren 24h-Niederschlagsmengen in den Einzugsgebieten der fünf Talsperren und den jeweiligen Verschiebungen berechnet. In Abbildung 6 ist die relative Häufigkeit der von RADOLAN gemessenen Niederschläge in den fünf Talsperreneinzugsgebieten dargestellt. Am häufigsten vertreten sind Niederschlagsmengen bis zu 5 mm. Ab 30 mm nimmt die Häufigkeit ab und ab 50 mm wurden nur noch

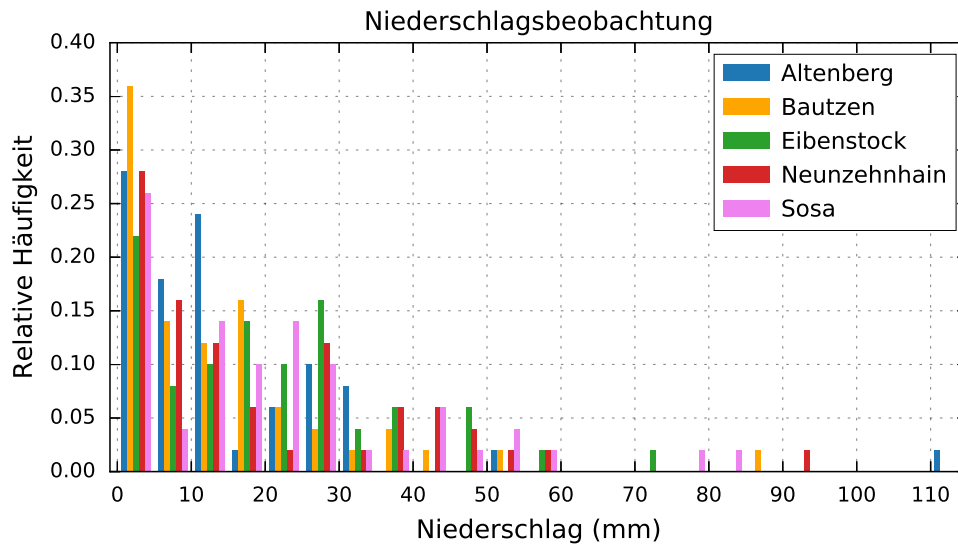


Abbildung 6: Relative Häufigkeit der von RADOLAN gemessenen Niederschläge in 5 mm-Schritten in den fünf Talsperreneinzugsgebieten.

einzelne Ereignisse registriert. Mit einer Niederschlagsmenge von 110,9 mm im Einzugsgebiet des SP Altenberg fiel am 09.08.2007 der meiste Niederschlag.

Kontinuierliche Gütemaße

In Abbildung 7 sind die Abweichungen zwischen Vorhersage und Beobachtung dargestellt. Daran, dass die Boxen der Boxplots meist unter Null liegen, ist zu erkennen, dass in den meisten Fällen zu wenig Niederschlag vorhergesagt wurde. Der Median und der mittlere Fehler liegen für alle Talsperren und Vorhersagezeitpunkte unter Null. Der Median und der mittlere Fehler der 24 h Vorhersage liegen meist am nächsten zur Null oder sind nur minimal schlechter als der der 36 h Vorhersage. Die Ausreißer wurden nur bis ± 60 mm dargestellt. Die maximale Überschätzung der Niederschlagsvorhersage mit 115,77 mm ist bei der 60 h Vorhersage an der TS Eibenstock und die maximale

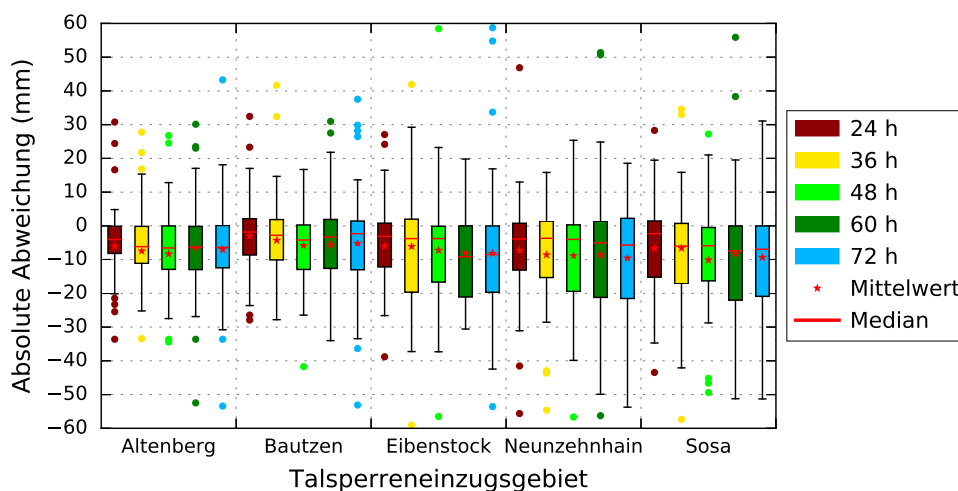


Abbildung 7: Absolute Abweichung zwischen Vorhersage und Beobachtung für die fünf Vorhersagezeitpunkte und Talsperreneinzugsgebiete.

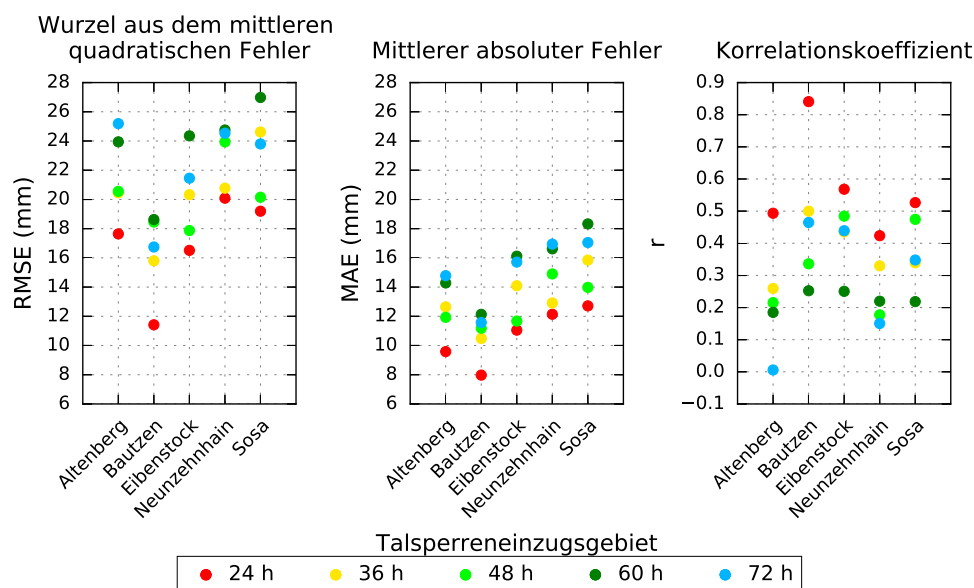


Abbildung 8: RMSE (links), MAE (Mitte) und Korrelationskoeffizient (rechts) für die fünf Vorhersagezeitpunkte und Talsperreneinzugsgebiete.

Unterschätzung mit $-110,78$ mm ist bei der 72 h Vorhersage an der TS Neunzehnhain. Der IQR des SP Altenberg und der TS Bautzen sind im Vergleich zu den anderen drei Talsperren am kleinsten. Bei diesen beiden Talsperren liegen 50 % der absoluten Abweichungen zwischen Vorhersage und Beobachtung zwischen -13 und 2 mm. Die 24 h, sowie auch die 36 h Vorhersage, haben die geringste Streuung.

Der RMSE (Formel 3) als Maß für die Fehlervarianz befindet sich im Bereich zwischen $11,44$ mm bei der 24 h Vorhersage für die TS Bautzen und $27,54$ mm bei der 60 h Vorhersage für die TS Sosa (siehe Abb. 8 links). Der RMSE für die 24 h Vorhersage ist an allen Talsperren am geringsten. Insbesondere hat die TS Bautzen die kleinsten RMSE Werte. Dies könnte daran liegen, dass das Einzugsgebiet das Größte der untersuchten Talsperren ist. Es kann keine einheitliche Aussage darüber getroffen werden, welche Vorhersagezeit nach der 24 h Vorhersage das bessere Gütemaß hat. Während am SP Altenberg, der TS Bautzen und der TS Neunzehnhain den zweitgeringsten RMSE Wert die 36 h Vorhersage hat, hat an der TS Eibenstock und der TS Sosa die 48 h Vorhersage den zweitgeringsten Wert. Nach dem RMSE ist die 72 h Vorhersage bei vier von den fünf Talsperren besser als die 60 h Vorhersage. Der RMSE gibt größeren Fehlern ein größeres Gewicht als der MAE (Formel 2). So ist beim Vergleich zwischen RMSE und MAE (Abb. 8) zu erkennen, dass der RMSE immer größer als der MSE ist. Dies spricht für eine hohe Fehlervarianz.

Der Korrelationskoeffizient (Formel 4) zeigt den Zusammenhang zwischen Vorhersage und Beobachtung. Die Ergebnisse zeigen eine ähnliche Tendenz wie die des RMSE. Auch hier ist die Korrelation der 24 h Vorhersagen am besten, insbesondere die der TS Bautzen (siehe Abb. 8 rechts). Zwischen $0,2$ und $0,6$ befinden sich die meisten Korrelationskoeffizienten. Dies spricht für viele Ausreißer in der Vorhersage. Mit $0,03$ ist der Korrelationskoeffizient bei der 72 h Vorhersage für den SP Altenberg der schlechteste, hier ist kein Zusammenhang zwischen Beobachtung und Vorhersage zu erkennen. Die 72 h Vorhersage hat aber auch wie beim RMSE nicht immer den schlechtesten Korrelationskoeffizient einer Talsperre. Meist bildet die 60 h Vorhersage mit Werten zwischen

0,17 und 0,25 das Schlusslicht.

Verschobene Einzugsgebiete

Bei der Berechnung der Vorhersagegüte für die verschobenen Einzugsgebiete wird der Mittelwert der Niederschlagsvorhersage vom verschobenen Einzugsgebiet mit dem Mittelwert des beobachteten Niederschlags im tatsächlichen Einzugsgebiet verglichen. Die Einzugsgebiete werden hierfür jeweils 7 km nach Norden, Osten, Süden und Westen verschoben. Die Abbildung 9 zeigt einen Boxplot für die absolute Abweichung zwischen Vorhersage und Beobachtung für den SP Altenberg. In Redelstein (2017) sind die Box-plots für die weiteren Talsperreneinzugsgebiete dargestellt. Bei allen Talsperreneinzugsgebieten ist die Größe der Box sowie Mittelwert und Median ähnlich wie die bei dem nicht verschobenen Einzugsgebiet (dunkel Blau). Dabei spielt die Größe der Talsperreneinzugsgebiete keine Rolle. Es gibt also keine Verbesserung der Vorhersage durch eine Betrachtung von Niederschlagsvorhersagen in der näheren Umgebung.

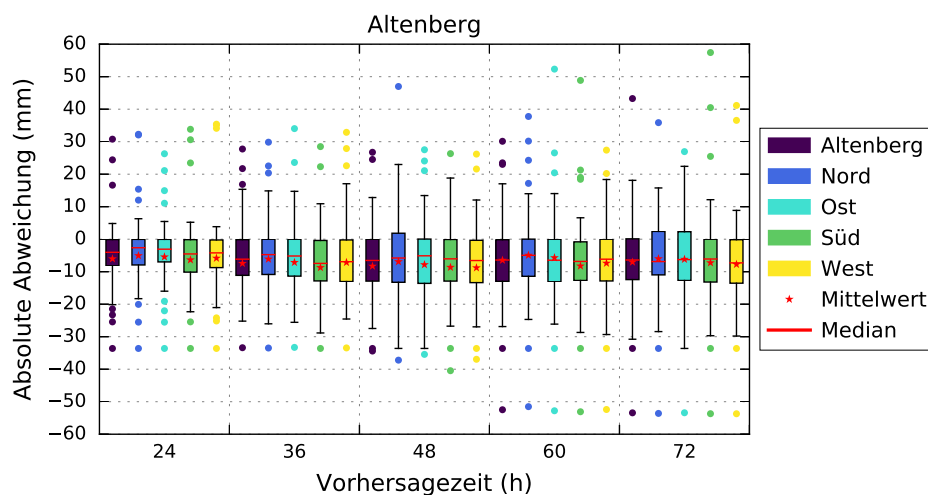


Abbildung 9: Absolute Abweichung zwischen Vorhersage und Beobachtung für die Einzugsgebiete des SP Altenberg und der verschobenen Positionen zu verschiedenen Vorhersagezeitpunkten

Großwettertypen

Beim Niederschlag spielt die Anströmrichtung eine wichtige Rolle, da es insbesondere im Gebirge zu unterschiedlichen Stau- und Abschirmungseffekten kommt. Für eine statistische Auswertung von unterschiedlichen Anströmrichtungen ist eine Einteilung in Großwetterlagen (GWL), welche nach immer wiederkehrenden Strömungsmustern erfolgt, sinnvoll. Die hier verwendete Klassifikation ist die nach Hess und Brezowsky (1952). Für statische Auswertungen sind die Häufigkeitsangaben seltener GWL nicht repräsentativ. Hierfür ist es sinnvoll, verwandte GWL in Großwettertypen (GWT) einzuteilen. In diesem Abschnitt wird die Güte der Niederschlagsvorhersage für die GWT Tief Mitteleuropa (TM), Nord und Süd bestimmt. Diese drei GWT sind an den Analysetagen am häufigsten vertreten. Insbesondere herrschen GWL mit zyklonalem Witterungscharakter an den Analysetagen vor und sorgen für das feuchte Klima.

Der meiste Niederschlag fiel im Mittel beim GWT TM. Insbesondere an den Talsperren, welche im Erzgebirge liegen, fiel mehr Niederschlag als an der TS Bautzen, welche

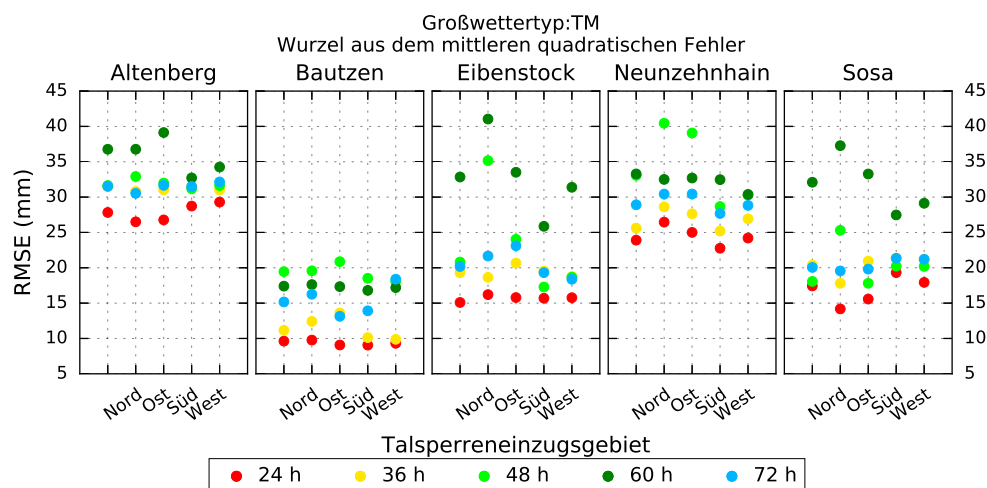


Abbildung 10: RMSE für den Großwettertyp Tief Mitteleuropa (TM) zu verschiedenen Vorhersagezeitpunkten und für die fünf untersuchten Einzugsgebiete sowie deren verschobenen Einzugsgebiete.

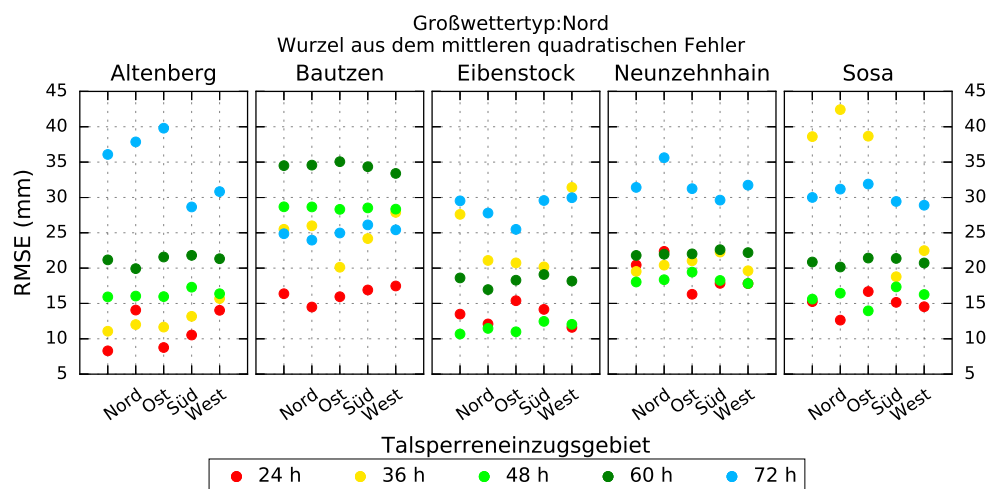


Abbildung 11: Wie Abb. 10 für den GWT Nord.

im Lausitzer Bergland liegt. Im Mittel wurde der Niederschlag meist unterschätzt. Der RMSE (Abb. 10) zeigt, dass die Differenz zwischen Vorhersage und Beobachtung bei allen 24 h Vorhersagen am geringsten ist. Dabei ist die Fehlervarianz an der TS Bautzen am geringsten. Dies könnte daraus resultieren, dass dort auch am wenigsten Niederschlag gefallen ist. Beim Vergleich vom RMSE an den verschobenen Einzugsgebieten ist keine einheitliche Verbesserung zu erkennen. Während am SP Altenberg und an der TS Sosa bei der 24 h Vorhersage die Vorhersage beim nach Norden verschobenen Einzugsgebiet etwas besser ist, ist bei der TS Neunzehnhain die Vorhersage beim nach Süden verschobenen Einzugsgebiet besser und bei der TS Bautzen und TS Eibenstock sind kaum Differenzen zwischen den unterschiedlichen Gebieten zu erkennen. Bei der TS Eibenstock und TS Sosa, welche nahe beieinander liegen, sind die Differenzen des RMSE zwischen den verschobenen Gebieten bei der 60 h Vorhersage am größten. Hier wäre bei einer Verschiebung des Einzugsgebiets nach Süden die Vorhersage am besten.

Beim GWT Nord gelangt durch die nördliche Anströmung feuchte Luft aus dem polaren Raum nach Europa und bei zyklonalen Lagen kommt es zu Stauniederschlägen im

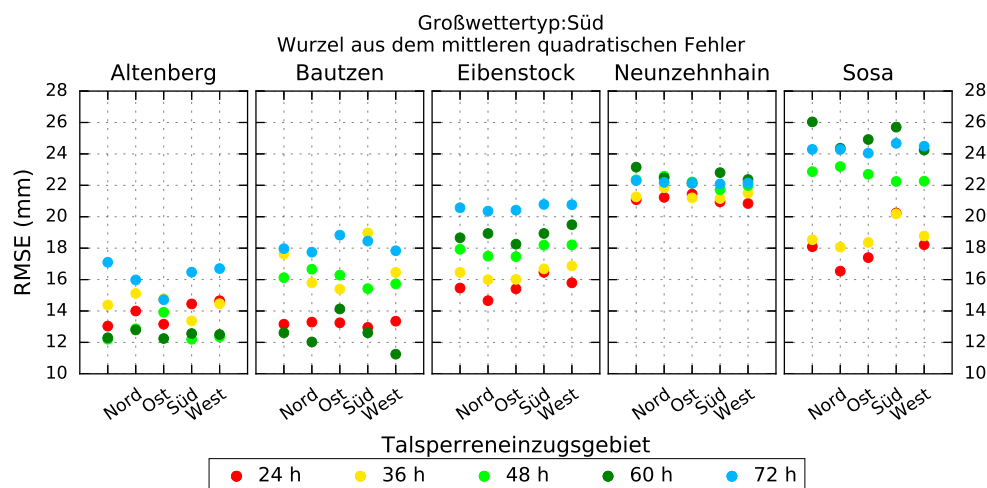


Abbildung 12: Wie Abb. 10 für den GWT Süd.

Luv der Gebirge. Auch bei diesem GWT wird die Niederschlagshöhe der Vorhersage in den meisten Fällen im Mittel unterschätzt. Die Werte des RMSE (Abb. 11) liegen auch im Größenbereich wie die des GWT TM. Jedoch ist der RMSE der 24 h Vorhersagen im Schnitt etwas geringer. Dies spricht für geringere Differenzen zwischen Vorhersage und Beobachtung bei der 24 h Vorhersage. Bei den Talsperren Eibenstock, Neunzehnhain und Sosa erzielt auch die 48 h Vorhersage ähnliche Ergebnisse wie die 24 h Vorhersage. Auch bei diesem GWT ist keine Verbesserung der Vorhersage bei Verschiebung des Einzugsgebietes zu erkennen.

Der GWT Süd sorgt bei einer zyklonalen Lage für eine wechselhafte Witterung mit Niederschlägen. Insbesondere Hitzegewitter werden durch aus Süden kommende subtropische Warmluft ausgelöst. Im Vergleich zu den anderen beiden GWT fällt beim GWT Süd im Mittel der wenigste Niederschlag. Der Niederschlag wird im Mittel zwischen $-3,4$ mm (SP Altenberg) und $-15,3$ mm (TS Eibenstock) unterschätzt. Der RMSE (Abb. 12) zeigt für den SP Altenberg und die TS Bautzen eine geringere Fehlervarianz als bei den anderen drei Einzugsgebieten. Hier ist insbesondere die 60 h Vorhersage gut. Die 24 h und 36 h Vorhersage ist bei den Talsperren Eibenstock, Neunzehnhain und Sosa am besten. Bei Verschiebung des Einzugsgebietes nach Norden verbessert sich die Vorhersage bei den Talsperren Eibenstock und Sosa leicht. Aber auch schon wie bei den anderen beiden GWT ist keine signifikante Verbesserung bei der Betrachtung des Niederschlags in der Umgebung zu erkennen.

5. Zusammenfassung

Der Niederschlag zählt zu den meteorologischen Größen, welche am schwierigsten vorherzusagen sind. Insbesondere wegen der großen räumlichen und zeitlichen Variabilität. Wie Verifikationen der Modelvorhersagen von COSMO-EU (siehe Abb. 1) zeigen, wurden in den letzten Jahren kaum Verbesserungen der Niederschlagsvorhersage erzielt. Für die Wasserbewirtschaftung ist es wichtig rechtzeitig und richtig gewarnt zu werden, um Schutzmaßnahmen einzuleiten. Jedoch werden zu unterschiedlichen Warnzeitpunkten oft unterschiedliche Niederschlagswerte prognostiziert. Es stellt sich nun die Frage, ob es einen Tag im Warnzeitraum gibt, welcher eine bessere Prognose liefert als die anderen. Zur Bestimmung eines optimalen Warnzeitpunktes werden die Prognosezeitpunkte

24, 36, 48, 60 und 72 Stunden vor dem Analysetag mit der Beobachtung verglichen. Es wurden Vorhersagen des COSMO-EU, dem regionalen Wettervorhersage-Modell des DWD, mit den radargestützten Analysedaten von RADOLAN verglichen. Dazu wurde der mittlere Niederschlag in den Einzugsgebieten des SP Altenberg, der TS Bautzen, der TS Eibenstock, der TS Neunzehnhain und der TS Sosa bestimmt und unterschiedliche Gütemaße berechnet. Ausgewertet wurden die 24 h-Niederschlagssummen von 57 Tagen in den Jahren 2006-2014.

Bei der Betrachtung der absoluten Abweichung zwischen Vorhersage und Beobachtung zeigt sich, dass in den meisten Fällen der Niederschlag unterschätzt wurde. Dabei haben die 24 h und 36 h Vorhersagen den kleinsten IQR und somit die geringste Streuung. Der SP Altenberg und die TS Bautzen haben im Vergleich zu den anderen drei Talsperren kleinere IQR. Bei der TS Bautzen könnte dies daran liegen, dass das Einzugsgebiet das größte ist. Der SP Altenberg hat das kleinste Einzugsgebiet. Hier haben zwar viele Vorhersagen eine geringe Differenz zur Beobachtung, aber wie der RMSE zeigt gibt es beim SP Altenberg hohe Ausreißer. Beim Vergleich von RMSE und MAE ist zu erkennen, dass der RMSE immer größer als der MAE ist. Dies spricht für eine hohe Fehlervarianz. Die Bewertung durch RMSE, MAE und Korrelationskoeffizient zeigt, dass die 24 h Vorhersage an allen Talsperren die beste Güte hat. Bei den anderen Prognosezeitpunkten gibt es keinen gemeinsamen Zeitpunkt mit der nächst besten Güte. Dieser ist bei jeder Talsperre unterschiedlich, jedoch nimmt die Güte nicht in allen Fällen bei Verlängerung der Prognosezeit ab. Dieses Ergebnis verdeutlicht, dass eine Niederschlagsprognose über den 24h Zeitraum hinaus beim derzeitigen Stand der Prognostik mit größeren Unsicherheiten verbunden ist.

Beim Niederschlag spielt auch eine räumliche Variabilität in der Vorhersage eine Rolle. Es wurde bei der Verifikation auch der mittlere Niederschlag der Vorhersage in den Talsperreneinzugsgebieten, welche um 7 km nach Norden, Osten, Süden und Westen verschoben wurden, mit dem mittleren Niederschlag der Beobachtung im tatsächlichen Einzugsgebiet verglichen. Bei diesem Vergleich konnte keine systematische Verschiebung der Niederschlagsfelder erkannt werden, unabhängig von der Größe des Talsperreneinzugsgebiets. Auch bei der Betrachtung von Großwettertypen (GWT), welche nach immer wiederkehrenden Strömungsmustern eingeteilt werden, konnte keine Verbesserung der Vorhersage durch Verschiebung der Einzugsgebiete festgestellt werden. Es wurden die GWT TM Nord und Süd betrachtet, diese waren am häufigsten bei den Analysetagen vertreten. An den Tagen mit dem GWT TM und Nord ist mit mehr Niederschlag im Mittel zu rechnen, als an den Tagen mit dem GWT Süd. Der GWT Süd ist insbesondere bekannt für Hitzegewitter. Hier ist also mit kleinräumigen hohen Niederschlagswerten zu rechnen.

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Forschungsbericht 2016

Bearbeitete Forschungsprojekte

Institut für Meteorologie

Direktor Prof. Dr. M. Wendisch

Allgemeine Meteorologie

AG Atmosphärische Strahlung

Flugzeuggetragene und bodengebundene Messungen von Albedo, BRDF und Schneeeigenschaften in der Antarktis und deren Kopplung zur Verbesserung prognostischer Schneemodelle

Coupling of airborne and in situ ground based measurements of surface albedo, BRDF and snow properties in Antarctica to improve prognostic snow models

Schlagworte: Antarktis, Schnee, Albedo, flugzeuggetragene Messungen, atmosphärische Strahlung

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Projektbeginn: 2013

Projektende: 2017

Beschreibung

Im Rahmen des Projekts werden die zeitliche und räumliche Variabilität von Oberflächenalbedo, bidirektionaler Reflektivität BRDF und Schneeeigenschaften in der Antarktis untersucht. Das Hauptziel dieses Vorhabens ist eine Verbesserung von prognostischen Schneemodellen und von Parametrisierungen der Schneealbedo, wie sie derzeit in regionalen und globalen Klimamodellen verwendet werden. Diese Parametrisierungen werden in Abhängigkeit von Schneekorngröße, Schneeoberflächenrauigkeit und atmosphärischen Parametern formuliert. Um dieses Ziel zu erreichen, werden bodengebundene in situ Messungen (zeitliche Variabilität) und flugzeuggetragene Fernerkundungsmessungen (räumliche Variabilität) miteinander kombiniert. Die vom Flugzeug erhobenen Daten umfassen die spektrale Bodenalbedo, BRDF, Bodenrauigkeit und Schneekorngröße. Die dazu benötigten Fernerkundungsverfahren werden im Rahmen des Projekts verbessert bzw. entwickelt. Die gleichen Größen werden auf dem antarktischen Plateau mittels bodengebundener Messungen an der Kohnen Station erhoben werden. Die bodengebundenen Daten decken dabei die zeitliche Variabilität von Schnee- und Atmosphäreneigenschaften ab, was es ermöglicht, prognostische Schneemodelle zu validieren und zu verbessern, die an ein Strahlungstransfermodell angekoppelt sind. Durch die Einbindung von Messdaten in die Modelle und einem anschließenden Vergleich zwischen simulierter und gemessener Schneealbedo sowie durch Sensitivitätsstudien werden Parametrisierungen der Schneealbedo, wie sie in Strahlungs- und Klimamodellen verwendet werden, validiert und verbessert. Diese Erkenntnisse werden dazu dienen, Unsicherheiten in Vorhersagen der zukünftigen Klimaänderung in der Antarktis zu reduzieren.

Description

We propose to investigate the temporal and spatial variability of surface albedo, bidirectional reflectivity BRDF and snow properties in Antarctica. The overall goal of the project is to improve prognostic snow models and parameterizations of snow albedo used in regional and global climate models. The parameterizations will be formulated in dependence on snow grain size, snow surface roughness and atmospheric parameters. To achieve this goal we will couple ground based in situ (temporal variability) and airborne remote sensing measurements (spatial variability). Airborne data will include spectral surface albedo, BRDF, surface roughness and snow grain size. Corresponding remote sensing retrieval algorithms will be improved and developed in the project. The same quantities will be measured in situ on the Antarctic plateau by ground based instruments installed at Kohnen Station. The ground based measurements covering the temporal variability of snow and atmospheric properties will allow validating and improving prognostic snow models coupled to a radiative transfer code. By implementing measurement data in the models and comparing simulated and measured snow albedo and by sensitivity studies, snow albedo parameterizations for use in radiative transfer and climate models will be validated and improved. This will reduce uncertainties in predicting future climate change in Antarctica.

Weiterführung: ja

Mittelgeber: Uni Leipzig, DFG WE 1900/29-1

Allgemeine Meteorologie**AG Atmosphärische Strahlung****Räumlich inhomogene Zirren: Einfluss auf die atmosphärische Strahlung**

Spatially Inhomogeneous Cirrus: Influence on Atmospheric Radiation

Schlagworte: Zirren, atmosphärische Strahlung, flugzeuggetragene Fernerkundung

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Projektmitarbeiter: [F. Finger \(f.finger@uni-leipzig.de\)](mailto:f.finger@uni-leipzig.de)

Projektbeginn: 2010

Projektende: 2016

Beschreibung

Die Strahlungseffekte durch inhomogene Zirren werden mit Hilfe einer Kombination von Flugzeuggetragenen Messungen (Strahlung und mikrophysikalische Eigenschaften), einem 3D Strahlungsmodell und einem dynamischen wolkenauflösenden Zirrus-Modell untersucht. Ein instrumentiertes Flugzeug (Lear-Jet) misst die spektrale Strahlung über Zirren im Rahmen einer Feldmesskampagne. Daraus werden die mikrophysikalischen Felder der Zirren abgeleitet. Diese werden verglichen mit gleichzeitigen in situ Messungen, welche mit einer Schleppsonde gesammelt werden. Diese wird gleichzeitig vom Flugzeug durch die Zirren gezogen. Parallel dazu werden die örtlichen Inhomogenitäten der Zirren Felder mit Hilfe einer abbildenden digitalen CCD Kamera beobachtet. Zusätzlich wird ein wolkenauflösendes Zirren-Modell zur Berechnung der mikrophysikalischen Zirren-Felder benutzt. Die aus den kombinierten in situ und indirekten Messungen abgeleiteten sowie modellierten mikrophysikalischen Zirren-Felder werden als

Eingabe für ein 3D Strahlungsmodell benutzt, um die 3D-Effekte inhomogener Zirren zu untersuchen.

Description

The radiative effects of inhomogeneous cirrus fields will be studied by a combination of airborne measurements (radiation and microphysical properties), a three-dimensional (3D) radiative transfer model and a dynamic cloud-resolving cirrus model. An instrumented aircraft (Lear-Jet) will sample spectral radiation above cirrus within a field campaign. From these data the microphysical cirrus properties will be retrieved and compared to simultaneous in situ measurements collected with an aircraft-towed sensor shuttle which is mounted below the Lear-Jet. In close collocation the spatial inhomogeneities of the sampled cirrus fields will be observed by an imaging digital CCD camera. In parallel, a cloud-resolving model will simulate microphysical cirrus fields. The combined in situ measured and retrieved microphysical cirrus fields as well as the simulated microphysical cirrus fields will be used as input to a 3D radiative transfer model to investigate the radiative effects of spatially inhomogeneous cirrus.

Weiterführung: nein

Mittelgeber: DFG WE 1900/19-1

Allgemeine Meteorologie AG Atmosphärische Strahlung

HALO Koordination von "Aerosol, Cloud, Precipitation, and Radiation Interactions and Dynamics of Extra-Tropical Convective Cloud Systems" (ACRIDICON)

HALO coordination of ACRIDICON

**Schlagworte: konvektive Wolken, flugzeuggetragene atmosphärische
Beobachtungen, flugzeuggetragene Fernerkundung**

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Projektmitarbeiter: D. Rosenow (d.rosenow@uni-leipzig.de)

Projektbeginn: 2010

Projektende: 2016

Beschreibung (Deutsch- Pflicht; <2000 Zeichen)

Konvektive Wolken können erheblichen ökonomischen Schaden verursachen aufgrund von starken Windböen, heftigen Schauern und Niederschlägen, welche teilweise mit Hagel, Graupel, und Gewittern verbunden sein können. Die Dynamik und Heftigkeit dieser ausgeprägten Wettererscheinungen werden bestimmt durch mikrophysikalische Prozesse bei der Wolken- und Niederschlagsbildung, welche beeinflusst werden können durch Aerosolpartikel und Wechselwirkungen mit atmosphärischer Strahlung. Weiterhin werden durch konvektive Wolken Spurengase und Aerosolpartikel durch vertikalen Transport sowie Ein- und Ausmischen der Wolke mit der Umgebungsluft prozessiert und umverteilt. Um diese Wechselwirkungen zwischen Spurengasen, Aerosolpartikeln und der Wolken- und Niederschlagsbildung sowie atmosphärischer Strahlung in außertropischen,

konvektiven Wolken zu untersuchen, wurde die HALO Demo-Mission "Aerosol, Wolken, Niederschlag und Strahlungswechselwirkungen sowie Dynamik von außertropischen, konvektiven Wolkensystemen (ACRIDICON)" vorgeschlagen. ACRIDICON trägt zu zwei Schwerpunkten des SPP 1294 bei: „Wolken und Niederschlag“ und „Transport und Dynamik in der Troposphäre und der unteren Stratosphäre“. Der vorliegende Antrag beinhaltet hauptsächlich die Organisation und das Management von ACRIDICON sowie teilweise einen Beitrag zur Analyse und Auswertung der Strahlungsmessungen, welche bei dieser HALO Demo-Mission gesammelt werden.

Weiterführung: nein

Mittelgeber: DFG WE 1900/22-1

Allgemeine Meteorologie
AG Atmosphärische Strahlung

Koordination des Schwerpunktprogramms 1294 "Atmosphären- und Erdsystemforschung mit dem Forschungsflugzeug HALO (High Altitude and Long Range Research Aircraft)"
HALO coordination project

Schlagnworte: flugzeuggetragene Forschung

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Professor Dr. Joachim Curtius, Goethe-Universität Frankfurt am Main, Institut für Atmosphäre und Umwelt

Dr.-Ing. Mirko Scheinert, Technische Universität Dresden, Institut für Planetare Geodäsie

Projektmitarbeiter: Gunda Nitzsche, Jörg Schmidt

Projektbeginn: 2010

Projektende: 2019

Beschreibung

Das Projekt dient vornehmlich der Kooperation und der Kommunikation unter den Einzelprojekten des Schwerpunktprogramms. Im Rahmen des Projekts werden ein jährliches Statusseminar sowie jährliche Themen-Workshops geplant und durchgeführt. Die drei Koordinatoren vertreten den SPP gegenüber der DFG, dem Wissenschaftlichen Lenkungsausschuss von HALO (WLA), dem HALO Projektteam des Deutschen Zentrums für Luft- und Raumfahrt (DLR) und nach außen. Das Koordinatoren-Team betreibt Maßnahmen zur Nachwuchs- und Gleichstellungsförderung. Zentrale Initiativen wie gemeinsame Sammelveröffentlichungen in einem Sonderband oder die Durchführung von Sitzungen zu Themenschwerpunkten ("special sessions") bei internationalen Konferenzen sowie der Internetauftritt des SPP werden im Rahmen dieses Projekts koordiniert und durchgeführt.

Description

funds for the central coordination of SPP 1294 HALO are requested within this proposal. The project serves most of all the promotion of cooperation and communication among

the individual scientific projects of the SPP. An annual status seminar as well as topical workshops are organized and conducted within this project. The coordinators represent the SPP via the DFG, the scientific steering committee of HALO (WLA), the HALO project team of the German Aerospace Center (DLR) and the public. The funds for measures to promote gender equality are managed and measures for training of young researchers are coordinated. Within the project special sessions at international conferences or publication of special issues are initiated. An SPP web page is set up and maintained. To support the coordinators in conducting these tasks, staffing for a half-time position of a scientific administrator is applied for.

Weiterführung: ja

Mittelgeber: DFG WE 1900/24-1

Allgemeine Meteorologie
AG Atmosphärische Strahlung

EUFAR2 - European Facility for Airborne Research in Environmental and Geosciences

Schlagworte: flugzeuggetragene Forschung

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Projektmitarbeiter:

Projektbeginn: 2014

Projektende: 2018

Beschreibung (Deutsch- Pflicht; <2000 Zeichen)

Im Rahmen dieses Projektes werden die Expert Working Groups koordiniert. Workshops werden organisiert, und ein Buch wurde geschrieben:

Wendisch, M., and J.-L. Brenguier (Eds.), 2013: Airborne Measurements for Environmental Research: Methods and Instruments. Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany. ISBN: 978-3-527-40996-9. 655 pp., doi:10.1002/9783527653218.

Description

Within the project Expert Working Groups were coordinated. Workshops were organized with the aim to publish a book reviewing airborne atmospheric measurement methods.

Weiterführung: ja

Mittelgeber: EU

Allgemeine Meteorologie
AG Atmosphärische Strahlung

Ein Monte Carlo Modell zur Berechnung spektraler atmosphärischer Strahlungsgrößen unter Berücksichtigung von Polarisationsprozessen
A Monte Carlo Model to calculate atmospheric radiation considering polarization

Schlagworte: Strahlungstransfermodellierung, Polarisation

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)
A. Macke (macke@tropos.de)

Projektmitarbeiter: Vasilis Barlakas

Projektbeginn: 2012

Projektende: 2016

Beschreibung

Hierbei wird ein neues Strahlungsübertragungsmodell aufgebaut, welches explizit Polarisationseffekte berücksichtigt. Das Modell soll nach Fertigstellung mit ähnlichen Modellen verglichen und durch entsprechende Messungen validiert werden.

Weiterführung: nein

Mittelgeber: Leibniz-Doktorandenschule

Allgemeine Meteorologie
AG Atmosphärische Strahlung

Flugzeuggetragene spektrale solare Strahlungsmessungen während ACRIDICON zur Untersuchung hochreichender Konvektion und Validierung satellitengetragener Fernerkundungssysteme.

Airborne spectral solar radiation measurements during ACRIDICON to investigate deep convection and validate space borne remote sensing.

Schlagworte: flugzeuggetragene Fernerkundung, Satellitenvalidierung, hochreichende Konvektion.

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Projektmitarbeiter: Trismono Candra Krisna

Projektbeginn: 2014

Projektende: 2018

Beschreibung

Innerhalb des ACRIDICON Projektes wurden flugzeuggetragene solare Strahlungsmessungen an Bord des Forschungsflugzeuges HALO durchgeführt. Die Messungen fanden in Brasilien im tropischen Regenwald statt und hatten das Ziel hochreichende konvektive Bewölkung zu untersuchen. Die spektralen Messungen sollen für zwei Ziele verwendet werden. In einem ersten Schritt sollen kalibrierte Strahldichtemessungen des SMART-Albedometers genutzt werden, um die Genauigkeit von Satellitenmessungen zu quantifizieren. Im zweiten Schritt werden die Daten verwendet, um Wolkeneigenschaften abzuleiten. Ein Vergleich der Ergebnisse mit den

vom Satelliten abgeleiteten Wolkenparametern soll dazu dienen, die Unsicherheiten in den Satellitenmessungen zu bestimmen. Die Möglichkeiten zur Verbesserung der Ableitungsalgorithmen durch die Nutzung der vollen spektralen Information soll untersucht werden. Die abgeleiteten Wolkenparameter sollen über statistische Verfahren genutzt werden, um den Strahlungseinfluss der Wolken im Verlaufe ihres Lebenszyklus zu verfolgen.

Weiterführung: ja

Mittelgeber: DAAD

Allgemeine Meteorologie AG Atmosphärische Strahlung

Einfluss der Eisphase auf den Strahlungsantrieb von Wolken: Messungen und Representation in numerischen Wettervorhersagemodellen

Influence of ice phase on radiative forcing of clouds: Observations and representation in numerical weather prediction models

Schlagworte: flugzeuggetragene Messungen, Wolken, Strahlungsantrieb, Eisphase

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Projektmitarbeiter: Kevin Wolf

Projektbeginn: 2016

Projektende: 2019

Beschreibung

Methoden der flugzeuggetragenen passiven Fernerkundung mit Hilfe spektraler, solarer und reflektierter Strahldichten werden zur Ableitung der thermodynamischen Phase, der optischen Dicke und des Partikeleffektivradius von Wolken während der HALO Missionen NARVAL-II und NAWDEX angewendet. Insbesondere werden die horizontalen und vertikalen Verteilungen der thermodynamischen Phasen in unterschiedlichen Wolkentypen untersucht. Die Kombination mit anderen HALO-Fernerkundungsinstrumenten einschließlich Radar und Mikrowellensensoren ist geplant. Gleichzeitige Messungen der Wolkenalbedo werden durchgeführt und zur Analyse der Abhängigkeit des Strahlungsantriebs von Wolken-makrophysikalischen und mikrophysikalischen Eigenschaften verwendet. Auf der Basis von breitbandigen und spektralen Strahlungsgrößen dient die gemessene spektrale Wolkenalbedo zur Bewertung von Ergebnissen des ECMWF Integrated Forecast System (IFS). In mehreren Schritten werden 1D und 3D Strahlungstransfermodelle zusammen mit Beobachtungen verwendet, um die Unsicherheiten in der ECMWF-Vorhersage zu identifizieren. Unsicherheiten in Bezug auf das Strahlungsschema und die simulierten Wolkeneigenschaften werden separiert.

Description

The airborne passive solar remote sensing of spectral reflected radiance will be applied to derive cloud thermodynamic phase, optical thickness, and particle effective radius during the HALO Missions NARVAL-II and NAWDEX. In particular, cloud thermodynamic phase and its horizontal and vertical distribution in different cloud types will be investigated. Combination with other remote sensing instruments of HALO including active radar and passive microwave sensors is planned. Simultaneous measurements of cloud top albedo will be derived and used to analyse the dependence of cloud radiative forcing on cloud macrophysical and microphysical properties. Measured spectral cloud top albedo will be employed to evaluate the ECMWF Integrated Forecast System (IFS) on the basis of broadband and spectral radiative quantities. In different steps, 1D and 3D radiative transfer models will be utilized in combination with the observations to identify and quantify uncertainties in IFS forecasts and analysis fields. Uncertainties due to the radiations scheme and simulated cloud properties will be separated.

Weiterführung: ja

Mittelgeber: DFG, SPP 1294

Allgemeine Meteorologie AG Atmosphärische Strahlung

Hochaufgelöste Messungen von Turbulenz, Wolkenmikrophysik, und Strahlungsabkühlungsraten in der Einmischungszwischenschicht von marinen Stratocumulus-Wolken.

High resolved measurements of turbulence, cloud microphysical properties and radiative cooling rates in the entrainment zone of marine strato cumulus.

Schlagworte: hubschraubergetragene Messungen, Stratocumulus, Energiebilanz, Strahlungsabkühlung.

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Dr. Holger Siebert, Leibniz-Institut für Troposphärenforschung e.V. (TROPOS)

Projektmitarbeiter: Felix Laueremann

Projektbeginn: 2015

Projektende: 2018

Beschreibung

Obwohl bisher schon viele Fortschritte im allgemeinen Verständnis von Mischungs- und Strahlungsprozessen in Stratocumulus (Sc) gemacht wurden, verursachen wolkenbedingte Rückkopplungseffekte von Sc Wolken erhebliche Unsicherheiten in Klimaprojektionen. Diese Probleme werden teilweise verursacht durch eine unrealistische Beschreibung der feinskaligen Mischungsprozesse, die hauptsächlich am Oberrand der Wolken stattfinden. Die Strahlungs-Abkühlung am Wolkenoberrand ist eng mit dynamischen und turbulenten Wolkenprozessen verbunden. Abkühlung am Oberrand der Wolken verursacht ein Absinken. Diese Vertikalbewegungen bedingen Turbulenzen wodurch trockene und warme Umgebungsluft in die Wolke eingemischt wird, so dass sich die damit verbundene Verdunstungsabkühlung erhöht. Zur Untersuchung dieser Vorgänge schlagen wir folgende wesentlichen Projektziele vor: (a) die Verbesserung des

Verständnisses der feinskaligen Struktur der Einmischungsinversionszwischen-schicht (entrainment interface layer, EIL), (b) die Quantifizierung des Einflusses der EIL auf die Einmischung trockener und warmer Umgebungsluft in Sc Wolken, (c) die Bewertung der Rolle von Strahlungserwärmungs- und Abkühlungsraten bei Einmischungsprozessen in Sc Wolken. Um diese Ziele erreichen zu können, werden Beobachtungen mit den zwei kombinierten, Hubschraubergetragenen Messsystemen ACTOS (Airborne Cloud Turbulence Observation System) und SMART--HELIOS (Spectral Modular Airborne Radiation measurement sysTem) vorgeschlagen. Die Messungen finden auf den Azoren statt. Beide Messsysteme werden durch einen langsam fliegenden Hubschrauber getragen. Das kombinierte Messsysteme-Paket ermöglicht in-situ Messungen von dynamischen, thermodynamischen, Wolken-mikrophysikalischen und Strahlungsparametern mit hoher örtlicher Auflösung (überwiegend im cm-Bereich). Kein anderes Messsystem weltweit erreicht diese hohe Auflösung, die allerdings unabdingbar ist für die Erreichung der Projektziele ist. Dies trifft insbesondere auf die Vermessung der Vorgänge in der EIL zu, welche meist eine vertikale Dicke von nur 10 m aufweist.

Weiterführung: ja

Mittelgeber: DFG, WE 1900/33-1

Allgemeine Meteorologie
AG Atmosphärische Strahlung

STRATOCLIM - Stratospheric and upper tropospheric processes for better climate predictions

Schlagworte: flugzeuggetragene Forschung

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Projektmitarbeiter:

Projektbeginn: 2013

Projektende: 2018

Beschreibung (Deutsch- Pflicht; <2000 Zeichen)

STRATOCLIM wird verlässlichere Vorhersagen von Klimaänderungen und stratosphärischer Ozonverteilung erreichen, durch eine Verbesserung des Systemverständnisses von wichtigen Prozessen in der oberen Troposphäre und unteren Stratosphäre. Unsere Gruppe ist mit Modellberechnungen zur Bestimmung von Erwärmungs- und Abkühlungsraten in der Tropopausenregion beteiligt.

Description

StratoClim will produce more reliable projections of climate change and stratospheric ozone by a better understanding and improved representation of key processes in the Upper Troposphere and Stratosphere (UTS). This will be achieved by an integrated approach bridging observations from dedicated field activities, process modelling on all scales, and global modelling with a suite of chemistry climate models (CCMs) and Earth system models (ESMs). At present, complex interactions and feedbacks are inadequately represented in global models with respect to natural and anthropogenic emissions of greenhouse gases,

aerosol precursors and other important trace gases, the atmospheric dynamics affecting transport into and through the UTS, and chemical and microphysical processes governing the chemistry and the radiative properties of the UTS. StratoClim will (a) improve the understanding of the microphysical, chemical and dynamical processes that determine the composition of the UTS, such as the formation, loss and redistribution of aerosol, ozone and water vapour, and how these processes will be affected by climate change; (b) implement these processes and fully include the interactive feedback from UTS ozone and aerosol on surface climate in CCMs and ESMs. Through StratoClim new measurements will be obtained in key regions:

- (1) in a tropical campaign with a high altitude research aircraft carrying an innovative and comprehensive payload,
- (2) by a new tropical station for unprecedented ground and sonde measurements, and
- (3) through newly developed satellite data products.

The improved climate models will be used to make more robust and accurate predictions of surface climate and stratospheric ozone, both with a view to the protection of life on Earth. Socioeconomic implications will be assessed and policy relevant information will be communicated to policy makers and the public through a dedicated office for communication, stakeholder contact and international co-operation.

Weiterführung: ja

Mittelgeber: EU

Allgemeine Meteorologie
AG Atmosphärische Strahlung

SFB/Transregio 172 „Arktische Verstärkung“
Zentrale Dienstleistungen, Verwaltung und Koordinierung (Z01)
Central services, administration and coordination (Z01)

Schlagworte: Arktis.

Projektleiter:

M. Wendisch (m.wendisch@uni-leipzig.de)

Prof. Dr. Susanne Crewell, Universität zu Köln, Institut für Geophysik und Meteorologie

Prof. Dr. Justus Notholt, Universität Bremen, Institut für Umweltphysik

Projektmitarbeiter: Dr. Marlen Brückner

Projektbeginn: 2016

Projektende: 2019

Beschreibung (Deutsch- Pflicht; <2000 Zeichen)

Innerhalb des TR 172 Antrages werden Mittel für die zentrale Koordinierung beantragt. Dieses Teilprojekt dient dazu, die Kooperationen und Kommunikation im Verbund unter den einzelnen wissenschaftlichen Projekten und Clustern zu fördern. Aus diesem Grund werden monatliche Videokonferenzen, halbjährliche Meetings, jährliche wissenschaftliche

Konferenzen, als auch spezielle Workshops organisiert und durchgeführt. Die Mittel für Gleichstellungsmaßnahmen werden dazu verwendet um junge Wissenschaftler/innen in Zusammenarbeit mit lokalen Graduiertenschulen zu trainieren. Die internationale Präsenz des TR 172 wird etabliert. Eine Internetseite wird erstellt und implementiert. Die logistische Organisation und wissenschaftliche Planung von intensiven Messkampagnen innerhalb des TR 172 werden durch das Projekt Z01 unterstützt. Öffentlichkeitsarbeit zwischen den verschiedenen Partnern wird organisiert und koordiniert.

Description

Funds for the central coordination of TR 172 are requested within this proposal. The project serves the promotion of cooperation and communication among the individual scientific projects and clusters. Monthly video conferences, biannual general assemblies, annual scientific conferences, as well as topical workshops will be organized and conducted. The funds for measures to promote gender equality are managed the training of young researchers is coordinated, in collaboration with local graduate schools. The international visibility of TR 172 will be fostered. A web page will be set up and maintained. The logistic organization and scientific planning of the extensive observational campaigns within TR 172 will be supported by project Z01. Public outreach activities will be organized and coordinated between the different partners.

Weiterführung: ja

Mittelgeber: DFG, TRR 172

Allgemeine Meteorologie AG Atmosphärische Strahlung

SFB/Transregio 172 „Arktische Verstärkung“ Fesselballongetragene Messungen des Energiebudgets in der wolkenbedeckten Zentralarktis (A02)

Tethered balloon-borne energy budget measurements in the cloudy central Arctic (A02)

Schlagworte: Arktis, ballongetragene Messungen, Energiebilanz, Strahlungsabkühlung.

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Dr. Holger Siebert, Leibniz-Institut für Troposphärenforschung e.V. (TROPOS)

Projektmitarbeiter: Matthias Gottschalk

Projektbeginn: 2016

Projektende: 2019

Beschreibung

Während der Forschungsfahrt von FS Polarstern im Frühsommer (Mai bis Juni) 2017 werden Fesselballon-getragene Messungen von einer Eisschollenstation analysiert. Atmosphärische Vertikalprofile (bis zu einem Kilometer Höhe) der turbulenten Energieflüsse (sensible und latente Wärme), Strahlungsenergieflüsse und turbulente Impulserhaltung werden gemessen. Die Beobachtungen werden den Einfluss von

makrophysikalischen (Wolkenbasishöhe, Temperatur, geometrische Dicke, Wolkenbedeckung) und mikrophysikalischen (effektiver Tropfenradius) Eigenschaften von arktischen tiefen Wolken auf (i) die Profile der Flüsse, (ii) den entsprechenden Strahlungsantrieb und (iii) die damit verbundenen netto Erwärmung/Abkühlung der bodennahen Lufttemperatur untersuchen.

Description

Tethered balloon-borne measurements from an ice-floe camp during the cruise of RV Polarstern in early summer (May to June) 2017 will be analysed. Atmospheric vertical profiles (up to one-kilometer altitude) of turbulent energy fluxes (sensible and latent heat), radiative energy fluxes, and turbulent fluxes of momentum will be measured. The observations will investigate the influence of macrophysical (cloud base height and temperature and geometric thickness, cloud cover) and microphysical (effective radius) properties of Arctic low-level clouds on (i) the profiles of fluxes, (ii) the respective radiative forcing, and (iii) the related net warming/cooling of the near-surface air temperature.

Weiterführung: ja

Mittelgeber: DFG, TRR 172

Allgemeine Meteorologie AG Atmosphärische Strahlung

SFB/Transregio 172 „Arktische Verstärkung“

Einfluss von tiefen Wolken auf die arktische atmosphärische Grenzschichtturbulenz und -Strahlung (A03)

Impact of low-level clouds on Arctic atmospheric boundary layer turbulence and radiation (A03)

Schlagworte: Arktis, flugzeuggetragene Messungen, Energiebilanz, Strahlungsabkühlung.

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Dr. Christof Lüpkes, Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung

Projektmitarbeiter: Johannes Stapf

Projektbeginn: 2016

Projektende: 2019

Beschreibung (Deutsch- Pflicht; <2000 Zeichen)

Vertikalprofile von Strahlungsenergie- und Turbulenzenergieflüssen sowie Impulserhaltung werden untersucht durch (i) Verwendung vorheriger Schiffs- und Flugzeugkampagnen und (ii) durch die Analyse neuer Messungen von zwei geplanten Flugzeugkampagnen über dem Arktischen Ozean. Die beiden neuen Kampagnen beziehen die AWI Forschungsflugzeuge Polar 5 & 6 ein, um die vertikalen Flussprofile als Funktion von Wolken- und Meereisbedeckung unter verschiedenen synoptischen Bedingungen zu messen. Die Flugzeugbeobachtungen sind für Mai/Juni 2017 und März

2019 geplant und decken somit Zeiträume starker (Spätwinter) und schwacher (Frühsommer) arktischer Verstärkung ab.

Description

Tethered balloon-borne measurements from an ice-floe camp during the cruise of RV Polarstern in early summer (May to June) 2017 will be analysed. Atmospheric vertical profiles (up to one-kilometer altitude) of turbulent energy fluxes (sensible and latent heat), radiative energy fluxes, and turbulent fluxes of momentum will be measured. The observations will investigate the influence of macrophysical (cloud base height and temperature and geometric thickness, cloud cover) and microphysical (effective radius) properties of Arctic low-level clouds on (i) the profiles of fluxes, (ii) the respective radiative forcing, and (iii) the related net warming/cooling of the near-surface air temperature.

Weiterführung: ja

Mittelgeber: DFG, TRR 172

Allgemeine Meteorologie AG Atmosphärische Strahlung

SFB/Transregio 172 „Arktische Verstärkung“

Einfluss von Bodenheterogenität auf den Strahlungsantrieb und Ableitung von Aerosol- und Wolkeneigenschaften in der Arktis (C01)

Influence of surface heterogeneity on radiative forcing and retrieval of aerosol and cloud properties in the Arctic (C01)

Schlagworte: Arktis, flugzeuggetragene Messungen, Eis- und Schneeralbedo, BRDF

Projektleiter: M. Wendisch (m.wendisch@uni-leipzig.de)

Dr. Georg Heygster, Universität Bremen, Institut für Umweltphysik (IUP)

Projektmitarbeiter: Dr. Evelyn Jäkel

Projektbeginn: 2016

Projektende: 2019

Beschreibung

Für die Arktis ist ein diskontinuierlicher Albedo Unterschied zwischen hoch reflektierenden Schnee/Eisoberflächen und meist stark absorbierenden Meeresoberflächen typisch. In diesem Teilprojekt wird quantifiziert, inwiefern diese Heterogenität der Reflektionseigenschaften der Erdoberfläche (i) den Strahlungsantrieb von Wolken (Erwärmung/Abkühlung) und (ii) die Fernerkundungsprodukte von Wolken und Aerosolpartikeln beeinflussen. Aus diesem Grund werden flugzeuggetragene Messungen und Strahlungstransfermodellierungen vorgeschlagen.

Description

In the Arctic, a discontinuous albedo contrast between highly reflecting snow/ice and mostly absorbing sea surfaces is typical. In this project it will be quantified how these affect (i) the radiative forcing of clouds (warming/cooling), and (ii) the remote sensing

products of clouds and aerosol particles. For this purpose, airborne measurements and Radiative Transfer modelling studies are proposed.

Weiterführung: ja

Mittelgeber: DFG, TRR 172

Allgemeine Meteorologie
AG Atmosphärische Strahlung

SFB/Transregio 172 „Arktische Verstärkung“

Charakterisierung von arktischen Mischphasenwolken durch flugzeuggetragene in-situ Messungen und Fernerkundung (B03)

Characterization of Arctic mixed-phase clouds by airborne in-situ measurements and remote sensing (B03)

Schlagworte: Arktis, flugzeuggetragene Messungen, Mischphasenwolken.

Projektleiter: Dr. André Ehrlich (a.ehrlich@uni-leipzig.de)

Professor Dr. Susanne Crewell, Universität zu Köln, Institut für Geophysik und Meteorologie

Professor Dr. Andreas Macke, Leibniz-Institut für Troposphärenforschung e.V. (TROPOS)

Projektmitarbeiter: Elena Ruiz

Projektbeginn: 2016

Projektende: 2019

Beschreibung

Dieses Teilprojekt schlägt neuartige Beobachtungsstrategien für arktische Wolken vor durch Kombination von flugzeuggetragenen Fernerkundungsmethoden mit in-situ mikrophysikalischen Messungen von Wolken- und Aerosoleigenschaften. Unter der Verwendung von zwei nebeneinanderfliegenden Flugzeugen (Polar 5 & 6) wird es möglich sein die mikrophysikalischen Partikeleigenschaften innerhalb von Wolken gleichzeitig durch in-situ Sensoren zu messen. Ebenfalls werden die vertikale Säule und deren Strahlungseinfluss mittels Fernerkundungsmessungen oberhalb von Wolken gemessen. Beide Kampagnen werden im Sommer 2017 (ACLOUD, Svalbard) und Frühling 2019 (AFLUX, Svalbard und Grönland) durchgeführt, um typische arktische Grenzschichtwolken als Teil der hauptsächlichen experimentellen Aktivitäten innerhalb des TR 172 zu untersuchen.

Description

The project proposes novel observation strategies for Arctic clouds by combining airborne remote sensing with in-situ microphysical measurements of cloud and aerosol properties. Using two identical collocated aircraft, Polar 5 and 6, it will be possible to simultaneously measure the microphysical particle characteristics within clouds by in-situ sensors and probe the vertical column and radiative impact from remote sensing measurements above clouds. Two campaigns will be performed in summer 2017 (ACLOUD, Svalbard) and spring 2019 (AFLUX, Svalbard and Greenland) to investigate typical Arctic boundary layer clouds as part of the major experimental activities of the TR 172.

Weiterführung: ja

Mittelgeber: DFG, TRR 172

Allgemeine Meteorologie
AG Atmosphärische Strahlung

SFB/Transregio 172 „Arktische Verstärkung“
Wechselwirkungen von Schnee auf Meereis mit atmosphärischen Bestandteilen
inklusive Ruß (C02)

Interactions of snow on sea ice with atmospheric constituents including black carbon (C02)

Schlagworte: Arktis, flugzeuggetragene Messungen, Black Carbon, Eis und Schneeralbedo

Projektleiter: Dr. André Ehrlich (a.ehrlich@uni-leipzig.de)

Dr. Rüdiger Gerdes, Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung

Projektmitarbeiter: Tobias Donth

Projektbeginn: 2016

Projektende: 2019

Beschreibung

Gleichzeitige Beobachtungen von atmosphärischem Ruß und Rußpartikeln in Schnee- und Bodeneigenschaften sind selten. Daher wird dieses Teilprojekt flugzeug- und bodengebundene Beobachtungen von Aerosolen und Rußkonzentrationen kombinieren, sowie optische Schneeeigenschaften und deren Rückkopplungsmechanismen in der arktischen Region untersuchen. In-situ Messungen von atmosphärischen Rußpartikeln (boden- und flugzeuggetragen) in Verbindung mit Rußpartikeln in Schneeproben und Fernerkundungsbeobachtungen von Schneeeigenschaften werden zusammengefügt.

Description

Concurrent observations of atmospheric Black Carbon (BC), and BC in snow and surface properties are rare. Hence, this project will combine airborne and ground-based observations of aerosols and BC concentrations and snow optical properties to investigate their feedback mechanisms in Arctic regions. In-situ measurements of atmospheric BC (ground-based and airborne) along with sampling of BC in snow and remote sensing observations of snow properties will be merged.

Weiterführung: ja

Mittelgeber: DFG, TRR 172

Theoretische Meteorologie
AG Wolken und globales Klima

Wolken und Niederschlag im Klimasystem
High Definition Clouds and Precipitation for Climate Prediction (HD(CP)²) –
Teilprojekte
HD(CP)² - O2 Full-domain observations
HD(CP)² - S1 Diagnostics
HD(CP)² - S6 PDF cloud schemes

Schlagworte: Wolken, Niederschlag, Klimawandel, Parametrisierungen, hochaufgelöste Modellierung

Projektleiter: Koordinator: Bjorn Stevens, Max-Planck-Institut für Meteorologie
(bjorn.stevens@zmaw.de)
J. Quaas (johannes.quaas@uni-leipzig.de)

Projektmitarbeiter:
Christine Nam (christine.nam@uni-leipzig.de)
Odran Sourdeval (odran.sourdeval@uni-leipzig.de)
Andreas Foth (andreas.foth@uni-leipzig.de)

Projektbeginn: 2011

Projektende: 2019

Beschreibung

Ziel von HD(CP)² ist es, Parametrisierungen von Wolken- und Niederschlagsprozessen in Klimamodellen zu verbessern und die Verbesserung der simulierten Wolken-Klima-Feedbacks nachzuweisen. Dazu wird in den Teilprojekten zur Modellierung eine hochaufgelöste (100 m horizontal) Simulation für mehrere Monate über Mitteleuropa vorbereitet, die als Referenz dienen kann. In den Teilprojekten zur Beobachtung werden Datensätze erstellt, die der Evaluierung dieses Modells und der Erstellung oder Verbesserung und Evaluierung von Klimamodellparametrisierungen dienen. In O2 werden konkret Messnetze (Niederschlagsradar, GPS, Ceilometer) und Satellitendaten für flächige Informationen über dem gesamten HD(CP)²-Gebiet aufgearbeitet. In den Teilprojekten zur Synthese wird darauf hingearbeitet, die sehr großen Datenmengen der geplanten Simulation sinnvoll zu verarbeiten. Konkret werden in Teilprojekt S1 Diagnostiken entwickelt, die relevante Metriken online während der Simulation berechnen, so dass kein Herausschreiben von sehr großen Datensätzen und Postprocessing nötig ist. Im Beitrag der Universität Leipzig werden hier Joint-PDFs konstruiert, die für Wolkenparametrisierungen relevant sind. In Teilprojekt S6 wird die Nutzung dieser PDFs für die Evaluierung von Wolkenparametrisierungen in Klimamodellen, die auf Wahrscheinlichkeitsdichtefunktionen (probability density functions, PDFs) der subskaligen Verteilung von der gesamtwasser-spezifischen Feuchte und ggf. anderen Größen basieren, vorbereitet. Dazu werden Sensitivitätssimulationen mit ECHAM6 mit verschiedenen Wolkenparametrisierungen durchgeführt und eine Evaluierung auf der Basis der HD(CP)²-Beobachtungen vorgenommen.

Weiterführung: ja

Mittelgeber: BMBF (Programm Verbundprojekt HD(CP)²)

**Theoretische Meteorologie
AG Wolken und globales Klima**

**Quantifizierung von Aerosol-Wolken-Klima-Effekten für Wolkenregime
Quantifying Aerosol-Cloud-Climate Effects by Regime**

Schlagworte: Aerosol, Wolken, Klimawandel, Strahlungsantrieb

Projektleiter:

Koordinator: Johannes Quaas, Universität Leipzig (johannes.quaas@uni-leipzig.de)

Projektmitarbeiter:

Claudia Unglaub (unglaub@rz.uni-leipzig.de)

Karoline Block (karoline.block@uni-leipzig.de)

Projektbeginn: 2011

Projektende: 2017

Beschreibung

Ziel von QUAERERE ist die verlässliche Quantifizierung des Strahlungsantriebs von anthropogenen Aerosolen durch ihren Effekt auf Wolken. Aufbauend auf früheren Arbeiten sollen hierzu Satellitendaten verschiedener Instrumente kombiniert und in einem statistischen Ansatz ausgewertet werden. Die Aerosol-Informationen für diese Studie stammen dabei nicht direkt aus Satellitendaten, sondern in wesentlich verbesserter Qualität aus der Reanalyse des MACC-II-Projekts. Die statistische Analyse soll für einzelne Wolken-Aerosol-Regime durchgeführt werden. Neben dieser beobachtungsbasierten Abschätzung sollen Simulationen mit dem regionalen Aerosol-Klima-Modell COSMO-MUSCAT (in Zusammenarbeit mit dem Leibniz-Institut für Troposphärenforschung) durchgeführt werden, die in Sensitivitätsstudien mit abgeschalteten anthropogenen Emissionen dazu dienen können, in den statistischen Korrelationen aus den Satellitendaten Kausalzusammenhänge nachzuweisen. Schließlich soll in Simulationen mit dem globalen Aerosol-Klima-Modell ECHAM6-HAM2 eine globale Abschätzung erzielt werden, die konsistent ist mit der beobachtungsgestützten Abschätzung.

Weiterführung: ja

Mittelgeber: Europäischer Forschungsrat (ERC) Starting Grant

**Theoretische Meteorologie
AG Wolken und globales Klima**

Learning about cloud brightening under risk and uncertainty: Whether, when and how to do field experiments (LEAC)

Schlagworte: Klima-Engineering, Klimawandel, Wolken impfen

Projektleiter:

Koordinator: Johannes Quaas, Universität Leipzig (johannes.quaas@uni-leipzig.de)

Projektmitarbeiter: Aswathy Nair (aswathy.nair@uni-leipzig.de)

Projektbeginn: 2013

Projektende: 2016

Beschreibung

Im Rahmen des Schwerpunktprojekts „Climate engineering – risks, challenges, opportunitites?“ der Deutschen Forschungsgemeinschaft untersucht das Projekt „LEAC“ den Vorschlag, mit Hilfe des Impfens von marinen Grenzschichtwolken mit Meersalzaerosol diese heller zu machen und so das Klima zu kühlen. Ein möglicher nächster Schritt der Forschung wäre gerade für diesen Vorschlag ein Feldexperiment, das in Raum und Zeit begrenzt sein könnte. Durch Analyse von Satellitendaten und Modellsimulationen wird zunächst untersucht, wie die Unsicherheit bezüglich des zu erreichenden Strahlungsantriebs als Funktion der Größe in Raum und Zeit eines Feldexperiments reduziert werden könnte. Auch mögliche Nebeneffekte werden untersucht. In Zusammenarbeit mit der Arbeitsgruppe Umweltökonomie der Universität Kiel werden sozio-ökonomische Aspekte der Frage beleuchtet.

Weiterführung: nein

Mittelgeber: Deutsche Forschungsgemeinschaft (DFG) SPP 1689

Theoretische Meteorologie AG Wolken und globales Klima

Marine Stratocumulus Cloud Cover and Climate

Schlagworte: Stratokumulus, Aerosol-Wolken-Wechselwirkungen

Projektleiter: Koordinator: Tom Goren (tom.goren@uni-leipzig.de)

Projektmitarbeiter: Tom Goren (tom.goren@uni-leipzig.de)

Projektbeginn: 2016

Projektende: 2018

Beschreibung

Das Projekt untersucht anhand von Satellitendaten und globalen Modellen den Einfluss anthropogener Aerosol-Emissionen auf marine Grenzschichtwolken. Dabei soll insbesondere untersucht werden, ob das Aufbrechen der geschlossenen Wolkendecken in verschmutzten Luftmassen später erfolgt als ohne anthropogenes Aerosol.

Weiterführung: ja

Mittelgeber: EU Horizon 2020 Marie Skłodowska-Curie Individual Fellowship.

**Theoretische Meteorologie
AG Wolken und globales Klima**

Learning about cloud brightening under risk and uncertainty: Investigation of feasibility, traceability, Incentives and de-centralised governance of limited-area climate engineering (LEAC-II)

Schlagworte: Klima-Engineering, Klimawandel, Wolken impfen

Projektleiter:

Koordinator: Johannes Quaas, Universität Leipzig (johannes.quaas@uni-leipzig.de)

Projektmitarbeiter: Dipu Sudhakar (dipu.sudhakar@uni-leipzig.de)

Projektbeginn: 2016

Projektende: 2019

Beschreibung

Im Rahmen des Schwerpunktprojekts „Climate engineering – risks, challenges, opportunitites?“ der Deutschen Forschungsgemeinschaft untersucht das Projekt „LEAC-II“ in Zusammenarbeit mit dem Fachbereich Umweltökonomie an der Universität Kiel, inwiefern eine Beeinflussung des Klimas auf regionaler Skala machbar wäre. Dabei wird untersucht, ob etwa durch technische Änderung von Wolkeneigenschaften lokal Hitzewellen abgemildert werden könnten und inwiefern die Änderung des Klimas in einer Region Auswirkungen auf benachbarte Regionen hat.

Weiterführung: ja

Mittelgeber: Deutsche Forschungsgemeinschaft (DFG) SPP 1689

**Theoretische Meteorologie
AG Wolken und globales Klima**

Forcing in the long-wave spectrum due to aerosol-cloud interactions: satellite and climate modelling vs. HALO (FLASH)

Schlagworte: Eiswolken, Eiswolken-Aerosol-Wechselwirkungen, Strahlungsantrieb, HALO

Projektleiter:

Koordinator: Johannes Quaas, Universität Leipzig (johannes.quaas@uni-leipzig.de)

Projektmitarbeiter:

Johannes Mülmenstädt (johannes.muellenstaedt@uni-leipzig.de)

Projektbeginn: 2016

Projektende: 2019**Beschreibung**

In der Arbeitsgruppe wurden neue Satellitendaten für die Eiskristallkonzentration entwickelt. Diese sollen im Projekt FLASH mit Hilfe von HALO-In-situ-Beobachtungen evaluiert werden. Dabei soll unter anderem zusammen mit dem DLR-Institut für Physik der Atmosphäre das Satellitenprodukt für kombinierte Radar-Lidar-Retrieval mit Daten der luftgetragenen Instrumente verglichen werden; daneben sollen die Satellitenprodukte mit in-situ-Beobachtungen evaluiert werden.

Weiterführung: ja

Mittelgeber: Deutsche Forschungsgemeinschaft (DFG) SPP 1294

Theoretische Meteorologie
AG Wolken und globales Klima

Copernicus Atmospheric Monitoring Service 74 - Radiative Forcings

Schlagworte: Aerosol-Strahlungsantrieb, Reanalyse, Aerosol-Wolken-Wechselwirkungen

Projektleiter:

Koordinator: Nicolas Bellouin, Universität Reading (n.bellouin@reading.ac.uk)
 J. Quaas (johannes.quaas@uni-leipzig.de)

Projektmitarbeiter: Johannes Mülmenstädt (johannes.muellenstaedt@uni-leipzig.de)

Projektbeginn: 2016

Projektende: 2019

Beschreibung

Ziel dieses Services des COPERNICUS Atmospheric Monitoring Service ist die Bereitstellung einer Diagnostik für den anthropogenen Strahlungsantrieb durch verschiedene Mechanismen auf Basis der Reanalyse der Atmosphärenzusammensetzung. Beitrag der Uni Leipzig ist hierbei der Strahlungsantrieb durch Aerosol-Wolken-Wechselwirkungen.

Weiterführung: ja

Mittelgeber: Europäische Union, COPERNICUS-Programm, COPERNICUS Atmospheric Monitoring Service (Subcontractor der Uni Reading)

Theoretische Meteorologie
AG Wolken und globales Klima

Modelling aerosols and aerosol-cloud interactions in the Arctic (D02)

Schlagworte: Arktischer Klimawandel, Aerosol-Wolken-Wechselwirkungen, Modellierung

Projektleiter:

Koordinator: Johannes Quaas, Universität Leipzig (johannes.quaas@uni-leipzig.de)

Projektmitarbeiter:

Jan Kretzschmar (jan.kretzschmar@uni-leipzig.de)

Projektbeginn: 2016

Projektende: 2019

Beschreibung

In diesem Beitrag zum SFB/Transregio (AC)³ soll mit Hilfe von globaler Modellierung in Kombination mit verschiedenen Beobachtungen der Einfluss anthropogener Aerosole auf den arktischen Klimawandel untersucht werden. In Kooperation mit dem Leibniz-Institut für Troposphärenforschung liegt hierbei der Schwerpunkt auf dem Meridionaltransport der Aerosole (TROPOS) und der Wechselwirkung von Aerosol mit Wolken (LIM).

Weiterführung: ja

Mittelgeber: Deutsche Forschungsgemeinschaft (DFG) TRR 172 (AC)³

Theoretische Meteorologie

AG Wolken und globales Klima

Assessment of Arctic feedback processes in climate models (E01)

Schlagworte: Arktischer Klimawandel, Feedbacks, Modellierung

Projektleiter:

Koordinator: Johannes Quaas, Universität Leipzig (johannes.quaas@uni-leipzig.de)

Projektmitarbeiter:

Karoline Block (karoline.block@uni-leipzig.de)

Projektbeginn: 2016

Projektende: 2019

Beschreibung

In diesem Beitrag zum SFB/Transregio (AC)³ sollen mit Hilfe von globaler Modellierung in Kombination mit verschiedenen Beobachtungen die verschiedenen Klima-Feedback-Mechanismen quantifiziert und in den Klimamodellen evaluiert werden. Spezielles Augenmerk ist hierbei in Kooperation mit der Uni Köln auf dem Wolken-Feedback.

Weiterführung: ja

Mittelgeber: Deutsche Forschungsgemeinschaft (DFG) TRR 172 (AC)³

Hochatmosphäre
Upper Atmosphere

Untersuchung der Anregungsmechanismen der 8-stündigen solaren Gezeiten in der mittleren Atmosphäre
Analysis of forcing mechanisms of the terdiurnal tide in the middle atmosphere

Schlagworte: Mittlere Atmosphäre, Gezeiten, Wellen

Projektleiter:
Prof. Dr. Christoph Jacobi (jacobi @ rz.uni-leipzig.de)

Projektmitarbeiter:
F. Lilienthal

Projektbeginn: 1.1.2014

Projektende: 31.12.2017

Beschreibung

Ein nichtlineares mechanistisches Zirkulationsmodell der mittleren Atmosphäre wird verwendet, um die Anregungsmechanismen der 8-stündigen Gezeiten in der mittleren Atmosphäre zu untersuchen. Das verwendete Modell MUAM (Middle and Upper Atmosphere Model) verfügt über Strahlungsroutinen zur selbstkonsistenten Anregung von Gezeiten. Zur Analyse der Gezeitenanregung werden im Modell die potenziellen Anregungsmechanismen einzeln und gemeinsam abgeschaltet. Die zu untersuchenden Anregungsmechanismen sind einerseits die direkte Anregung durch die 8-stündige Komponente im Strahlungsantrieb und andererseits die nichtlineare Wechselwirkung der ganz- und halbtägigen Gezeiten, repräsentiert in den Advektionstermen der Bewegungsgleichungen. Durch Vergleich mit Referenzläufen mit vollständiger Gezeitenanregung wird es möglich sein, die Anteile der jeweiligen Anregungsmechanismen am gesamten Wellenantrieb zu bestimmen. Die Arbeiten werden komplettiert durch Analyse von Radar- und Satellitendaten.

Weiterführung: ja

Mittelgeber: Deutsche Forschungsgemeinschaft (DFG JA 836/32-1)

Hochatmosphäre
Upper Atmosphere

Kopplung der Stratosphäre und Troposphäre während plötzlicher Stratosphärenenerwärmungen in der Nordhemisphäre
Stratosphere-troposphere coupling during sudden stratospheric warming events in the Northern Hemisphere

Schlagworte: Stratosphäre, Kopplung

Projektleiter:

Prof. Dr. Christoph Jacobi (jacobi @ rz.uni-leipzig.de)

Projektmitarbeiter:

-

Projektbeginn: 1.9.2015**Projektende:** 31.8.2016**Beschreibung**

An der Staatlichen Russischen Hydrometeorologischen Universität (RSHU) St. Petersburg werden intensive Untersuchungen zur Analyse der Dynamik der mittleren Atmosphäre durchgeführt. Diese erfolgen mit Hilfe numerischer Simulation und der Verwendung von Reanalysedaten, speziell MetOffice Reanalysen. Diese Daten sollen verwendet werden, um die Kopplung von unterer und mittlerer Atmosphäre während rascher winterlicher Stratosphärenwärmungen zu untersuchen. Die Arbeiten werden innerhalb einer Masterarbeit an der RSHU, St. Petersburg, durchgeführt. Das Projekt umfasst weiterhin einen einmonatigen Besuch der Stipendiatin in Leipzig.

Weiterführung: nein

Mittelgeber: DAAD (Leonhard Euler, 57196870)

Hochatmosphäre***Upper Atmosphere*****Untersuchung von Aerosol und Wolkeneigenschaften*****Properties of aerosols and clouds*****Schlagworte:** Aerosole, Wolken**Projektleiter:**

Prof. Dr. Christoph Jacobi (jacobi @ rz.uni-leipzig.de)

Projektmitarbeiter:

-

Projektbeginn: 1.9.2015**Projektende:** 31.8.2016**Beschreibung**

Innerhalb des Projekts sollen einerseits Wolkenkondensationskerne untersucht werden und die Beziehung zwischen Aerosolquellen und Kondensationsaktivität bestimmt werden, andererseits sollen mikrophysikalische Eigenschaften atmosphärischen Aerosols untersucht werden, insbesondere im Hinblick auf ihre Variabilität. Die Arbeiten werden innerhalb einer Masterarbeit und einer Dissertation an der Staatlichen Universität St. Petersburg durchgeführt. Das Projekt umfasst weiterhin den jeweils einmonatigen Besuch der Stipendiatinnen in Leipzig.

Weiterführung: nein

Mittelgeber: DAAD (Leonhard Euler, 57196970)

Hochatmosphäre
Upper Atmosphere

Analyse globaler Felder
Analysis of global fields

Schlagworte: Quasi 2-jährige Schwingung, planetare Wellen, Polarwirbel

Projektleiter:
Prof. Dr. Christoph Jacobi (jacobi @ rz.uni-leipzig.de)

Projektmitarbeiter:

-

Projektbeginn: 1.9.2016

Projektende: 31.8.2017

Beschreibung

Innerhalb des Projekts sollen dynamische und chemische Parameter der Troposphäre und Stratosphäre anhand von Reanalysedaten untersucht werden. Dabei sollen einerseits die Verteilungen meteorologischer Größen in Abhängigkeit der äquatorialen stratosphärischen quasi 2-jährigen Schwingung (QBO) untersucht werden, andererseits ein Schwerpunkt auf den arktischen Polarwirbel gelegt werden um dessen Tiefe und Dauer in Abhängigkeit planetarer Wellenaktivität zu untersuchen. Diese Arbeiten sollen mehr Einsicht in die dynamischen Zusammenhänge der unteren und mittleren Atmosphäre ermöglichen. Die Arbeiten werden innerhalb zweier Masterarbeiten an der Russischen Staatlichen Hydrometeorologischen Universität (RSHU), Abteilung Meteorologische Vorhersagen, St. Petersburg, durchgeführt. Das Projekt umfasst weiterhin je einen einmonatigen Besuch der Stipendiatinnen in Leipzig.

Weiterführung: ja

Mittelgeber: DAAD (Leonhard Euler, 57290950)

Hochatmosphäre
Upper Atmosphere

Large-scale dynamical impacts on regional Arctic climate change
Der Einfluss großräumiger Dynamik auf regionale arktische Klimaänderungen

Schlagworte: Arktische Verstärkung, Klimavariabilität

Projektleiter:

Prof. Dr. Christoph Jacobi (jacobi @ rz.uni-leipzig.de), Prof. Dr. Johannes Quaas (johannes.quaas @ uni-leipzig.de)

Projektmitarbeiter: Daniel Mewes

Projektbeginn: 1.1.2016

Projektende: 31.12.2019

Beschreibung

Das Projekt umfasst die Wechselwirkung zwischen der variablen großskaligen Zirkulation und regionalen arktischen Klimaänderungen und der Diagnose der arktischen Verstärkung auf regionaler Skala als Reaktion auf Variationen großskaliger Zirkulation in der Vergangenheit sowie in Klimaszenarien zukünftigen Klimawandels. Es werden hierzu Reanalysedaten und CMIP5-Modellergebnisse herangezogen. Die Kopplung von Troposphäre und Stratosphäre als wichtiger Bestandteil der Variabilität der polaren Atmosphäre wird auch mit numerischen Simulationen untersucht.

Weiterführung: ja

Mittelgeber: Deutsche Forschungsgemeinschaft, SFB-Transregio 172

Allgemeine Meteorologie

AG Bodengebundene Fernerkundung
Ground-based remote sensing

Hochaufgelöste Wolken- und Niederschlagsstudien zur Verbesserung von Klimaprojektionen

HD(CP)²-High definition clouds and precipitation for advancing climate prediction

Schlagworte: Wasserdampf, Wolken, Ramanlidar, Mikrowellenradiometer

Projektleiter:

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Projektbeginn: 01.10.2012

Projektende: 31.03.2016

Beschreibung

Dieses Projekt beschäftigt sich mit einem sehr relevanten Thema in der aktuellen meteorologischen Forschung, nämlich der Repräsentation von Wolken in Atmosphärenmodellen. Dabei sind noch viele Unsicherheiten, sowohl auf der Beobachtungs- als auch auf der Modellseite zu bemängeln. Im Rahmen von HD(CP)² wird die Expertise zu diesem Themenkomplex deutschlandweit gebündelt. Intensivierte Beobachtungen an verschiedenen Orten, sowie die Kombination verschiedener

Messverfahren, sollen es u.a. ermöglichen, bessere Parametrisierungen von Wolken in Modellen zu erhalten.

Am LIM wird in diesem Zusammenhang ein neuer Algorithmus zur Bestimmung vertikaler Wasserdampfverteilung aus Fernerkundungsdaten (passive Mikrowellenradiometer und Raman-Lidar) erstellt. Dabei werden Daten, die im Rahmen des Projekts bei Messkampagnen in Jülich (HOPE) und Melpitz (HOPE-2) gewonnen wurden, verwendet. Außerdem wird der Algorithmus auf andere Datensätze aus Leipzig, Lindenberg (DWD) sowie von Polarsternfahrten angewandt

Description

This project deals with a very relevant topic in the current meteorological research, namely the representation of clouds in atmospheric models. There are still many uncertainties, both in observations and model. Within HD(CP)², experts on these topics are connected among different German research institutions. Intensified observations at different locations, as well as the combination of different measurement methods, will allow obtaining better parameterizations of clouds in models.

At the LIM, a new algorithm to determine the vertical distribution of water vapor from remote sensing data (passive microwave radiometer and Raman Lidar) is created within HD(CP)². Data which have been obtained within the project at measuring campaigns in Jülich (HOPE) and Melpitz (HOPE-2) are used. In addition, the algorithm will be applied to other datasets from Leipzig, Lindenberg (DWD) as well as Polarstern cruises.

Weiterführung: nein

Mittelgeber: BMBF, FKZ: 01LK1209D

**Publikationen
LIM 2016**

Autor_Name	Vorname	weitere Autoren	Titel	ID, DOI	Weitere Angaben, Publikationsort
Baraskar	A	M. Bhushan, C. Venkataraman, and R. Cherian	An offline constrained data assimilation technique for aerosols: Improving GCM simulations over South Asia using observations from two satellite sensors	10.1016/j.atmosenv.2016.02.026	Atmos. Environ., 132, 36 - 48
Barlakas	Vasileios	A. Macke, and M. Wendisch	SPARTA - Solver for Polarized Atmospheric Radiative Transfer Applications: Introduction and application in Saharan dust fields	doi:10.1016/j.jqsrt.2016.02.019	J. Quant. Spectr. & Rad. Trans, Vol. 178, 77-92
Bellouin	Nicolas	L. Baker, Ø. Hodnebrog, D. Olivié, R. Cherian, C. Macintosh, B. Samset, A. Esteve, B. Aamaas, J. Quaas, and G. Myhre	Regional and seasonal radiative forcing by perturbations to aerosol and ozone precursor emissions	10.5194/acp-16-13885-2016	Atmos. Chem. Phys., 16, 13885-13910
Bleisteiner	Markus	Barth, M., Raabe, A.	Tomographic reconstruction of indoor spatial temperature distributions using room impulse responses,	doi:10.1088/0957-0233/27/3/035306	Meas. Sci. Technol. 27 (2016),
Boucher	Olivier	Y. Balkanski, Ø. Hodnebrog, C. Lund Myhre, G. Myhre, J. Quaas, B. H. Samset, N. Schutgens, P. Stier, and R. Wang	The jury is still out on the radiative forcing by black carbon	10.1073/pnas.1607005113	Proc. Nat. Acad. Sci. USA, 113, E5092-E5093
Finger	Fanny	F. Werner, M. Klingebiel, A. Ehrlich, E. Jäkel, M. Voigt, S. Borrmann, P. Spichtinger, and M. Wendisch	Spectral optical layer properties of cirrus from collocated airborne measurements and simulations	doi:10.5194/acp-16-7681-2016	Atmos. Chem. Phys., 16, 7681-7693,
Fuchs	Tobias	Raabe, A.	Special issue on METTOOLS_IX;		Meteorologische Zeitschrift Vol. 25

					No. 3 (2016), p. 247 - 249
Göhler	Robby	A. Raabe, J. Zimmer:	Darstellung und Einfluss von durchbrochener Bewölkung auf den Ertrag von Photovoltaik-Anlagen und dessen Prognose.		Wiss. Mitteil. Inst. f. Meteorol., 54, S. 67-80
Gross	A.	B. L. Turner, Tom Goren, A. Berry, and A. Angert	Tracing the Sources of Atmospheric Phosphorus Deposition to a Tropical Rain Forest in Panama Using Stable Oxygen Isotopes	10.1021/acs.est.5b04936	Environ. Sci. Technol., 50, 1147-1156
Gryspeerd	Edward	J. Quaas, and N. Bellouin	Constraining the aerosol influence on cloud fraction	10.1002/2015JD023744	J. Geophys. Res., 121, 3566-3583
Holstein	Peter	A. Raabe, N. Bader, A. Tharandt, M. Barth, H.-J. Münch	Energetische Probleme und akustische Verfahren.		B. Weller, S. Horn Hrsg., Denkmal und Energie – 2017, Springer Vieweg, 189-199
Jacobi	Christoph	F. Lilienthal, T. Schmidt, A. de la Torre	Modeling the Southern Hemisphere winter circulation using realistic zonal mean gravity wave information in the lower atmosphere	ISBN: 978-3-9814401-4-0	Wiss. Mitteil. Institut. f. Meteorol. Universität Leipzig Bd. 54, S. 37-46
Jacobi	Christoph	A. Krug, E.G. Merzlyakov	Radar wind climatology of the quarterdiurnal tide in the mesopause region over Central and Eastern Europe	ISBN: 978-3-9814401-4-0	Wiss. Mitteil. Institut. f. Meteorol. Universität Leipzig Bd. 54, S. 47-56
Jacobi	Christoph	N. Samtleben, G. Stober	Meteor radar observations of mesopause region long-period temperature oscillations	doi: 10.5194/ars-14-175-2016	Adv. Radio Sci., 14, 169-174.

Jacobi	Christoph	N. Jakowski, G. Schmidtke, T.N. Woods	Delayed response of the global total electron content to solar EUV variations	doi: 10.5194/ars-14-175-2016	Adv. Radio Sci., 14, 175-180.
Kedia	S	R. Cherian, S. Islam, S. K. Das, and A. Kagainalkar	Regional simulation of aerosol radiative effects and their influence on rainfall over India using WRFChem model	10.1016/j.atmosres.2016.07.008	Atmos. Res., 182, 232 - 242
Lilienthal	Friederike	Ch. Jacobi	The role of solar heating in the forcing of the terdiurnal tide	ISBN: 978-3-9814401-4-0	Wiss. Mitteil. Instit. f. Meteorol. Universität Leipzig Bd. 54, S. 57-66
Martin	Scott	Artaxo, P., Machado, L. A. T., Manzi, A. O., Souza, R. A. F., Schumacher, C., Wang, J., Andreae, M. O., Barbosa, H. M. J., Fan, J., Fisch, G., Goldstein, A. H., Guenther, A., Jimenez, J. L., Pöschl, U., Silva Dias, M. A., Smith, J. N., and Wendisch, M.	Introduction: Observations and Modeling of the Green Ocean Amazon (GoAmazon2014/5)	doi:10.5194/acp-16-4785-2016	Atmos. Chem. Phys., 15 (2016), 4785-4797

Martin	Scott	<p>P. Artaxo, L. Machado, A.O. Manzi, R. A. F. Souza, C. Schumacher, J. Wang, T. Biscaro, J. Brito, A. Calheiros, K. Jardine, A. Medeiros, B. Portela, S. de Sá, K. Adachi, A.C. Aiken, R. Albrecht, L. Alexander, M.O. Andreae, H.M.J. Barbosa, P. Buseck, D. Chand, J.M. Comstock, D.A. Day, M. Dubey, J. Fan, J. Fast, G. Fisch, E. Fortner, S. Giangrande, M. Gilles, A.H. Goldstein, A. Guenther, J. Hubbe, M. Jensen, J.L. Jimenez, F.N. Keutsch, S. Kim, C. Kuang, A. Laskin, K. McKinney, F. Mei, M. Miller, R. Nascimento, T. Pauliquevis, M. Pekour, J. Peres, T. Petäjä, C. Pöhlker, U. Pöschl, L. Rizzo, B. Schmid, J.E. Shilling, M.A. Silva Dias, J.N. Smith, J.M. Tomlinson, J. Tóta, and M. Wendisch, and U. Schlink</p>	<p>The Green Ocean Amazon Experiment (GoAmazon2014/5) Observes pollution affecting gases, aerosols, clouds, and rainfall over the rain forest</p>	<p>doi:10.1175/BAMS-D-15-00221.1</p>	<p>Bull. Am. Meteorol. Soc. Online</p>
Quaas	Johannes	<p>M. F. Quaas, O. Boucher, and W. Rickels</p>	<p>Regional climate engineering by radiation management: Prerequisites and prospects</p>	<p>10.1002/2016EF000440</p>	<p>Earth's Future, 4, 618-625</p>

Quennehen	Boris	J.-C. Raut, K. S. Law, N. Daskalakis, G. Ancellet, C. Clerbaux, S.-W. Kim, M. T. Lund, G. Myhre, D. J. L. Olivié, S. Safieddine, R. B. Skeie, J. L. Thomas, S Tsyro, A. Bazureau, N. Bellouin, M. Hu, M. Kanakidou, Z. Klimont, K. Kupiainen, S. Myriokefalitakis, J. Quaas, S. T. Rumbold, M. Schulz, R. Cherian, A. Shimizu, J. Wang, S.-C. Yoon, and T. Zhu	Multi-model evaluation of short-lived pollutant distributions over East Asia during summer 2008	10.5194/acp-16-10765-2016	Atmos. Chem. Phys., 16, 10765-10792
Šácha	Petr	F. Lilienthal, Ch. Jacobi, P. Pišoft	Influence of the spatial distribution of gravity wave activity on the middle atmospheric circulation and transport	doi: 10.1002/2016JA023043	Atmos. Chem. Phys., 16, 15755-15775
Sadavarte	P	C. Venkataraman, R. Cherian, N. Patil, B.L. Madhavan, T. Gupta, S. Kulkarni, G. R. Carmichael, and B. Adhikary	Seasonal differences in aerosol abundance and radiative forcing in months of contrasting emissions and rainfall over northern South Asia	10.1016/j.atmosenv.2015.10.092	Atmos. Environ., 125, Part B, 512 - 523
Salzmann	Marc		Global warming without global mean precipitation increase?	10.1126/sciadv.1501572	Sci. Adv., 2, e1501572
Schutgens	Nick	E. Gryspeerdt, N. Weigum, S. Tsyro, D. Goto, M. Schulz, and P. Stier	Will a perfect model agree with perfect observations? The impact of spatial sampling	10.5194/acp-16-6335-2016	Atmos. Chem. Phys.
Sourdeval	Odran	L.-C. Labonnote, A. J. Baran, J. Mülmenstädt, and G. Brogniez	A methodology for simultaneous retrieval of ice and liquid water cloud properties. Part 2: Near-global retrievals and evaluation against A-Train products	10.1002/qj.2889	Q. J. R. Meteorol. Soc., 142, 3063-3081

Voigt	Christiane	U. Schumann, A. Minikin, A. Abdelmonem, A. Afchine, S. Borrmann, M. Boettcher, B. Buchholz, L. Bugliaro, A. Costa, J. Curtius, M. Dollner, A. Dörnbrack, V. Dreiling, V. Ebert, A. Ehrlich, A. Fix, L. Forster, F. Frank, D. Fütterer, A. Giez, K. Graf, J.-U. Groß, S. Groß, K. Heimerl, B. Heinold, T. Hüneke, E. Järvinen, T. Jurkat, S. Kaufmann, M. Kenntner, M. Klingebiel, T. Klimach, R. Kohl, M. Krämer, T. C. Krisna, A. Luebke, B. Mayer, S. Mertes, S. Mollenker, A. Petzold, K. Pfeilsticker, M. Port, M. Rapp, P. Reutter, C. Rolf, D. Rose, D. Sauer, A. Schäfler, R. Schlage, M. Schnaiter, J. Schneider, N. Spelten, P. Spichtinger, P. Stock, A. Walser, R. Weigel, B. Weinzierl, M. Wendisch, F. Werner, H. Wernli, M. Wirth, A. Zahn, H. Ziereis, and M. Zöger	ML-CIRRUS - The airborne experiment on natural cirrus and contrail cirrus with the high-altitude long-range research aircraft HALO	doi:10.1175/BAMS-D-15-00213.1	Bull. Am. Meteorol. Soc. Online
Watson-Parris	Duncan	N Schutgens, N Cook, Z Kipling, P Kerhsaw, Edward Gryspeerd, B Lawrence, and P. Stier	Community Intercomparison Suite (CIS) v1.4.0: A tool for intercomparing models and observations	10.5194/gmd-9-3093-2016	Geosci. Model Dev., 9

Wendisch	Manfred	<p>U. Pöschl, M. O. Andreae, L. A. T. Machado, R. Albrecht, H. Schlager, D. Rosenfeld, S. T. Martin, A. Abdelmonem, A. Afchine, A. Araujo, P. Artaxo, H. Aufmhoff, H. M. J. Barbosa, S. Borrmann, R. Braga, B. Buchholz, M. A. Cecchini, A. Costa, J. Curtius, M. Dollner, M. Dorf, V. Dreiling, V. Ebert, A. Ehrlich, F. Ewald, G. Fisch, A. Fix, F. Frank, D. Fütterer, C. Heckl, F. Heidelberg, T. Hüneke, E. Jäkel, E. Järvinen, T. Jurkat, S. Kanter, U. Kästner, M. Kenntner, J. Kesselmeier, T. Klimach, M. Knecht, R. Kohl, T. Kölling, M. Krämer, M. Krüger, T. C. Krisna, J. V. Lavric, K. Longo, C. Mahnke, A. O. Manzi, B. Mayer, S. Mertes, A. Minikin, S. Molleker, S. Münch, Björn Nillius, K. Pfeilsticker, C. Pöhlker, A.-E. Roiger, D. Rose, D. Rosenow, D. Sauer, M. Schnaiter, J. Schneider, C. Schulz, R. A. F. de Souza, A. Spanu, P. Stock, D. Vila, C. Voigt, A. Walser, D. Walter, R. Weigel, B. Weinzierl, F. Werner, M. A. Yamasoe, H. Ziereis, T. Zinner, M. Zöger</p>	<p>The ACRIDICON-CHUVA campaign: Studying tropical deep convective clouds and precipitation over Amazonia using the new German research aircraft HALO</p>	<p>doi:10.1175/BAMS-D-14-00255</p>	<p>Bull. Am. Meteorol. Soc., 97, 10, 1885-1908</p>
Wu	Qian	<p>A. Maute, V. Yudin, L. Goncharenko, J. Noto, R. Kerr, C. Jacobi</p>	<p>Observations and Simulations of mid latitude ionospheric and thermospheric response to the January 2013 Stratospheric Sudden Warming even</p>	<p>doi: 10.1002/2016JA023043</p>	<p>J. Geophys. Res. Space Physics, 121, 8995–9011</p>

Fakultät für Physik und Geowissenschaften

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Forschungsbericht 2016

3. Weitere Angaben

3.1 KOOPERATION

Instituto de Pesquisa da Amazônia (INPA), Instituto de Pesquisas Espaciais (INPE), Sao Paulo, Brasilien
"Aerosol, Cloud, Precipitation, and Radiation Interactions and Dynamics of Convective Cloud Systems (ACRIDICON)"

Staatliche Russische Hydrometeorologische Universität, St. Petersburg, Prof. Alexander Pogoreltsev:
"Kopplung der Stratosphäre und Troposphäre"

Staatliche Universität, St. Petersburg, Prof. Gustav Shved: "Untersuchung von Aerosol und Wolkeneigenschaften"

Universidad Austral, Buenos Aires, Argentinien, Prof. Alejandro de la Torre: „Atmospheric Gravity Waves: Observations and Modeling“ (BMBF 01DN14001)

University of Colorado at Boulder, CIRES, Dr. Ostashev; "Acoustic tomography of the atmosphere at the Boulder Atmospheric Observatory"

University of Basilicata, Potenza, Italien, P. di Girolamo: "Kalibration von Raman-Lidar-Wasserdampfprofilen mittels Mikrowellenradiometer"

Universität Innsbruck, Österreich: „Temperaturprofile in einem Alpental aus Mikrowellenradiometer-Beobachtungen“

University of Reading, UK, A. Illingworth: "COST-Aktion TOPROF"

MeteoSchweiz, Payerne, Schweiz, A. Haefele: "Kombinierte Temperatur- und Feuchteprofile mit Mikrowellenradiometer und Raman-Lidar"

University of Reading, N. Bellouin und K. Shine, COPERNICUS-Projekt

CICERO Oslo, G. Myhre: COPERNICUS

University of Leeds, P. Forster, K. Carslaw, COPERNICUS

LMD/CNRS Paris, O. Boucher, COPERNICUS

Hebrew University of Jerusalem, D. Rosenfeld: ACPC initiative

University of Oxford, P. Stier: gemeinsamer Workshop

3.2 GREMIUMMITGLIEDSCHAFT

Prof. Dr. Manfred Wendisch:

- Mitglied des Wissenschaftlichen Beirats des Leibniz-Instituts für Troposphärenforschung (TROPOS) Leipzig, seit 2012 stellvertretender Vorsitzender.
- Ordentliches Mitglied der Sächsischen Akademie der Wissenschaften
- Mitglied des Präsidiums der Sächsischen Akademie der Wissenschaften
- Mitglied im Vorstand der Meteorologischen Gesellschaft, Sektion Mitteldeutschland
- Gewähltes Mitglied im IRC (Internationale Strahlungskommission) innerhalb von IAMAS
- Koordinator Expert Working Groups innerhalb von EUFAR (European Facility for Airborne Research)
- Mitglied des „User Group Selection Panel“ (UGSP) innerhalb von EUFAR

- Koordinator des DFG-SPP (Schwerpunktprogramm) 1294 zu HALO (High Altitude and Long Range Research Aircraft), gemeinsam mit Prof. J. Curtius (Uni Frankfurt am Main) und Mirko Scheinert (TU Dresden)
- Vize-Sprecher der „Leibniz-Graduate School on Clouds, Aerosols, and Radiation (LGS-CAR)“
- Mitglied des Gutachtergremiums für Atmosphärenwissenschaften der Finnländischen Akademie der Wissenschaften
- Mitglied des Wissenschaftlichen Beirats des Deutschen Wetterdienstes (DWD)
- Mitglied des Programmrates „Hans-Ertel-Zentrum für Wetterforschung (HErZ)“ des DWD
- Stellvertretender Vorsitzender des wissenschaftlichen Lenkungsausschusses (WLA) für HALO (High Altitude and Long Range Research Aircraft)
- Sprecher des Sonderforschungsbereiches SFB-Transregio 172: „Arktische Verstärkung: Klimarelevante Atmosphären- und Oberflächenprozesse, und Rückkopplungsmechanismen (AC)³“

Prof. Dr. Johannes Quaas:

Co-chair, Aerosols, Clouds, Precipitation and Climate (gemeinsame Aktivität des IGBP/iLEAPS und WCRP/GEWEX; Mitglied des wissenschaftlichen Lenkungsausschusses seit 2010; Co-Chair seit 2013)
Mitglied der International Commission on Clouds and Precipitation (IAMAS-ICCP), 2008-2016
Mitglied des Leibniz-Instituts für Troposphärenforschung e.V. (TROPOS)

Prof. Dr. Christoph Jacobi:

Mitglied im Vorstand der Meteorologischen Gesellschaft, Sektion Mitteldeutschland
Stellv. Leiter der Division II der IAGA
Leiter der Arbeitsgruppe II-D der IAGA: „External Forcing of the Middle Atmosphere“
Vorsitzender der Mitgliederversammlung des TROPOS

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Vorsitzender der Deutschen Meteorologischen Gesellschaft e.V., Sektion Mitteldeutschland
Mitglied Sektorkomitee Erneuerbare Energien bei Deutsche Akkreditierungsstelle (DAkKS) des BMWiUT,

Dr. M. Salzmann

Annales Geophysicae Co-Editor

3.3 Mitgliedschaften in Redaktionskollegien, Herausgebergremien**Prof. Dr. Manfred Wendisch:**

Atmos. Meas. Tech. Co-Editor
Meteorologische Zeitschrift Co-Editor
Herausgeber: Wiss. Mitt. Inst. f. Meteorol. Univ. Leipzig

Prof. Dr. Christoph Jacobi:

Meteorologische Zeitschrift Mitglied im Advisory Board
Annales Geophysicae Editor-in-Chief

Prof. Dr. Johannes Quaas

Atmos. Chem. Phys. Co-Editor

Dr. A. Raabe:

Herausgeber: Wiss. Mitt. Inst. f. Meteorol. Univ. Leipzig

3.4 VERANSTALTUNEN

Advanced Training Module und Workshop „Cloud droplet number concentration“, 17.-19. Oktober 2016
Aerosols-Clouds-Precipitation and Climate, workshop Oxford 13.-15. April 2016

Co-convener International Conference on Clouds and Precipitation, Manchester, 25.-29. Juli 2016

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5. Immatrikulationen am Institut f. Meteorologie

BSC Meteorologie													
Datum	Semester	1.FS	2. FS	3.FS	4.FS	5.FS	6. FS	7.FS	8.FS	9. FS	10.FS	>10.FS	Meteo_BSC
Datum	Semester	BSC_FS1	BSC_FS2	BSC_FS3	BSC_FS4	BSC_FS5	BSC_FS6	BSC_FS7	BSC_FS8	BSC_FS9			Meteo_BSC
15.10.2016	WS 16/17	48		7		5		3					63
15.10.2015	WS 15/16	35		5		9		3					52
15.10.2014	WS 14/15	35		14		15		3		3		1	71
15.10.2013	WS 13/14	39		23		21		13		4			100
15.10.2012	WS 12/13	60		29	1	22	2	16	1	2			133
15.10.2011	WS 11/12	60		27		26	1	19		1			134
15.10.2010	WS 10/11	64		34		20							118
15.10.2009	WS 09/10	67	0	21	0	20	0						108
15.10.2008	WS 08/09	71	0	28	0	12							111
15.10.2007	WS 07/08	98	0	15									113
13.12.2006	WS 06/07	31											31

MSC Meteorologie							
Datum	Semester	1.FS	2. FS	3.FS	4.FS	5.FS	6. FS
Datum	Semester	MSC_FS1	MSC_FS2	MSC_FS3	MSC_FS4	>MSC_FS5	Meteo_MSC
15.10.2016	WS 16/17	9		13		17	39
15.10.2015	WS 15/16	13		19		18	50
15.10.2014	WS 14/15	19		18		16	53
15.10.2013	WS 13/14	18		16		20	54
15.10.2012	WS 12/13	18		20	1	15	54
15.10.2011	WS 11/12	21		17		10	48
15.10.2010	WS 10/11	20		9		5	34
15.10.2009	WS 09/10	11					11

Diplom Meteorologie													
Datum	Semester	1.FS	2. FS	3.FS	4.FS	5.FS	6. FS	7.FS	8.FS	9. FS	10.FS	>10.FS	Meteo_Diplom
15.10.2013	WS 13/14											2	2
17.10.2012	WS 12/13											3	3
16.10.2011	WS 11/12											3	3
15.10.2010	WS 10/11											14	14
15.10.2009	WS 09/10								0	14	0	7	21
15.10.2008	WS 08/09						0	14	0	23	1	25	63
15.10.2007	WS 07/08				0	22	0	26	1	18	2	19	88
13.12.2006	WS 06/07		0	40	0	36	0	24	2	14	1	17	175
15.10.2005	WS 05/06	109	0	49	0	30	2	16	1	17	1	13	237
08.12.2004	WS 04/05	97	0	35	1	20	0	19	0	12	1	15	200
03.12.2003	WS 03/04	68	1	25	0	20	1	13	1	12	1	13	155
14.10.2002	WS 02/03	45	0	19	0	16	0	15	1	12	1	9	118
06.12.2001	WS 01/02	43	0	21	0	16	0	13	0	7	0	5	105
07.12.2000	WS 00/01	41	1	27	0	22	0	8	0	6	1	6	112
01.12.1999	WS 99/00	40	0	24	0	9	0	9	0	6	1	6	95
16.12.1998	WS 98/99	36	0	11	0	17	1	9	1	5	0	8	88
10.11.1997	WS 97/98	29	0	17	0	10	1	8	0	7	0	4	76

6. Abschlussarbeiten Institut für Meteorologie 2016

Promotionen

Michael Jähn

Abschluss: 21.03.2016

Large Eddy Simulation Studies of Island Effects in the Caribbean Trade Wind Region

Roland Schrödner

Abschluss: 29.02.2016

Modeling the tropospheric multiphase aerosol-cloud processing using the 3-D chemistry transport model COSMO-MUSCAT

Anja Schwarz

Abschluss: 29.02.2016

Aerosol typing over Europe and its benefits for the CALIPSO and EarthCARE missions - Statistical analysis based on multiwavelength aerosol lidar measurements from ground-based EARLINET stations and comparison to spaceborne CALIPSO data

Vasileios Barlakas

Abschluss: 04.07.2016

A New Three-Dimensional Vector Radiative Transfer Model and Applications to Saharan Dust Fields

Alexander Myagkov

Abschluss: 19.09.2016

Shape-temperature relationship of ice crystals in mixed-phase clouds based on observations with polarimetric cloud radar

Michael Schäfer

Abschluss: 04.07.2016

Optical Thickness Retrievals of Subtropical Cirrus and Arctic Stratus from Ground-Based and Airborne Radiance Observations Using Imaging Spectrometers

Stefan Barthel

Abschluss: 24.10.2016

Regionale Modellstudien zur Untersuchung von Emissionsparametrisierungen des primären marinen Aerosols

Heiner Matthias Brück

Abschluss: 24.10.2016

Evaluation of statistical cloud parameterizations

Li Li

Abschluss: 24.10.2016

Stokes parameters of skylight based on simulations and polarized radiometer measurements

Bachelor- Abschlussarbeiten:

Name / Vorname	Thema
Hellmuth, Franziska	Investigation of the regional variability of the ice water content produced by supercooled stratiform clouds
Wenke, Marius	Agrarklimatologische Untersuchungen thermischer Zustandsgrößen in ausgewählten räumlichen und zeitlichen Skalen
Chevalier Santos Bulhoes, Karine	Phenology-based agroclimatological evaluations of selected climate elements and comparison with calendar-based evaluations of different natural areas of Germany for the period of 1992-2014
Noth, Robert	Atmosphärische Heizraten in bewölkten und unbewölkten Bedingungen aus Flugzeugmessungen in der Arktis
Urbanneck, Claudia	Berücksichtigung von Eisflächen in LES-Modellen zur Simulation arktischer Grenzschichten
Metzner, Enrico	Untersuchung numerischer Probleme in Parametrisierungen der Wolkenmikrophysik
Strätz, Alexander	Ableitung des Gesamtwasserdampfgehalts aus GPS-Bodenmessungen
Hermes, Kilian Franz	The weekly cycle in cloud and radiation variables to detect indirect cloud-aerosol effects
Pangert, Johanna	Bodentemperaturen vor dem Hintergrund unterschiedlicher Bodenbearbeitungsverfahren

Master-Abschlussarbeiten

Name / Vorname	Thema
Mewes, Daniel	Stochastic Parameterization of Precipitation in the ECHAM6 General Circulation Model
Schacht, Jacob	Parametrisation of the Wegener-Bergeron-Findeisen process in global climate models
Leucht, Robin	Ableitung der optischen Dicke aus Messungen der Strahldichte mithilfe einer Allsky-Kamera
Griesche, Hannes	Evaluation of the Effect of Mineral Dust Aerosol on the Forecast Skill of Numerical Weather Prediction Models based on Remote Sensing Observations
Stapf, Johannes	Ableitung von Temperaturprofilen aus Infrarot-Kamera Messungen
Kretschmar, Jan	Frühe anthropogene Erwärmung und Aerosolformung
Geißler, Christoph	Trends der Temperatur und des Windes in der Mesosphäre
Samtleben, Nadia	Numerical simulation of the circulation in the middle atmosphere during winter 2005/2006

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Teil I: Beiträge zur Alfred-Wegener-Konferenz, Leipzig 1997
Teil II: Aktuelle Beiträge aus dem Institut für Meteorologie
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D. Hinneburg, A. Raabe und G. Tetzlaff: Vergleich Windatlas – Beobachtungsdaten; M. Börngen, H.-J. Schönfeldt, F. Riechmann, G. Panin und G. Tetzlaff: Seegangsatlas; M. Stephan und H.-J. Schönfeldt: Sedimenttransportatlas
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