# Talk Abstracts

Sebastian Zeppenfeld et al.:

## Oceanic Transfer and Atmospheric Transformation of Marine Carbohydrates in the Polar Regions

Marine carbohydrates are released by microbes at the surface of the oceans and contribute significantly to dissolved and particulate organic carbon in the seawater. Recent studies showed that the carbohydrates released by Arctic microorganisms exhibit an extraordinarily high ice nucleating activity making them potentially important ice nucleating particles (INP). These carbohydrates enter the atmosphere as part of sea spray aerosol (SSA) through wind-driven processes and eventually contribute to cloud formation processes. However, the emission processes of marine carbohydrates and their atmospheric aging are still not well understood.

Here, we present marine carbohydrates found in bulk seawater (at 1 m depth), the SML, size-resolved aerosol particles and fog water and their contribution to organic carbon. Chemical and statistical analyses revealed a chemo-selective transfer of carbohydrates towards sodium during the sea-air transfer. Additionally, strong evidence could be found for bacterial modifications of the aerosolized carbohydrates in the atmosphere after their oceanic emission causing their quick aging. As a consequence of the retreat of sea ice enhanced by Arctic amplification, these processes may lead to a changing availability of potential INP changing the cloud formation and their microphysical properties.

Moritz Zeising et al.:

## Organic aerosol precursors from the Arctic Ocean - coupled ecosystem ocean modeling compared to in-situ and satellite observations

Biogenic aerosols from phytoplankton production localized in leads or open water were shown to act as cloud condensation nuclei (liquid phase) or ice nuclei (ice phase) in remote regions. We conduct a modeling study with AWI-developed models FESOM2-REcoM2 and use acidic polysaccharides and transparent exopolymer particles (TEP) as tracers for these biogenic aerosol precursors. The results are evaluated by comparison to a set of in-situ and remote-sensing measurements.

Anisbel Leon et al.:

## Modeling the impact of primary marine organic aerosol on clouds

Marine organic aerosol is a major contributor to cloud condensation nuclei and ice nucleating particles over pristine open-ocean and coastal regions and thus has an important impact on radiation, precipitation and atmospheric dynamics. In the Arctic, the summer-time loss of sea ice and the rapid ice retreat are key factors for potentially increased marine aerosol emissions. In our planned studies with the aerosol-climate model ICON-HAM, we want to investigate the influence of primary marine organic aerosol on the Arctic climate and its rapid warming. The implementation of a detailed, species-resolved ocean emission and the interactions with mixed-phase clouds in ICON-HAM allows for studying the efficiency of marine organic species as potential ice nucleating particles (INP). Here, we present various sensitivity model simulations and the first results of the comparison with satellite retrievals, in-situ aerosol, and INP measurements to evaluate the ice nucleation potential of marine organic aerosols over dust particles transported from mid-latitudes.

Zsofia Juranyi et al.:

## Black Carbon properties in the Arctic from a decade of spring and summertime aircraft measurements

Average Arctic black carbon properties were derived from 9 years of aircraft measurements focusing on the spring and summer time differences. We would like to offer this unique data-set for model validation and improvement.

Carola Barrientos-Velasco et al.:

## Cloud Radiative Effect during MOSAiC based on Polarstern and CERES observations

The Arctic is a sensitive and focal region to investigate climate change. The warming in the Arctic has been much faster than the rest of the Earth. There are several processes and feedback mechanisms that contribute to Arctic amplification. Cloud feedback introduces the largest uncertainty in climate models. Therefore, it is essential to exploit the effective combination of ground-based and satellite observations to understand Arctic clouds accurately, address uncertainties in Arctic climate data records on clouds and radiative fluxes, and ultimately improve climate models.

It is our aim to evaluate satellite products from Clouds and the Earth's Radiant Energy System (CERES) over the central Arctic with the unique and remarkable in-situ and remote sensing observations collected during the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition aboard the ice-breaker Polarstern.

The remote sensing instrumentation aboard Polarstern is used to characterise clouds' macro- and microphysical properties by means of the synergistic Cloudnet algorithms. The resulting products are then used as input parameters for 1D radiative transfer simulations. Within the scope of this analysis, the consistency of our simulations, CERES synoptic products (SYN) and shipborne and ice-floe-based upwelling and downwelling shortwave (SW) and longwave (LW) radiative fluxes are evaluated. This analysis is brought into a more comprehensive perspective considering the broad contrast between day and night Arctic periods, variability of atmospheric characteristics, and clear-sky, single or multilayer cloud conditions.

Imke Schirmacher et al.:

## Assessing Arctic low level clouds and precipitation – a remote sensing perspective

60% of Arctic clouds are low level Mixed-Phase-Clouds (MPCs), which have a large radiative impact. Mostly, active measurements by CloudSat assess MPCs. However, CloudSat lacks a complete representation of MPCs because the coarse along-track sampling conceals spatial cloud patterns. Furthermore, the blind zone prevents the assessment of the lowest kilometer. Thus, higher resolved observations of cloud characteristics are needed to better determine how the cloud fraction varies close to the surface and how it depends on surface characteristics, season and meteorological situation, to ultimately address the influence of MPCs on Arctic Amplification.

Our study investigates the low level hydrometeor fraction of Arctic clouds over the ocean using airborne remote sensing measurements by the Microwave Radar/radiometer for Arctic Clouds (MiRAC) and Airborne Mobile Aerosol Lidar for Arctic research (AMALi) flown on the POLAR 5 aircraft. Four campaigns have been conducted in the vicinity of Svalbard during different seasons: ACLOUD, AFLUX, MOSAiC-ACA and HALO-AC3. We compare Cloud-Sat radar reflectivity simulations, which base on MiRAC radar reflectivities, with airborne observations over all campaigns and investigate the effects of CloudSat's spatial resolution, clutter mask, and sensitivity on the low level hydrometeor fraction. Measurements reveal high hydrometeor fractions of up to 60% in the lowest 1.5 km, which CloudSat would miss due to the blind zone. CloudSat would especially underestimate the total precipitation amount by 51%. During cold air outbreaks, when rolling cloud structures evolve, CloudSat overestimates the hydrometeor fraction most. Moreover, CloudSat does not resolve the separate layers of multilayer clouds but rather merges them because of its coarse vertical resolution.

Kamesh Vinjamuri et al.:

## Arctic Cloud optical properties observed from space

Clouds are believed to be one of the most important aspects of Arctic Amplification (AA). The main objective of subproject B01 is to study radiation and clouds in terms changes in top-of-atmosphere reflectance (TOAR) as observed by satellites. The initial results of Lelli et al. (2022) show almost no change in pan-Arctic TOAR values, which is contrary to expectations (expectation: the observed significant loss of sea ice extent should decrease TOAR systematically). It is concluded that the loss of brightness due to sea- ice loss is compensated by a systematic change in cloud phase. The study also showed significant regional changes with clouds cooling the Arctic surface except over the permanent and marginal sea ice zones. To assess the quality of the cloud data used (dataset from the cloud Climate Change Initiative, CCI) over the Arctic, we compared the CCI cloud products with the standard ground-based Atmospheric Radiation Measurements (ARM) measurements. The results showed good agreement with some exceptions (notably over Greenland and clouds at high altitudes). One of the main drawbacks of the CCI dataset is the lack of a mixed-phase cloud phase for a given pixel. This is one of the major deficiencies in satellite remote sensing of Arctic clouds, which could affect our understanding of the effects of mixed-phase Impact on TOAR.

Current focus is thus, to create a spectral database to identify (mainly spectral) sensitivities of mixed- phase clouds using SCIATRAN Radiative Transfer Model (RTM). SCIATRAN (polarized) RTM is available in its version 4.5 equipped with the latest water and ice spectral databases. The RTM is used with a pseudo-spherical atmosphere for various atmospheric and geometric conditions and the obtained results are presented.

Michael Lonardi et al.:

## Tethered balloon-borne measurements in the cloudy ABL: Overview and first results

The presence of clouds significantly affects Arctic boundary layer dynamics. However, the accessibility of clouds over the Arctic sea ice for in-situ observations is challenging.

Airborne observations are limited by icing and logistics, leading to a lack of high-resolution data needed for model evaluation.

The tethered balloon system BELUGA (Balloon-bornE moduLar Utility for profilinG the lower Atmosphere) was employed to profile the boundary layer at the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC), and in Ny Alesund. The 90 m3 helium-filled tethered balloon was specifically developed for the Arctic and carried a set of scientific payloads covering broadband radiation, turbulence, aerosol particles, and cloud microphysics properties.

Measurements obtained under various cloud covers are analyzed and binned to derive typical heating rates profiles. The resulting quantities are compared to the available literature, and further used to validate sensitivity studies performed by radiative transfer simulations.

In-situ observations of radiative fluxes display the importance of radiation-induced cloud top cooling in maintaining stratocumulus clouds over the Arctic sea ice (Lonardi et al., 2022). Case studies display the subsequent turbulent mixing that entrains aerosol particles into the cloud.

Hannes Griesche et al.:

## Low-level Arctic clouds can stay under the radar – Challenging determination of their impact on the surface radiation budget

Understanding the role of clouds for the radiative budget is essential for gaining progress in the understanding of the causes and consequences of changes in the atmospheric composition. This is especially true for the Arctic, as this region is currently facing rapid climate change. Here, we use the recently developed TROPOS (Leibniz Institute of Tropospheric Research) – Cloud and Aerosol Radiative effect Simulator (T–CARS) to evaluate the appropriateness of a state-of-the-art combination of ground-based cloud remote sensing observations, a radiative transfer model, and irradiance measurements for capturing the role of clouds for the radiation budget. The radiative transfer simulations were conducted based on observations obtained in the Arctic ocean in summer 2017. Spatiotemporal cloud microphysical properties were derived by the instrument synergy approach of Cloudnet and used as input for radiative transfer simulations. The input was improved by an effective approach to include low-level liquid-containing clouds, which were otherwise missed by standard remote-sensing instrumentation. The approach resulted in a closure of the radiative flux densities at the surface. The presented case study highlights the need for improvement in the applied radiative transfer model, the cloud microphysical input used to calculate the radiative flux densities, but also the irradiance sensors.

Bianca Zilker et al.:

## Investigation of weather conditions and BrO during ozone depletion events between 2010 and 2021 in Ny-Ålesund

Ozone Depletion Events (ODEs) have been observed since the late 1990s in the polar regions during spring often in combination with Bromine Explosion Events (BEEs). In a heterogeneous, autocatalytic, chemical chain reaction cycle, inorganic bromine is released from the cryosphere into the troposphere and depletes ozone sometimes to below detection limit. Besides cold temperatures favoring the bromine explosion reactions, two different meteorological conditions are mainly observed during these events: on the one hand, low wind speeds and a stable boundary layer, where bromine can accumulate and deplete ozone, and on the other hand, high wind speeds above approximately 10 m/s with blowing snow and a higher, unstable boundary layer. The second condition often occurs in combination with polar cyclones, where bromine can be recycled aloft on snow and aerosol surfaces.

In this study, a long term ozone data set from the Zeppelin mountain – located close to Ny-Ålesund – has been evaluated between 2010 and 2021 to detect ODEs. To analyze the prevailing weather conditions during the events, ERA5 reanalysis data has been used and separated between weather conditions during ODEs and no-ODEs based on the ozone data set. During ODEs lower pressure is observed east of Svalbard and higher pressure over Greenland, leading to a transport of cold polar air from the north to Ny-Ålesund. Also higher wind speed and a higher boundary layer are noticed, supporting the assumption, that ODEs often occur in combination with polar cyclones.

Using the same approach, the long-term tropospheric BrO data set from Bougoudis et al., 2020 in combination with S5P TROPOMI retrievals of tropospheric BrO have been used to analyze BrO patterns during ODEs. During ODEs in Ny-Ålesund, the satellite data show elevated values all over the Arctic, but especially north of Svalbard.

Janna Rückert & Andreas Walbröl et al.:

## New insights into atmospheric water vapor, cloud liquid water and sea ice emissivity from Polarstern expedition PS131 in the Marginal Sea Ice Zone

In summer 2022 the marginal ice zone (MIZ) north of Svalbard and in the Fram Strait was extensively studied by the multi-disciplinary Polarstern research cruise PS131 ATWAICE. We were part of the secondary-use project Water Vapor, Cloud Liquid Water, and Surface Emissivity over the Arctic Marginal Ice Zone in Summer (WALSEMA). Using radiosondes, microwave radiometers, visual and thermal infrared cameras, as well as in-situ data obtained on the sea ice floes, we were able to collect summertime data of important variables including integrated water vapor (IWV) and liquid water path (LWP). In this talk we give an overview of our measurements, involving a new microwave radiometer installation to measure ice and ocean microwave emissions, and present some preliminary results.

Most of the time, the radiometers were operated in atmospheric mode, pointing in zenith direction. From the measured atmospheric radiation, expressed as brightness temperature, we derive IWV, LWP, and profiles of temperature and water vapor with a high temporal, but coarse vertical resolution. The radiometer data is complemented by radiosondes that we launched 3 to 4 times per day to obtain temperature and humidity profiles with a high vertical resolution. Additional information about the sky conditions is given by the sky camera (infrared sensor and optical camera). These measurements allow us to analyze the spatio-temporal variability of water vapor and LWP in the Arctic Ocean and marginal sea ice zone and how they are influenced by different surface types. Here, we show an example of a strong warm air intrusion observed at Polarstern and which extended far into the MIZ.

In addition to the atmospheric mode, the radiometers were also run in surface mode: a new, self-made mirror construction allowed to measure surface brightness temperatures at different incidence angles. Mostly this was done at 53°, an angle typical for satellite observations, but we also studied the effect of changing incidence angles. A visual and an infrared camera pointing towards the surface were complementing the microwave measurements, giving us information over a broad range of frequencies. Microwave emissions are not only influenced by the temperature but also by material properties such as density or salinity of the sea ice. Thus, our on-ice in-situ measurements which we have performed on twelve ice stations complement the radiation measurements and will be used to constrain modeling studies of sea ice emissions. The observed large variability of these quantities and their up-scaling to satellite footprints are known to be major challenges and our PS131 data contributes to tackling them.

Alexander Mchedlishvili et al.:

## Pan-Arctic Sea Ice-Atmosphere Drag Coefficients Derived from ICESat-2 Topography Data

The effect that sea ice topography has on the momentum transfer between ice and atmosphere is not fully quantified due to the limitations of our current measurement techniques. Estimates derived from in-situ and airborne remote sensing measurements have insufficient temporal and spatial coverage to characterize the entire Arctic climate system. This is problematic since the Arctic Ocean is a highly dynamic environment and sea ice roughness and therefore the associated momentum transfer varies with respect to both time and space. Here we present a method to better estimate pan-Arctic momentum transfer by linking sea ice-atmosphere 10-m neutral drag coefficients with surface feature height and spacing measured by Cloud and land Elevation Satellite-2 (ICESat-2) laser altimeter satellite.

Ran Tao et al.:

## Availability and variability of light under the Arctic sea ice

Nina Maherndl et al.:

## Observations of riming in arctic mixed-phase clouds during HALO-(AC)³

Ice crystal formation and growth processes in mixed-phase clouds (MPCs) are not sufficiently understood, which leads to uncertainties of atmospheric models in representing MPCs. This talk is centered around riming, which occurs when liquid water droplets freeze onto ice crystals. While it is challenging to observe riming directly, we retrieve a proxy for riming from airborne radar measurements using data collected during the (AC)3 aircraft campaign HALO-(AC)3 performed in 2022. For this campaign, two closely collocated aircraft were flying in formation for obtaining collocated in situ and remote sensing observations.

We aim to quantify the normalized riming mass M by two methods:

1. First, we present an Optimal Estimation algorithm to retrieve M from measured radar reflectivities. We find M by matching measured to simulated radar reflectivities Ze obtained from measured in situ particle number concentrations. As forward operators, we use the Passive and Active Microwave radiative TRAnsfer tool (PAMTRA) and empirical relationships of M and particle properties. The latter are derived via model calculations done by an aggregation and riming model.

2. We then compare to M estimates derived from particle shape. We calculate the complexity of in situ measured particles, which relates particle perimeter to area. We then derive M estimates from empirical relationships that were again obtained from synthetic particles.

We compare the obtained M results derived by both methods and relate the occurrence of riming in to meteorological conditions and cloud properties to understand drivers of riming. This will lead to a better understanding of riming as a key process occurring in arctic MPCs.

Giovanni Chellini et al.:

## Does turbulence enhance ice-particle growth by aggregation and riming in Arctic low-level mixed-phase clouds? Observational evidence from Ny-Alesund

Low-level mixed-phase clouds (LLMPCs) are ubiquitous in the Arctic, and are known to significantly impact the surface energy budget. They typically display a supercooled liquid layer at cloud top, which generates intense cloud-top radiative cooling, which in turn drives buoyant production of turbulence. The effect of cloud-top turbulence on the growth of ice particles into precipitation has been widely overlooked, and lack of understanding of this interaction might impact our ability to accurately simulate Arctic LLMPCs.

We investigate the interplay between turbulence and ice growth in LLMPCs at the high Arctic site of Ny-Alesund, employing a 1-year dataset of dual-frequency polarimetric Doppler cloud radar, microwave radiometer and in-situ hydrometeor observations. The cloud radar observations in fact provide an indication of the size, shape and fall speed of ice particles. Turbulent kinetic energy dissipation rate (EDR) is retrieved employing a widely-used mean Doppler velocity (MDV) based approach. The remote sensing dataset is complemented with observations from a Video in-Situ Snowfall Sensor (VISSS).

We find evidence of enhancement of aggregation by turbulence at temperatures compatible with dendritic growth, i.e. cloud-top temperatures (CTTs) between -18 and -12°C. Dendrites are in fact known to aggregate efficiently, and higher turbulence is likely to increase the ice-ice collision rates. VISSS data suggests that the enhanced collision rates caused by higher EDRs might further lead to widespread fragmentation of dendrites. Increasing MDV with EDR and LWP is observed in MPCs with CTT warmer than -20°C, suggesting that intense turbulence increases ice-liquid collision rates as well, leading to higher degrees of riming. This effect is especially observed at CTTs warmer than -10°C. Our findings thus highlight the fundamental interplay between ice-growth processes and turbulence in Arctic mixed-phase boundary layer clouds, and we discuss the implications of our findings for widely used microphysical schemes.

# Poster Abstracts

## Poster Session I

### #01 E. Akansu et al. (A02): Determining Atmospheric Boundary Layer Height in Polar Night Using Tethered Balloon-Borne Data from MOSAiC

The Arctic lower atmosphere is characterized by a basically always present temperature inversion and often stable stratification. The vertical structure of the atmospheric boundary layer (ABL) influences the presence and longevity of clouds and, in turns, clouds have a large radiative effect on the ABL, its thermodynamic structure and turbulent processes. A helium-filled tethered balloon (volume of 9 m3) was operated during the yearlong Multidisciplinary drifting Observatory for the Study of Arcitc Climate (MOSAiC) providing in-situ measurements of turbulence during winter and spring. In winter, two distinct states of the ABL were observed: radiatively clear sky with very shallow boundary layers and, on the other hand, cloudy conditions leading to the development of a mixed layer and thus increasing the depth of the ABL. Turbulence observations facilitate the analysis of the (mostly) stable Arctic ABL in bot12h winter and spring. The turbulence profiles are used to define the depth of the surface mixed layer and to understand the influence of clouds on the vertical structure of the lower atmosphere in winter. Further, a bulk Richardson number criterion approach for defining the ABL depth is applied and compared to the turbulence method.

### #02 L. Aue et al. (D03): New Insights into Cyclone Impacts on Sea Ice in the Atlantic Sector of the Arctic Ocean in Winter

Transient cyclones are a dominant feature of short-term atmospheric variability in the Arctic winter impacting local wind speed and direction and transporting heat and moisture from lower latitudes to the Arctic. Consequences for the Arctic sea ice cover are increased wind-induced ice drift and deformation as well as ice melt or reduced ice growth due to increased downward fluxes of longwave radiation and sensible heat at the snow/ice surface.

Based on the ERA5 reanalysis and a storm tracking algorithm, we report on statistically significant impacts of transient cyclones on sea ice concentration (SIC) in the Atlantic sector of the Arctic Ocean in winter under 'New Arctic' conditions (2000 - 2020). A reduction in SIC is found prior to and during cyclones for the whole study domain, while an increase in SIC following cyclones is limited to the Barents Sea. This results in a regional difference between increased SIC in the Barents Sea and reduced SIC in the Greenland Sea as the net effect from 3 days prior to 5 days after the cyclone passage. Hereby, largest SIC changes occur during intense cyclones, in particular when preconditioned by locally low to medium SIC. We further provide evidence that cyclone impacts on SIC have amplified compared to the 'Old Arctic' (1979 - 1999), particularly in the Barents Sea.

To decompose cyclone impacts on sea ice into dynamics and thermodynamics, we analyze a series of three intense winter cyclones that occurred in February 2020 in the Barents Sea utilizing nudged coupled model simulations. The first results indicate that the response of the sea ice cover to this series of cyclones is dominated by dynamic processes, while the advection of warm and moist air masses only plays a secondary role on the considered timescale of up to three weeks.

### #03 A. Walbröl et al. (B05): Combining a low with a high frequency microwave radiometer to retrieve atmospheric water vapour and liquid water path

### #04 J. Hachmeister et al. (associated): Trend analysis of XCH4 in the Arctic

Methane (CH4) is a globally well-distributed greenhouse gas and one of the most important drivers of climate change. The global mean concentration of CH4 has increased by 156% between 1750 and 2019 reaching 1866+-3.3 ppb in 2019. The time dependence of the trend is not well understood. For example, it is not clear why methane growth rates reached record high values in 2020 and 2021. Roughly speaking an increase in global methane concentrations can be observed between the 1980s until 2000 and from 2007 until the present, with a plateau between 2000-2007. Afterwards the increase continued with accelerated growth in the last few years.

The Arctic contains large amounts of soil organic carbon (SOC) which is stored in the permafrost regions (ca. 1300 Pg) of which roughly 800 Pg is perennially frozen. Continuous warming of the Arctic may lead to increased permafrost degradation and rapid SOC loss through release of carbon dioxide (CO2) and/or methane. The comparatively high temperature increase in the Arctic, compared to the rest of the world, also called "Arctic amplification" and the current records in global methane increase during the years 2020 and 2021 according to various calculations call for enhanced monitoring of global methane emissions. Satellite data from Sentinel-5P (S5P) brings an unprecedented spatio-temporal coverage of the globe and allows for a detailed examination of changes in column-averaged dry air mole fractions of methane (XCH4). On this poster we present yearly methane increases derived from S5P/TROPOMI data for both global and zonal averages.

### #05 F. Heukamp et al. (D04): Control of Varying Atmospheric Forcing Mechanisms on the Barents Sea Atlantic Water Inflow

The Barents Sea Atlantic water inflow is governed by two main mechanisms. Downstream in the Nordic Seas, along coast winds at the Norwegian coast modify the sea surface height gradient and thus geostrophic flow of the Norwegian Atlantic Current. Thereby, the main variability of inflow of Atlantic Water into the Barents Sea is controlled by large scale patters as the North Atlantic Oscillation having a dominant impact on the large scale winds. Locally in the Barents Sea, cyclonic wind systems over the shelf of Svalbard have an impact of the return flow of modified Atlantic Water - a mixture of cold Polar waters and warm Atlantic water - leaving the Barents Sea in the northern part of the Barents Sea Opening towards the west. In dedicated model experiments, we disentangle the contributions of locally and downstream forced variability of the Atlantic water flow through Barents Sea Opening. Our results show decadal variations in the dominance of the two main drivers of the flow. Additionally, we observe periods with strong co-variability as well as periods with no co-variability in the two contributions to the Atlantic water flow.

## #06 M. Klingebiel et al. (B03): Airborne Remote Sensing Measurements of Liquid-Phase Cloud Properties over the Open and Sea Ice-Covered Arctic Ocean

To study the contrast of cloud properties over the open and sea ice-covered Arctic Ocean, data from two airborne campaigns are analyzed. For this purpose, we apply a retrieval technique using spectral solar radiance measurements reflected from clouds to derive cloud properties of Arctic liquid-phase clouds. We quantify the effects of ice particles on the results of the retrieval method, and conclude that accurate values of the effective radius of the cloud particles can be retrieved for clouds that are dominated by liquid water droplets. However, in this case the liquid water path can be derived with large uncertainty only. These results are confirmed by a comparison with concurrent in-situ measurements. Considering these limitations, the retrieval method is applied to airborne measurements of cloud-reflected spectral solar radiances to characterize and understand the differences between microphysical properties of clouds observed over open ocean and sea ice. The results show that more large cloud droplets form over the open Arctic Ocean than over the sea ice. This systematic difference is mostly caused by the temperature difference of the underlying surfaces and corresponding convection processes. Furthermore, we identified significant differences of ice particle number concentrations in the upper parts of the clouds between the two campaigns, which are related to the different atmospheric temperatures prevailing during the two campaigns.

## #07 M. Lauer et al. (E04): Influence of Atmospheric Rivers and associated weather systems on precipitation in the Arctic

The stronger warming in the Arctic compared to the global mean – a phenomenon called as Arctic Amplification - has different effects, including changes in the hydrological cycle and thus the precipitation. In the Arctic, there are two major sources of moisture leading to increased precipitation formation: These are the enhanced local evaporation due to the missing insulation of sea ice and the poleward moisture transport which is often associated with atmospheric rivers (ARs).

Preliminary results have shown that ARs are a significant source for rain and snow in the Arctic. However, precipitation associated with an AR was not only concentrated within the AR itself. Precipitation also occurs within a wider area of the cyclones often connected to ARs. Therefore, we developed a new method based on ERA5 reanalysis to distinguish precipitation within the AR shape and the precipitation related to cyclones and fronts. The application of this method for case studies during two campaigns (ACLOUD May/June 2017; AFLUX March/April 2019) has shown seasonal differences. During the early summer campaign, precipitation (both rain and snow) was more confined within the AR shapes and warm fronts. Whereas during the late winter and early spring campaign, precipitation (predominantly snow) was more restricted to the cyclone regions. Generally, a higher precipitation intensity was found in cases where ARs and cyclones were connected to each other. However, how do the seasonal differences look like when analyzing the last few decades? To answer this question, we apply this method to quantify the occurrence and influence of ARs and related cyclones during the last decades. For this climatological analysis we use the ERA5 reanalysis data for the period from 1979-2020 as input for two AR detection algorithms (Guan & Waliser, 2018; and Gorodetskaya, 2020).

## #08 L. Mei et al. (B01/B02): Tropospheric aerosol optical thickness trend above the ocean in the Arctic during 1981-2020

## #09 J. Michaelis et al. (A03): Turbulence measurements during HALO-(AC)³ and AFLUX in the atmospheric boundary layer over the Arctic MIZ

The structure of the polar atmospheric boundary layer (ABL) over the marginal sea ice zone (MIZ) is strongly influenced by the environmental conditions, such as cloud cover and state of the sea ice. Here, we present vertical profiles of mean and turbulent ABL quantities obtained in springtime conditions during Arctic cold air outbreaks (CAOs) from the campaigns AFLUX and HALO-(AC)3. Although both cases represent CAOs, the environmental conditions (clouds, sea ice) for the two cases strongly differed. Thus, we raised three questions:

- How do clouds and sea ice fraction affect the vertical profiles of mean and turbulent quantities over both MIZ and open ocean?
- How strong is the impact of an upper cloud layer in slightly convective conditions?
- Is the impact of only one cloud layer 'visible' in the turbulence structure over the open ocean in a strongly convective situation?

We find that in one case a loose sea ice cover and open leads caused a convective ABL already upwind of the ice edge, whereas a stable ABL is found over sea ice for the other case. This difference strongly influences the vertical profile of all quantities analysed. Over open water, a strongly convective ABL is found in both cases but with large differences among them, concerning especially the profile of the turbulent momentum flux and turbulent kinetic energy. Moreover, the shapes of the latter profiles point to an impact not only of clouds but also external mesoscale effects. We propose that the most reasonable explanation for this is an influence by the orography of Svalbard on the northeasterly flow (tip jet).

### #10 H. Niehaus et al. (C01): Melt Pond Fractions in the Arctic from Different Perspectives

Melt ponds forming on Arctic sea-ice in summer have a significant influence on the Arctic climate. They reduce the surface albedo and impact the heat and mass balance of the sea ice. The seasonal development of melt ponds features fast and local changes in areal fraction of surface types, showing the necessity of improving melt pond fraction (MPF) products and datasets on regional and pan-Arctic scales. However, the retrieval of surface properties is characterized by balancing spatial resolution with coverage and temporal resolution. Here, we present melt pond fraction analysis from in-situ measurements as well as from air-borne and satellite observations. The focus is on the Fram Strait area using measurements obtained during the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition, in summer 2020, and the Atlantic Water pathways to the ice in the Nansen Basin and Fram Strait (ATWAICE) campaign, in summer 2022.

### #11 N. Risse et al. (associated): Evaluation of TELSEM2 using observed sea ice emissivities up to 340 GHz in preparation for the Ice Cloud Imager (ICI)

The use of Ice Cloud Imager (ICI) observations for atmospheric applications in polar regions requires robust sea ice emissivity estimates. Whereas the atmosphere is nearly opaque above 200 GHz in lower latitudes, the surface contributes significantly to satellite observations up to 480 GHz under cold and dry conditions. Due to the challenging physical modelling of the sea ice radiative transfer and the limitation of current spaceborne capabilities in the polar orbit to frequencies below 200 GHz, little is known about the spectral sea ice emissivity variation at ICI frequencies.

The Tool to Estimate Land Surface Emissivity from Microwave to Submillimeter Waves (TELSEM2) provides a first-guess emissivity estimate for land and sea ice surfaces and is widely used in fast radiative transfer models. TELSEM2 is anchored to an SSM/I climatology and was extrapolated up to 700 GHz in preparation for ICI using satellite observations above 100 GHz. We use sea ice emissivities calculated from observations with the passive channel of the Microwave Radar/radiometer for Arctic Clouds (MiRAC) cloud radar MiRAC-A (89H GHz) at an inclination of 25° and the nadir-viewing radiometer MiRAC-P (six double-side bands around 183.31V, 243H, 340H GHz) combined with a KT- 19 infrared radiometer on-board the Polar 5 aircraft during the ACLOUD (May/June 2017) and AFLUX (March/April 2019) campaigns to evaluate TELSEM2. Contributions by atmospheric gases are taken into account using the Passive and Active Microwave radiative TRAnsfer (PAMTRA) model with ancillary information on the thermodynamic structure of the atmosphere. In addition, data measured by the radiometers Humidity And Temperature PROfiler (HATPRO; seven K-band channels with V-pol, seven V-band channels with H-pol) and MiRAC-P deployed on the R/V Polarstern from June to August 2022 will provide information on the angular variation of the sea ice emissivity up to sub-mm waves under ICI geometries.

A comparison of the emissivity gradients between different window channels observed from the aircraft and TELSEM2 shows a good agreement above 183 GHz, whereas the positive emissivity gradient from 89 to 183 GHz which is also found during past airborne campaigns is not captured by TELSEM2. Additionally, a consistent bias is found between airborne nadir emissivities and TELSEM2 in spring, which may be explained by the angular extrapolation from SSM/I geometries to nadir within TELSEM2 or seasonal effects during the campaign period.

### #12 P. Saavedra Garfías (B07): Studying the Influence of Sea Ice Lead Fraction on Wintertime Cloud Macro- and Microphysical Properties During the MOSAiC

This study explores the influence of sea ice lead fraction on the micro- and macrophysical cloud properties during the wintertime of the MOSAiC expedition. Cloud properties such as cloud base height, liquid- and ice water content have been previously found to have statistically distinguished features under the presence of sea ice leads that are thermodynamically coupled to the clouds observed above the central observatory RV Polarstern .

The study exploits a novel sea ice lead fraction product based on sea ice divergence. Sea ice divergence is estimated from sequential images of space-borne synthetic aperture radar with a spatial resolution of 700 m. The lead divergence product, being independent of cloud coverage, offers the unique advantage to detect opening leads at high spatial resolution.

Statistics for the wintertime cloud properties based on the coupling state with the sea ice fraction and sea ice divergence will be presented as an approach to study Arctic clouds and their interaction with sea ice.

Results are shown based on a recent improvement on the lidar-based cloud droplet detection in thick or multi-layer clouds by Cloudnet (Illingworth et al. 2007, Tukiainen et al. 2020) by applying a deep learning convolution neural network (CNN) to cloud radar Doppler spectra (Schimmel et al. 2022). The CNN has been specifically trained for this study using multi-year Arctic wintertime observations from the Atmospheric Radiation Measurement (ARM) North Slope of Alaska site in Utqiaġvik, Alaska.

### #13 M. Schäfer et al. (A03): First Analysis and Potential of Thermal Infrared Imagery measured with VELOX during HALO-(AC)3

The new airborne thermal infrared imager VELOX (Video airbornE Longwave Observations within siX channels), which is operated on board of the German High Altitude and Long Range Research Aircraft (HALO) of the German Aerospace Center (Deutsches Luft und Raumfahrtzentrum, DLR) was used during the HALO-(AC)3 campaign. It measures two-dimensional (2D) fields of upward radiance, which can be converted into 2D fields of brightness temperature. The imager provides six spectral bands in the thermal infrared wavelength range from 7.7 µm to 12 µm. It covers a field of view of 35.5° by 28.7° distributed over 640 by 512 spatial pixels (10 m spatial resolution at target distance of 10 km). Examples of VELOX observations obtained during HALO-(AC)3 will be presented, including ideas for the investigation of Arctic cloud (fraction, phase, top altitude, effective particle size) and surface (snow/ice/water discrimination, snow grain size) properties. Based on the existing literature, simulations and combinations of the specific VELOX band characteristics will be shown to provide first estimates of the VELOX capabilities for such retrievals. First comparisons, using the same simulation setups for MODIS and VELOX, reveal that the VELOX band characteristics lead to comparable or even better sensitivities with respect to cloud and surface property retrievals.

### #14 N. Schnierstein et al. (A01): A year in LES: Standardized daily high-resolution Large Eddy Simulations of the Arctic boundary layer during the MOSAiC drift

### #15 B. Basudev et al. (B02): Spring and summertime aerosol optical depth variability over Arctic snow and ice from space-borne observations and GEOS-Chem 3-D model simulations.

The Arctic is a unique part of the earth's system and its climate is undergoing a period of change which is known as the Arctic Amplification. Our knowledge and understanding of the spatiotemporal variability, direct and indirect effects of aerosols on Arctic climate change in global climate models is not yet adequately understood. The number of ground and satellite based remote sensing based observational studies investigating the impact of atmospheric aerosols on Arctic climate is up to now limited. In this study, the total aerosol optical depth (AOD) is retrieved from space-based Advanced Along-Track Scanning Radiometer (AATSR) data over the Arctic snow and ice using a new retrieval algorithm called AEROSNOW during the period 2003 to 2011. The AOD, retrieved by AEROSNOW has been validated by comparison to ground based measurements made by AERONET ground based measurements at PEARL, 0PAL, Hornsund and Thule stations in the Arctic.

AEROSNOW AOD is typically less than 0.15. The comparison with AOD values yields a Pearson correlation coefficient of $R = 0.61$ and $RMSE = 0.02$ were obtained for the monthly mean satellite and ground observations during spring and summer. Furthermore, AEROSNOW results were used to compare the estimates of aerosol optical properties and seasonal variability in the Arctic derived from GEOS-Chem global 3-D chemical transport model over pan-Arctic snow and ice region. Further by combining the datasets from satellite-based observations and model we present a climatology of spring and summer AOD over Arctic snow and ice for the period from 2003 to 2011. Both the space-based observations and the model simulations show a consistent spatiotemporal distribution and climatology in both spring and summer. The distinct variability of the AOD components derived from the GC simulations is observed in spring and summer, which can be attributed to their sources of origin in these two different seasons. In spring, aerosols in the Arctic originate predominantly from long-range anthropogenic transport from low and mid-latitudes, while in summer natural aerosol sources within the Arctic Circle (>60°N) predominate.

AOD values in the Arctic are generally highest in spring and lowest in summer. The latter is due to the fact that more precipitation falls in summer and consequently more wet scavenging occurs than in spring. Although precipitation and wet scavenging are high, primary carbonaceous aerosols, especially organic carbon (OC), peak in summer because of its high hydrophobicity. The combination of hydrophobicity and expected increasing boreal forest fires means that carbonaceous aerosols (black carbon, BC, and organic carbon, OC) are an increasingly important contributor to total AOD over Arctic sea ice in summer.

In addition, the study showed, that the relative contribution of sulfate to the total AOD over Arctic sea ice decreases, while carbonaceous aerosols increase when moving from spring to summer. The shift of the higher fraction of biomass burning aerosols in summer suggests that boreal forest fires penetrate deeper into the high-latitude Arctic sea ice than expected, which will be of relevance for the future Arctic climate.

### #16 S. Tiedeck et al. (E04): Atmospheric River during MOSAiC in Mid-November 2019: Transformation Processes and Impact on the Surface Energy Budget

Atmospheric Rivers (ARs) can carry anomalously high amounts of water vapor into the Arctic. It has been shown that the associated enhanced moisture in the atmosphere leads to increased downward longwave radiation and related surface warming. In this work we focus on an event which occurred in mid-November 2019, where an AR penetrated the Arctic from the northern North Atlantic and passed over the RV Polarstern during the MOSAiC expedition.

We provide a comprehensive study of this AR event, its spatiotemporal structure and impact on the surface energy budget (SEB) with respect to the surface type. We use ERA5 reanalysis data and model output from limited area simulations of ICON (ICON-LAM). The Eulerian view is complemented by Lagrangian trajectories to evaluate the transformation of air masses. Furthermore, results from ICON-LAM sensitivity studies concerning different parameters (e.g., amount of intruding moisture) are discussed to provide enhanced process understanding.

We find that the event shows a less negative SEB over open ocean and a change from negative to positive SEB over sea ice. The main contribution of this effect over open ocean is due to both a less negative surface sensible heat flux and less negative longwave net radiation, whereas over sea ice the dominant factor is a positive sensible heat flux. Reducing the inflowing moisture causes a reduced impact on the SEB, especially due to less clouds over open ocean and less downward longwave radiation.

### #17 G. Wallentin et al. (associated): Sensitivity Studies on Arctic Multilayer Clouds

Multilayer clouds have been shown to frequently occur in the Arctic but have not yet been studied in great detail. Preliminary data from the MOSAiC campaign shows a high frequency of these clouds, highlighting their importance to the Arctic climate system. Previous studies have shown the radiation impact of multilayer clouds but here we focus on analysing the cloud system on a microphysical level as well as their sensitivity to initialisation and resolution. In this project we are setting up the ICON model for real cases in a one-way nested limited area mode with turbulence partially resolved using the ICON-LEM module for large eddy simulations. Three nests are used with the highest resolution at 200 meters with 38 data points in the lowest kilometre of the vertical column. Both CCN and INP activation are currently prescribed. However, the KIT developed ICON-ART module is being set-up for the use of interactive aerosols including emission, dynamics and transport of sea salt and sulfate for warm cloud nucleation. Here I will present a case of multilayer clouds that has been chosen from the MOSAiC campaign from the 1st to the 3rd of September 2020 and studied in detail. The effects of horizontal and vertical resolution, initialisation data and boundary conditions as well as sensitivity studies on INP scaling have been investigated. Preliminary results on hydrometeors show a larger variation with horizontal resolution than INP scaling, hinting that ice crystal concentration is governed by updrafts rather than microphysics. This project is funded through the BMBF.

## Poster Session II

### #18 S. Becker et al. (A03): Airborne measurements of the surface cloud radiative effect in the Fram Strait during different conditions

The radiative energy budget (REB) of the surface in the Arctic largely depends on the presence of clouds and their properties. The impact of clouds on the REB is quantified by the surface cloud radiative effect (CRE). Due to the counteracting effects of clouds in the solar and thermal-infrared spectral ranges, the combination of, i.a., cloud, surface, and illumination conditions determines the total (warming or cooling) effect of clouds.

This study uses airborne broadband radiation measurements performed during low- level flight sections to characterize the surface CRE over the highly contrasting sea ice and open ocean surfaces, and during different meteorological conditions. The data from three campaigns conducted during different seasons in the vicinity of Svalbard are analyzed. It was found that clouds mostly have a warming effect over sea ice, while they cool open ocean surfaces. Furthermore, first analyses of various cases revealed distinct CRE characteristics during warm air intrusions and marine cold air outbreaks.

### #19 K. Ebell et al. (E02): Multi-year precipitation characteristics based on in-situ and remote sensing observations at the Arctic research site Ny-Ålesund, Svalbard

Precipitation is a key variable in the hydrological cycle. However, observations of precipitation are quite challenging and even more so in remote locations such as the Arctic.

The Arctic is experiencing a rapid changing climate with a strong increase in near-surface air temperature, known as Arctic Amplification. In particular, the Svalbard archipelago being located in the warmest region of the Arctic reveals the highest temperature increase (Dahlke and Maturilli, 2017).

Such changes also affect the hydrological cycle. For example, climate models reveal a strong increase in precipitation in the Arctic (McCrystall et al., 2021) with rain becoming the most dominant precipitation type (Bitanja and Andry, 2017). Continuous detailed observations, which can also be set in context to satellite products and reanalyses data, are necessary to better understand precipitation and precipitation related processes in the Arctic.

In this study, we make use of the complementary precipitation observations performed as part of the Transregional Collaborative Research Centre on Arctic Amplification TR172 (http://www.ac3-tr.de; Wendisch et al., 2017) at the Arctic research station AWIPEV at Ny-Ålesund, Svalbard, to analyze precipitation characteristics in detail. The observations include an OTT Pluvio2 weighing gauge, an OTT Parsivel2 distrometer and a METEK MRR-2 micro rain radar (MRR). While the Pluvio and the Parsivel provide information on surface precipitation amount and type, the MRR provides information on the vertical structure of precipitation up to a height of 1 km. Measurements are available since spring/summer 2017 allowing for an analysis of more than 4 years of data.

First results show that the yearly precipitation amount based on Pluvio ranges from 306 mm to 552 mm (values are uncorrected for undercatch). Using the one-minute resolved data of Parsivel, precipitation frequency is highly variable within the different months ranging from 0.4 % to 18.8 % with solid precipitation being the most dominant type typically from September to March and liquid precipitation in the months May to August.

In addition to monthly and yearly statistics, we will also characterize and analyze in detail the individual precipitation events. One question to be addressed is how much of the precipitation is related to atmospheric rivers (ARs). ARs are long, narrow, and transient corridors of strong horizontal water vapor transport which transport 80-90 % of the poleward moisture transport. Although their occurrence in the Arctic is limited, they are a significant source of rain and snow in the Arctic.

Understanding linkages between precipitation and weather events and using observational data to evaluate models and reanalysis in the current climate will aid developing more accurate future predictions.

### #20 L. Heizmann et al. (associated): Water vapour profile retrieval over Ny-Ålesund (Svalbard) using Fourier transform emission spectroscopy

We present results of water vapour profile retrievals over Ny-Ålesund (Svalbard) from measurements taken between September 2019 and April 2021. Using a Fourier transform spectrometer, we measure clear-sky mid infrared emission spectra in zenith direction with a resolution of 0.08 $cm^{-1}$. This is sufficient to separate individual water vapour emission lines. The retrieval code SFIT4 is used to obtain water vapour profiles via an optimal estimation approach which are compared to daily radiosonde measurements.

### #21 Z. Hofmann et al. (C04): Subduction as Observed at a Submesoscale Front in the Marginal Ice Zone in Fram Strait

The marginal ice zone in Fram Strait is a highly variable environment, in which dense Atlantic Water and lighter Polar Water meet and create numerous mesoscale and submesoscale fronts. Here we present the first results of a front study conducted near the ice edge in central Fram Strait, where Atlantic Water subducted below Polar Water. We posit that the frontal dynamics associated with the sea ice edge also apply beyond, both to the open and the ice-covered ocean in the vicinity. The study comprises a total of 54 high resolution transects taken over the course of a week during July 2020, most of which were oriented across-front. They include current velocity measurements from a vessel-mounted ADCP, and temperature and salinity measurements from either an underway CTD or a TRIAXUS towed vehicle, with the latter also providing measurements of various biogeochemical properties. Additionally, 22 CTD stations were conducted, and 31 surface drifters deployed. We discuss the dynamics of the frontal development, including potential sources of instability and subduction of Atlantic Water and biological material in a highly stratified region. Beneath the stratified upper ocean, subduction is clearly visible in the biogeochemical properties, and water samples indicate a substantial vertical transport of smaller particles. Surface drifters accumulated in subduction areas, where sea ice, if present, would also accumulate. Our study thus demonstrates the importance of frontal dynamics for the vertical transport of water properties and biological material, and the highly variable development of the marginal ice zone in Fram Strait.

### #22 I. Höschel et al. (D01): Influence of variations in sea ice concentration on Arctic climate in an ensemble of idealized simulations with ICON

The global numerical weather prediction model ICON is used in climate mode to perform long-term sensitivity simulations under different boundary conditions. Sea ice cover and concentration of greenhouse gases are modified to assess their influence on atmospheric circulation in the troposphere and stratosphere. The presentation will focus on the modulation of large-scale horizontal energy transport in the model by the modified forcing.

### #23 E. Jäkel et al. (C01): Performance of the revised surface albedo scheme of HIRHAM-NAOSIM

### #24 D. Ji et al. (E02): Ground-based remote sensing of aerosol properties using high resolution infrared emission and Lidar observations in the high Arctic

Arctic amplification, the phenomenon that the Arctic is warming faster than the global mean, is still not fully understood. The Transregional Collaborative Research Centre TR 172 - Arctic Amplification: Climate Relevant

Atmospheric and Surface Processes (AC)3 funded by the DFG (German research foundation) contribute towards this research topic. For the purpose of measuring aerosol components, a Fourier-Transform InfraRed spectrometer (FTS) for measuring downwelling emission since 2019 and a Raman-Lidar are operated at the AWIPEV research base in Ny-ÄJesund, Spitsbergen (11 ° E, 78°N).

To do aerosol retrieval using measurements from the FTS, a retrieval algorithm based on Line-by-Line Radiative Transfer Modeland DIScrete Ordinate Radiative Transfermodel (LBLDIS), is modified for different aerosol types (dust, sea salt, black carbon, and sulfate), aerosol optical thickness (AOT) and effective radius (Reff). Using Lidar measurement an aerosol and cloud classification method is developed for providing basic information about the distribution of aerosols or clouds in the atmosphere and used as an indicator to do aerosols or clouds retrieval in FTS. Therefore, a two-instruments joint observation scheme is designed and is performing on the data measured from 2019 to present. In order to show this measurement technique in details, two case studies are selected, one is an aerosol-only case on the 10th of June 2020 and the another is a cloud-only case on 11th of June 2020. In the aerosol-only case, the retrieval results show that sulfate is the dominant aerosol during the whole day, followed by dust and black carbon. Sea salt shows the lowest AOT value as its weakest emission ability in infrared waveband. Such proportions of sulfate, dust and BC also show good agreement with Merra-2 reanalysis data. Besides, comparing with sun-photometer (AERONET), the daily variation of aerosol AOT retrieved from FTS is similar with that in sun-photometer. In the cloud-only case study, Lidar distinguishes the cloud signal from aerosols accurately, giving a very good information on the state of the atmosphere. For showing the importance of Lidar measurement in the retrieval of FTS, two versions of retrieval algorithm, one for cloud retrieval and another for aerosols retrieval are applied for gaining cloud parameters and aerosol parameters respectively. The result shows that without information from Lidar measurement, the signal of cloud is misunderstood and retrieved as four aerosols in FTS, which indicates that the combination of both measurements is necessary and helpful in our aerosol retrieval.

### #25 B. Kirbus et al. (associated): Airborne observation of air mass transformations during HALO-(AC)3

Synoptic-scale events termed Warm Air Intrusions and Cold Air Outbreaks push large amounts of air either into or out of the Arctic. The accompanying air mass transformations (AMTs) still challenge models. Uncertainties lie e.g. in the correct depiction of phase transitions of boundary-layer clouds, correctly assessing heating/cooling rates, and the spatiotemporal scales of the AMTs. Fortunately, the HALO-(AC)3 airborne campaign which took place in spring 2022 offers an unprecedented observational database of Arctic AMTs.

Here, we describe how a Lagrangian analysis of the full airborne campaign is performed. Using all long-range flights of HALO as input, a large database of same-day and next-day trajectory matches is presented. Finally, a short case study depicts how Lagrangian analysis can be applied to track the evolution of warm and moist air on its pathway into the central Arctic. Overall, our results confirm that HALO-(AC)3 indeed was the first successful Lagrangian Arctic airborne campaign.

### #26 T. Kiszler et al. (E03): Studying the representation of macro- and microphysical cloud properties at Ny-Ålesund in ICON-LEM12

Using several months of high-resolution ICON-LEM simulations, we evaluated the representation of the liquid water path, integrated water vapour, as well as vertical profiles of humidity and temperature at Ny-Ålesund (Svalbard). We found a good agreement in the large-scale dynamics and variables between the model and observations we used from the super-site AWIPEV. As next step we want to understand the deficiencies which we found related to the phase-partitioning in the clouds, which showed too much ice production in the model. To achieve this we created a tool to run the 2-moment microphysics scheme, implemented in ICON, independently of the model. Using the output of actual ICON runs as input for our offline microphysics runs, we can evaluate the impacts of changes to the microphysical processes on the development of the clouds.

### #27 W. Körtke et al. (C04): Circulation Changes in the Atlantic Water derived from Transient Tracers in the Arctic Ocean

The circulation of the Atlantic Water in the Arctic Ocean is changing over time and under the influence of different atmospheric pressure systems as the Arctic Oscillation. Transient anthropogenic tracers, e.g. SF6 and CFC-12, can be used to calculate water ages and thus provide information on circulation and ventilation processes. The input of these gases into the ocean only happens if the water is in contact with the atmosphere, since this is the only source to the ocean. For the Atlantic Water of the Arctic Ocean, the Fram Strait is the location with the last atmospheric contact, before the water mass subducts below the surface layers and spreads further into the Arctic Ocean. The exact pathways of the Atlantic Water are not known, especially in the Canada Basin far away from Fram Strain, and their dependence on the phases of the Arctic Oscillation. In this study, we show that a previously suggested circulation pattern for the mixed phase of the Arctic Oscillation is not inline with observed tracer ages. While the transect located approximately at 180°W (T1) shows young ages in agreement with an inflow branch of the Atlantic Water, the ages are up to 10 years higher along a transect located at 150°W (T2) indicating a discontinuity in the circulation in 2015. These same transects are also analysed for 1994 (T1) and 2005 (T2) during a positive and negative phase of the Arctic Oscillation index, respectively. The results show agreement between previously proposed pathways and the tracer ages.  Our results show that the transient tracer add important additional information, and that we can use them to improve our knowledge of the flow pattern of the Atlantic Water in the Arctic Ocean during different Arctic Oscillation phases. Especially since the Arctic Oscillation is changing, it is of large interest to predict how the circulation could react.

### #28 C. Lüpkes et al. (A03): A package of momentum and heat transfer coefficients for the stable atmospheric surface layer

The polar atmospheric surface layer is often stably stratified, which strongly influences turbulent transport processes between  the atmosphere and sea ice/ocean. Transport is usually parametrized applying Monin Obukhov Similarity Theory (MOST) which delivers transfer coefficients as a function of stability parameters (see below). In a series of papers (Gryanik and Lüpkes, 2018;  Gryanik et al., 2020,2021; Gryanik and Lüpkes, 2022) it has been shown that differences between existing parametrizations are large, especially for strong stability. One reason is that they are based on different data sets, for which the  origin of differences is still unclear.  In this situation Gryanik et al. (2021) as well as   Gryanik and Lüpkes (2022) proposed a numerically efficient method, which can be used for most of the existing data sets and their specific stability dependences. A package of parametrization resulted  that is suitable for its application in weather prediction and climate models. Especially, calculation of fluxes over sea ice were improved. Combined with latest parametrizations of surface roughness it has a large impact on large scale fields as shown recently by Schneider et al. (2021) who applied some members of the package.

### #29 S. Mehrdad et al. (D01): Sensitivity of Arctic large-scale circulation to regional radiative forcing over Europe using Deep Learning

Global warming has been observed to be more severe in the Arctic compared to the rest of the world. This enhanced warming, i.e., Arctic Amplification is not just the result of local feedback processes in the Arctic. Here, we investigate the sensitivity of the Arctic large-scale circulation to regional radiative forcing over Europe by analyzing sensitivity experiments using the Max Planck Institute Earth System Model (MPI-ESM) coupled atmosphere-ocean–land surface model. A Deep Learning algorithm is used to analyze the Arctic circulation regimes' response to negative radiative forcing anomalies over Europe. The radiative forcing over Europe does not introduce new circulation patterns, while it modifies the circulation regime occurrence frequencies. In particular, the blocking over Western/Central Europe shows reduced occurrence frequency in autumn/early winter if the negative forcing is exerted. This reduces the wave propagation to the stratosphere in autumn/early winter, which in turn results in a stronger and more undisturbed stratospheric polar vortex. The stronger polar vortex then feedbacks the tropospheric circulation by decreasing the North Atlantic Oscillation negative phase (NAO-) occurrence in spring. Both blocking over Europe and NAO- circulation regimes are associated with the Arctic sea ice loss in the Atlantic section. Thus, modified radiative forcing over Europe can contribute to Arctic amplification by modifying the occurrence frequency of circulation regimes.

### #30 S. Mertes et al. (B03): Comparison of cloud particle residual and ambient aerosol particle properties inside and outside arctic clouds measured during ACLOUD and HALO-AC3

Low-level supercooled and mixed-phase clouds are suspected to contribute considerably to the amplified warming of the Arctic. Therefore, a better understanding of the formation and persistence of these arctic clouds is needed. Closely related to the cloud formation is the question, on which arctic aerosol particles these clouds are formed and what are the sources of those nuclei. They might be locally produced, emitted or advected within the boundary layer reaching the cloud base or might be long range transported through the free troposphere and entrained into the cloud from above. This again seems to depend mainly on the situation whether the cloud is capped by or extends into the inversion layer.

Therefore, the investigation of the microphysical and chemical aerosol properties of particles that were involved in arctic cloud formation, which should furthermore result in indications about their sources, was part of the aircraft-based field campaigns ACLOUD and HALO-AC3, which took place in May/June 2017 and March/April 2022 from Longyearbyen (Svalbard). Research flights were carried out over open sea water, the marginal sea ice zone and sea ice, whereby hydrometeors of arctic low and mid-level clouds were sampled in-situ by means of a Counterflow Virtual Impactor (CVI) inlet aboard the Polar 6 aircraft. After evaporating the condensed water inside the CVI, dry cloud particle residuals (CDR) which are considered as the original cloud forming particles, were released and characterized. Below and above the clouds, the CVI was deployed as an aerosol inlet to sample the prevailing ambient particles (AP) characterized in the same way as the CPR. The inferred aerosol parameters of AP and CDR are related in order to derive whether the cloud forming particles have been located before in the boundary layer or the free troposphere.

### #31 M. Moser et al. (associated): A year in LES: Standardized daily high-resolution Large Eddy Simulations of the Arctic boundary layer during the MOSAiC drift

Airborne in-situ cloud observations were carried out over the northern Fram Strait between Greenland and Svalbard during late spring 2019 and late summer 2020. Due to different seasons, sea ice extent differed strongly in this region between the two periods. In total 734 minutes of low-level in-situ cloud measurements have been performed during 20 research flights over the sea ice, the marginal sea ice zone and the open ocean. The instruments were operated on the Polar 5 research aircraft belonging to the Alfred Wegener Institute.

In this study, we investigate microphysical cloud properties during two different seasons and reveal a strong connection to surface conditions. Depending on the present environmental state, we observe median cloud particle number concentrations from 0.28 to 55 $cm^{-3}$ and median estimated cloud water content between 0.05 and 0.17 $m^{-3}$.

In summer, we find an overall enhanced particle number concentration which exceeds the spring values by close to a factor of 90. A consistent increase of particle number concentration over the sea ice and independent from seasons is explained by different surface processes emitting sea salt. Over the ocean and in general in summer, the atmospheric conditions favour an enhanced cloud water content and lead to an increased growth rate of droplets and ice particles.

By analysing microphysical properties of 1 Hz bulk particle measurements in total 4 different classes of particle types can be detected: particles in a mixed-phase state, liquid phase, ice-phase and aerosols. We relate the classes to their environmental conditions and show the mixed-phase state is the most dominant phase during spring, pure ice clouds exist mainly over the ocean during spring and particles in summer are most likely in a liquid state.

This work presents microphysical properties of Arctic low-level clouds, using airborne in-situ observations, and relate changes to environmental conditions. This study addresses the question of how the microphysics of Arctic clouds may transform as the region warms, large scale weather pattern changes and sea ice extend reduces.

### #32 H. Müller et al. (associated): Representation of Arctic mixed-phase clouds in ECMWF forecasts during ACLOUD

The representation of Arctic clouds in numerical weather prediction models is challenging, especially for mixed-phase clouds with both a liquid and ice phase present. This cloud type is frequently observed in the Arctic with a pronounced longevity. We compare measurements conducted during the Arctic CLoud Observations Using airborne measurements during polar Day (ACLOUD) campaign, which took place in May/June 2017 northwest of Svalbard, Norway, with the operational 'Atmospheric Model high resolution' configuration (HRES) of the Integrated Forecasting System (IFS), operated by the European Centre for Medium-Range Weather Forecasts (ECMWF). Instead of using cloud retrieval products from airborne remote sensing, the comparison is performed in the observational space of spectral solar irradiances reflected by the clouds. To allow such an analysis along the flight track at flight level, the operational ecRad radiation scheme of the IFS is used in offline mode. Besides the HRES model output, vertical profiles of concentrations of trace and greenhouse gases provided by the ECMWF Atmospheric Composition Reanalysis 4 serve as the input for ecRad. The ability of the IFS to realistically represent the airborne radiation measurements collected during ACLOUD is evaluated for flight sections above sea ice and open ocean. Based on the good agreement of the HRES output with common sea ice concentration satellite products, the radiation measurements are not significantly biased by sea ice fraction. The impact of cloud fraction and different ice optics parameterizations on the spectral irradiance is investigated. For one case study, we detected during flight sections above open ocean a sub-grid cloud cover variability that is not seen by IFS and during flight sections above sea ice an overestimation of the measurements by ecRad that can be explained by the lack of cloud brightness. The choice of the applied ice optics parameterization becomes more important with an increasing ice water path in the clouds and is investigated in detail within the NIR bands of ecRad.

### #33 J. Röttenbacher et al. (associated): Radiative Effect of Arctic Cirrus - Observations and Modelling

Broadband and spectral irradiance measurements are used to evaluate the radiative effect of Arctic cirrus over sea ice.