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Station Nord

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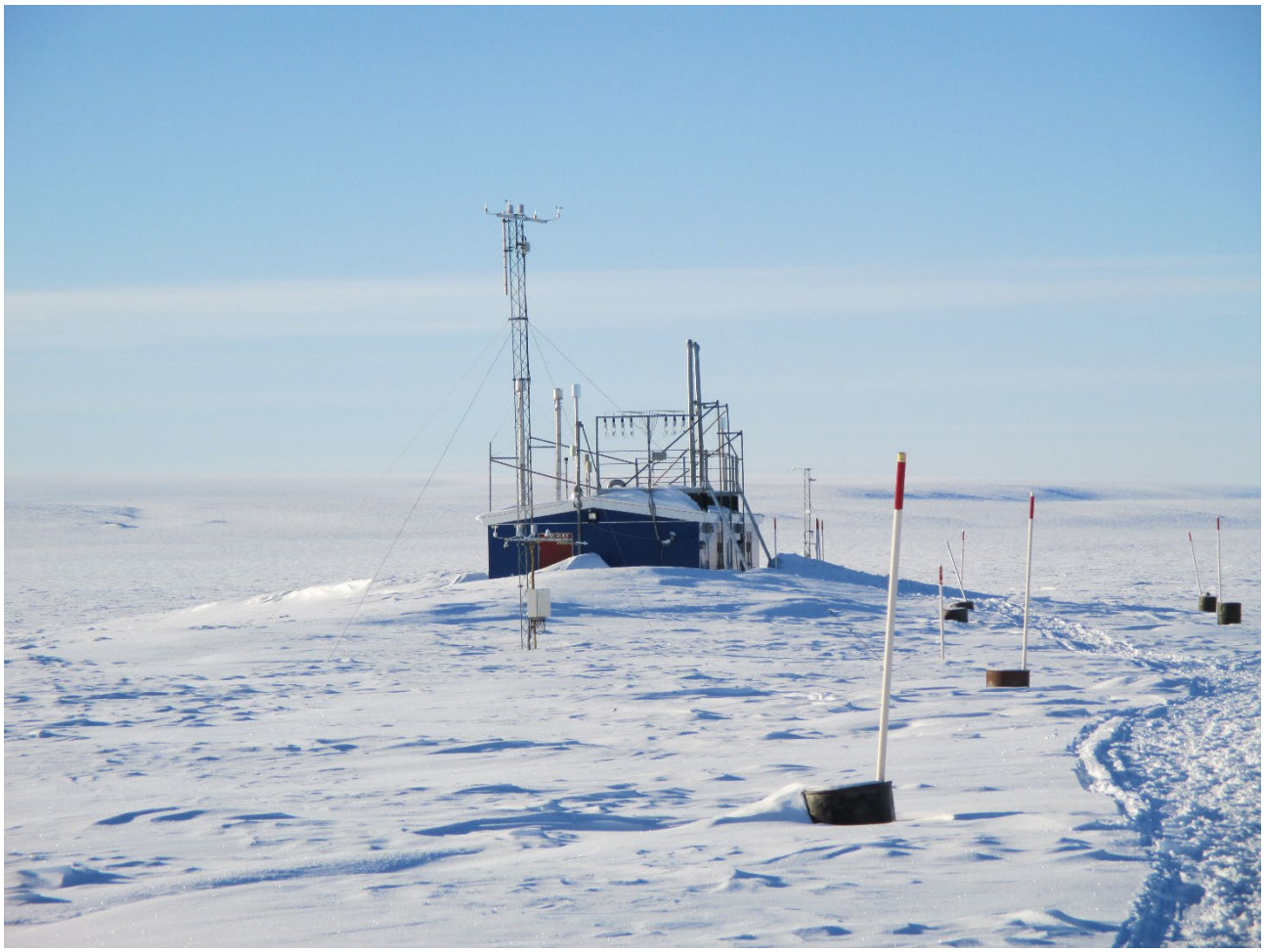
Content

Introduction

By Professor Henrik Skov, Scientific head of Villum Research Station



Welcome to the seventh annual report of The Villum Research Station. Due to the lockdown imposed during the COVID-19 epidemic, our activities were limited from 2019 to 2022. Therefore, I am greatly relieved to report that we nearly returned to normal conditions in 2023 from a still challenged year in 2022, although we still faced challenges stemming from the limited access in previous years. I would like to take this opportunity to express my gratitude to our brilliant technicians, who did there uppermost to keep everything running and ensured that most of our long-term monitoring continued despite the limiting access to the Station and the missing discussion of the analysis due as many of us without daily work in the laboratories had to work at home.

The high Arctic is experiencing an accelerating temperature increase, which will precipitate significant changes in the chemical and physical circulation of elements, as well as alterations to biological food webs and ecosystems not only within the Arctic but globally. Temperature is rising four times faster in the Arctic than the global average, underscoring the urgent need for research on climate and the environment. We are therefore grateful for the ongoing support from the Danish Environmental Protection Agency and the Ministry of Climate, Energy, and Utilities for projects such as "Long Term Monitoring of Contaminants in the Greenlandic Atmosphere (AMAP CORE Atmosphere)", "Short-lived Climate Forcers in Greenland", and ICOS Arctic Atmosphere. These long-term endeavours are particularly valuable as they provide essential context for interpreting shorter-term campaigns, allowing us to determine if observed phenomena are typical or attributable to special events and providing important knowledge on how pollutants interact with climate over long time frames due to changing emissions and increasing temperatures.

The effects of human influence have led to irreversible changes, which will continue despite human climate abatement efforts. Thus, we focus on studies where we study human impacts and what happens when the emissions from fossil fuel combustion wannish leading to a "modified natural system". While most projects at VRS have focused on atmospheric processes, we are increasingly hosting studies on the climate's impact on marine and terrestrial biological systems, as well as the dynamics of the cryosphere, as reflected in this report.

As of the latest update, there have been 143 peer-reviewed articles, 3 book chapters, 6 reports, and 6 PhD dissertations based on research conducted at Villum, marking a notable increase in productivity in recent years. Additionally, Villum Research Station contributes to several important international research networks, including The Aerosol, Clouds, Trace Gases Research Infrastructure (ACTRIS), the Arctic Monitoring and Assessment Program (AMAP), the WMO-Global Atmospheric Watch (WMO-GAW), and the Global Observation System for Mercury (GOS4M).

I hope you will enjoy reading the articles in this report reflecting the multiple research projects carried out at Villum Research Station.

Warm regards,

Henrik Skov

Professor

Head of Villum Research Station

1 Measurements of aerosols within ACTRIS at the high-Arctic Villum Research Station

By Andreas Massling and Henrik Skov

Arctic temperatures are increasing nearly four times as fast as in the rest of the world considering the last decades (Rantanen et al., 2022). This phenomenon is called Arctic amplification and emphasizes how strong the Arctic is affected by climate change. In general, there is very limited knowledge on the causes of this fast temperature increase in the Arctic but several controlling parameters have been identified. Aerosols are particles suspended in air and they are short-lived climate forcers as they have limited lifetimes in the atmosphere such as ozone or methane and affect the radiation budget at the Earth. They are key players in this context, as rising temperatures in the Arctic are partly due to changes in radiative forcing caused by changes in aerosol concentrations and their physico-chemical properties (Quinn et al., 2008). Aerosols influence the radiative balance both directly by scattering and absorbing the incoming sunlight and indirectly by serving as cloud condensation nuclei for the formation of clouds and fog.

On the one hand side, the role of aerosols by long-range transported anthropogenic pollution has been discussed as e.g. black carbon aerosols are absorbing solar radiation in air and after deposition on snow- and ice-covered surfaces. These polluted air masses typically reach the Arctic most efficiently in the late winter and early spring. Nevertheless, it has been found that this type of pollution is decreasing due to air quality regulations in Europe, Asia and the US. These regulations are set up for reducing exposure levels of aerosols to humans. One of the consequences of the before-mentioned temperature increase in the Arctic is an enhanced sea ice melt and thus reducing sea ice area, which open up for more shipping activity on the Arctic Ocean. Thus, it may introduce a new source of aerosols and especially black carbon aerosols in the near future.

On the other hand, it is known that the changing Arctic climate affects the formation and transformation of natural Arctic aerosols as well as their transport pathways within the Arctic. The changing surface structure in the high Arctic (more open waters, marginal ice zones, open leads, refreezing leads, melt ponds, etc.) promotes changes in the exchange rates of gases and aerosols between the surfaces and the atmosphere. As such the number of aerosols and potential number of cloud condensation nuclei may change and ultimately affect Arctic climate via direct and indirect effects.

As natural emissions of aerosols and their precursor gases are only poorly understood, the described possible feedback mechanism affecting their emissions in a warmer climate cannot be projected, despite having substantial impacts on the Arctic climate with respect to aerosol-cloud-climate interactions. This feedback mechanism might be a significant process determining the Arctic climate now, and in the future potentially leading to climatic changes of catastrophic dimensions. The climate forecasting for the Arctic is partly based on this limited knowledge of current and future aerosol emission scenarios within the Arctic and the development and fate of long-range pollution reaching the Arctic in the decades to come.

The detailed characterization of the physico-chemical properties of observed aerosols, including their processing in the high Arctic is the main reason why our group has been setting up an aerosol measurement program at Villum Research Station (VRS).

The program follows the ACTRIS (Aerosol, cloud and trace gases research infrastructure) guidelines, which is a European standard for aerosol measurements, where aerosol parameters using specific instrument types and techniques are determined. ACTRIS prescribes the monitoring of some parameters as e. g. relative humidity, temperature, and pressure along with the respective aerosol parameters. In addition, special requirements are set out for the inlets used for sampling and the data must be reported in regular intervals to specified databases following the FAIR principles.

At VRS we measure continuously the particle number size distribution within the range between 10 and 800 nm (MPSS TROPOS type), the total particle number concentration above sizes of 10 nm (TSI CPC 3772), the scattering potential at three wavelengths (Ecotech Aurora 3000) and the absorbing potential at seven wavelengths (Magee Aethalometer AE33). The setup is shown in Figure 1.1, where all ACTRIS instruments are sampling downstream

of aerosol inlets that were specifically designed for high Arctic climatic conditions.

Figure 1.1. left) Monitoring room in the measurement hut at VRS showing the ACTRIS instruments; middle) High Volume Sampler in the measurement hut at VRS; right) Aerosol inlet specifically designed for Arctic weather conditions on the roof at VRS (credit: Christel Christoffersen).

In addition, the mass concentrations of organic carbon (OC) and elemental carbon (EC) are determined by a thermal desorption followed by catalytical conversion for final detection using flame ionization detector of weekly quarts filter samples provided by a High Volume Sampler (Digitel 1071).

One overall objective of our work on aerosols in the Arctic is to unravel how warmer Arctic climate affects the presence and properties of Arctic aerosols and their cloud-climate interactions. A second objective is to understand how long-range pollution reaching the Arctic will change based on emission regulation and cleaner air activities in Europe, Asia and US and how transport patterns will change in a warmer climate. All these issues have evidently large implications for the radiative balance of the Arctic atmosphere and thus will impact on the temperature development in the area.

Therefore, we ask the following questions: Which conditions in the Arctic are favorable for the formation of Arctic aerosols? What does this mean in a future Arctic with lower sea ice cover, more marginal sea ice zones, and changed surface structures for the number of potential cloud condensation nuclei (CCN)? Which kind of pollutants and levels of pollutants will reach the Arctic in the decades to come and which additional anthropogenic emissions and corresponding levels do we expect in the future? How do these changes affect Arctic cloud and fog formation and the scattering and absorbing potential of the Arctic atmosphere and correspondingly the radiative balance there?

The VRS ACTRIS station has been set up to help answering these questions. Within previous studies we already have investigated changing transport patterns in the Arctic and how they influence the aerosol population (Pernov et al., 2022). Also, our group studied hygroscopicity (Massling et al., 2023) and cloud condensation activity of the observed aerosol at VRS (Lange et al., 2019) in addition to the levels of relevant chemical species impacting Arctic climate (Massling et al.; 2016). Many other studies have been published in the last decade with focus on the physico-chemical properties of observed aerosols at VRS involving our group.

To illustrate a climatology of Arctic submicrometer aerosols the median particle number size distribution measured at VRS over the years 2010 to 2018 has been calculated for each month and a seasonal cycle of this calculation is shown in Figure 1.2.

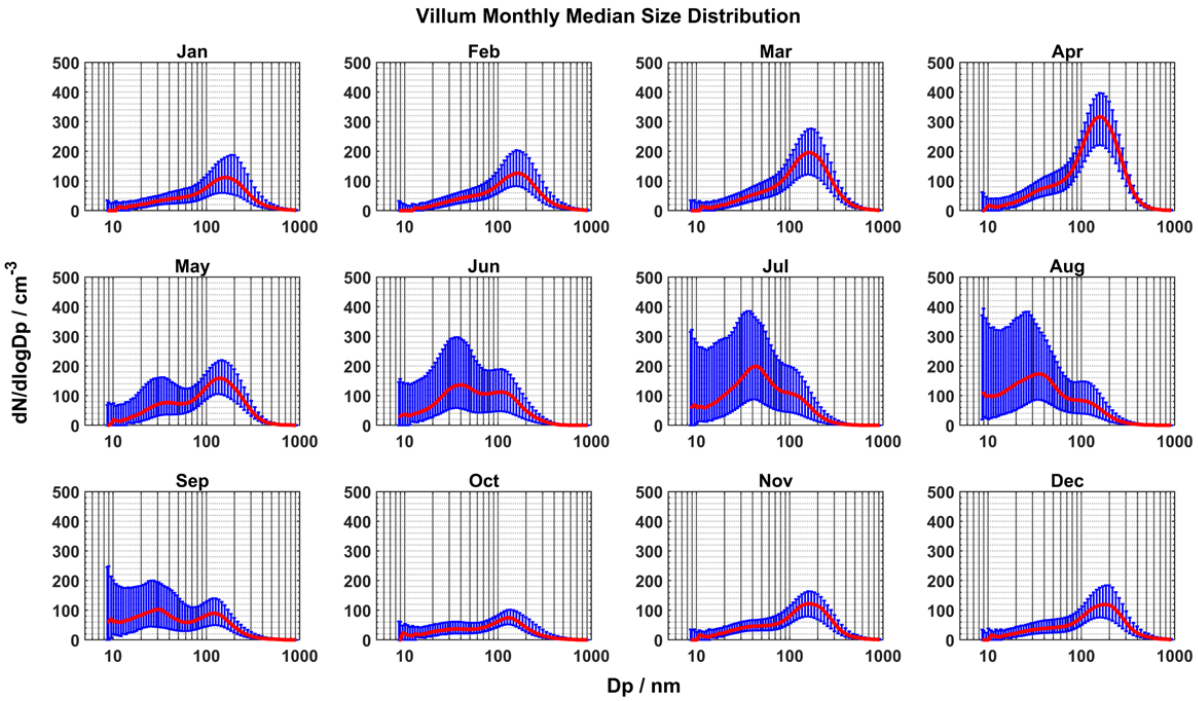


Figure 1.2. Graph of the median (between 2010 to 2018) monthly particle number size distribution measured at VRS, x-axis showing the diameter in nm and y-axis showing the number of particles in dN/dlogDp (credit: Jakob Boyd Pernov)

Starting with a view on Figure 1.2 in the month of October it can be clearly seen that a distinct accumulation mode between 100 and 300 nm in diameter is evolving for the upcoming months. This mode peaks in April while at the same time low levels of Aitken mode particles in the range between 30 and 100 nm in diameter are observed compared to the larger accumulation mode particles. This pronounced accumulation mode identifies the Arctic haze period, where long-range transported and further processed aerosol particles reach the high Arctic that are originated mostly in Europe and Asia. VRS is without sunlight (sunset is on October 16th and sunrise is on February 25th) and thus freshly formed particles (between 10 and 30 nm in diameter) are missing due to a lack of biogenically originated emissions and photochemistry.

From April and onwards a clear decline of the accumulation mode is observed because long-range transported air masses no longer efficiently reach the lower Arctic atmosphere as anthropogenic emission sources are now located outside the polar dome. In contrast, Aitken mode particles increase in abundance and reach their maximum in July, then declining again towards October. These particles are so small that their origin must be within the Arctic.

Our team will continue monitoring the presence and processing of short-lived climate forcers in the future to clear the picture of how aerosols impact on the dramatic temperature increase observed in the high Arctic.

Acknowledgement:

We thank Villum Foundation for support of the instruments, the Ministry of Energy and Climate for funds operating and servicing the station, ACTRIS for guiding us operating our activities on the highest scientific level and the staff at Station Nord for brilliant support of the logistics at Villum Research Station.

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2 Methane Methane trends at VRS measured at the ICOS-SNO station

By L.L. Sørensen, B. Jensen, T. Jensen, G. Jakobsen, K. Mortensen, ENVS, Aarhus University, ARC, iClimate

2.1 Introduction

Methane (CH_4) is the second most important anthropogenic greenhouse gas contributing to about 20% of radiative forcing increase since the pre-industrial era due to long-lived greenhouse gases. Changing the methane mixing rate from 700 to 2000 ppb between 1850 and 2021 has shown an increase of 186% since the industrialization.

Methane emissions mix through the troposphere on timescales shorter than the globally-averaged atmospheric lifetime (AMAP assessment 2015) thus the average trend in atmospheric concentration is about the same everywhere on Earth. While global concentrations have increased at varying rates, the mechanisms behind the trend variation are still not fully understood. From approximately 2000 to about 2005 there was a zero-growth in global CH_4 mixing ratios, but from about 2007 the growth has increased again with an even more rapid growth rate from 2015 (Nisbeth et al. 2019) and in 2020-2021, the growth rate rose sharply and reached the highest level on record (Nisbeth et al. 2023). Explanations for the increases and stabilization have involved changes in tropical wetlands, livestock, fossil fuels, biomass burning, and the methane sink. Contradictions in these hypotheses arise because our current observational network cannot clearly link recent CH_4 variations to specific sources (Nisbeth et al. 2019; Turner et al. 2019).

At Villum Research Station (VRS), we operate the Atmospheric ICOS station ICOS-SNO, where continuous measurements of the greenhouse gases CO_2 and CH_4 are conducted. Using the CH_4 data along with meteorological measurements, we aim to investigate trend in CH_4 concentration and the long-range transport of CH_4 that contributes to the high concentrations observed in the Arctic during winter. Our goal is to determine whether these concentrations have changed over the past few decades and to identify potential sources of CH_4 emissions that may be contributing to Arctic winter levels.

Figure 2.1. ICOS-SNO at Villum Research Station, Station Nord

2.2 Methodology

2.2.1 Methodology to analyse the trend in CH_4 concentration and amplitude

Atmospheric CH_4 monitoring has taken place at several Arctic sites since the early 1980's using discrete flask sampling followed by gas chromatography analysis (AMAP Assessment, 2015). Data compatibility and accuracy are ensured through participation in the WMO GAW program. The Global Greenhouse Gas Reference Network (GGGRN) measures the atmospheric distribution and trends of the three main long-term drivers of climate change, CO_2, CH_4, and N_2O. The Reference Network is a part of NOAA's Global Monitoring Laboratory in Boulder, Colorado.
However, over the past 10 years an increasing number of stations have initiated measurements with monitors, which can measure at hourly resolution.
The ICOS network (https://icos-atc.lsce.ipsl.fr/) has been established and growing since 2015 providing uniform calibrated measurements of atmospheric CH_4 concentrations at high time resolution (< 1 hour) and CH_4 fluxes at some Arctic sites and recently ICOS atmosphere network has been recognized as contributing network to WMO GAW for the greenhouse gases.
To study the trend in concentration and amplitude of CH_4 in the high Arctic we here mainly use data from the three ICOS sites ICOS-ZEP, ICOS-PAL and ICOS-SNO at Zeppelin station, Svalbard, Norway at Pallas station, Finland and at Villum Research Station, Station Nord, Greenland, respectively. At ICOS-SNO, which is the most recent Arctic ICOS atmosphere station, labeled in 2022 we measure CO_2 and CH_4 as well as wind speed, wind direction, RH and temperature in a tall mast at 20, 40 and 85 meters.

2.3 Trends in concentrations of CH_4 in the Arctic

Measured CH_4 from 2018 to 2023 at the two remote Arctic sites (ICOS-SNO and ICOS-ZEP) and the regional influenced Arctic site (ICOS-PAL) show an annual CH_4 cycle with an amplitude of about 50-100 ppb from the minimum observed in July/August to the maximum observed in February (Fig 2).

The seasonal variation is likely caused by transport of polluted air masses from lower latitudes during winter and a stronger photochemical OH sink during summer, where the transport from lower latitudes also decreases. The annual CH_4 cycle at the two regionally influenced sites also shows a maximum during winter, but elevated relative to the remote sites, due to their closer proximity to anthropogenic source regions.

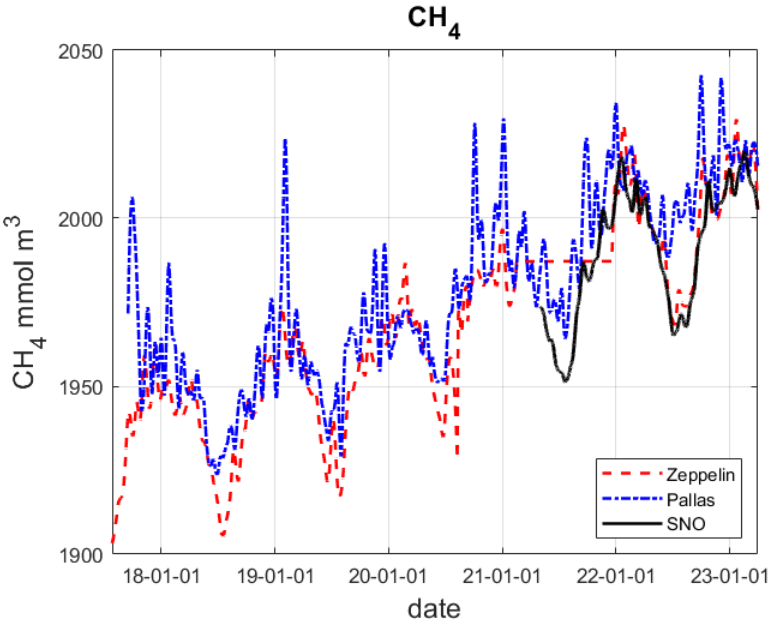

Figure 2.2. Measurements of CH_4 at the Arctic ICOS Stations ZEP (Zeppelin, Svalbard) , PAL (Finland) and SNO (VRS, Station Nord, Greenland) 1 hour sampling. The data are 800 point smooth of 1 hour sampling.

The measurements from the ICOS-ZEP station, which has the longest CH_4 record of the Arctic stations, show a decrease in the seasonal amplitude from 1994 to 2015 (Fig 3). This decline in amplitude is also found by Dowd et al. 2023. However, CH_4 data from the last 6 years at ICOS-ZEP at Svalbard, indicate the amplitude has become more constant and since 2010 it has varied between 40-50 ppb

b.

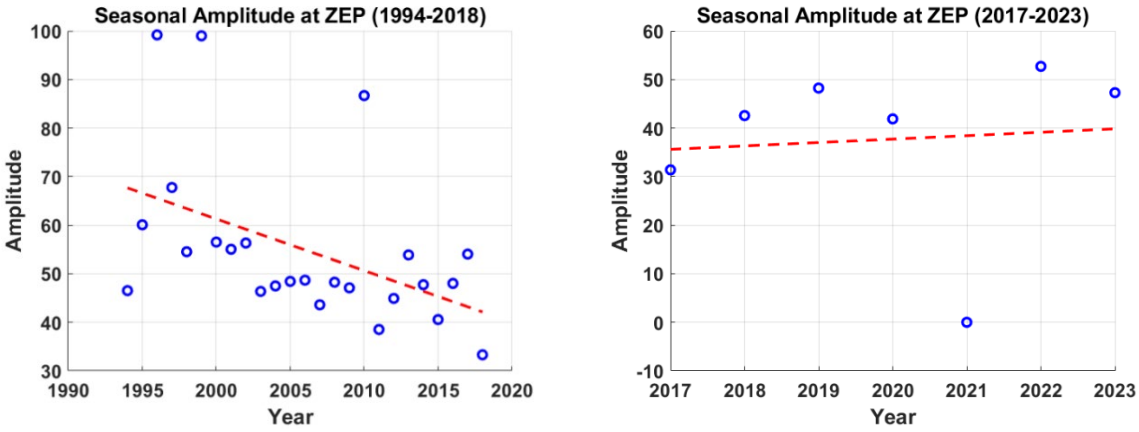

Figure 2.3. The seasonal amplitude of CH4 (here in ppb) has been decreasing from 1994 to about 2015 (first graph), but since 2017 (second graph) measurements indicates the amplitude has become constant. In 2021 there was a large data gap at ICOS-ZEP.

2.4 Discussion and conclusions

Arctic atmospheric methane concentration has been observed since the early 1980's and the observations have shown an increase but with a zero-growth from 2000 to about 2005. However, the growth rate of the methane concentration has increased again since 2007 and with an increasing rate from 2015 to 2020.

Arctic methane concentration measurements reveal an annual variation, with a higher concentration in late winter and a minimum in summer. The annual amplitude varied from 70-80 in the 1980's but the amplitude has decreased over the last three decades and is now about 40-50 ppb. New data from high-resolution measurements show high variability of the concentration within the same season and this is especially evident in the winter season but also variations over the summer occurs. The high variation during winter is likely due to varying meteorological conditions transporting the polluted air from lower latitude sources. The measurements expose a distinct peak of atmospheric CH_4 during summer at the remote sites as well as a "shoulder" occurring slightly later in early fall. The variability found in the high-resolution data is large and is about the same magnitude as the annual amplitude; however, it is not known if this variability has changed while the high-resolution measurements were only initiated recently.

Both anthropogenic and natural processes can influence the variability. While the primary drivers for the variability remain unclear, earlier emission studies (Pirk et al., 2017) suggest that natural emissions may contribute to the late summer/early fall peaks. To better understand the main factors behind short-term variability, high-resolution data and further emission studies are essential. Fortunately, high-resolution atmospheric concentration measurements have become more widely available in recent years. However, the high-resolution data from Arctic stations currently spans only a few seasons. The upcoming years of data will provide valuable insights into the development of local Arctic CH_4 variability and the underlying factors driving it.

Moreover, the decreasing annual amplitude suggests a shift in the relative contributions of emissions, potentially indicating an increase in biogenic emissions during summer or a decrease in winter emissions. Further studies that combine high-resolution measurements with back trajectory analysis are necessary to more confidently explain the increasing growth rate of methane concentrations and change in amplitude.

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3 Observations of new chlorine species in the Arctic air

By Alfonso Saiz-Lopez, Department of Atmospheric Chemistry and Climate Instituto de Química Física Blas Cabrera, CSIC, Serrano 119, 28006 Madrid

Active chlorine cycling has been known to play key roles in the depletion of surface ozone (O_3) and the degradation of methane (CH_4) in the Arctic troposphere. This process is particularly effective during the springtime following polar sunrise, as the chlorine-containing species in the atmosphere will undergo rapid photochemistry processes activating the cycling of chlorine atoms (Cl), which is a strong oxidant in the polar troposphere.

Despite decades of research on the atmospheric chlorine cycling, a largely unexplored aspect entails the formation of higher oxidized products of chlorine, chlorine oxyacids (such as chloric acid ($HClO_3$) and perchloric acid ($HClO_4$)), thus, limiting our full understanding of the atmospheric chlorine cycle and its associated environmental impacts. The presence of atmospheric $HClO_4$ was first proposed in the early 1990s to be important in the polar stratosphere and was believed to be an important missing atmospheric sink process of chlorine. More and more recent chemical measurements of environmental samples have also hypothesized the potential formation of $HClO_3$ and $HClO_4$ in the lower polar atmosphere; however, until today there was no direct evidence of the presence of $HClO_3$ and $HClO_4$ in the atmosphere due to a lack of suitable technologies to detect parts-per-trillion mixing ratios of these chlorine species.

Our research team have first deployed a nitrate based chemical ionization atmospheric pressure interface time-of-flight mass spectrometry (CI-APi-TOF) to measure atmospheric $HClO_3$ and $HClO_4$, at various locations above the Arctic Circle: first at Villum Research Station, Greenland, where we observed significant levels of gas-phase $HClO_3$ in the springtime (Fig.1). To confirm the Greenland observations, we also conducted further studies at Ny-Ålesund in Svalbard Island and over the central Arctic Ocean onboard research vessel Polarstern during the Multidisciplinary drifting Observatory for the Study of the Arctic Climate (MOSAiC) campaign. In these campaigns, the concentrations of gas-phase $HClO_3$ in the springtime was estimated to be up to 7×10^6 molecule cm^{-3}.

We also proposed a novel plausible mechanism for the formation and loss of $HClO_3$ and $HClO_4$ during the springtime. The increase in $HClO_3$, concomitantly with that in $HClO_4$, was linked to the increase in bromine levels and decrease in O_3. These observations indicated that the increase of bromine chemistry decreases O_3 and at the same time enhances the formation of chlorine dioxide (OClO), which is subsequently oxidized into $HClO_3$ and $HClO_4$ by hydroxyl (OH) radicals. For the loss processes, our computed UV–Vis absorption spectra and cross-sections of chlorine oxyacids showed that $HClO_3$ and $HClO_4$ are not photoactive, and therefore their loss through heterogeneous uptake on aerosol and snow surfaces may be important and can function as a previously missing atmospheric sink for reactive chlorine.

As a summary, our study shows the presence of $HClO_3$ and $HClO_4$ for the first time in the ambient Arctic air masses and their widespread occurrence over the pan-Arctic during spring. The existence of these new chlorine species in the atmosphere should be considered when evaluating the environmental and climate impacts of chlorine chemistry in the Arctic.

Read more: If you like to read more about the details of this study, please check out Nature Communications journal, in which the following manuscript has been published: Tham Y.J. *et al.*, Widespread detection of chlorine oxyacids in the Arctic atmosphere, Nature Communications, 2023 (https://doi.org/10.1038/s41467-023-37387-y).

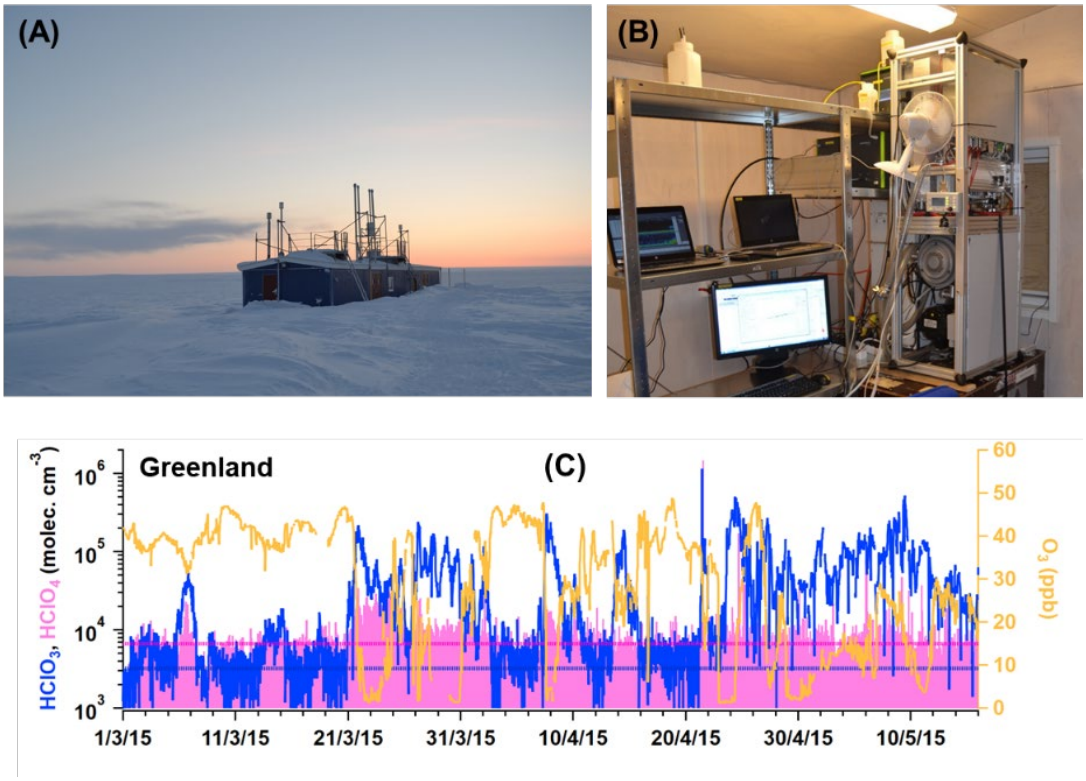

Figure 3.1. (A) The atmospheric observations cabin at Villum Research Station; (B) CI-APi-TOF used for the measurement of $HClO_3$ and $HClO_4$; and (C) An example of the time-series for the observations $HClO_3$, $HClO_4$ and O_3 at Villum Research Station, Greenland. The dotted-line represents the instrument detection limits for $HClO_3$ and $HClO_4$

4 Snow and meteorological conditions based on the PAMARCMiP 2018 campaign

By Daniela Krampe [1,2], Frank Kauker[2,3], Andreas Herber[2]

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Snow plays an important role in the climate system, in Arctic amplification and the energy balance due to its versatile physical properties such as high insulation and high albedo. However, due to the remote location of the high Arctic, including Villum Research Station (VRS), snow measurements in these regions are rare. In spring 2018, the PAMARCMiP[1] campaign took place as part of the AC3[2] project. During the campaign, both ground-based and airborne measurements were carried out around the VRS to investigate the properties of aerosols and snow (Universität Leipzig:2024). Measured snow properties include snow depth, snow density, snow specific surface area (SSA) and black carbon (BC) concentration in a distance less than 500 m away from VRS, between 10 March and 8 April 2018, see Figure 4.1 to 4.3 for photo of the field work. The snow data collected during the campaign was analysed together with snow depth measurements and meteorological data continuously measured by the station. In-situ snow depth at VRS is measured since 26 August 2014 (ASIAQ, 2014).

While the snow cover began to form uniformly at the end of August in the years 2014 to 2018, the end of the snow season in the same period varied from mid-July (2014/15) to the beginning of August (2017/18). The maximum snow depth during a snow season and its timing also showed large differences from 1.03 m (17 April 2017) to 1.62 m (15 June 2018). The high spatial variability of snow depth even at small scales is confirmed by snow depth measurements during the PAMARCMiP campaign. On 3 April 2018, snow depth varied between 0.60 m and 1.17 m (standard deviation: 0.22 m) (Krampe et al.:2023).

In general, thick ice lenses and compact snow hampered snow measurements during the PAMARCMiP campaign. These conditions made it difficult and time-consuming to dig snow pits, damaged the SnowMicroPen used for snow density and SSA measurements right at the beginning of the campaign and prevented snow density and SSA measurements with a density cutter and an IceCube in the respective snow layers. These conditions are most likely the result of a warm air intrusion event in the second half of February 2018, during which air temperatures were around 20°C warmer than in the weeks before and after the event and were occasionally even above freezing. High wind speeds (>20 m s^{-1}) were also measured during this event. During the PAMARCMiP campaign itself, air temperatures were around −20°C and wind speeds were around 6 m s^{-1}. Snowfall was measured on most days during the campaign. Thereby, the highest snowfall recorded was on 27 March (5.4 mm) (Krampe et al.:2023).

The snow measurements conducted show the typical snow stratigraphy for Arctic snowpacks. Snow density decreased towards the basal layers with a thin wind slab layer at the snow surface. In addition, observations during fieldwork indicate a bottom depth hoar layer (Krampe et al.:2023).

BC in snow leads to positive albedo feedbacks as it reduces the surface albedo and influences snow properties. Near VRS, BC particles generally do not originate from local sources but are

[1] Polar Airborne Measurements and Arctic Regional Climate Model Simulation Project

[2] ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms

transported over long distances (Donth et al., 2020). The station is far away from the nearest cities (Longyearbyen, Svalbard: 720 km east; Ittoqqortoormiit, Greenland: 1250 km south). This makes the station the only local source of BC particles. The snow pits where the BC concentration was measured, were located downwind (prevailing wind direction south-west) of the stations. Mean BC concentration in the snowpack was 0.67 ng g^{-1} (standard deviation 0.23 ng g^{-1}) in the upper 3 cm and the median concentrations of the profiles ranged between 0.42 ng g^{-1} and 1.11 ng g^{-1} (Krampe:2023).

Read more

The continuous snow depth measurements and meteorological measurements were used together with the snow data obtained during the PAMARCMiP campaign to investigate the performance of the snow model Crocus and ERA5 reanalysis. This work is published in Krampe et al. (2023). More regional snow modelling for VRS was performed and a study using the BC concentrations measured in snow was used for a dissertation, see Krampe (2023). If you like to read more about the laboratory analyses of BC samples in snow, see Zanatta et al. (2021).

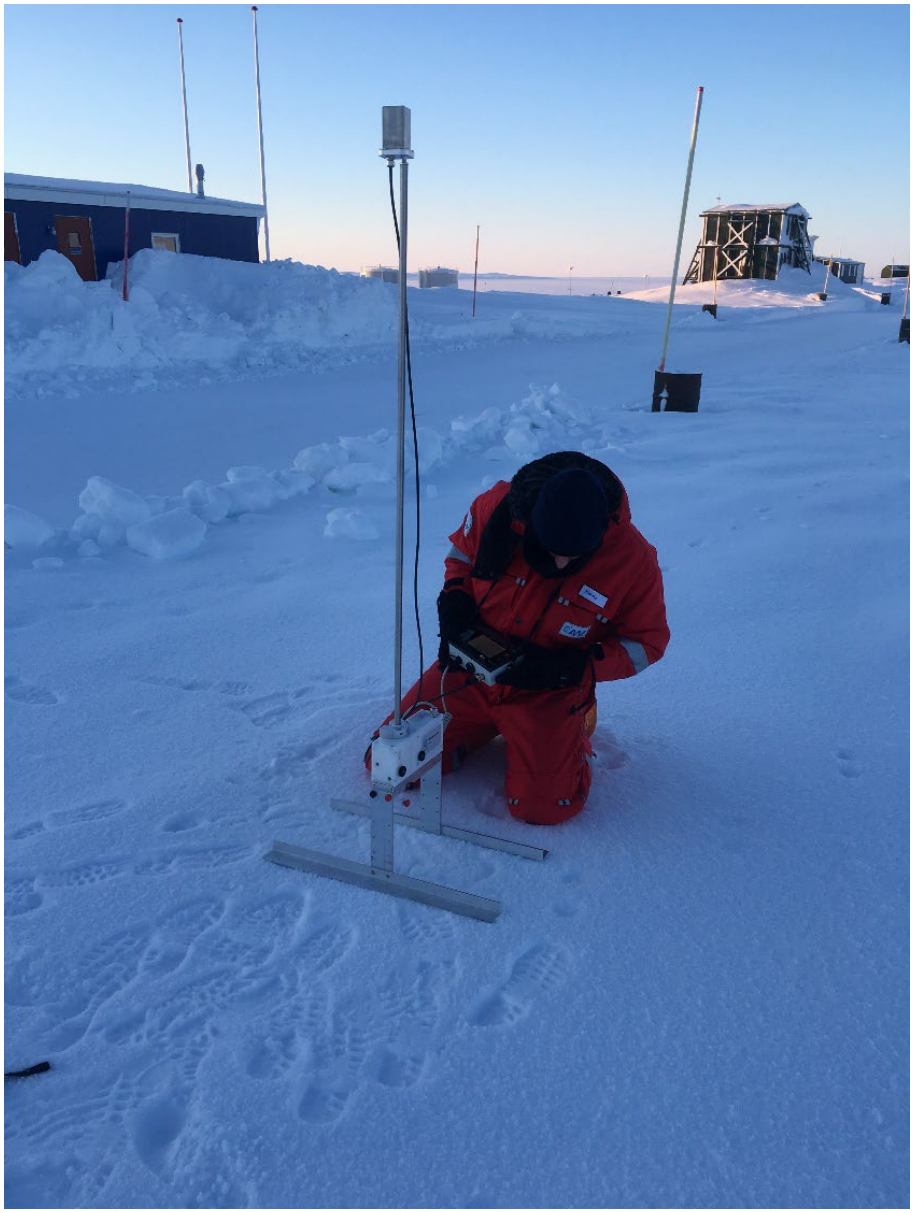

Figure 4.1. Testing of the SnowMicroPen before going into the field in front of Villum Research Station (Photo: Andreas Herber).

Figure 4.2. Bad weather conditions with low contrast (Photo: Andreas Herber).

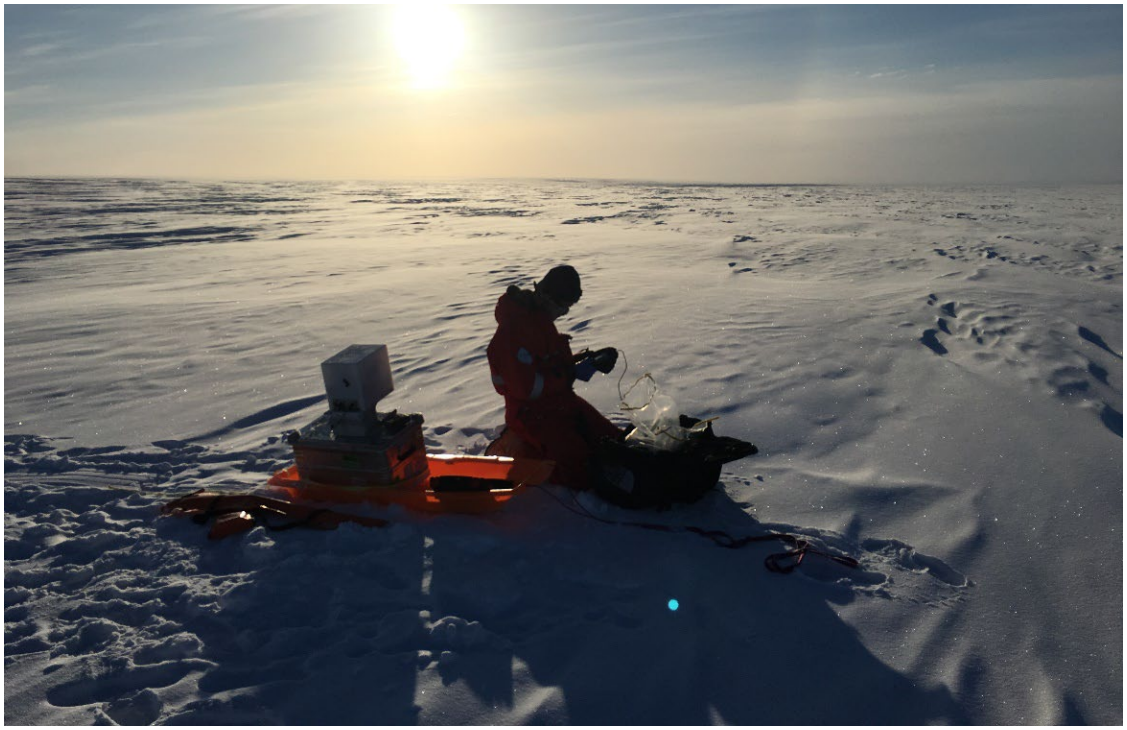

Figure 4.3. Preparation of snow measurements at a site around Villum Research Station (Photo: Andreas Herber).

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5 Arctic microbes can degrade bioplastics

By Beat Frey and Joel Rüthi; Swiss Federal Research Institute WSL, Switzerland

The problem of plastic debris in the world has received fast growing attention over recent years. The worldwide plastic pollution does not stop at the most remote regions like northeast Greenland. Plastics most important feature is their high durability and their resistance to biodegradation. Most plastics decompose very slowly or never at all especially in cold regions.

During fieldwork in Villum Research Station (VRS) at Station Nord in northeast Greenland we made a coastal survey of microplastic litter in the vicinity of VRS (Figures 5.1 - 5.3). Based on our observations made during field work, the amount of plastic litter was very low with four items per 1 km of coastline with a width of 5 m. These values were far lower than macroplastic litter densities compared to other values from shorelines in West Greenland or other regions in the Arctic. Collected plastics were weighed to get some rough estimates of the weight of litter per kilometre coastline. Overall, the macroplastic litter weight was very small with approximately 0.05 kg per km. The material we found were foils, textile fibres and fisheries litter. Even that plastic pollution does not stop at the most remote regions like here in northeast Greenland, suggesting long-range source, there are still almost unpolluted places on this earth.

As a next step we wanted to know whether the plastic pieces at VRS were colonized by microorganisms. These microorganisms accumulate on the plastic surface and form the "plastisphere" – a microbial ecosystem on plastic analogous to the rhizosphere surrounding plant roots (Rüthi et al. 2020). The plastisphere selects for particular microbial communities that differ from those in the surrounding environment. Microorganisms are tiny, microscopically small, invisible to the eye and are everywhere on earth. They have been living for the longest time, billions of years, adapted to all kinds of habitats and are able to break down all kind of refractory natural polymers. During fieldwork in 2018, we buried plastic litter in VRS soils and exposed them for one year (**Figure 5.4**). Analysing DNA in the plastisphere helped us to determine which microorganisms are present on the plastic surface. By using DNA metabarcoding we discovered that the plastisphere contained a remarkable microbial diversity in VRS soils. Many of the organisms found are still completely unknown and we therefore do not know a lot about their metabolic abilities (Sannino et al. 2023).

We tested whether these microorganisms living on the plastisphere offer a way to partially break down synthetic polymers (plastics) in cold Arctic environments as they do for refractory plant polymers such as small *Salix* sp. shrubs found in the vicinity of VRS (Figure 5.5). Our view is that these specialised enzymes have evolved from eating tough plant polymers and can now break down the polymers that make up plastics. Microbes have been shown to break down complex plant polymers in the VRS soils (Adamczyk et al. 2020).

We hypothesized that plastics might select for microorganisms able to use the plastics as energy and nutrient source. To test this hypothesis, we isolated microbes from the buried plastic surfaces of VRS soils (Figure 5.6). We used classical microbiological techniques to isolate and cultivate microbes in the laboratory. The isolated microbes grow as single-strain cultures in darkness and at 15°C. More than 80 bacterial and fungal strains were isolated from plastic pieces buried in VRS soil in the field but also during a laboratory incubation experiment (Figure 5.7). We used genetic markers to identify them in particular to find out whether the isolated microbes belong to already known species or if they represent so far unknown species. The isolated bacterial and fungal strains were then tested for their ability to break down synthetic polymers.

Our main aims were to find cold-adapted plastic-degrading microorganisms on plastic surfaces because of the potential to save energy due to their enzymes being active at lower temperatures. Microbial plastic degradation needs usually temperatures above 20°C, therefore requiring more energy and higher costs. We performed a fast screening of the isolated strains using a model polymer substance called polyurethane (PUR). Screening for PUR degradation was performed by placing the

microbial strains on agar plates containing dispersed PUR amended as Impranil as sole carbon source. Impranil is a milky liquid added to the agar medium but when microorganisms are able to degrade Impranil the agar plates clear up. Impranil plates containing the plastisphere strains were incubated at 10°C in the dark and optically evaluated for clear zone ('halo') formation (Figure 5.8). Most of the plastisphere microbial strains were able to degrade PUR.

Curious about the microbes' plastic-degrading abilities, we ran more sophisticated tests with the most promising strains for 5 months at 15°C. To do this, we exposed the microbes to different plastics, including the most common plastic pollutant, polyethylene, which is nonbiodegradable, and three biodegradable plastics: polyester-polyurethane, a common textile coating, and polybutylene adipate terephthalate (PBAT) and polylactic acid (PLA), both used in compostable waste bags. The best performers were two uncharacterized fungal strains of the genera *Neodevriesia* and *Lachnellula,* which broke down every biodegradable material used (Rüthi et al. 2023). However, none of the northeast Greenlandic microbes degraded polyethylene, even after 5 months of incubation. The next big challenge will be to identify the plastic-degrading enzymes produced by the microbial strains and to optimize the process to obtain large amounts of proteins. From this we hope that we can find enzymes working at lower temperatures which might be used in enzymatic recycling applications in future.

Acknowledgements

The authors are grateful for the opportunity to collaborate with VRS on the High Arctic tundra soil microbiome. In particular, we would like to thank Jørgen Skafte, Kirsten Christoffersen and the Station Nord military personnel for helping with logistics and creating an excellent research environment. We also thank Beat Stierli, Carla Perez Mon and Damian Bölsterli contributing to a successful fieldwork. The study received financial support from a WSL internal grant (Metagenomics 5233.00388.001.01), from the Swiss National Science Foundation (SNSF) [grant number IZLSZ2_170941] and Polar Access Fund (Swiss Polar Institute in collaboration with the BNP Paribas Swiss Foundation). The results from VRS are integrated in various scientific publications.

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Figure legends

Figure 5.1. We made a coastal survey to quantify the macro-plastic litter in the vicinity of the Station Nord. So far the abundance, distribution, and sources of plastic litter around nordeast Greenland are unknown

Figure 5.2. Most of the shorelines were free from microplastic litter

Figure 5.3. Litter was far lower than litter densities compared to other values from shorelines in West Greenland or other regions in the Arctic.

Figure 5.4. We buried plastic pieces in field pots close to the Villum Research Station for one year and then isolated microbial strains from the plastisphere in the laboratory.

Figure 5.5. *Salix sp.* plants close to the Villum Research Station at Station Nord. While synthetic polymers (plastics) have only been in wide use since the 1950s, microorganisms are able to degrade complex natural polymers since millions of years because they resemble some structures found in plant cells.

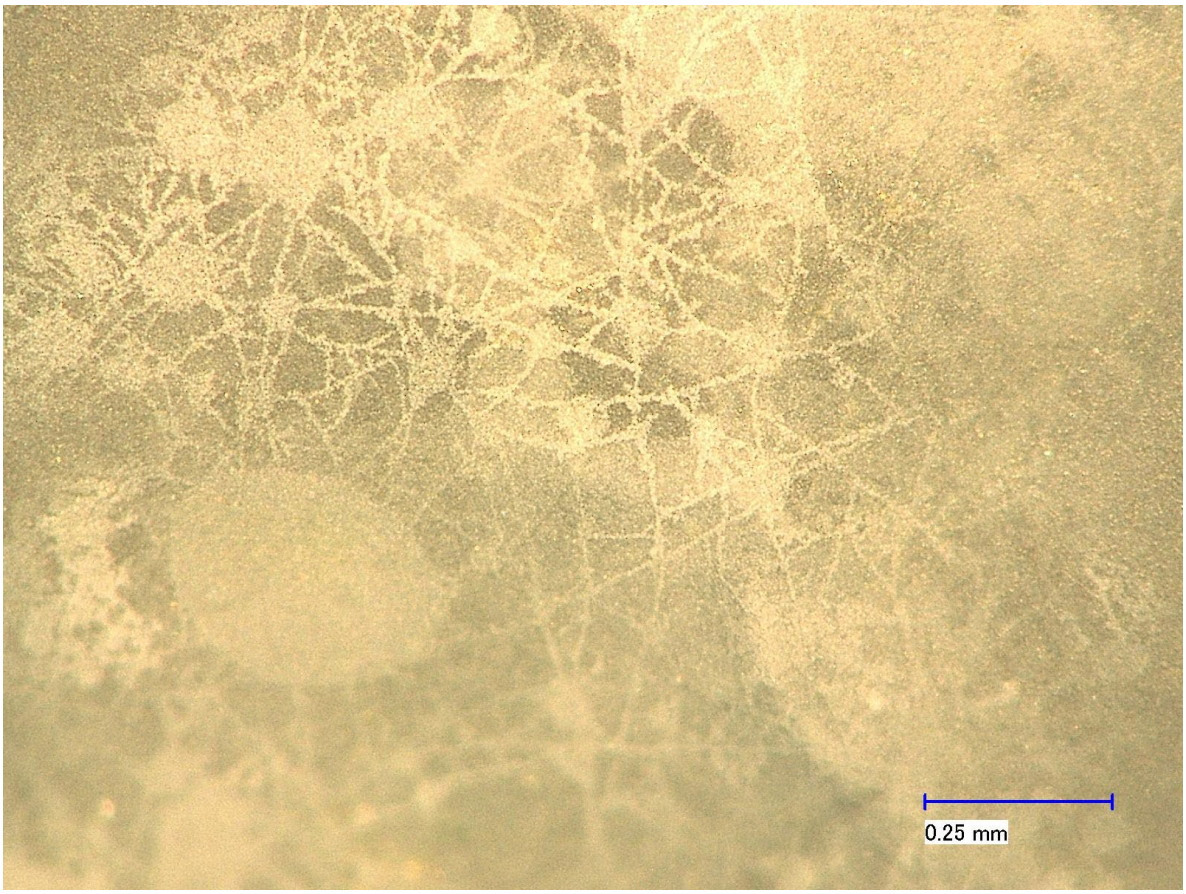

Figure 5.6. The plastic surface is colonized by fungal mycelium potentially using plastic as a carbon and energy source.

Figure 5.7. Some examples of plastisphere fungal strains from the culture collection. There is an Enormous diversity of plastic colonizing microorganisms which are now tested for their potential to degrade plastics at low temperature.

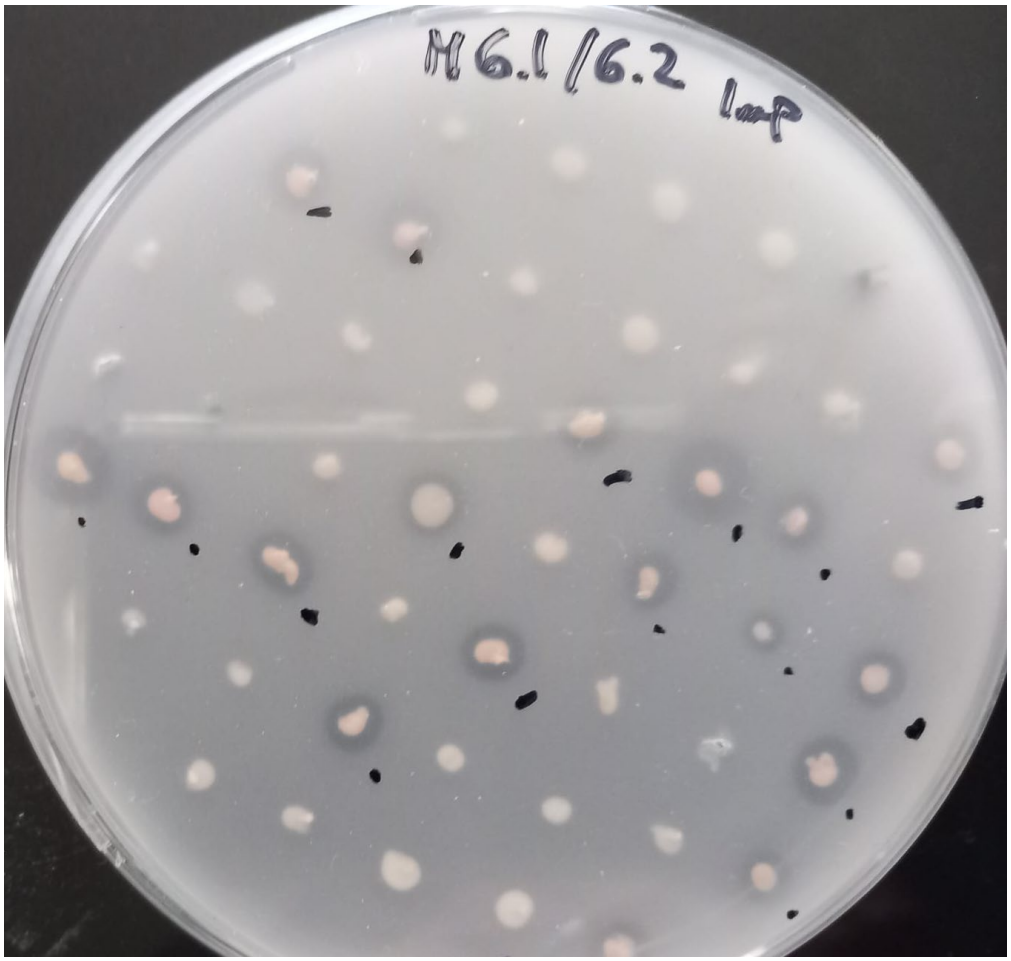

Figure 5.8. Bacterial strains from the plastisphere that produce a halo around the bacterial colonies Are able to produce esterases in order to degrade the polymer polyurethane.

6 Environmental change and impacts on prehistoric human colonization of Inutoqqaq Nunaat (Peary Land, northernmost Greenland)

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Field Party Members: Jostein Bakke, University of Bergen; Aart Verhage, University of Bergen; Bianca Perren, British Antarctic Survey; William J. D'Andrea, Columbia University, New York; Frederick Larsen, Greenland National Museum, Nuuk; Hans Lange, Greenland National Museum, Nuuk; Inaluk Jacobsen, Greenland National Museum, Nuuk.

The goal of this project is to understand changes and interactions among arctic system components (climate, people, terrestrial and marine ecosystems, sea-ice and glacier extent) in Inutoqqaq Nunaat (Peary Land), north of the Greenland Ice Sheet, where people with stone tool technology managed to survive for prolonged periods during the past ~4500 years. We propose to produce multi-proxy high resolution, quantitative records of climate and vegetation from lake sediments, and to examine the persistence of polynyas along the coast, where marine mammals congregate, using high- resolution model simulations. Paleoenvironmental records will be coupled with new archaeological data generated from a field mapping campaign to comprehensively survey sites and a program to radiocarbon date existing archeological materials to improve the chronology of human activities in the region. We will explore the extent to which periods of settlement and times of abandonment were related to climatic fluctuations and changes in sea ice that affected the availability of terrestrial and marine resources, which were essential for survival in this very remote region.

Specific Objectives in 2022

The main goal of the 2022 fieldwork was to focus on the major gathering site of the Independence people, the first people to occupy the region (around 4500 B.P.) (Figure 6.1). This was referred to as "Pearylandville" by the Danish archeologist Eigil Knuth who studied the site in the 1960s. Henceforth, this archeological site will be referred to as Aasiviqotuaq ("Gathering Place of the Ancient People"). As no archeologists have visited it since Eigil Knuth, we planned to re-visit this area, to map and document the archeological features, collect artifacts and dateable material, while also recovering sediment cores from the adjacent lake (Nedre Midsommer) which would provide the paleoenvironmental context for human activity in the region. At the same time, preparations for modelling offshore sea-ice extent were initiated.

Significant Results

Despite significant delays due to weather and logistical problems which curtailed the duration of the field program, fieldwork in early August 2022 was very successful. A comprehensive bathymetric survey of Nedre Midsommer Lake was carried out (Figure 6 . 2). Several distinct sedimentary basins were identified and "Chirp" sub-bottom sediment profiles and hydrolab profiles were obtained in key areas (Figure 6.3). Coring in 4 locations (Figure 6.4) successfully recovered over 20m of sediment, with the longest core 5.68m in length. These sediments will provide complete coverage of Holocene conditions in the lake, which is currently situated in a true polar desert. In addition, a smaller, organic-rich lake near to Aasiviqotuaq was studied and a 3.4m sediment core was recovered. This offers excellent prospects for multi-proxy biomarker analysis to shed light on ecological conditions in the past. Radiocarbon dating of that core provides an excellent age model extending back ~7400 years.

At the same time as the lake sediment work was underway, a complete re-survey of the Independence cultural sites at Aasiviqotuaq was carried out. More than 40 features were re-located and thoroughly documented. Besides Aasiviqotuaq, eight other sites in Lower Midsummer Lake in Wandel Dal ('Mellembygden', 'Plateau Ø', 'Skruenæs', 'Søndre Sandterrasserne', 'Teltnæs', 'Sølejren', 'Slusen') were also documented with new GPS position and camera and drone footage. New finds of lithic artefacts and flakes were collected as well as

bone & charcoal for dating. Samples of plants and soil were also obtained for DNA analysis.

A Wandel Dal Project web page has been set up (www.wandeldal.com) , and sites on Instagram and Facebook are currently being populated with images and information for the general public.

Current work involves scanning the sediment cores and sampling for C-14 and other dating techniques. This will then provide the basis for a further sampling strategy (for, *inter alia*, biomarkers, diatoms, chironomids, sedaDNA, pollen etc).

Figure 6.1. Location of Field camp in 2022 at archeological site Aasivitoqarsuaq ("Pearylandville') on Nedre Midsommer Lake, and Lake SW where a sediment core was recovered in 2021

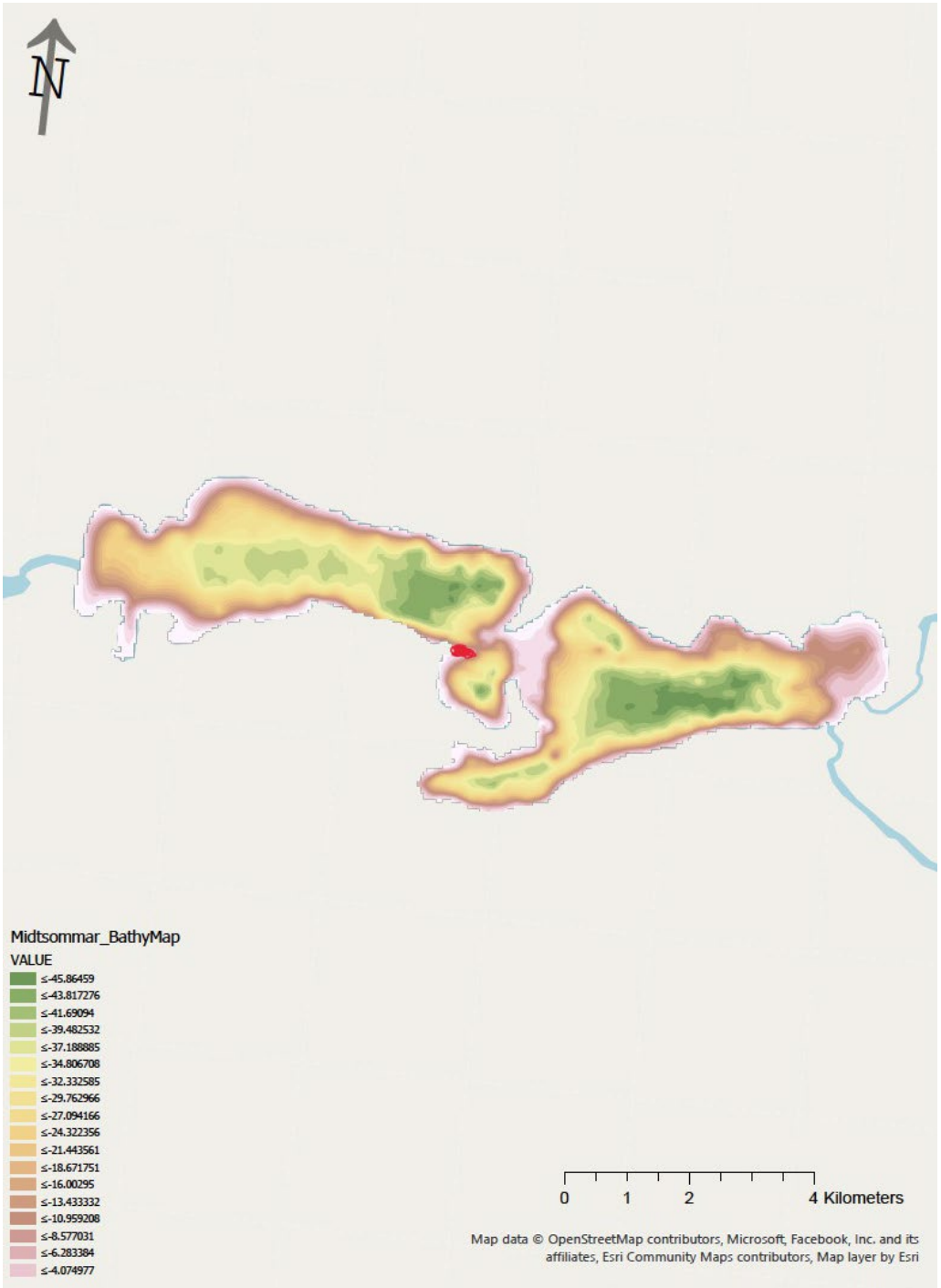

Figure 6.2. Preliminary bathymetric map of Nedre Midsommer. Aasiviqotuaq (Pearylandville) is marked by the red dot.

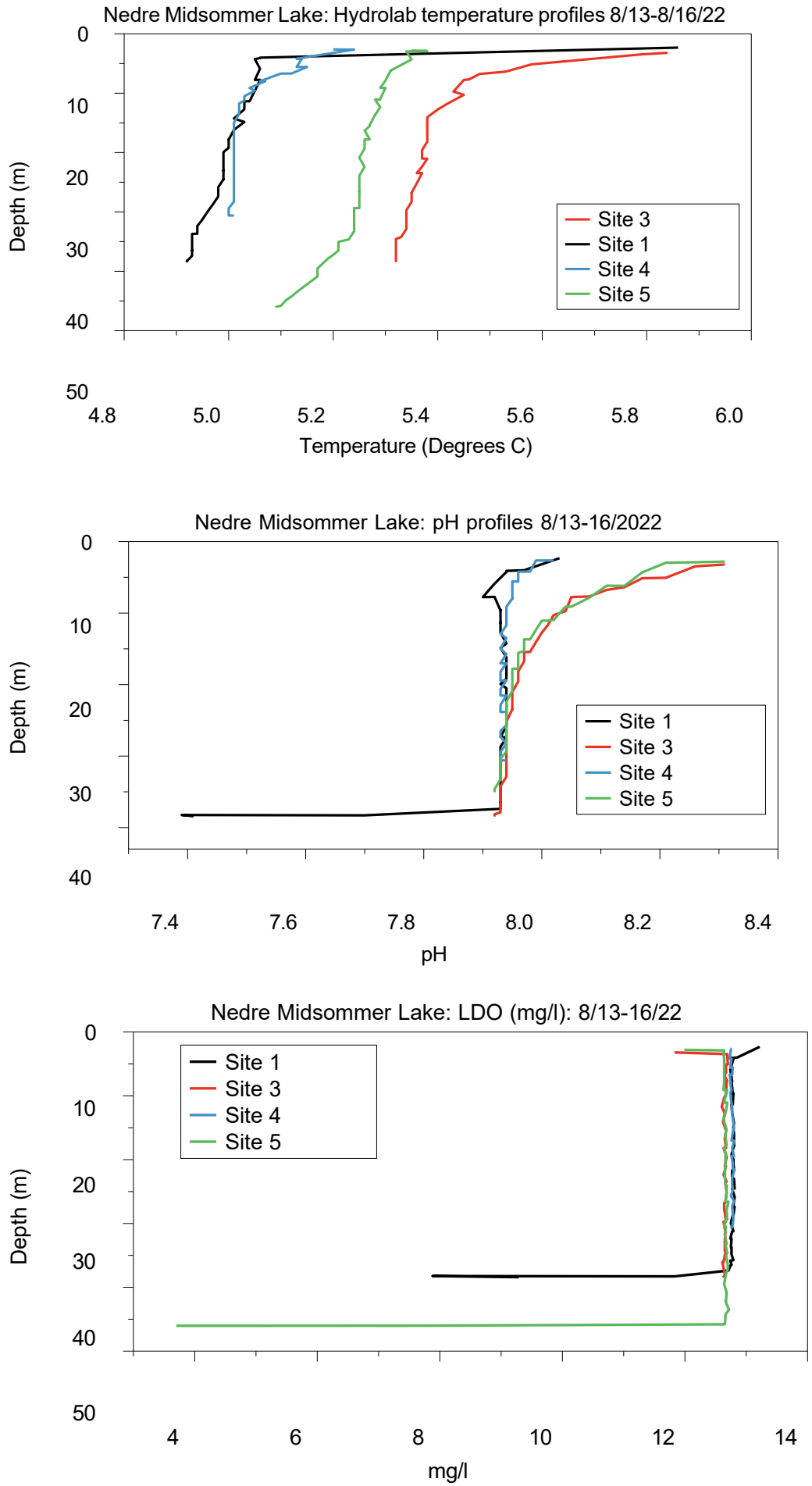

Figure 6.3. Profiles of temperature, pH and dissolved oxygen in Nedre Midsommer Lake.

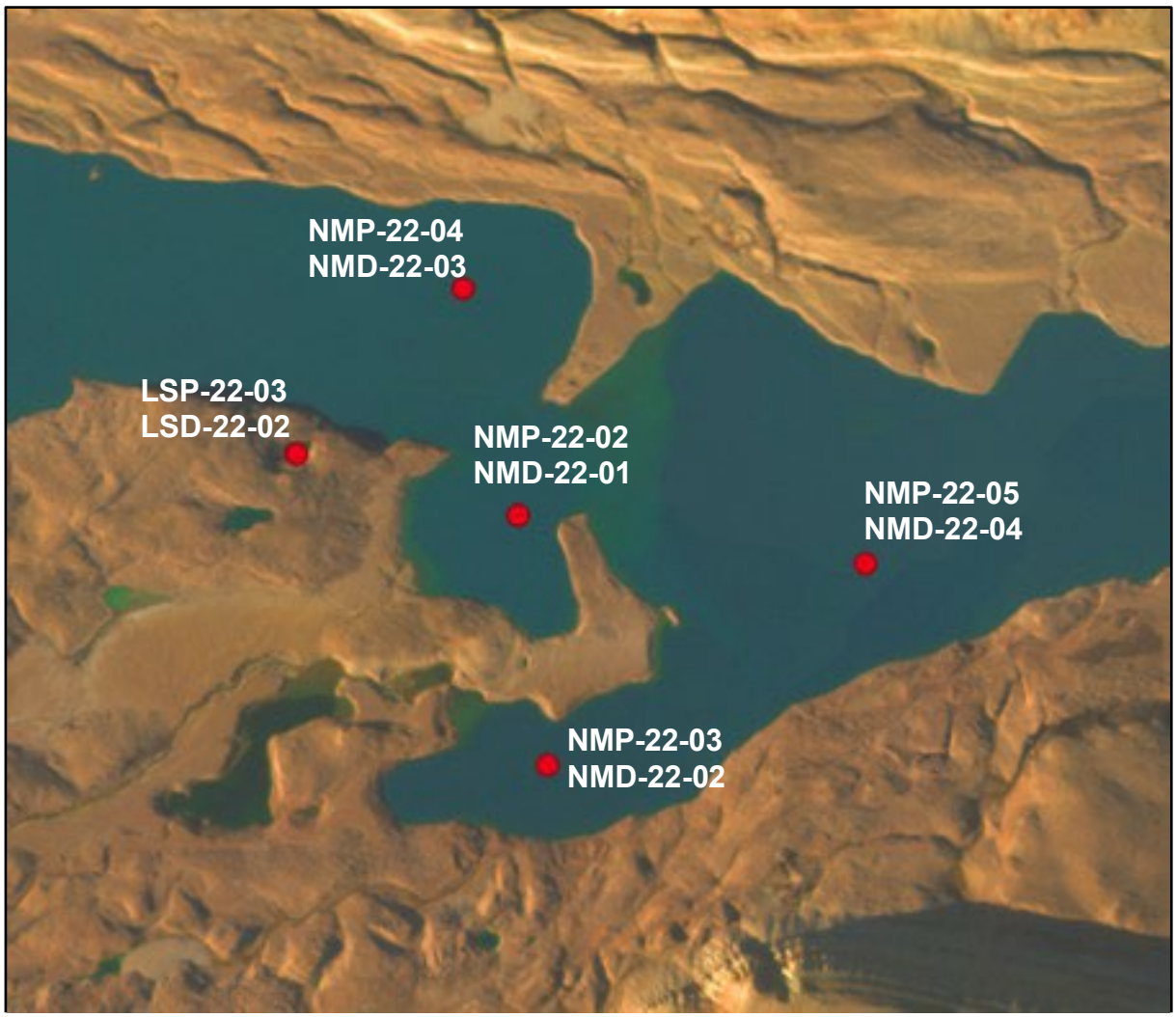

Figure 6.4. Coring and Hydrolab sites in Nedre Midsommer Lake.

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