From clouds to fjords, the Arctic bears witness to climate change

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EPFL scientists travel to the Arctic to measure the consequences of climate change. Credit: EPFL/SENSE- CC-BY-SA 4.0

Climate change is particularly intense in the Arctic. To assess its consequences and determine what role this region plays in global warming, two teams of scientists from EPFL have visited the area. One to gain a better understanding of the region's air composition, the other to quantify the greenhouse gases sequestered in Greenland fjords sourced by glacial water.

In the Arctic—a region where temperatures are rising three to four times faster than anywhere else on Earth. In parallel, the amount of "life" in the Arctic Ocean is increasing, which is affecting the production of biological aerosols and impacting cloud formation.

Julia Schmale, head of EPFL's Extreme Environments Research Laboratory (EERL), and her research group are working to quantify this critical process. An increase in clouds in the Arctic could either warm or cool the region, depending on the extent of sea ice.

"We know that Arctic clouds are generally made up of water droplets and ice crystals," says Schmale. "But a lot remains to be learned about their exact composition and how they're formed.

"For example, the seeds of water droplets and ice crystals—are they sea salt, organic particles, inorganic particles, or mineral dust? And most importantly, what percentage of these seeds comes from natural sources and what percentage from human activity?"

Beginning of an answer

Two studies led by Schmale's research group shed light on this complex and strategically important field of study. They looked specifically at the natural aerosol particles which act as cloud seeds, or the seeds that enable ice crystals in clouds to be formed.

The first study, published in *Elem Sci Anth*, quantifies for the first time the amount of fluorescent biological aerosols contained in Arctic air. These aerosols are mainly bacteria and amino-acid-containing particles that are produced in the ocean or on land.

They're very efficient at seeding ice crystals: ice begins to form at –9°C, whereas with mineral dust, for example, ice begins to form at around –20°C.

This study draws on data collected on an icebreaker over a full year (between 2019 and 2020) during the MOSAIC expedition. "We used a laser-based instrument to take second-by-second measurements of the fluorescence of air particles," says Schmale.

"Particles that fluoresce are generally of biological origin." These data enabled the scientists to estimate the concentration of natural biological aerosols in the air and form hypotheses about where they came from.

In the winter, for example, the scientists observed "bursts" of these aerosols, which was surprising given that the ocean is frozen over during that time and there isn't much biological activity. The scientists hypothesized that the aerosols had been carried over, such as within clouds, from distant areas.

In June, the concentration of biological aerosols started to rise dramatically—coinciding with a peak in biological activity as measured by high chlorophyll levels in the water.

There was also a sharp increase in the quantity of ice nucleating particles at –9°C. While no direct causation could be shown, this is a strong indication that locally sourced biological particles contribute to ice nucleating cloud seeds in the central Arctic. Parallel processes were observed over the course of the year.

"Interestingly, as chlorophyll production dropped in the fall and larger microbes in the ocean water were replaced by smaller ones, the size of fluorescent aerosols also decreased," says Schmale. "This reflects a seasonal marine microbial transition that also occurred in the air."

Machine learning analysis

The second study, published in *npj Climate and Atmospheric Science*, is based on a machine-learning analysis of aerosol measurements and weather data over the past decade.

It's the first to identify which meteorological factors are behind the production of methanesulfonic acid (MSA), an important marine aerosol created by phytoplankton blooms, and how this production will likely change over the next 50 years. MSA is a key component of cloud condensation nuclei, or the seeds for cloud droplets, and is therefore climate relevant.

Meanwhile, the Climate and Atmospheric Science study examined possible MSA trends in the Arctic. EERL scientists worked with the Swiss Data Science Center to combine field observations with analyses of weather data and air-mass back trajectories.

They developed a data-driven model in order to gain greater insight into the factors responsible for MSA production today. For example, the scientists found that solar radiation, cloud cover, and cloud water content are critical factors, pointing to specific atmospheric chemical processes.

The research team then calculated trends in these factors over the past decades and extrapolated them to outline scenarios for MSA seasonality in the Arctic going forward.

"Our key finding is that there will probably be less MSA in the spring and much more in the fall," says Schmale. "That's due to seasonal changes in precipitation in the spring and a marked retreat in sea ice in the fall." This suggests that climate change affects the aerosols influencing cloud formation, which in turn affects climate change.

Asking the right questions

Scientists are already planning another international expedition into the Arctic, and are preparing a research vessel—the Tara Polar Station—to collect central Arctic data over the next 20 years.

"The advances achieved by these two studies are fascinating in my opinion because they show how important natural sources of aerosol particles are for the Arctic climate system, and suggest these sources will change drastically in the coming decades," says Schmale.

"These initial results tell us that more research is urgently needed to predict what the Arctic will look like in 2050. They'll help us ask the right questions for future studies in this field."

Gases stored in Greenland fjords may contribute to global warming

In June 2024, another team of EPFL scientists traveled through two beautifully wild fjords of Greenland. In the depths of these inlets sourced by century-old glaciers, they map the amount of two greenhouse gases dissolved in water at depth.

They want to determine if these greenhouse gases could potentially amplify global warming via some unknown natural feedback mechanism. This project is part of the GreenFjord international expedition, scheduled to run from 2022 to 2026, financed by the Swiss Polar Institute and scientifically led by Julia Schmale.

"We bring our technological expertise to Greenland, engineering the right instruments to analyze dissolved greenhouse gases in aquatic environments and document their spatial variability. Our aim is to answer fundamental questions about Greenland's role in the future of global climate change," says Jérôme Chappellaz who leads EPFL's Smart Environmental Sensing in Extreme Environments (SENSE) Laboratory.

In past interglacial periods when Greenland was partially melted, it is possible that the melted regions were covered with tundra and boreal forests, known to lead to soil rich in organic material. As these organically rich soils decompose, they emit carbon dioxide and methane, which is one of the reasons why scientists are so interested in Greenland's contribution to global emissions.

Note that the glaciers in Greenland are different from the ones in Switzerland.

"It's highly unlikely that we'd encounter the same phenomenon in Swiss glaciers since they were formed at very high altitudes where vegetation is almost inexistent," explains Chappellaz.

Impacts on microbiology

Fjords are a long, narrow and deep inlet of the sea between high cliffs, typically formed by submergence of a glaciated valley.

Chappellaz and his team benefit from an interdisciplinary project called GreenFjord, coordinated by Julia Schmale, who leads the Extreme Environments Research Laboratory (EERL) of EPFL. They have engineered advanced instruments specifically to measure dissolved methane (CH_4) and nitrous oxide (N_2O) at various depths of water in the two fjords in southwest Greenland, down to 700 m of depth.

The fjord fed by a marine-terminating glacier consists in fact of a continuum of fjords, Ikersuaq, Brederfjord and Sermilik, where glacier water arrives from below the floating glacier into the fjord and then to the Labrador sea, progressively forming a layer of glacial water floating atop of seawater.

In contrast, fjord Tunulliarfik, inhabited by the settlement Igaliku founded in 1783, is sourced by a glacier that ends on land and where glacial meltwater invades the surface of fjord waters from the onset of the fjord itself.

"The distinct features of the two settings generate large differences in the physical structure of the water column as well as in the input of nutriments, both affecting the microbiology in the two fjords and then the fate of these two greenhouse gases. This is what we want to compare and quantify. In a situation of a disintegrating Greenland ice cap, it's an open question if such mechanisms could add another unexpected source of greenhouse emissions on top of human being sourced ones," explains Chappellaz.

An unexpected source of greenhouse gases?

Chappellaz and his team visited both the marine- and land-terminating fjords aboard the oceanographic vessel Sanna. Aboard the Swiss sailboat, the Forel, they focused on the marine-terminating one. Scientists were able to get close enough to the glacier front in the marine-terminating glacier fjord, to measure and hopefully characterize how much methane gets into the fjord through the subglacial water system.

In a 1995 publication, Chappellaz shows that greenhouse gas production in Greenland soil is strong and that large concentrations of carbon dioxide (CO_2) and methane are currently trapped in basal ice, located at the heart of the Greenland ice cap.

"The natural question is then how much of these greenhouse gases are released when the glacier water melts? How much is getting to the coast and possibly contributing to significant fluxes released into the atmosphere? In a situation of a disintegrating Greenland ice cap, it's an open question if such mechanisms could add another unexpected source of greenhouse emissions on top of human being sourced ones," says Chappellaz.

Future climate change is about two major contributions: emissions due to human activity and amplifications from natural sources in a warmer world. In other words, how much will human societies add in terms of greenhouse gas emissions and at what pace; and how much amplification in a warmer world would appear from natural feedback.

"Our work in Greenland explores possible natural feedback mechanisms, giving us urgent insight into fundamental science questions about the future of our climate in a context where there are still many uncertainties and unknown processes," says Chappellaz.

More information: Ivo Beck et al, Characteristics and sources of fluorescent aerosols in the central Arctic Ocean, *Elem Sci Anth* (2024). DOI: 10.1525/elementa.2023.00125

Jakob Boyd Pernov et al, Pan-Arctic methanesulfonic acid aerosol: source regions, atmospheric drivers, and future projections, *npj Climate and Atmospheric Science* (2024). DOI: 10.1038/s41612-024-00712-3

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