3rd QuIESCENT Arctic workshop

22-24 October 2024

Lausanne - Switzerland

EPFL campus, Auditorium MXF1

(All times given in CEST, local Lausanne time)

zoom link: https://epfl.zoom.us/j/61310629276

DAY 1 : Tuesday 22/10/2024

PLENARY SESSION

Co-chairs: ***Gijs de Boer, Radiance Calmer, Jean-Christophe Raut***

13.15 – 13.30: **Welcome & QuIESCENT introduction**
13.30 – 13.40: The 'Air Pollution in the Arctic: Climate, Environment and Societies (PACES)' program **(Kathy Law, LATMOS - ONSITE)**
13.40 – 13.50: The 'Cryosphere and Atmospheric Chemistry (CATCH)' program **(Paul Zieger, Stockholm University - ONLINE)**
13.50 – 14.00: The 'Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII) program **(Letizia Tedesco, Finnish Environment Institute - ONLINE)**
14.00 – 14.10: The 'Antarctic Sea-ice Processes and Climate (ASPeCt)' program **(Petra Heil, University of Tasmania - ONLINE)**
14.10 – 14.20: questions to PACES/CATCH/BEPSII/ASPECT representatives
14.20 – 15.00: **keynote 1:** Arctic aerosols, Ice Nucleating Particles and possible sea spray generation of the latter (**Heike Wex, TROPOS - ONLINE)**
15.00 – 15.40: **keynote 2:** Could mixed-phase cloud thinning be a potential geoengineering option to mitigate some of the Arctic amplification? **(Ulrike Lohmann, ETH Zurich - ONLINE)**

15.40 – 16.10: **Coffee Break**

16.10 – 17.30: Networking Session (*round-the-table introductions*)

DAY 2 : Wednesday 23/10/2024

09.00 – 09.10: Opening remarks, housekeeping

SESSION 1: Sources of Arctic Aeorosol Particles

***Co-chairs:**, Radiance Calmer, Hannah Frostenberg, Olimpia Bruno*

09:10 – 09.25: Sea ice, snow caps, and freshwater lenses: The hurdles local Arctic aerosols must overcome to become airborne **(Camille Mavis, Colorado State University - ONSITE)**

09.25 – 09.40: Marine isoprene and its contribution to secondary aerosols and clouds in an Earth system model **(Ulas Im, Aarhus university - ONLITE)**

09.40 – 09.55 Arctic sea spray aerosol particles: Chemical composition and incorporation into cloud droplets **(Kerri Pratt, University of Michigan - ONSITE)**

09.55 – 10.10: Pan-Arctic Methanesulfonic Acid Aerosol: Source regions, atmospheric drivers and future projections **(Jakob Pernov, EPFL - ONLINE)**

10.10 – 10.25: Monitoring the aerosol trends in the Arctic region and a future projection **(Esra Günaydın, Istanbul Technical University - ONSITE)**

10.25 – 10.40: Discussion

10.40 – 11.10: Coffee Break

SESSION 2: Arctic Ice Nucleating Particles

***Co-chairs:** Gijs de Boer, Julia Asplund, Kathryn Moore*

11.10 – 11.25: Evaluating the complexities of the seasonal cycle of central Arctic ice nucleating particles, **(Kevin R. Barry, Colorado State University - ONSITE)**

11.25 – 11.40: High ice-nucleating particle concentrations associated with Arctic haze in springtime cold-air outbreaks **(Erin Raif, University of Leeds - ONSITE)**

11.40 – 11.55: Long-range transported dusts are very important for Arctic ice nucleating particle concentrations **(Ross Herbert , University of Leeds - ONLINE)**

11.55 – 12.10: Examination of surface-coupling effects on heterogeneous ice formation at low supercooling temperatures in mixed-phase clouds during MOSAiC **(Hannes Griesche, TROPOS - ONSITE)**

12.10 – 12.25: Discussion

12.25 – 13.30: Lunch Break

SESSION 3: Aerosol impacts on Arctic cloud properties

***Co-chairs:** Jean-Christophe Raut, Camille Mavis, Imogen Wadlow*

13.30 – 13.45: Cloud changes driven by dust and marine aerosols, and their radiative impacts on

the Arctic Ocean surface **(Lauren Zamora, NASA Goddard Center - ONSITE)**

13.45 – 14.00: Increasing aerosol emissions from boreal biomass burning exacerbate Arctic warming **(Qirui Zhong, Peking University - ONLINE)**

14.00 – 14.15: Aerosol Influences on Enhanced Riming Processes in Low-Level Arctic Mixed-Phase Clouds **(Kyle Fitch, Air Force Institute of Technology - ONSITE)**

14.15 – 14.30: Seasonal and vertical trends in black carbon properties in the Arctic during ARCSIX **(Eva-Lou Edwards, NASA Langley Research Center - ONLINE)**

14.30 – 14.45: In situ vertical observations of aerosol and cloud properties within low-level clouds during the Arctic melt season (**Roman Pohorsky, EPFL - ONSITE)**

14.45 – 15.00: Discussion

15.00 – 15.30: poster session

15.30 – 16.00: Coffee Break

SESSION 4: Interactions between Arctic clouds and their environment

Co-chairs: ***Radiance Calmer, Remy Lapere, Nora Bergner***

16.00 – 16.15: Effect of air parcel transport on the spatial distribution of the thermodynamic phase of Arctic clouds **(Quentin Coopman, Université de Lille - ONSITE)**

16.15 – 16.30: Observing aerosol-cloud and precipitation interactions during the onset of sea ice melt **(Lea Haberstock, Stockholm University - ONSITE)**

16.30 – 16.45: Ice fog increase in the Arctic Ocean: 17 years analysis using CALIOP measurements **(Olimpia Bruno, KIT - ONSITE)**

16.45 – 17.00: A Preliminary Look at Data Collected during the 2024 Cold Air outbreaks Experiment in the Sub-Arctic Region (CAESAR) **(Greg McFarquhar, University of Oklahoma - ONLINE)**

17.00 – 17.30: Closing Discussion of Day 2

DAY 3 : Thursday 24/10/2024

SESSION 5: Filling the gaps; novels approaches to understand the Arctic indirect effect

Co-chairs: *Jean-Christophe Raut, Hannes Griesche, Lea Haberstock*

09.00 – *0*9.10: Opening remarks, housekeeping

PART I: In-situ approaches

09.10 – 09.25: The potential role for autonomous systems during the next IPY in understanding the interplay between aerosols and clouds **(Gijs de Boer, CIRES - ONSITE)**

09.25 – 09.40: Airborne observations of the spatial distribution of Arctic aerosols at different sites **(Schuchard Malte, Technische Universität Braunschweig - ONLINE)**

09.40 – 09.55: Tethered balloon measurements reveal enhanced aerosol occurrence aloft interacting with Arctic low-level clouds **(Christian Pilz, TROPOS - ONLINE)**

09.55 – 10.10: Vertical distribution of aerosols in the Arctic lower atmosphere during the transition between winter and springtime observed with a tethered balloon at Villum Research Station **(Radiance Calmer, EPFL - ONSITE)**

PART II: Remote-sensing approaches

10.10 – 10.25: Observing the timescales of aerosol-cloud interactions in the Arctic **(Edward Gryspeerdt, Imperial College of London - ONSITE)**

10.25 – 10.40: Discussion

10.40 – 11.10: Coffee Break

PART III: Modeling approaches

11.10 – 11.25: What is the origin of cloud ice in the Arctic **(Hannah Frostenberg, Chalmers University of Technology - ONSITE)**

11.25 – 11.40: Leveraging THINICE airborne observations to assess how ICOLMDZ captures the properties of Clouds Embedded in Arctic Cyclones**(Étienne Vignon, CNRS - ONSITE)**

11.40 – 11.55: Towards an improved Arctic aerosol representation in NorESM2 **(Julia Asplund, Stockholm University - ONSITE)**

11.55 – 12.10: Discussion

IPY SESSION:

Co-chairs: *Gijs de Boer, Radiance Calmer, Jean-Christophe Raut*

12.10 – 12.30: Introductiont to IPY session

12:30 – 13:30: Lunch Break

13.30 – 14.30: world-cafe I *(identify research challenges & priorities)*

14.30 – 15.00: world-cafe II *(present results from individual discussions)*

15.00 – 15.30: Coffee Break

15.30 – 16.30: world-cafe III *(suggest research strategies to follow during IPY)*

16.30 – 17.30: Closing Discussion, Summary, and Next Steps

ORAL PRESENTATIONS:

1. Lauren Zamora, University of Maryland, College Park / NASA-Goddard Space Flight Center (ONSITE) :

Cloud changes driven by dust and marine aerosols, and their radiative impacts on the Arctic Ocean surface

The amount of liquid and ice in clouds affects how much they warm or cool the surface in the rapidly warming Arctic. Dust aerosols facilitate cloud droplet freezing and may be why clouds at similar temperatures are substantially icier over the Arctic than over the cleaner Antarctic. Marine aerosols can also impact cloud raditaive effects, for example by enhancing cloud fraction as has been observed in the Antarctic. We used seven years of satellite observations and model and reanalysis products to control for co-varying meteorology, and to assess how dust and marine aerosols impact cloud phase and cloud fraction over the summertime Arctic Ocean. At 3 km, where dust modeling is most reliable, dust aerosols caused about 4.5% of clouds below -15 ^{o}C to either contain some ice particles mixed with liquid droplets, or to become fully composed of ice particles. This occurs less often at warmer temperatures. Sulfate aerosol also seems to have an effect, though smaller, on the amount of liquid and ice in Arctic summertime clouds. Dust is associated with cloud-mediated surface cooling of up to a 6.3 W m-2 below single-layer clouds at ~3 km in June. Summertime clouds associated with dimethyl sulfide (DMS), a proxy for marine new particles, were substantially more extensive near the surface ocean, with important radiative effects. This information can help constrain models and enable future field experiments more optimally target measurements to better understand the mechanisms behind aerosol effects in Arctic clouds

2. Jakob Pernov, EPFL (ONLINE) :

Pan-Arctic Methanesulfonic Acid Aerosol: Source regions, atmospheric drivers, and future projections

Natural aerosols are an important, yet understudied, part of the Arctic climate system. Natural marine biogenic aerosol components (e.g., methanesulfonic acid, MSA) are becoming increasingly important due to changing environmental conditions. In this study, we combine in situ aerosol observations with atmospheric transport modeling and meteorological reanalysis data in a data-driven framework with the aim to (1) identify the seasonal cycles and source regions of MSA, (2) elucidate the relationships between MSA and atmospheric variables, and (3) project the response of MSA based on trends extrapolated from reanalysis variables and determine which variables are contributing to these projected changes. We have identified the main source areas of MSA to be the Atlantic and Pacific sectors of the Arctic. Using gradient-boosted trees, we were able to explain 84 % of the variance and find that the most important variables for MSA are indirectly related to either the gas- or aqueous-phase oxidation of dimethyl sulfide (DMS): shortwave and longwave downwelling radiation, temperature, and low cloud cover. We project MSA to undergo a seasonal shift, with non-monotonic decreases in April/May and increases in June-September, over the next 50 years. Different variables in different months are driving these changes, highlighting the complexity of influences on this natural aerosol component. Although the response of MSA due to changing oceanic variables (sea

surface temperature, DMS emissions, and sea ice) and precipitation remains to be seen, here we are able to show that MSA will likely undergo a seasonal shift solely due to changes in atmospheric variables

3. Qirui Zhong, Pekinh University (ONLINE):

Increasing aerosol emissions from boreal biomass burning exacerbate Arctic warming

The boreal region is undergoing rapid climate warming, leading to an upsurge in biomass burning (BB) activities with impacts on regional and global climate dynamics. While previous studies have primarily focused on greenhouse gas emissions from BB, less attention has been given to biomass burning aerosols (BBA). Here, with satellite-constrained modeling, we assess the radiative effect of aerosols originating from boreal fires on Arctic climate. Our findings reveal a substantial increase in boreal BBA emissions primarily driven by climate warming over the past two decades, leading to pronounced positive radiative effects during Arctic summer mostly due to solar absorption (e.g., by black carbon). Furthermore, under a global warming scenario of 1 above the current level, boreal BBA emissions are projected to increase sixfold, and the resulting positive radiative forcing over the Arctic would lead to additional warming, entirely negating the benefits of ambitious anthropogenic black carbon mitigation efforts. Our results underscore the important role of BBA in Arctic climate dynamics, becoming increasingly relevant due to the high sensitivity of boreal and Arctic fires to climate change

4. Gijs de Boer, CIRES (ONSITE):

The potential role for autonomous systems during the next IPY in understanding the interplay between aerosols and clouds

The Arctic environment is rapidly changing. Temperatures are increasing, ice is melting, and the surface state is evolving to reveal more open water and bare terrestrial surfaces, and decreasing amounts of snow and ice. Additionally, there is a trend towards industrialization in the Arctic that introduces anthropogenic sources of particulate matter in the atmosphere. Together, these changes are influencing the population of particles in the Arctic atmosphere, which, in turn has impacts on the development and lifecycle of Arctic clouds. In this presentation, we will review previous studies that demonstrate the relationships between aerosols and clouds in the Arctic, and offer some insights into how new observing technologies may be able to help us evaluate the evolution of these relationships in a changing climate. Such discussions will be framed within the context of the upcoming International Polar Year (2032) and provide examples from northern Alaska, the MOSAiC expedition, and other locations

5. Olimpia Bruno, KIT (ONSITE):

Ice fog increase in the Arctic Ocean: 17 years analysis using CALIOP measurements

Fog is typically a very low cloud touching the ground and consists of tiny liquid droplets or ice particles. Ice fog can form in very cold areas such as polar regions or high mountains at temperatures below -30°C. Few field campaigns have focused on ice fog and fewer have shown the presence of ice fog at warmer temperatures, suggesting that limitation in time and space may lead to an underestimation of this phenomenon with implications on the biosphere and the estimation of the Earth's energy budget. By analysing CALIOP data from 2006 to 2023, we have found a reduction of both liquid fog (~ -33% up to 0.5km; ~ -32% up to 2km) and ice fog (~ -29% up to 0.5km; ~ -30% up to 2km) over time. The geographical distribution of ice fog shows that ice fog mainly occurs at latitudes above 50°, where ice is more likely to form due to low temperatures. Separating the regions with ice fog occurrence into North/South and continental/maritime sub-regions, we have found an increase in ice fog of about 35% (up to 0.5km; +30% up to 2km) over time in the maritime region at latitudes above 60° North, despite a decrease in ice fog in the other areas analysed. The aerosol types provided by CALIOP have been analysed for two temperature ranges

to distinguish the homogeneous glaciation (T < -38°C) and the heterogeneous glaciation (-38°C ≤ T ≤ 0°C) of possible ice nucleating particles. This analysis have been used to derive probability density functions of single aerosol types, from which glaciation temperatures have been estimated. Below 1km altitude, marine aerosols show a glaciation temperature warmer than continental aerosols. This result is only partially true for altitudes below 0.5km.

6. Greg McFarquhar, University of Oklahoma (ONLINE) :

A Preliminary Look at Data Collected during the 2024 Cold Air outbreaks Experiment in the Sub-Arctic Region (CAESAR)

Cold-air outbreaks (CAOs) have an overwhelming influence on global atmospheric and oceanic circulations, yet their cloud regimes remain poorly sampled and are therefore not fully understood nor well-represented in weather models. The Cold-Air Outbreak Experiment in the Sub-Arctic Region (CAESAR) field campaign addressed this gap by gathering and synthesizing crucial observations that help clarify the underlying processes governing these phenomena. CAESAR is investigating CAOs over the relatively warm North Atlantic Ocean, and more specifically, examining the structure of marine boundary layer clouds during CAOs. Utilizing the National Science Foundation (NSF)/National Center for Atmospheric Research (NCAR) C-130 aircraft, CAESAR conducted research flights out of Kiruna, Sweden to over the far northern Atlantic Ocean from 28 February to 3 April 2024. A wide variety of atmospheric instrumentation was used to obtain the necessary measurements: dropsondes for vertical thermodynamic profiles; radar and lidar systems for characterizing cloud and aerosol layers; sensors for flight-level temperature, pressure, humidity, wind, and vertical velocity; and probes characterizing cloud microphysical properties such as the King probe, Rosemount Icing Detector, Cloud Droplet Probe, Two-Dimensional Stereo probe, Particle Habit Imaging and Polar Scattering probe, Holographic Detector for Clouds, High Volume Precipitation Spectrometer, Counter-flow Virtual Impactor and others. The analysis to be presented will characterize CAO cloud microphysical properties (e.g., liquid water content, total water content, liquid mass fraction, particle size distributions, median mass-diameter, effective radius, and other identifying characteristics) and how they vary with environmental conditions such as updraft/downdraft velocities, open and closed cell clouds, cloud streets, aerosol amounts, distance from sea ice edge, and temperature and position within the cloud.

7. Kyle Fitch, Air Force Institute of Technology (ONSITE):

Aerosol Influences on Enhanced Riming Processes in Low-Level Arctic Mixed-Phase Clouds

Riming is a highly efficient process for removing water mass, cloud condensation nuclei (CCN), and ice nuclei (IN) aerosols from ubiquitous low-level mixed-phase clouds in the Arctic. Measurements along the North Slope of Alaska (NSA; Fitch & Garrett, 2022a; 2022b), and more casual, anecdotal observations during summer expeditions into the Central Arctic (Tjernstrom et al, 2020) indicate that riming is a common occurrence in this region. Counterintuitively, this is most commonly observed with clouds that have low liquid water content (LWP < 50 g/m2) at least on the NSA (Fitch & Garrett, 2022a; 2022b). Thus, the traditional model of a continuous collection kernel falling in still air through a cloud of supercooled liquid water droplets is insufficient to explain such enhanced riming. Furthermore, it is not clear which aerosol types (e.g., marine vs. anthropogenic) and sources (local vs. long-range transport) are most favorable for this enhanced riming process (Heutte et al., 2023; Maahn et al., 2017). Here we use U.S. Department of Energy Atmospheric Radiation Measurement (DOE ARM) measurements from two NSA sites (2017-2024) and the (Multidisciplinary Drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition (2019-2020) to better constrain the relationships between enhanced riming events and their associated aerosols. Initial results indicate that enhanced riming is more likely to be observed in cases where polluted (i.e., anthropogenic) aerosols dominate. Two competing hypotheses are presented to suggest potential modelling strategies to help explain the connection between aerosol types and enhanced riming processes, with the

hope that better parameterizations can lead to more accurate prediction of low-level Arctic mixed-phase cloud sustainment or dissipation

8. Esra Günaydın, Istanbul Technical University (ONSITE):

Monitoring the aerosol trends in the arctic region and a future projection

The Arctic region is warming significantly faster than the global average, with the resultant warming effects in the other areas being directly or indirectly linked to the rise in aerosols and changes in greenhouse gas emissions. Given the sensitivity of the region's climate to radiative forcings, it is crucial to conduct long-term monitoring of aerosol increases and their underlying causes. This approach provides valuable insights into the magnitude and variability of these forcings. In this study, long-term changes of satellite-based aerosol optical depth data in the Arctic region were examined, and the causes of critical variations in the amount of aerosol were investigated such as changes in atmospheric parameters at lower latitudes, volcanic eruptions, and forest fires. In this context, it was compared MODIS Aqua and Terra data with OMI observations over 20 years, revealing consistent trends. Especially during specific months such as June and July, it was observed that aerosol optical depth values had reached their peak points. Additionally, the study revealed the sources of aerosols and their seasonal transportation dynamics, identifying peak levels during certain periods. In addition, aerosol optical depth values for the future were predicted with a selected forecast model. It is expected that this study will be beneficial for future studies in polar regions where the global climate change effects are the most observable with the long-term projection of aerosols in the region

9. Camille Mavis, Colorado State University: (ONSITE)

Sea ice, snow caps, and freshwater lenses: The hurdles local Arctic aerosols must overcome to become airborne

Aerosols and clouds play a critical role in regulating radiation reaching the Arctic, which is warming faster than anywhere else globally. However, the magnitude of their effects is not adequately quantified, especially in the Arctic Ocean directly over the sea ice. Specifically, aerosols from open leads, melt ponds, and the snow-covered sea ice surface remain poorly understood, yet could have significant impacts on cloud condensation nuclei (CCN) and ice nucleating particle (INP) concentrations, and thus, central Arctic cloud formation. While marine biological processes have been demonstrated to be potentially key sources of aerosols in the Arctic summer, exact sources and emission processes of these particles remain highly uncertain. For this presentation, we provide an overview of aerosol observations from two recent Arctic field campaigns: the 2019 Multidisciplinary drifting Observatory for Study of Arctic Climate (MOSAiC) and the 2023 Atmospheric rivers and the onset of Arctic melt (ARTofMELT) expeditions. We highlight preliminary findings focused on aerosols that have the potential to impact cloud formation over the Arctic Ocean, specifically those from local sources in the summer. The evolution of open water within the pack ice in late spring and the Arctic melt season coincides with an increase in aerosol particle concentration, which may be attributed to biological activity within seawater and sea ice. However, the emission of aerosol particles is contingent on features like open leads and melt ponds, and whether they are covered by snow, freshwater melt layers, or ice lids. This integrative study involves the use of detailed aerosol, meteorological, oceanographic, and sea ice observations from MOSAiC and ARTofMELT. Overall, this work will enable us to assess local aerosol processes associated with cloud formation to better understand the Arctic system through a holistic approach.

10. Hannah Frostenberg, Chalmers University of Technology (ONSITE):

What is the origin of cloud ice in the Arctic?

The phase of clouds plays a crucial role in their interaction with radiation, particularly in the Arctic. This region experiences a high abundance of low-level mixed-phase clouds during the periods of sea ice melt and

freeze-up in spring and fall. Despite the Arctic's notably clean air, characterized by low aerosol and ice nucleating particle (INP) concentrations, cloud ice can still be observed at relatively high sub-zero temperatures. We present a modeling closure analysis of a low-level mixed-phase cloud observed during the ARTofMELT (Atmospheric rivers and the onset of sea ice melt) campaign using the large eddy simulation model MIMICA. Comprehensive measurements of INP and aerosols were taken at the surface, within, and above the cloud. To further understand the composition of the observed INPs, we will perform peroxide and heat-treatment analyses. These analyses will provide insights into the types and sources of INPs contributing to ice formation in Arctic clouds. The minimum observed in-cloud temperature was -8 ^{o}C, with ice present throughout the cloud existence. The highest temperature at which INP were detected was -13^{o}C, with an INP concentration of approximately 1.6e^{-4} L^{-1}. An extrapolation of the observed INP concentrations is insufficient to produce a significant amount of ice in the model. However, by utilizing the model and including secondary ice processes, we aim to determine the INP concentrations or properties necessary to account for the observed ice. This includes analyzing the importance of local versus long-range transported aerosols

11. Lea Haberstock, Stockholm University (ONSITE):

Observing aerosol-cloud and precipitation interactions during the onset of sea ice melt

Aerosol-cloud interactions play a crucial role in the Arctic's radiative budget, particularly due to clouds' ability to retain heat in the lower atmosphere, thus impacting sea ice melt. During the campaign Atmospheric rivers and the onset of sea ice melt (ARTofMELT) we aimed to improve our understanding of these interactions and their impact during the onset of the Arctic melting season through in-situ measurements of microphysical and chemical properties of aerosols, cloud droplets, and precipitation. A ground-based fog and aerosol spectrometer (GFAS) and a fog monitor (FM-120) from Droplet Measurement Technologies (DMT) were used to measure among other things droplet size, number concentration, and liquid water content. Precipitation was measured using a meteorological particle spectrometer (MPS, DMT). Throughout the campaign, we observed several fog and blowing snow events, along with occasional precipitation. A key observation was a 23-hour fog event when the air temperature rose significantly above zero degrees, initiating melting. These events provided an opportunity to investigate and compare the distinctive microphysical properties associated with each event. Our findings reveal significant variations in the size distribution and particle phase of blowing snow, precipitation and fog. Notably, during fog events, we observed a low number concentration of droplets, but the measured droplets were relatively large

12. Erin Raif, University of Leeds (ONSITE):

High ice-nucleating particle concentrations associated with Arctic haze in springtime cold-air outbreaks

In March 2022, concentrations of ice-nucleating particles (INPs) were measured in springtime cold-air outbreaks over the Norwegian and Barents Seas using aircraft filter sampling. Throughout the campaign, INP concentrations above, below and upstream of the clouds were comparable to the highest previously observed in the Arctic and were similar to typical terrestrial midlatitude INP concentrations. This is important because shallow cloud systems such as those in mid- to high-latitude cold-air outbreaks are highly sensitive to INPs and are a highly uncertain contributor to cloud feedbacks. We hypothesise that these high INP concentrations were most likely associated with aged aerosol in the Arctic Haze that had undergone long-range transport from lower-latitude regions. Evidence for this was provided by scanning electron microscopy (SEM), analysis of aerosol particle size measurements to obtain INP active site densities for each sample and back-trajectory analysis. SEM analysis of samples taken upwind of cloud decks showed that super-micron aerosol was dominated by mineral dusts. Comparing active site densities of samples to different aerosol types suggested that sea spray was unlikely to be a dominant INP type. Additionally, these active site densities were too great for mineral components alone to be the dominant INP type above -20 oC. Accordingly, it is likely that the dominant INP type was mineral dust mixed with other ice nucleating materials, possibly of biogenic

origin. Finally, back-trajectory analysis, meteorological conditions and active site densities that were greater above the cloud than below suggested a lack of local INP sources

13. Kevin R. Barry, Colorado State University (ONSITE):

Evaluating the complexities of the seasonal cycle of central Arctic ice nucleating particles

The Arctic is warming at a rapid rate, with potential implications for the persistence and properties of mixed-phase clouds that affect the surface energy budget. The presence of ice nucleating particles (INPs) strongly modulates the phase of these clouds, and long-term measurements are important to elucidate their seasonal sources and sinks and thus enable predictors of future changes. Previous work has involved either shorter-term measurements within the central Arctic, or a mixture of long- and short-term measurements from fixed terrestrial sites. The 2019-2020 Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition provided the first year-long seasonal measurements of INPs in the central Arctic. Here, we report additional measurements of the INP seasonal cycle, including investigations of INP composition and their relation to the seasonal cycle of bacteria and eukaryotes to identify INP sources. Two recent campaigns measured INPs in the boundary layer and free troposphere, sampling clouds, clear air, and aerosol layers during winter, spring, and summer in the central Arctic, including the Cold-Air outbreak Experiment in the Sub-Arctic Region (CAESAR) in February-April 2024 and the Arctic Radiation-Cloud-Aerosol-Surface-Interaction eXperiment (ARCSIX) in May-August 2024. Compositionally, the INPs during MOSAiC largely contained heat stable and labile organics at all times of year, with some mineral influence present in the fall and winter. Summer was the most static time, with virtually all of the INPs heat labile, presumably biological material. In contrast, the airmasses throughout the year were more variable and complex and were often a mixture of both terrestrial and marine sources. The sequenced proximate sources to the ship generally did not contribute to the sampled aerosol outside of mid-summer, which bolstered by coincident INP data collected at Mount Zeppelin, suggests the INPs were primarily tied to regional or long-range transport. Preliminary findings from CAESAR and ARCSIX will be compared with relevant times from MOSAiC, as well as highlighting new findings. Initial results from CAESAR indicate generally higher INP concentrations below versus above cloud during sampled cold air outbreaks.

14. Étienne Vignon, CNRS (ONSITE):

Leveraging THINICE airborne observations to assess how ICOLMDZ captures the properties of Clouds Embedded in Arctic Cyclones

Despite their essential role in the high-latitude climate, the representation of arctic mixed-phase clouds is still a challenge for atmospheric model's cloud schemes. In this study we propose a methodology for robustly assessing Arctic mixed-phase cloud condensed water contents in the ICOLMDZ model using airborne measurements. We leverage data collected during the THINICE airborne campaign that took place near Svalbard in August 2022 to evaluate the simulation of fontal clouds associated with Arctic cyclones. Airborne radar and microphysical probes measurements are then used to evaluate the simulated clouds. A comparison method has been set-up to guarantee as much as possible the spatiotemporal co-location between observed and simulated clouds. We mostly focus on the representation of ice and liquid in-cloud contents and on their vertical distribution. Results show that the model, that uses a common temperature-dependent phase partitioning, overestimates the amount of cloud condensates and exhibits a poor cloud phase spatial distribution, with too much liquid water far from cloud top and too much ice close to it. The gradual downward increase in snowfall flux is also not reproduced by the model which questions the ability of the precipitation parameterization to capture properly the snowfall growth processes. The second part of the work will be dedicated to the development and test of a new phase-partitioning scheme in the ICOLMDZ model based on theoretical considerations on the maintenance of supercooled liquid droplets in a turbulent environment with the presence of ice crystals. 1D and 3D ICOLMDZ simulations with this new parameterizations show promising results

15. Julia Asplund, Stockholm University (ONSITE):

Towards an improved Arctic aerosol representation in NorESM2

The aerosol population in the high Arctic is typically characterized by a bimodal size distribution and low particle number concentrations. It is therefore highly sensitive to changes in aerosol growth processes, sources, and sinks. In this pristine environment, where cloud droplet number concentrations are often limited by the abundance of particles acting as cloud condensation nuclei (CCN), even small changes in the aerosol population will therefore affect the physical properties of clouds. Climate models are essential tools to understand how the warming Arctic will continue to change, and affect the global climate. However, many models lack adequate representation of aerosol-cloud processes. This is particularly true in the Arctic where key local sources and processing of particles can be missing, as aerosol schemes are often developed based on knowledge from lower latitudes that does not necessarily apply in the Arctic. We present an evaluation and development study of NorESM2, a global Earth system model (which contributed to the sixth Coupled Model Intercomparison Project), regarding Arctic aerosol and low-level clouds. Our comparison between model output and observations from the Arctic Ocean 2018 expedition and the Zeppelin observatory revealed that NorESM2 underestimates particle number concentrations, mass, and organic mass fractions in the Arctic, and consistently misrepresents the aerosol size distribution. This results in an average underestimation of CCN of more than an order of magnitude. We will show the steps we have taken to improve the model, focusing on better representation of marine organic emission and aerosol growth, and address the potential impacts on the radiative forcing.

16. Ross Herbert, University of Leeds (ONLINE):

Long-range transported dusts are very important for Arctic ice nucleating particle concentrations

Ice-nucleating particles (INPs) are a subset of aerosol that can initiate the formation of ice in clouds. The temperature at which the INPs cause freezing is dependent on the species of aerosol and their relative abundance. Therefore, linking the source regions to the receptor regions where supercooled liquid clouds exist is an important step towards quantifying the role of INPs in the climate system. In many regions the INP concentrations will be closely linked to localised emissions of sea spray and dust. This includes the Southern Ocean and regions close to the major dust source regions. However, in the Arctic, local INP sources are relatively weak. Here, the long-range transport of INPs from lower latitudes may play an important role and help to explain the presence of relatively high INP concentrations (Raif et al., 2024). Here we use the UK climate model to explore the role of long-range transported dust in the Arctic and impact on INP concentrations. We find that although locally-emitted high-latitude dust contributes towards most of the dust mass in the Arctic, the INP contribution is weighted towards the fine mode dust emitted from low-latitude sources and transported into the Arctic. For example, in late summer, 10% of the dust mass in the Arctic lower atmosphere accounts for 65% of the INP concentration, with half of this concentration from dust that has been in the atmosphere for over 60 days. This arises due to changes in the dust population size distribution, which will progressively become smaller with time and distance from source. This highlights an important role for aged dust and low-latitude dust sources on Arctic mixed-phase clouds. It also highlights a particular sensitivity of INP concentrations to smaller size modes, such as the accumulation mode.

17. Kerri Pratt, University of Michigan (ONSITE):

Arctic sea spray aerosol particles: Chemical composition and incorporation into cloud droplets

Thinning and loss of Arctic sea ice is increasing sea ice fractures (leads) and open water (including polynyas), increasing sea spray aerosol emissions. During bubble bursting, marine organic compounds are incorporated as coatings on sea salt aerosol, thereby connecting marine microbial communities to sea spray aerosol

composition. Sea spray aerosol are an important source of cloud droplet nuclei, yet our understanding of incorporation of these particles into Arctic clouds is limited. We have conducted measurements of the chemical composition of individual atmospheric particles and cloud residual particles through several field campaigns over the High Arctic Ocean, Chukchi Sea, and northern Baffin Bay. This presentation will focus on the chemical composition of individual sea spray aerosol particles identified by single-particle mass spectrometry and computer-controlled scanning electron microscopy with energy-dispersive X-ray spectroscopy. Marine organic coatings on sea salt aerosol are characterized by Raman microspectroscopy and matched to a Raman library of marine organic compounds, including saccharides, fatty acids, and amino acids. Ambient sea spray aerosol particles are compared to those generated using a marine aerosol reference tank using locally collected seawater samples in the central Arctic in the late summer.

18. Edward Gryspeerdt, Imperial College of London (ONSITE):

Observing the timescales of aerosol-cloud interactions in the Arctic

Clouds are a central component of the Earth's energy budget, exerting strong controls on the top-of-atmosphere and surface energy balances. Small changes in cloud properties can induce significant radiative forcings, with strong regional variation. Satellite-based estimates of the effective radiative forcing from aerosol-cloud interactions (ERFaci) have typically focused on lower latitudes, despite the significant uncertainty in climate model estimates of the ERFaci in the Arctic and evidence that it will weaken as the Earth warms. The cloud adjustment processes responsible for a large fraction of the ERFaci uncertainty are also time-dependent, a vital consideration in the Arctic due to the strong variations in surface properties and aerosol sources over short distances. This work demonstrates how the timescales of aerosol impacts on clouds in the Arctic can be assessed using a range of satellite instruments and sampling to remove potential retrieval biases. The development of a novel time-since-ice methodology is used to characterise the timescales of aerosol impacts on clouds. The time dependence of the cloud response to aerosol is clearly seen in clouds during cold air outbreaks, with aerosols modifying the timing of cloud development. Natural experiments into cloud evolution driven by shipping emissions are then used to assess causality of observed aerosol-cloud relationships, providing new constraints on cloud and aerosol processes in the Arctic.

19. Hannes Griesche, TROPOS (ONSITE):

Examination of surface-coupling effects on heterogeneous ice formation at low supercooling temperatures in mixed-phase clouds during MOSAiC

Surface-coupled Arctic summertime clouds show a higher probability of ice formation at temperatures above -15^{o}C. The reason behind this is likely a larger reservoir of marine INPs of biogenic origin in the Arctic surface-coupled marine boundary layer. The increased number of INPs then lead to a higher freezing efficiency in the clouds which have at least their base in the boundary layer. However, the data basis of this study is so far limited to a two-month expedition in the Arctic summer 2017 in the marginal sea-ice zone. Observations from the MOSAiC campaign were analyzed for similar effects based on the same approach. The cloud phase was identified based on the lidar depolarization signal. The cloud top was derived using the cloud radar reflectivity. The cloud top temperature and the coupling state was identified based on the temporal closest radiosonde profile. Effects of enhanced turbulence in the boundary layer on secondary ice formation were also investigated by means of Eddy dissipation rates derived from the cloud radar Doppler velocity within clouds. In the summer months liquid precipitating clouds frequently prevented a correct phase detection based on the lidar signal. Excluding these periods from the analyzed data, the MOSAiC observations revealed similar effects during spring and summer. During these periods, an increased frequency of occurrence of ice containing clouds was found during surface-coupled situations, especially at low supercooling temperatures >-15 ^{o}C.

20. Christian Pilz, TROPOS (ONLINE):

Tethered balloon measurements reveal enhanced aerosol occurrence aloft interacting with Arctic low-level clouds

Low-level clouds in the Arctic affect the surface energy budget and vertical transport of heat and moisture. The limited availability of cloud-droplet-forming aerosol particles strongly impacts cloud properties and lifetime. Vertical particle distributions are required to study aerosol-cloud interaction over sea ice comprehensively. This workshop contribution presents vertically resolved measurements of aerosol particle number concentrations and sizes using tethered balloons. The data were collected during the Multidisciplinary drifting Observatory for the Study of Arctic Climate expedition in the summer of 2020. Thirty-four profiles of aerosol particle number concentration were observed in 2 particle size ranges: 12-150 nm ($N_{12\text{-}150}$) and above 150 nm ($N_{>150}$). Concurrent balloon-borne meteorological measurements provided context for the continuous profiles through the cloudy atmospheric boundary layer. Radiosoundings, cloud remote sensing data, and 5-day back trajectories supplemented the analysis. The majority of aerosol profiles showed more particles above the lowest temperature inversion, on average, double the number concentration compared to below. Increased $N_{12\text{-}150}$)up to 3,000 cm-3were observed in the free troposphere above low-level clouds related to secondary particle formation. Long-range transport of pollution increased $N_{>150}$ to 310 cm-3 in a warm, moist air mass. Droplet activation inside clouds caused reductions of $N_{>150}$ by up to 100%, while the decrease in $N_{12\text{-}150}$) was less than 50%. When low-level clouds were thermodynamically coupled with the surface, profiles showed 5 times higher values of $N_{12\text{-}150}$ in the free troposphere than below the cloud-capping temperature inversion. Enhanced $N_{12\text{-}150}$ and $N_{>150}$ interacting with clouds were advected above the lowest inversion from beyond the sea ice edge when clouds were decoupled from the surface. Vertically discontinuous aerosol profiles below decoupled clouds suggest that particles emitted at the surface are not transported to clouds in these conditions. It is concluded that the cloud-surface coupling state and free tropospheric particle abundance are crucial when assessing the aerosol budget for Arctic low-level clouds over sea ice

21. Quentin Coopman, Université de Lille (ONSITE):

Effect of air parcel transport on the spatial distribution of the thermodynamic phase of Arctic clouds

At temperatures between -40^{o}C and 0^{o}C, clouds can be mixed phase, so called because they consist of a mixture of both liquid cloud droplets and ice crystals. This type of cloud is especially poorly represented in climate models. One of the reasons is that both hydrometeors are assumed to be homogeneously mixed in global models, but observations show that ice and liquid are heterogeneously mixed and exist in separate "pockets". This difference in the 3-dimensional spatial distribution of ice and liquid is important to assess and quantify precipitation, cloud processes, radiative properties, and consequently their impact on climate change. The present study aims to better characterize mixed phase clouds and especially the spatial distribution of the thermodynamic phase and understand how meteorology, air parcel transport and aerosols impact it. We defined a parameter to describe the spatial distribution of liquid and ice phases within mixed-phase clouds from observations from the space-based lidar CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarisation). We spatially and temporally collocated the satellite measurements with reanalysis retrievals of aerosol concentration and meteorological parameters from ERA5 (European Centre for Medium-Range Weather Forecasts Reanalysis v5) and MERRA-2 (Modern-Era Retrospective analysis for Research and Applications, version 2) and then applied a multi-linear linear regression fit to quantify the influence of the external parameters on the spatial distribution of the cloud phase up to first order. A second part of the study focuses on ground-based measurements from the North Slope Alaska Station (NSA), where the transport of air parcels is analysed according to cloud type. Focusing on the Arctic region, the results show that temperature is the most important parameter influencing the liquid-ice interface: for example, clouds with a temperature above 265 K have seven times more liquid-ice interfaces and are more homogeneously mixed than clouds with a temperature below 253 K. Vertical velocity and black carbon concentration are also important parameters to describe the phase distribution. At NSA, clouds associated with higher transport

may be more heterogeneously mixed. The results could be used to refine the parameterisation of clouds in models and their impact on climate change

22. Radiance Calmer, EPFL (ONSITE):

Vertical distribution of aerosols in the Arctic lower atmosphere during the transition between winter and springtime observed with a tethered balloon at Villum Research Station

Within the warming context of the Arctic, aerosol-cloud interactions remain one of the key processes connected with largest uncertainty for understanding climate change. Questions associated with the sources of aerosols, either local or transported from mid-latitudes, keep captivating scientific interests, and clouds, particularly mixed-phased clouds, raise challenges to quantify their impacts on the Arctic surface radiative budget. Stable boundary layers with strong surface inversion also defy the established ground-based measurements, as aerosol properties measured from a station might not represent the vertical profile above. To address the knowledge gap, an aerosol-cloud instrument package has been developed for a tethered balloon, the HELIKITE, to deploy instruments from the surface to 800 m. The platform was operated at Villum Research Station in North Greenland, from March 23 to May 2, 2024, as part of the VAERTICAL (Vertical properties of Aerosols in the Arctic lower atmosphere and their impact on cloud radiative effects) and CleanCloud (Clouds and climate transitioning to post-fossil aerosol regime) projects. During the field campaign, the HELIKITE conducted 57 flights for a total of 160 hours of scientific vertical measurements of dynamic and thermodynamic parameters and aerosol number size distributions between 8 nm and 3 um. As the season transitioned from winter to springtime, measurements spanned a diversity of climatic conditions, from observations of the Arctic haze to new particle formation, with strong surface inversion prevailing in most cases. This presentation will provide an overview of the campaign and some insights into specific case studies.

23. Schuchard Malte, Technische Universität Braunschweig (ONLINE):

Airborne observations of the spatial distribution of Arctic aerosols at different sites

Aerosol particles play a crucial role in the Arctic, in particular as they strongly contribute to a systematic incompleteness of understanding the processes and impacts of the Arctic amplification. Thus, a better knowledge of formation, growth, mixing and transport of aerosol particles is of vital importance, especially with regard to dynamically driven factors such as wind flow phenomena. This is of special relevance in the atmospheric boundary layer (ABL), where high data gaps exist due to missing measurement devices, but the data lacks can be filled via suitably equipped airborne platforms that are operated within the lowest 1-3 km height. The presentation focuses on aerosol particles observations from two uncrewed airborne systems during two field campaigns in the Arctic. Both systems consist of similar aerosol instrumentation and allow among others combining aerosol size distribution and number concentration with meteorological parameters that are sampled with a high temporal and spatial resolution at different scales (several 100 m up to a few 10 km) to identify possible sources, transport and the occurrence of ultra-ultrafine aerosol particles (UFPs, here defined as size by a particle diameter of 3-20 nm). The helicopter borne sensor system HELiPOD was deployed for 12 measurement flights (~26.5 h of sampling time) from the Swedish icebreaker ODEN within the ARTofMELT expedition in the Fram Strait in spring/summer 2023. A high horizontal variability of UFPs was observed, depending on the distance of HELiPOD to ODEN, and the vertical distribution was characterized by the highest concentrations of UFPs close to the sea ice surface, assuming open water sectors as a major source. However, during other case studies, UFPs appeared above the top of the ABL so that air mass transport or local entrainment processes involving supersaturation is more likely, characterized by dry air masses and high ozone concentration. The fixed-wing research drone ALADINA was deployed for 40 measurement flights on nine days (~35 h of sampling time) as part of the AIDA project at the coastal site Ny-Alesund, Svalbard, during the melting season in 2024. The occurrence of UFPs was observed on eight different measurement days during the campaign. As an example, measurement data from 24 May 2024 are

presented, showing particularly high concentrations of UFPs reaching around 10,000 particles per cm-3 with a slow growth rate. The new particle formation event, defined as class Ib, was characterized by a high temporal and spatial variability, which is strongly influenced by the orography and prevailing wind regime

24. Roman Pohorsky, EPFL (ONSITE):

In situ vertical observations of aerosol and cloud properties within low-level clouds during the Arctic melt season

Low-level mixed-phase clouds (LLMPCs) are ubiquitous and play a crucial role in Arctic climate. Because of their effect on radiation and atmospheric dynamics, LLMPCs affect the surface energy budget and vertical transport of heat and moisture. LLMPCs largely depend on the presence of aerosol particles acting as cloud condensation nuclei (CCN) or ice nucleating particles (INPs). Small changes in aerosol number and physiochemical properties (e.g., size, chemical composition, hygroscopicity) can have significant impacts on radiative properties and lifetime of Arctic LLMPCs. However, radiative forcing estimates from aerosol-cloud interactions (ACI) remain the largest uncertainty in climate change projections to this day. Vertical in situ observations of aerosols at cloud level remain scarce but are crucial to improve our understanding of ACI and their climatic effects in the Arctic. A key question in this context concerns the origin of aerosols that contribute to cloud formation, specifically whether they are CCN or INPs transported in the free troposphere over long distances, or from local sources at the surface. To address the need for more vertical observations of aerosols and clouds, a tethered balloon equipped with the Modular Multiplatform Compatible Air Measurements System (MoMuCAMS) was deployed from the Swedish icebreaker Oden.

25. Im Ulas , Aarhus University (ONLINE) :

Marine isoprene and its contribution to secondary aerosols and clouds in an Earth system model

The ocean is a source of isoprene to the atmosphere, formed both from biological activity (biotic) and chemical reactions over the sea surface microlayer (SML). Isoprene is a reactive volatile organic compound (VOC), playing an important role on the atmospheric chemistry. Although the global estimates of marine isoprene are relatively low compared with the terrestrial source, these emissions have an influence on atmospheric chemistry, including formation of secondary organic aerosols (SOA). We have implemented marine isoprene emissions in the NASA-GISS Earth system model (GISS-E2.1) to study its contribution to the SOA burden. Marine isoprene in the GISS-E2.1 are emitted by both biological processes and by the SML, following methodology described in Cui et al. (2023). We have conducted AMIP-type equilibrium simulations for the year 2000 with free climate for 35 years, where we used the last 30 years for analyses. We have conducted one base case simulation without marine isoprene emissions, one with only biological emissions, one with only SML emissions, and finally, one with both biological and SML emissions. Global marine isoprene emissions are calculated to be 0.6 Tg yr-1, almost equally contributed by the biotic and abiotic processes, and much smaller compared to the terrestrial isoprene emissions (528 Tg yr-1<Globally and over the Northern Hemisphere, , the emissions peaked in late spring, while in the Southern Hemisphere, highest fluxes were calculated for the southern summer (December and January). Observed fluxes are underestimated by 10% in the East China Sea to 90% in Malaysia Sea. Over the North Atlantic and Southern Ocean, GISS-E2.1 underestimated the observed fluxes by around 30%. >Globally, SOA burden increases by 2%, with regional changes of up to 20%. Over the ocean, SOA burdens increased by 1.5%, while over land, changes were much higher, suggesting an indirect effect of the impact of climate over the terrestrial isoprene emissions.

26. Eva-Lou Edwards, NASA Langley Research Center (ONLINE):

Seasonal and vertical trends in black carbon properties in the Arctic during ARCSIX

The Arctic has been severely impacted by climate change. Sea ice extent and thickness have drastically declined, and the region is expected to have its first ice-free summer between 2030 and 2060. One reason this prediction has a thirty-year range is because the Arctic radiation budget is highly complex and poorly understood. It is not entirely clear how clouds and aerosol particles interact with shortwave and longwave radiation in the Arctic, and relationships between clouds, particles, meteorology, and the surface are even more uncertain. Black carbon (BC) is a type of aerosol produced during fossil fuel combustion and biomass burning and is often present in the Arctic. BC plays a key role in the Arctic radiation budget as it efficiently absorbs radiation, thus warming the atmosphere and accelerating ice melt when deposited on surfaces covered in snow and ice. However, the magnitude of radiative forcing due to BC in the Arctic is highly uncertain as it depends on the vertical distribution of BC in the atmosphere and its microphysical properties (e.g., mass and number concentration, size distribution, fraction of coated particles, shell to core ratio, mixing state, and mass absorption efficiency [MAE]). This work presents and discusses the vertical profiles of these properties for both particles and cloud droplets containing BC obtained during the NASA Arctic Radiation-Cloud-Aerosol-Surface-Interaction Experiment (ARCSIX). Results from this work are compared to those from previous studies to better understand how atmospheric composition is changing in the Arctic, how these changes in composition are influencing the Arctic radiation budget, and how changes in atmospheric composition are related to cloud properties in the same climate system

POSTER PRESENTATIONS:

1. Berkay Dönmez, EPFL (ONSITE) :

Quantifying the Multi-Annual Characteristics of Warm and Moist Intrusions as Sources of Aerosol and Humidity to the Arctic

Individual case studies have provided insights into the effects of warm and moist air intrusions on the aerosol burden, cloud properties, and the resulting radiative forcing in the Arctic. However, there is a need to understand whether these impacts are climatically significant and consistent across various intrusion events over decadal time scales. Here, we investigate the multi-annual aspects of intrusion impacts on aerosol burden and characteristics using extensive aerosol data from multiple stations across the Arctic, covering a large swath of the Arctic Circle. We compile a list of intrusion events for each station, categorize them based on an intensity criterion, and analyze the differences in observed changes in aerosol number size distribution, number concentration, and optical coefficients among intrusions with different intensities. Furthermore, we support our analysis with basic information derived from the Lagrangian analysis tool LAGRANTO model, which helps to identify transport pathways.

2. Nora Bergner, EPFL (ONSITE) :

Characterization and effects of aerosols during blowing snow events in the central Arctic

Sea salt aerosol (SSaer) plays a crucial role in aerosol-radiation and aerosol-cloud interactions, and sublimated blowing snow is hypothesized to be a significant source of SSaer in polar regions. A better understanding of the climate-relevant properties of blowing snow and other wind-driven aerosols is important, particularly during winter when Arctic amplification is largest. Current knowledge of blowing snow SSaer largely comes from modeling studies, with limited direct observations. Moreover, multiple sources of SSaer make it challenging to disentangle emission processes. This study presents comprehensive observations

of wind-driven aerosol during blowing snow events from the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expedition in the central Arctic. We show that high wind speeds increase total aerosol number concentrations, submicron sodium chloride levels, cloud condensation nuclei concentrations, and scattering coefficients. The impact of wind speed on aerosol properties is most pronounced in the fall when aerosol concentrations are lowest. Enhanced cloud condensation nuclei concentrations from these aerosols could influence cloud longwave radiative effects, while increased aerosol scattering could be significant during spring in the polar day and near the marginal ice zone. Blowing snow events showed consistent aerosol properties, except during events with high snow age >6 days since the last snowfall). Coarse-mode number concentrations are better correlated with wind speed averaged over 12-hour air mass back trajectories than with local, instantaneous wind speeds, indicating the importance of regional blowing snow conditions and wind-driven aerosol production. The observations from MOSAiC offer new insights into wind-driven aerosols in the central Arctic and can help validate and improve model parameterizations, particularly for aerosol direct and indirect radiative forcing.

3. Kathryn Moore, University of Maryland, College Park & NASA Goddard Space Flight Center (ONSITE):

Addition and Evaluation of Northern High-Latitude Mineral Dust Sources in the NASA GEOS Model

Mineral and soil dust aerosol play important roles in Earth climate, particularly by impacting aerosol radiative forcing and through indirect effects on clouds, including their phase and lifetime. Desert dust, primarily from low latitude sources, has received significant attention from both the observational and modeling communities, but dust emissions from high latitude sources remain understudied. Such high latitude dust sources have been suggested to be a major contributor to the Arctic ice nucleating particle population, and may also contribute to Arctic mixed phase clouds being substantially more glaciated than similar Southern Ocean clouds, where lower dust concentrations are observed. Despite their potential importance for cloud radiative effects, dust ACI in the Arctic remains uncertain. One challenge is the variability observed in Arctic dust concentrations between models, many of which do not consider high latitude dust sources. This study aims to improve simulation of dust in the Arctic in the NASA GEOS model by adding such local sources at high latitudes >=50N). The dust emission map created for use with FLEXPART (FLEXDUST; Groot Zwaaftink et al. 2016) has been implemented in GEOS and we are assessing the dust emission sensitivity to model resolution and wind speed threshold. High latitude dust emissions are sensitive to snow cover and possibly soil temperature in addition to soil moisture and vegetation coverage, which contributes to the strong seasonality and regionality of such emissions. Results of sensitivity studies to assess the relative importance of snow cover, vegetation fraction, soil temperature, and soil moisture on high latitude dust emissions will be presented. The magnitude and locations of Arctic dust emissions in GEOS will be validated against CALIPSO retrievals, ground lidar observations from the NASA Micro-Pulse Lidar Network (MPLNET) and aluminum measurements from Villum Research Station (Station Nord) and Station Alert. Future studies will utilize the improved GEOS dust emissions to help constrain the uncertain impacts of local high latitude dust on Arctic aerosol-cloud interactions

4. Benjamin Heutte, EPFL (ONSITE):

Sources and processes governing the annual cycle of aerosol chemical composition in the central Arctic: implications for aerosol-cloud interactions

Aerosols, originating from both natural and anthropogenic sources and either locally emitted or long-range transported, play a crucial role in the Arctic radiative balance. Depending on their abundance, size, and chemical composition, aerosols can directly interact with the incoming solar radiation by absorbing or scattering light, and/or indirectly by serving as seeds for cloud formation. However, the scarcity of aerosol observations in the central Arctic leaves gaps in understanding aerosol dynamics year-round, which in turn impacts model predictions of climate-relevant properties. This is particularly true for the dark autumn and winter months.<p>In this study, we present the first annual high-time resolution observations of aerosol

physicochemical properties in the central Arctic, based on measurements performed during the Arctic Ocean 2018 (AO2018) and the 2019-2020 Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) expeditions. Using statistical clustering and source apportionment methods, we investigate the sources, emission processes, and potential radiative impacts of central Arctic aerosols. We find that cyclonic activity (storms) have a significant influence on aerosol variability in autumn and spring by enhancing wind-driven emissions from local sources and transporting aerosols from remote sources. Locally wind-generated particles were found to contribute up to 80% of the cloud condensation nuclei (CCN) population in autumn. By investigating the speciation of organic aerosols (OA), we find that long-range transported anthropogenic aerosols, of Eurasian origin, dominate the springtime central Arctic aerosol population, until at least the month of May. Highly photo-oxidized OA, combined with a major mass fraction of sulfate in the submicron aerosol population (~50%), make for generally very hygroscopic particles from the first Arctic sunrise early in March until the collapse of the polar dome in May. Episodic spikes in naturally-sourced marine OA become increasingly important during summer, when OA represent nearly two thirds of the total submicron aerosol mass. Finally, based on the analysis of OA speciation in activated fog droplets during summer, we infer which classes of marine OA are contributing to low-level clouds/fog formation. The results from this study will serve to improve our understanding of aerosol sources and related physicochemical properties in the central Arctic, as well as their role in the central Arctic radiative budget

5. Remi Lapere, LATMOS (ONSITE):

Potential impact of sea-ice leads on aerosols and clouds in the Arctic

In the Arctic ocean, open leads have the ability to release sea spray into the atmosphere. However, the magnitude and seasonality of this flux are relatively unknown, which is a limitation to our understanding of the polar climate. Most atmospheric models do not include sea spray from leads, because of the lack of existing parameterization. In this work we propose a parameterization for sea spray fluxes from open leads in the Arctic, which leverages aerosol flux measurements from a past campaign combined with the latest generation of sea ice modeling. Based on our parameterization, the annual total emitted mass of sea salt from open leads, [0.1-1.5] Tg/yr, is comparable to emissions from blowing snow and to the transported mass of sea salt from open ocean coming from the lower latitudes. Furthermore, the seasonality of open lead and blowing snow sea salt emissions have opposite phases, and their spatial distribution across the Arctic is also different. Therefore, we find that including both open lead and blowing snow sea salt fluxes can improve the reproduction of the annual cycle of sea salt aerosol atmospheric concentration at high latitude stations. Using sea ice concentration fields from the neXtSimv2 sea ice model and implementing our parameterization in the WRF-Chem chemistry-transport model, we evaluate the impacts of open lead emissions on sea salt concentrations and clouds in the high Arctic

6. Anderson Da Silva, LATMOS/ Sorbonne Université (ONSITE):

Evaluating the contribution of marine organic aerosols to INP population and their effect on ice nucleation in Arctic clouds

Ice nucleating particles (INPs) are critical for the formation and evolution of ice-containing clouds, especially in the Arctic where INPs are scarce. Indeed, the most well-known INP sources are mineral dust from erodible regions, but because INPs have a short lifetime in the atmosphere, these sources may appear as remote regions for the Arctic and therefore may be of limited importance for Arctic clouds. Recent studies suggest that local marine sources together with local dust emissions within the Arctic region could have a significant impact in the Arctic INP production. In this study, we implement emissions of primary biological aerosols particles (PBAPs) from marine sources in the WRF-Chem chemistry-transport model. Combined with the observational data from the MOCCHA campaign (high Arctic, summer 2018), this work shows how considering marine organics particles improves the representation of aerosols and their activation as INPs in the model. In the meantime, we test different ice nucleation parameterizations including the implementation

of a classical nucleation theory (CNT) scheme for PBAPs. This allows us to assess the effects of a more accurate representation of the Arctic INP population on cloud phase and radiative feedback

7. Yaël Le Gars, Université Pierre et Marie Curie - Sorbonne - LATMOS (ONSITE):

Modelling mixed-phase clouds in the European Arctic

Mixed-phase clouds, containing both supercooled liquid water and ice crystals, are predominant in the European Arctic region. Because their variability and their sustainability are inaccurately represented in models, they are an important source of uncertainty. The cloud phase is of particular concern as it impacts precipitation amounts, cloud lifetime and radiative effects. Assessing the vertical distribution of clouds, their optical properties and their phase distribution is therefore critical to accurately determine the surface energy balance (SEB). Here, the mesoscale WRF (Weather Research and Forecasting) including developments to be used in polar regions is run over the Arctic region from January to July 2015. The simulations are evaluated with observations from the N-ICE campaign conducted from January through June 2015 around Svalbard, satellite data derived from CALIPSO, CLOUDSAT and MODIS and lidar observations onboard drifting buoys as part of the IAOOS project. The simulated SEB as well as cloud distributions and phase partitioning are evaluated to get insight on the limitations of the model to represent Arctic clouds. Different parameterizations of cloud microphysics are tested to understand how it affects cloud representation and SEB

8. Imogen Wadlow, University of Leeds (ONSITE):

Factors controlling climate-relevant Arctic aerosols in UKESM

Improving the representation of aerosols in Global Climate Models (GCMs) is key in addressing uncertainties surrounding simulated aerosol-cloud interactions. This study presents the dominant parameters controlling accumulation-mode aerosols over the Arctic within the GCM, UKESM (United Kingdom Earth System Model). Size distributions of accumulation-mode aerosols, which form the majority of Cloud Condensation Nuclei, are evaluated in UKESM coupled with UKCA (United Kingdom Chemistry and Aerosols) and the aerosol microphysical scheme GLOMAP (Global Model of Aerosol Processes), using observations from several Arctic sites. A Perturbed Parameter Ensemble was run of UKESM-UKCA-GLOMAP, which simulated 220 combinations of 37 aerosol-cloud-relevant parameters, each perturbed within plausible ranges to investigate model performance across parameter domains with highly interconnected processes. Across all evaluation sites, a consistent seasonal bias pattern has been identified in simulated aerosol size. This research demonstrates the relative importance of natural/anthropogenic process parameterisations on accumulation-mode seasonal cycles, and aims to explain the cause of this bias in UKESM.

9. Romanos Foskinis, EPFL (ONSITE):

Preliminary Results from the CleanCloud Campaign in Greenland Villum Research Station

The Clean Cloud project aims to study the clouds and the climate transitioning to the post-fossil aerosol regime where the CO_2, the natural emissions and the temperature would be increased, while at the same time, the anthropogenic contribution to aerosols is expected to be reduced according to the Paris Agreement. Given that clouds are strong modulators of the radiative transfer in the atmosphere, we are interested in understanding how clouds will respond regarding the aerosol and cloud processes, the convective systems and extreme weather events, in the post-fossil aerosol regime. The arctic regions offer a great opportunity to study how the clouds will respond in such a change given that the weakening of the polar vortex drives the cloud condensation nuclei origins from anthropogenic to natural from spring to summer period, respectively. Thus, we performed field measurements during two campaigns (March-April & July-August) at the Villum

Research Station which is located in high arctic North Greenland (81°36N, 16°40W). Here, we present preliminary results regarding the study of the aerosol-cloud interactions for arctic clouds that develop throughout the studied periods using a synergy of remote sensing and in situ instrumentation

10. Salvatore Sodano, Australian Antarctic Program Partnership, Institute for Marine and Antarctic Studies, University of Tasmania, CSIRO Environment: (ONLINE)

Southern Ocean aerosol and cloud formation

The Southern Ocean (SO) is one of the last areas of the world where atmospheric conditions are similar to the pre-industrial period (Hamilton et al. 2014; Mallet et al. 2023). Some studies have demonstrated that synoptic- scale pollution is already altering the natural balance and dynamics (Bhatti et al. 2022). For this reason, it is now necessary to deepen our understanding before these environments are further impacted. Considering the diversity and complexity of aerosol measurements (Reddington et al. 2017), a multidisciplinary and international effort is necessary to enhance our understanding of the interactions between aerosols, clouds, and precipitation, as well as their variability with the biosphere (Marchand et al. 2014; McFarquhar et al. 2021; Humphries et al. 2023). This project will provide the first ever comprehensive validated long-term dataset of aerosol size distribution over the SO. This will include data collected from Kennaook-Cape Grim, the RVI Investigator, the RSV Aurora Australis, and the RSV Nuyina. This new long-term dataset will be created using a combination of novel machine-learning techniques, weather and climate models. The project will enhance our understanding of SO aerosol and cloud formation, their role in climate and improve aerosol property simulations in Earth System models by providing observational constraints on aerosol size and composition.