Arctic airborne campaigns workshop
Geophysical institute, University of Bergen, Norway
1-4 June 2026

Book of abstracts

Overview presentations

1. Manfred Wendisch: Overview of HALO-(AC)³

To collect data that help to constrain the models projecting Arctic weather, the HALO–(AC)³ aircraft campaign was conducted over the Norwegian and Greenland seas, the Fram Strait, and the central Arctic Ocean in March and April 2022. The campaign focused on the reasonable representation of transformations of air masses during their meridional transport into and out of the Arctic via northward moist- and warm-air intrusions (WAIs) and southward marine cold-air outbreaks (CAOs). Observations were made over areas of open ocean, the marginal sea ice zone, and the central Arctic sea ice. Two low-flying and one long-range, high-altitude research aircraft were flown in colocated formation whenever possible. To follow the air mass transformations, a quasi-Lagrangian flight strategy using trajectory calculations was realized, enabling us to sample the same moving-air parcels twice along their trajectories. Seven distinct WAI and 12 CAO cases were probed. From the quasi-Lagrangian measurements, we have quantified the diabatic heating/cooling and moistening/drying of the transported air masses. Furthermore, the development of cloud macrophysical (cloud-top height and horizontal cloud cover) and microphysical (liquid water path, precipitation, and ice index) properties along the southward pathways of the air masses were documented during CAOs.

2. Mario Mech: Polar 5/6 during HALO-AC3

During the HALO–(AC)³ airborne campaign in spring 2022, the two AWI research aircraft Polar 5 and Polar 6 conducted coordinated observations of Arctic atmospheric processes from Longyearbyen, Svalbard. The two aircraft operated as complementary platforms for observations in the lower troposphere, typically below 3–5 km altitude. Polar 5 carried a suite of active and passive remote-sensing instruments to observe clouds, precipitation, and radiative fluxes, including a dropsonde system for profiling the atmospheric column. Polar 6 focused on in-situ sampling of cloud microphysics and aerosol properties using a range of airborne probes. Both aircraft were equipped with noseboom systems for high-resolution measurements of wind, temperature, and turbulence. This overview presentation summarizes the scientific objectives, instrumentation, and flight strategies of Polar 5 and Polar 6 during HALO–(AC)³, highlights selected case studies from the campaign, and presents scientific findings and results from measurements taken during HALO-(AC)³ with the two aircraft.

3. Paquita Zuidema: Flying Into the Cold: An Overview of the The NSF Cold-Air outbreak Experiment in the Sub-ARctic (CAESAR)

This presentation provides an overview of the NSF-sponsored Cold-Air outbreak Experiment over the Sub-Arctic Region (CAESAR) campaign, and will aim to set the stage for further research. CAESAR characterized the aerosol, thermodynamic and dynamic environment occupied by mixed-phase clouds within air masses moving southward off the Arctic sea ice over the Greenland/Norwegian Seas in the spring of 2024. The aircraft campaign supported an unprecedented suite of remote sensing and in situ measurements below, within and above the mostly shallow convective clouds. Three flights reached the Greenland Marginal Ice Zone. A golden-case cold-air outbreak was sampled from its origin in clear skies over 100% sea ice to its convergence with a land-skirting polar low. Another flight focused on a polar low, and a third flight characterized a closed-to-open cell transition occurring under high aerosol loading originating from Siberia. Novel instrumentation included a Raman lidar able to profile sub-plane temperature and water vapor, an upward-point radiometer resolving mesoscale super-cooled liquid variability, and detailed cloud particle imaging. Combined ice particle and ice nucleating particle concentrations suggest most ice production is primary at cloud temperatures < -20 C, with secondary ice production evident at cloud temperatures > -20 C.

4. Steven Abel: Characterizing mixed phase clouds in diverse cold air outbreak environments: Observations from ACAO and M-Phase

Cold air outbreaks (CAOs) over high latitude oceans generate expansive mixed-phase cloud systems that remain a major source of uncertainty in weather and climate models. These uncertainties arise from challenges in representing mixed-phase microphysics, limited understanding of aerosol–cloud interactions, and the complex transitions between cloud regimes as CAOs evolve downstream. To address these gaps, two coordinated aircraft campaigns—ACAO and M-Phase—were designed to observe CAOs developing within contrasting thermodynamic and aerosol environments. ACAO, conducted in spring over the Barents and Norwegian Seas, sampled colder yet more aerosol rich Arctic CAOs, strongly influenced by long range transport. In contrast, M-Phase, carried out in the autumn over the Labrador Sea, captured warmer CAOs in a cleaner aerosol environment. Together, the campaigns encompass a representative range of CAO conditions across the North Atlantic–Arctic sector. Both campaigns employed targeted flight strategies that followed the CAO flow downstream, enabling consistent characterization of the evolving boundary layer structure, the aerosol population, and the mixed phase microphysical properties. This systematic along flow approach provides a strong basis for assessing how environmental differences influence cloud development. This talk will introduce the ACAO and M-Phase campaigns and share some insights from these datasets.

5. Harald Sodemann: Airborne measurements during the ISLAS2022 campaign

The ISLAS2022 field campaign had the overall objective to probe the entire water cycle of cold-air outbreaks by means of stable water isotopes. To that end, a research aircraft, a research vessel, controlled meteorological balloons were deployed, and measurements at a network of ground-based observations were conducted in the European Arctic during March and April 2022. A total of 10 research flights probed the lower troposphere in terms of thermodynamic state and vapour isotope composition within a triangular region over the Barents Sea and Northern Scandinavia between Ny-Ålesund on Svalbard, Andenes, and Sodankylä in Finland during CAO conditions. Instrumentation on the research vessel continuously acquired water vapour isotope composition within the Greenland, Norwegian, and Barents Seas. Ground-based water vapour isotope measurements were conducted along a transect of three sites, from the coast at Andenes, Norway to Abisko and Kiruna, Northern Sweden. A first intercomparison between isotope measurements from aircraft, ship, and ground stations confirms that the measurement network deployed during ISLAS2022 provided a consistent dataset of water vapour and precipitation isotope measurements that allow to investigate a range of aspects related to the turnover of water vapour in high-latitude weather systems, including mixed-phase cloud processes, orographic precipitation processes, as well as the assessment of water budgets and water vapour lifetimes within CAOs.

Short talks

1. Elise Rosky: Identifying mixed-phase microphysical processes using stable water isotope measurements

In-situ measurement techniques, particularly those collected by airborne platforms, capture the microphysical characteristics of a cloud but are unable to directly measure process rates and particle histories. In an attempt to determine ice growth processes more directly and quantitatively, in-situ measurement of stable water isotopes are utilized. The number of heavy water isotopes (deuterium or oxygen-18) contained in ice hydrometeors is dependent on the thermodynamic conditions experienced during their growth: in-situ temperature, relative humidity, and whether the particle was ice or liquid during its growth. Water isotopes within mixed-phase clouds were measured in-situ during the CAESAR 2024 (Cold Air Outbreak Experiment in the Sub-Arctic Region) airborne field campaign. By analyzing the co-located isotopic composition of cloud condensate and vapor at various heights within the clouds, information about whether ice formed through vapor deposition, riming, or through WBF process can be revealed. The CAESAR campaign included a suite of in-situ cloud probes (PHIPS, HOLODEC, and Optical Array Probes) which are used to validate results of the isotopic analysis.

2. Tim Carlsen: Composite approach to in situ observations: Microphysical development of mCAO clouds

When cold, dry polar air is advected over a warmer ocean, a rapid development of clouds is observed. Several airborne field campaigns have been dedicated to these marine Cold Air Outbreaks (mCAOs). However, their properties, as well as their impact on the energy budget and water cycle, remain poorly understood. This study investigates the evolution of cloud microphysics during mCAOs through use of airborne in situ observations of ice crystals and water droplets. As individual flights can only offer snapshots into certain parts of the mCAO evolution, a composite approach has been developed that integrates the in situ microphysical observations from multiple flights in order to capture the entire mCAO development. Starting with observations from the ISLAS2022 campaign, we highlight the potential of this approach in moving away from individual case studies to a more holistic microphysical picture of mCAOs integrating observations of multiple airborne campaigns represented at this workshop. In addition, Rob and I will be happy to present the campaign overview for MC2-ICEPACKS and CELLO-ARCTIC.

3. Robert David: Open or Closed: Tagging recent airborne observations by cloud type

Cold air outbreak (CAO) clouds typically organize into cloud streets and dense stratocumulus closed cells that eventually break up into open cumulus cells. The exact mechanisms driving this break-up remain a highly debated topic, and it is unclear how sensitive it is to climate change. Earlier studies have highlighted the potential roles of precipitation and boundary layer instability, but have either been limited to single CAO events or have not explicitly related cloud processes to the timing and location of cloud break-up. To gain a more general understanding of what drives this transition, we have developed a neural network trained on MODIS satellite imagery that classifies CAO closed and open cell clouds and automatically detects cloud break-ups. From these classifications, we investigate how cloud properties evolve from cloud streets and closed cell clouds to open cell clouds by collocating a suite of space-borne remote sensing observations. Here we will present some initial findings from this analysis and extend our classification to tag recent airborne measurements by cloud type for the community to further investigate the drivers of CAO cloud transitions.

4. ONLINE: Aymeric Dziduch: Ice crystal morphology and microphysical properties of Arctic Mixed-Phase Clouds from Svalbard campaigns

This study presents an extensive characterization of the microphysical and ice crystal morphological properties of low-level Arctic mixed-phase clouds (MPCs), based on in situ observations from four airborne campaigns conducted around Svalbard. The dataset includes 46 hours of cloud sampling and 731,600 ice crystal images classified using a convolutional neural network, providing an unprecedented statistical view of Arctic ice crystal habits. Using the Marine Cold Air Outbreak (MCAO) index, four meteorological regimes are identified: Cold Air Outbreak (CAO), Warm Air Intrusion (WAI), and two transitional regimes. Strong contrasts in cloud structure and phase partitioning are observed. CAO conditions are characterized by cold and moist environments supporting well-developed mixed-phase layers with enhanced riming and precipitation. In contrast, WAA conditions produce thinner, mostly liquid layers capped by strong temperature inversions. Surface conditions also exert a major control. Over open ocean, enhanced heat and moisture fluxes promote turbulence and glaciation efficiency, leading to higher ice water content and rimed ice crystals. Over sea ice, clouds remain shallower and are dominated by pristine or weakly aggregated crystals. These results highlight the strong coupling between surface fluxes, thermodynamic stability, and synoptic forcing in Arctic MPCs.

5. Georgios Dekoutsidis: Are Ice Clouds Melting the Arctic?

Ice clouds play a crucial role in the Earth's atmosphere system. Their net radiative effect is highly sensitive to their properties. Determining these and the resulting radiative effects remain challenging tasks. As a consequence, they are frequently under- or misrepresented in weather and climate models, contributing substantially to uncertainties in climate research. The Arctic climate system is undergoing significant changes, including retreat of the sea-ice, weakening of the polar jet-stream and most notably an accelerated warming. The term Arctic Amplification, is used to describe these changes. Ice clouds are expected to play an important role in Arctic Amplification, but there is a scarcity of observations in the Arctic and a missing link between their properties, the ambient conditions and their radiative effects. The German research aircraft HALO, is perfectly suited for the study of ice clouds in the Arctic. In this study we use observations from the WALES lidar system and the MIRA-36 cloud radar from HAMP, performed aboard HALO during the HALO-(AC)3 field campaign. In these observations we identify the ice clouds and group them according to the ambient conditions. We identify their macro-, microphysical and optical properties and estimate their radiative effects using the libRadtran software package.

6. Heiko Bozem: Arctic Trace Gas Variability and Trends from a Decade of in situ Aircraft Observations

We present in situ aircraft measurements of CO, CO_2, and O_3 conducted over the Arctic over a ten-year period to investigate long-term trends and variability in atmospheric composition. The dataset comprises numerous vertical profiles and horizontal transects across key regions of the Arctic troposphere, enabling the assessment of both seasonal and interannual variability. A statistically significant increase in CO_2 mole fractions is observed, consistent with global trends, while CO exhibits no clear trend, punctuated by episodic enhancements linked, for example, to boreal biomass burning and long-range transport from mid-latitudes. Correlations between trace gases and air mass origin diagnostics highlight the influence of anthropogenic emissions and atmospheric circulation on Arctic composition. More recent measurements during ASCCI 2025, based out of Kiruna, allowed us to extend the tropospheric trace gas observations of CO and O3 in time. These data sets can further be used to search for potential impact of stratospheric (polar vortex) air masses influencing tropospheric composition in the Arctic. Sustained airborne observations provide critical constraints for improving the representation of trace gas and dynamics in chemical transport and climate models, particularly in a rapidly changing Arctic environment.

7. Bart Geerts: Airborne observations of clouds and precipitation in marine cold air outbreaks

In support of the Cold-Air outbreak Experiment in the Sub-Arctic Region (CAESAR), the United States National Science Foundation National Center for Atmospheric Research C-130 aircraft was equipped with an array of in-situ and remote sensing instrumentation, including profiling radars and lidars. We use these data to examine the vertical structure of open-cellular convection. In one case, on 2 April 2024, a polar low was traversed five times. This low was marked by a region of surface-driven, mostly open-cellular precipitating convection, and a separate region of deeper stratiform clouds driven by moist-isentropic ascent in an area of suppressed surface heat fluxes. The confluence of a cold airmass from the northeast, only briefly exposed to open water, with a more mature, warmer MCAO airmass with a deeper well-mixed boundary layer previously exposed to high surface heat fluxes over the Fram Strait, led to convergent, cyclonically sheared boundaries with enhanced convection. In another case, on 16 March 2024, stronger winds, higher M-indices, and stronger surfaces fluxes were encountered along the fetch from the Arctic sea ice. At a fetch of about 600 km, shallow convection (2-3 km deep) rapidly transition to larger cells, about twice as deep, combined with polar cyclogenesis.Sustained airborne observations provide critical constraints for improving the representation of trace gas and dynamics in chemical transport and climate models, particularly in a rapidly changing Arctic environment.

8. Roel Neggers: Modeling-guided planning of MCAO flights during the HALO-AC3 campaign

During the 2022 HALO-AC3 campaign various research flights successfully probed cloud transitions during MCAO events in the Fram Strait. Some of these flights were directly motivated by concrete modeling plans for advancing our insight into various aspects of MCAOs. One of these is the impact of mesoscale subsidence on glaciation, decoupling and the transition to cellular convective cloud patterns. To optimize the sampling strategy, Large-Eddy Simulation (LES) modelers were directly involved in the planning and execution of these flights, in close collaboration with the instrument experts. This presentation aims to briefly review the outcome of these joint efforts. For selected flights the overarching modeling goals, the decision-making process a priori the flights, the observational data actually collected, and their subsequent use in modeling will be briefly summarized. Of key interest is to convey experiences concerning the efficiency of this workflow, to identify successes and failures, and to formulate recommendations in this respect for future airborne field campaigns.

9. Ben Murray: Using cold-air outbreak clouds in ACAO and M-Phase as natural laboratories to understand ice production in mixed-phase clouds

Clouds made of mixtures of water and ice below 0°C are notoriously challenging to represent in our weather and climate models, but greatly influence our predictions of future warming. A key issue is whether ice concentrations are defined by heterogeneous nucleation on ice-nucleating particles (INPs, a subset of atmospheric aerosol) or through explosive secondary ice production (SIP) mechanisms where ice particles seed new ice particles. To study ice production in mixed-phase clouds, we used northern hemisphere mid-to-high latitude marine cold-air outbreaks (CAOs) as natural laboratories. We conducted aircraft observations on 18 CAO days across the Labrador, Barents, and Norwegian seas, sampling a range of cloud temperatures and aerosol loadings during M-Phase and ACAO. We show that greater INP concentrations lead to greater median ice concentrations, even when processes were actively producing cloud pockets with very high ice particle concentrations. Overall, our aircraft observations show that INPs are a primary driver of average ice particle concentrations in shallow marine mixed-phase clouds, while SIP serves to sporadically amplify the ice particle concentrations. This work shows that it is crucial that climate and weather models link ice production in clouds to the massive spatial and temporal variability of ice-nucleating.

10. Iris Thurnherr: Identifying Lagrangian matches of air masses during MOSAiC and ISLAS2020 using stable water isotope measurements

Limited understanding of how moist processes affect moisture cycling is an important source of model uncertainties. Stable water isotopes are a valuable natural tracer for studying moist processes within the water cycle and for identifying Lagrangian connections. Because isotopic signals reflect the effect of phase changes and mixing during moisture transport, they inherently contain Lagrangian information. Here, we use stable water isotopes together with Lagrangian models to assess the consistency of the atmospheric water cycle in numerical weather prediction models. During late winter 2020, simultaneous measurements of stable water isotopes in water vapour were conducted in the central Arctic on Polarstern during MOSAiC and at the sea ice edge in Ny Alesund during the ISLAS2020 field campaign. These parallel observations illustrate how the isotopic composition of water vapour can be used to track changes during atmospheric transport and to detect signatures associated with the onset of ocean evaporation close to the sea ice edge. By combining Lagrangian measurements with modelling using LAGRANTO air parcel trajectories and the particle dispersion model FLEXPART, we identify air mass matches, and assess the effect of moist processes occurring during moisture transport from the Central Arctic to the sea ice edge.

11. André Ehrlich: The vertical change of the solar and thermal-infrared radiative energy budget derived from multi-aircraft observations

Broadband solar and thermal-infrared irradiances are standard measurements on most research aircraft. During the HALO-(AC)³, ISLAS and ACAO campaigns, in total five aircraft were equipped with broadband radiometer and operated in parallel in the Norwegian and Greenland seas and the Fram Strait. The broadband irradiances are analyzed here in terms of the radiative energy budget (REB) in flight level. The aircraft flew in different altitudes from close to the surface up to the tropopause. Thus, the combination of all data sets allows to analyze the vertical change of the REB. The analysis will investigate, how clouds impact the REB in different altitudes and how these dependencies are linked to the present air mass (warm air intrusion vs. cold air outbreak). It will be evaluated if the data sets are suitable to calculate heating/cooling rates of the atmosphere layer between two aircraft. Such analysis may help to improve our understanding of air mass transformation.

12. Jonas Schaefer: Ice-Nucleating Particles in the Arctic free troposphere

Ice-nucleating particles (INPs) play a crucial role in ice formation in Arctic mixed-phase clouds above -38°C, yet their abundance in the free troposphere remains poorly constrained. This study presents in-situ INP measurements from three aircraft campaigns—HALO-AC³, BACSAM, and BACSAM2—using the HERA filter sampler aboard Polar 6 (AWI). Collected particles were analyzed offline at TROPOS with the INDA and LINA freezing arrays, quantifying INPs active between -15°C and -27°C. In the Arctic free troposphere, INP concentrations at -20°C were mostly below 1 per standard liter, at the lower end of mid-latitude values but often higher than ground-level Arctic observations. Backward trajectories show elevated free tropospheric INP levels when air masses originated from the Central Arctic or Eurasia, while air originating from the North-Atlantic had lower concentrations. Additionally, the effects of clouds on INP concentrations during the transport into the Arctic free troposphere is investigated. These results highlight the role of long-range transport and source regions in shaping the Arctic free tropospheric INP budget.

13. ONLINE: Yongjie Huang: Marine Boundary Layer Cloud Evolution along an Arctic Cold Air Outbreak: Results from CAESAR Airborne Observations and Simulations

This study analyzed CAESAR (Cold Air outbreak (CAO) Experiment in the Sub-Arctic Region) airborne measurements to investigate the properties of marine boundary layer clouds (MBCs) and their downstream evolution during a CAO case observed on 16 March 2024 with a focus on the dependence of cloud macro- and micro-physical properties in the marine boundary layer (BL) on environmental conditions. Based on variations in BL thermodynamics and cloud morphology, the aircraft flight track was divided into five zones: the sea ice zone, the shallow cumulus clouds zone, well-organized cloud streets zone, disorganized cloud streets zone, and the polar low zone. By conducting four Weather Research and Forecasting (WRF) simulations initialized with both NCEP-FNL and ERA5 reanalysis data at different starting times, this study successfully reproduced the observed BL cloud structures and properties, as well as the associated environmental conditions across different cloud zones during the CAO event. Additionally, this study applied a machine learning technique known as the random forest algorithm to identify key environmental parameters influencing MBC properties. The analysis revealed that lower tropospheric stability is the key parameter in predicting cloud cell number, while relative humidity is the key parameter in predicting cloud cell width and depth.

14. Russell Perkins: Overview of Ice Nucleating Particle Findings from CAESAR and ARCSIX

Ice Nucleating Particles (INPs) are responsible for primary cloud glaciation at temperatures greater than -38 °C, and a critical trigger for secondary ice production processes. These conditions are characteristic of mixed-phase clouds, which are prevalent during wintertime cold-air outbreak (CAO) events and in the Arctic during the warmer seasons. INP measurements were collected using offline (filter-based) and online (continuous flow diffusion chamber) based measurements for both the NSF-sponsored Cold Air Outbreak Experiment in the Sub-Arctic Region (CEASAR) and NASA-sponsored Arctic Radiation-Cloud-Aerosol-Surface Interaction Experiment (ARCSIX) campaigns in 2024. INP results will be discussed in light of aerosol and cloud measurements. Comparison of INP concentrations above-, below-, and in-cloud will be discussed, with some cases suggesting depletion of INPs in-cloud. Comparisons of INP concentrations measurements and cloud ice crystal concentrations yields large differences for many cases, suggesting the importance of secondary ice production (SIP) processes. However, for some of these occurrences cloud conditions do not support highly active SIP through known mechanisms. High-altitude layers of dust, rich in INPs were often observed, especially during ARCSIX, highlighting the potential impact of long-range transported aerosol sources.

15. Susanne Crewell: Chasing air mass transformations during HALO-(AC)3 with remote sensing and ICON simulations

The HALO-(AC)3 campaign performed dedicated flight patterns to investigate especially air mass transformations during Cold-Air Outbreaks and Warm-Air Intrusions. While the remote sensing observations of clouds from the aircraft give a very detailed view on the vertical structure - they are limited to a certain snapshot in space and time. We use hectometer simulations with the ICON model to complement this with a less detailed, but variable view in space and time to add further understanding of variability and process changes during air mass transformations. To compare the simulation output and observations, the instrument simulator PAMTRA has been applied on the output to bring the simulated quantities into observable parameter space. Just recently, a new development in the ICON framework allows the processing of PAMTRA as an in-situ operator during the model simulation, which enables an even higher output frequency and with this getting closer to observed scales. Due to this development, several cases have been re-simulated and combined in a new way with the remote sensing observations. We will present these results and ideas - with the potential to be combined with further airborne observations especially during joined flight days.

Posters

1. Zeqian (Hazel) Xia: Marine Boundary Layer Cloud Evolution along an Arctic Cold Air Outbreak: Results from CAESAR Airborne Observations and Simulations

This study analyzed CAESAR (Cold Air outbreak (CAO) Experiment in the Sub-Arctic Region) airborne measurements to investigate the properties of marine boundary layer clouds (MBCs) and their downstream evolution during a CAO case observed on 16 March 2024 with a focus on the dependence of cloud macro- and micro-physical properties in the marine boundary layer (BL) on environmental conditions. Based on variations in BL thermodynamics and cloud morphology, the aircraft flight track was divided into five zones: the sea ice zone, the shallow cumulus clouds zone, well-organized cloud streets zone, disorganized cloud streets zone, and the polar low zone. By conducting four Weather Research and Forecasting (WRF) simulations initialized with both NCEP-FNL and ERA5 reanalysis data at different starting times, this study successfully reproduced the observed BL cloud structures and properties, as well as the associated environmental conditions across different cloud zones during the CAO event. Additionally, this study applied a machine learning technique known as the random forest algorithm to identify key environmental parameters influencing MBC properties. The analysis revealed that lower tropospheric stability is the key parameter in predicting cloud cell number, while relative humidity is the key parameter in predicting cloud cell width and depth.

2. Nicholas Amundsen: The Impact of Aerosol and Environmental Conditions on Vertical Profiles of Cloud Properties Measured In-Situ

Cold-air outbreaks (CAOs) strongly influence atmospheric and oceanic circulations, yet their cloud regimes remain poorly sampled and represented in models. Improved observations of cloud microphysical and macrophysical properties and their dependence on environmental conditions are needed to better understand cloud processes and evaluate model and remote sensing performance in high latitudes. The Cold-Air Outbreak Experiment in the Sub-Arctic Region (CAESAR) campaign collected in-situ and remote sensing data during eight NSF/NCAR C-130 flights over the Norwegian Sea between 22 February and 7 April 2024. This study examines the vertical dependence of microphysical properties, including total number concentration, liquid water content, ice crystal concentration, ice mass content, effective radius, and median volume diameter, using data from the Cloud Droplet Probe, Two-Dimensional Stereo Probe, and High Volume Precipitation Sampler. Properties are analyzed as a function of normalized altitude (zn), where zn=0 at cloud base and zn=1 at cloud top. Most sampled clouds were liquid or mixed phase. Case studies show increasing liquid water content and effective diameter with zn, with graupel and rimed particles at mid-levels. However, across 58 in-cloud vertical profiles, variability was significant. Profiles were categorized by environmental conditions to better characterize this variability. Implications for CAO cloud processes are discussed.

3. Matt Evans: Characterising the spatial overlap between liquid and ice in mixed-phase clouds

Mixed-phase clouds are important for simulating precipitation formation and cloud radiative effects in numerical weather prediction (NWP) and climate models. One challenge to reduce model uncertainties is how best to represent the subgrid distribution of liquid and ice within a model grid box. This is poorly constrained by observations, yet is key for representing microphysical process rates that grow ice crystals at the expense of liquid droplets. This study uses in situ airborne observations from stratiform, shallow cumulus, deep convective, and frontal clouds to investigate the horizontal spatial overlap of liquid and ice phases on length-scales , which are appropriate for current regional NWP models. We place observational constraints on a simple parametrisation that describes the mixed-phase fraction as a function of subgrid liquid and ice cloud fractions and demonstrate that most of the observations show that, when ice and liquid are present, they are close to fully overlapped.

4. Nicolas Bonaventi: Clouds in Arctic weather systems along ISLAS2022 flight tracks

The ISLAS2022 field campaign provided a high-resolution dataset of the Arctic atmosphere, with a total of 10 flights across northern Norway, the Barents Sea, and Svalbard. Several flights were designed to probe the the entrainment zone at the top of the boundary layer, where supercooled liquid was present. In-situ measurements were supported by two depolarisation lidars and a horizontally point cloud radar. Here we use these in-situ and remote sensing measurements for a quantitative validation of the operational weather forecasting model AROME Arctic from the Norwegian meteorological institute. We investigate the model's ability to replicate the structure of the Arctic boundary layer and the moisture distribution in the vicinity of cloud boundaries in different Arctic weather systems.

5. Hans Christian Steen-Larsen: Title tbc

Abstract tbc

6. Mari B. Steinslid: A detailed comparison between cloud properties represented in the numerical weather prediction model HARMONIE-AROME and aircraft measurements during a marine cold air outbreak

Cold air outbreaks (CAO) in the Arctic are closely associated with mixed-phase convective clouds. These clouds are a challenge for numerical weather prediction (NWP) models as many of the formation processes and their interplay have to be represented by means of parameterisation schemes. In order to evaluate and further develop the model representation accurate observations of cloud properties are needed. Measuring all stages of the cloud evolution can be challenging, however marine CAOs encompass all processes within a relatively local space. For this reason, the ISLAS2022 field campaign targeted CAOs in the Arctic. Quasi-Lagrangian research flights were conducted to obtain high resolution measurements of the cloud evolution using a combination of in-situ cloud probes and remote sensing measurements, including depolarisation lidar and cloud radar. Here, we directly compare measurement data with high time-resolution output from the operationally used NWP model HARMONIE-AROME. We find that the model predicts a denser cloud cover with coarser structure and less variability compared to the measurements. The causes behind these differences are further studied using process-level insight based on parameterisation tendency output.

7. Andrew Dzambo: Evaluation of AROME-Arctic Sensible and Latent Heat Fluxes During the 16 March 2024 Norwegian Sea Marine Cold Air Outbreak

An important challenge for operational weather models such as AROME-Arctic is the proper representation of marine cold air outbreaks (MCAO). This study focuses modeled and measurement-derived sensible heat flux (SHF) and latent heat flux (LHF) measurements from the 16 March 2024 research flight during the Cold Air outbreak Experiment in the Sub-Arctic Region (CAESAR) experiment. Both SHF and LHF are derived from dropsonde measurements and are collocated with interpolated SHF and LHF produced by AROME-Arctic for forecast periods every 12 hours. Dropsonde estimated SHF values were on the order of 200-300 W/m2 in the polar low region increasing to nearly 400 W/m2 near the sea-ice edge. Likewise, LHF values were quite variable in the polar low region ranging between 150-300 W/m2, decreasing to below 120-200 W/m2 closer to the sea-ice edge. AROME-modeled SHF values were quite large through the beginning of the MCAO cloud street region, where SHFs exceeded the dropsonde estimated SHFs by 30-40%. Maximum SHF biases occurred at the sea-ice edge for all forecast periods. Likewise, a persistent LHF bias was produced for all forecast periods across the entire flight transect leading to the sea-ice edge. Additional variables and metrics related to fluxes are also discussed.

8. Olivier Jourdan: The Thinice field campaign August 2022 : interactions between arctic cyclones, clouds and sea ice

The THINICE field campaign, based in Svalbard in August 2022, provided unique observations of summertime Arctic cyclones, their coupling with cloud cover, and their interactions with tropopause polar vortices and sea ice conditions. THINICE was motivated by the need to advance our understanding of these processes and to improve coupled models used to forecast weather and sea ice, as well as long-term projections of climate change in the Arctic. The SAFIRE ATR42 aircraft, equipped with the radar–lidar (RALI) remote sensing instrumentation and in situ cloud microphysics probes, flew in the midtroposphere to observe the wind and multiphase cloud structure of Arctic cyclones. The BAS Twin Otter aircraft flew at low levels measuring sea ice properties and the turbulent fluxes that mediate exchange of heat and momentum between the atmosphere and the surface. Intense, shallow low-level jets along warm fronts were observed within three Arctic cyclones using the Doppler radar and turbulence probes. A detailed depiction of the interweaving layers of ice crystals and supercooled liquid water in mixed-phase clouds is revealed through the synergistic combination of the Doppler radar, the lidar, and in situ microphysical probes.

9. ONLINE: Erin Raif: Evolution of INP concentration in an Arctic CAO

Co-ordinated CAO measurements of INPs by the FAAM aircraft and the Andenes ground station suggested that INPs maybe strongly removed as a CAO evolves. However, calculations of cloud-phase feedback use models with fixed or aerosol-unaware INP concentrations. If INP removal is strong, these modelling choices are inappropriate since they will not represent the change in INP concentration over a cloud system. We performed regional modelling of a CAO using a two-moment microphysics scheme coupled to interactive aerosol processing (CASIM). Using a typical singular aerosol-aware INP parametrisation, we found that INPs were processed and removed in a CAO, though the rate of INP removal was smaller than suggested by measurements. However, such parametrisations make the simplifying assumption that there is a constant relationship between the aerosol concentration and the number of INPs, resulting in an overestimate of INP concentration when INPs are preferentially removed by precipitation. By implementing a new INP-limited INP parametrisation, we were able to simulate the strong reduction in INP concentrations observed through the evolution of the CAO. However, we were unable to simultaneously represent the magnitude of the INP concentration and the rate of INP removal.

10. Michael Biggart: Secondary ice production within shallow, mixed-phase clouds in cold air outbreaks over the Labrador Sea

Microphysical processes controlling the phase of shallow, mixed-phase clouds within marine cold air outbreaks (CAOs) remain poorly represented by climate models; of these, secondary ice production (SIP), describing mechanisms producing new ice crystals from existing primary ice, is a major contributor to uncertainties in the mixed-phase cloud response to future warming. We examine in-situ measurements of cloud microphysical properties made within CAOs over the Labrador Sea as part of the October-November 2022 M-Phase campaign. Peak ice particle concentrations were observed within the Hallett-Mossop (H-M) process temperature range (-3 to -8 °C), four orders of magnitude above expected ice-nucleating particle

(INP) concentrations. These SIP regions contained large, rimed columns and graupel mixed with smaller columnar crystals (< 200 µm), indicative of the H-M process. Splinter production rate calculations indicated the H-M process could feasibly account for most ice production in the largest ice enhancement regions. A secondary zone of SIP activity, between -15 and -18 °C, comprised fragile, branched crystals, aggregates and ice fragments, consistent with laboratory studies of ice-ice collisional breakup. SIP amplified across the stratiform-to-convective regime transition, favouring weak-to-moderate updrafts (0 to +2 ms-1) containing many large liquid droplets, suggesting regime-aware SIP schemes would benefit future CAO modelling.

11. Fiona Paulus: Impacts of mesoscale atmospheric subsidence on cloud glaciation and decoupling in Arctic marine cold air outbreaks

Marine cold-air outbreaks (MCAOs) occur when cold Arctic air flows over warmer open ocean, driving strong surface heat fluxes, rapid atmospheric boundary-layer (ABL) growth, and mixed-phase cloud formation. While cloud evolution in MCAOs is known to depend on microphysical processes, the role of mesoscale vertical motion in shaping boundary-layer development and cloud-phase transitions remains poorly constrained. We examine how mesoscale subsidence influences ABL structure and cloud evolution during a shallow MCAO over the Fram Strait in March 2022, observed during the HALO–$(AC)^3$ campaign. Mesoscale flight circles with regularly spaced dropsondes provide observational estimates of subsidence. Using quasi-Lagrangian large-eddy simulations constrained entirely by airborne in situ and remote sensing observations, we reproduce the observed thermodynamic and cloud evolution of the air mass. Sensitivity experiments show that weaker subsidence promotes earlier boundary-layer decoupling, deeper ABL growth, and faster cloud glaciation through enhanced graupel production. These results identify mesoscale subsidence as a key control on cloud-phase evolution and Arctic air-mass transformation during MCAOs.

12. David Simon: Airborne Studies on Arctic Aerosols: New Particle Formation and Sea Spray Fluxes

We present results obtained during the airborne BACSAM II measurement campaign (April 2024, Svalbard), utilizing the AWI's Polar 6 research aircraft together with the recently developed towed-body T-Bird (Jurányi et al., 2025), operated below the aircraft. Specifically, we report on sea spray aerosol fluxes derived from simultaneous particle and turbulence measurements as well as on the frequent occurrence of new particle formation (NPF). We confirm the emissions produced by several commonly used sea salt source functions in the sea salt size range, but show that the majority of these emission schemes underestimate our measured flux density values in the accumulation mode size range. Newly formed particles were detected frequently (about 25 % of the total air time), covered a large geographical area, and were observed throughout the lower Arctic troposphere in an altitude range from about 60 m to 3900 m above sea level. We identify three atmospheric scenarios for NPF occurrence during our campaign: NPF in the free troposphere, in the atmospheric boundary layer over sea ice, and in the vicinity of clouds. Our results suggest that regional Arctic processes as well as long-range transport play key roles in the formation of new particles.