SESS REPORT 2022

SUMMARY FOR STAKEHOLDERS

The State of Environmental Science in Svalbard – an annual report

SIOS
SVALBARD INTEGRATED ARCTIC EARTH OBSERVING SYSTEM

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Marjolein Gevers, Divya David T, Roseline C Thakur, Christiane Hübner, Jacek Jania (Editors)

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The State of Environmental Science in Svalbard
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Foreword

You are reading the 5th State of Environmental Science in Svalbard (SESS) report. This report includes six chapters on topics ranging from snow to the Sun's activity. The report is again an enjoyable collection of articles describing science and scientific tools in Svalbard and how to develop them. This is the first time I was not in the editorial board and only excitedly followed the creation of the 5th SESS report from the sidelines.

Last year I wrote in the foreword about living under the shadow of the COVID-19 pandemic, and just when we were almost back to normal the world took a tragic negative turn with the unjustified Russian invasion of Ukraine. This has also had a significant impact on polar science and scientific collaboration, with nearly half of the Arctic suddenly being inaccessible in many ways. The consequences are also seen here in Svalbard: collaboration at all levels between Russian settlements and research institutions has almost completely ceased. My honest hope is that cooperation will resume one day; how far in the future that day lies, we do not know. What we know is that science diplomacy will certainly play an important role. Arctic nations have always managed to collaborate despite the geopolitical turbulences, and it might well turn out that it is through the Arctic we start to build the bridges again.

Svalbard Integrated Arctic Earth Observing System (SIOS) entered a new funding phase this year. It was a natural time to renew our strategy, which we have started to implement. It includes among other things new methods to develop the observing system: the optimisation call programme. The first call is designed to make extensive use of the SESS reports' recommendations.

A synthesis of recommendations from the first four SESS reports was published this fall and it is being used to develop the observing system together with SIOS core data and the infrastructure optimisation report. As I write this, I have the new draft of the infrastructure optimisation report on my desk. The task force has taken big leaps forward spurred by its leader, who is new in the SIOS environment. It is refreshing to be observed from outside the SIOS bubble, in which our working groups and we staffers at the SIOS Knowledge Centre occasionally find ourselves. With the same idea in mind, it has been agreed that an external evaluation of SIOS will be conducted next year, and I am looking forward to receiving input on how SIOS could be even better.

I really appreciate the reviewers of the chapters in this SESS report; peer review is the cornerstone of the scientific process. I would like to express my gratitude to the editorial board for their engagement in the preparation of this report. It is hard work, but you have managed to find time to share your expertise. I would like to acknowledge my colleagues here at the SIOS Knowledge Centre; it is a privilege to work with such an enthusiastic and supportive team.

Longyearbyen, December 2022

Prof. Heikki Lihavainen
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Executive Summary

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The State of Environmental Science in Svalbard (SESS) reports document the current condition of the Arctic environment in and around Svalbard. The chapters highlight research conducted within the Svalbard Integrated Arctic Earth Observing System (SIOS). This contributes to a better understanding of the present status of the Arctic environment as a whole.

The chapters in this report emphasise atmospheric studies on temperature trends, show the importance of studying of dust in Svalbard, summarise two decades of columnar aerosol observations in and around Svalbard, plus 25 years of snow thickness studies. One chapter highlights the guidelines for operating Uncrewed Aerial Vehicles (UAVs) in Svalbard and is therefore relevant to researchers working within a variety of disciplines; it is an extension of the UAV Svalbard chapters in the 2020 and 2021 SESS reports.

Air temperatures are rising under a changing climate; changes for the Arctic exceed those for the globe. The Arctic warming trend is expected to strengthen in the coming decades and extend beyond the Arctic region (Rantanen et al. 2022[1]; Chylek et al. 2022[2]). The climate of the Arctic archipelago of Svalbard is very sensitive to these climatic changes. Between 1899 and 2018, Svalbard warmed 3.5 times more than the global mean air temperature (Nordli et al. 2020[3]).

Temperature measurements from several observatories in and above Svalbard are used by the authors of the first chapter, *Seasonal asymmetries and long-term trends in atmospheric and ionospheric temperatures in polar regions and their dependence on solar activity* (SATS), to study air temperature variations and their relation to solar activity. Their measurements show a trend towards higher values, less difference between summer and winter over the last decades, and an increasing seasonal asymmetry between air temperatures and season. No clear correlation was found between solar activity and air temperatures near the ground or in the lower atmosphere. However, the mesosphere and the ionosphere show a clear correlation between solar activity and air temperature.

1 Rantanen M, Karpechko AY, Lipponen A, Nordling K, Hyvärinen O, Ruosteenoja K, Vihma T, Laaksonen A (2022) The Arctic has warmed nearly four times faster than the globe since 1979. Nature Commun Earth Environ 3:168. https://doi.org/10.1038/s43247-022-00498-3

2 Chylek P, Folland C, Klett JD, Wang M, Hengartner N, Lesins G, Dubey MK (2022) Annual mean Arctic amplification 1970–2020: observed and simulated by CMIP6 climate models. Geophys Res Letters 49(13):e2022GL099371. https://doi.org/10.1029/2022GL099371

3 Nordli Ø, Wyszyński P, Gjelten H, Isaksen K, Łupikasza E, Niedźwiedź T, Przybylak R (2020) Revisiting the extended Svalbard Airport monthly temperature series, and the compiled corresponding daily series 1898–2018. Polar Res 39. https://doi.org/10.33265/polar.v39.3614

Aerosols are an important constituent of the atmosphere, both influencing the climate system and contributing to increased pollution of the Arctic. The chapter *Long-term observations of aerosol optical depth and their relation to in-situ aerosol properties in the Svalbard region* (LOAD-RIS) shows that Arctic haze, aerosols from anthropogenic pollution at lower latitudes, has decreased significantly over the last two decades, while aerosols from biomass burning events in spring and summer have increased in number and severity.

One of the aerosols conditioning the atmosphere and cryosphere in Svalbard is dust, which is produced in the lithosphere, travels in the atmosphere, can be deposited on the cryosphere and biosphere and can alter the hydrosphere. *Dust in Svalbard: local sources versus long-range transported dust* (SVALDUST) aims to summarise existing knowledge on local and long-range dust sources in Svalbard.

Harmonising environmental research and monitoring of priority pollutants and impurities in the Svalbard atmosphere (HERMOSA) shows that collecting information on many characteristics of the air may help solve some long-standing scientific problems in Svalbard, such as the origins of what floats in the air and the future of Arctic pollution in the changing world. It also links to SVALDUST by providing a rich list of analytical techniques used to characterise and quantify pollutants.

Surveys of the snow cover have been conducted in Svalbard for more than 25 years. The chapter *Ground penetrating radar measurement of snow in Svalbard - past, present, future* (SnowGPR), compiles information about the conducted GPR snow cover measurements and standards for measurements and data sharing. These measurements provide an insight on the spatial distribution of snow accumulation and its interannual variability.

As a part of a series of SESS chapters that give a comprehensive overview of research involving drones, *Practical guidelines for scientific application of uncrewed aerial vehicles in Svalbard* (UAV Svalbard 3), highlights practical issues related to planning and conducting fieldwork with Uncrewed Aerial Vehicles (UAV) in Svalbard, as well as storing and sharing drone-based datasets. The proposed practical recommendations are intended to guide scientists to become more successful in drone missions in Svalbard. This benefits the whole SIOS community as various research disciplines can make good use of these recommendations.

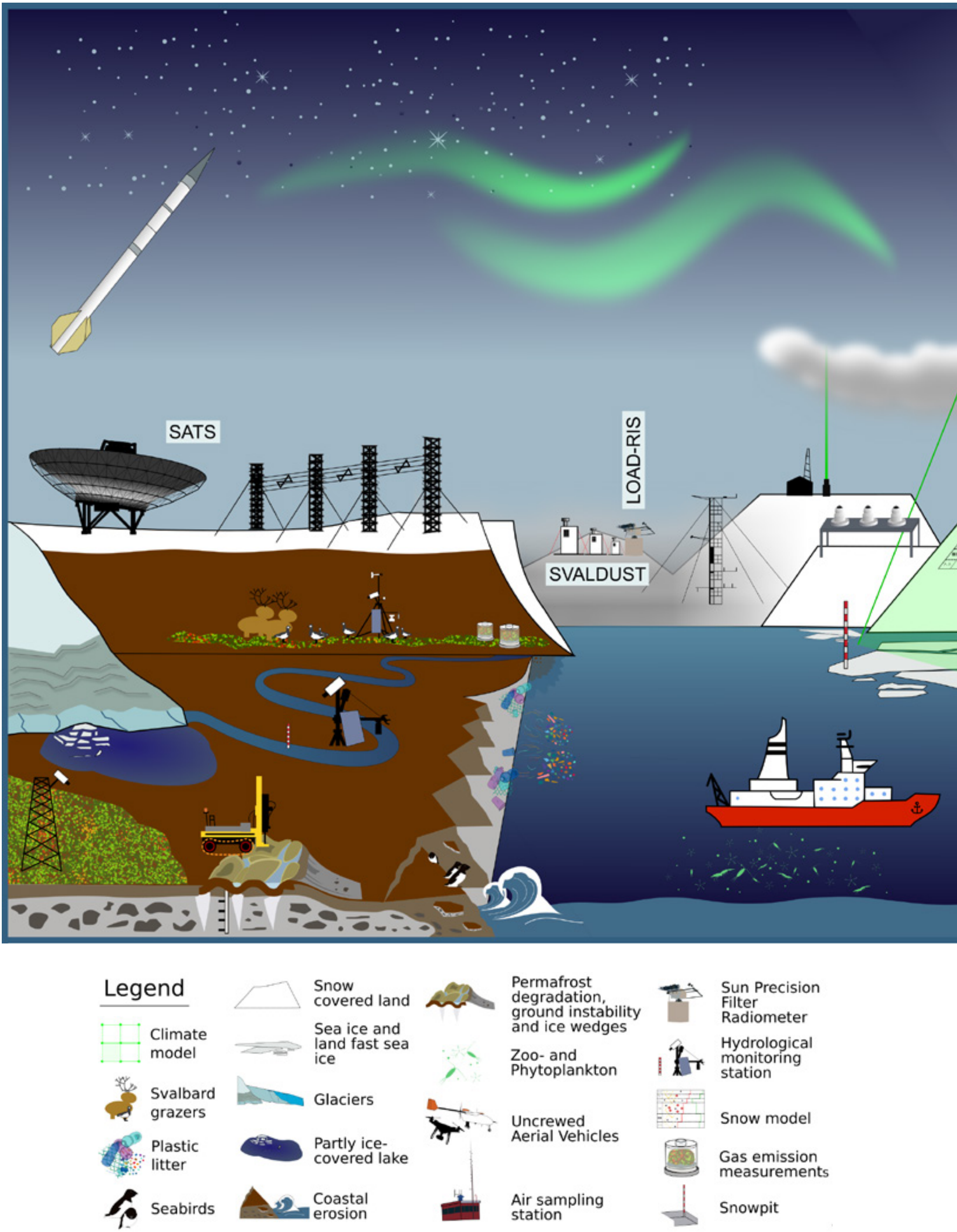
The authors have identified gaps and highlighted some unanswered questions in the above-mentioned critical areas of research. Concise and relevant recommendations summarise each chapter.

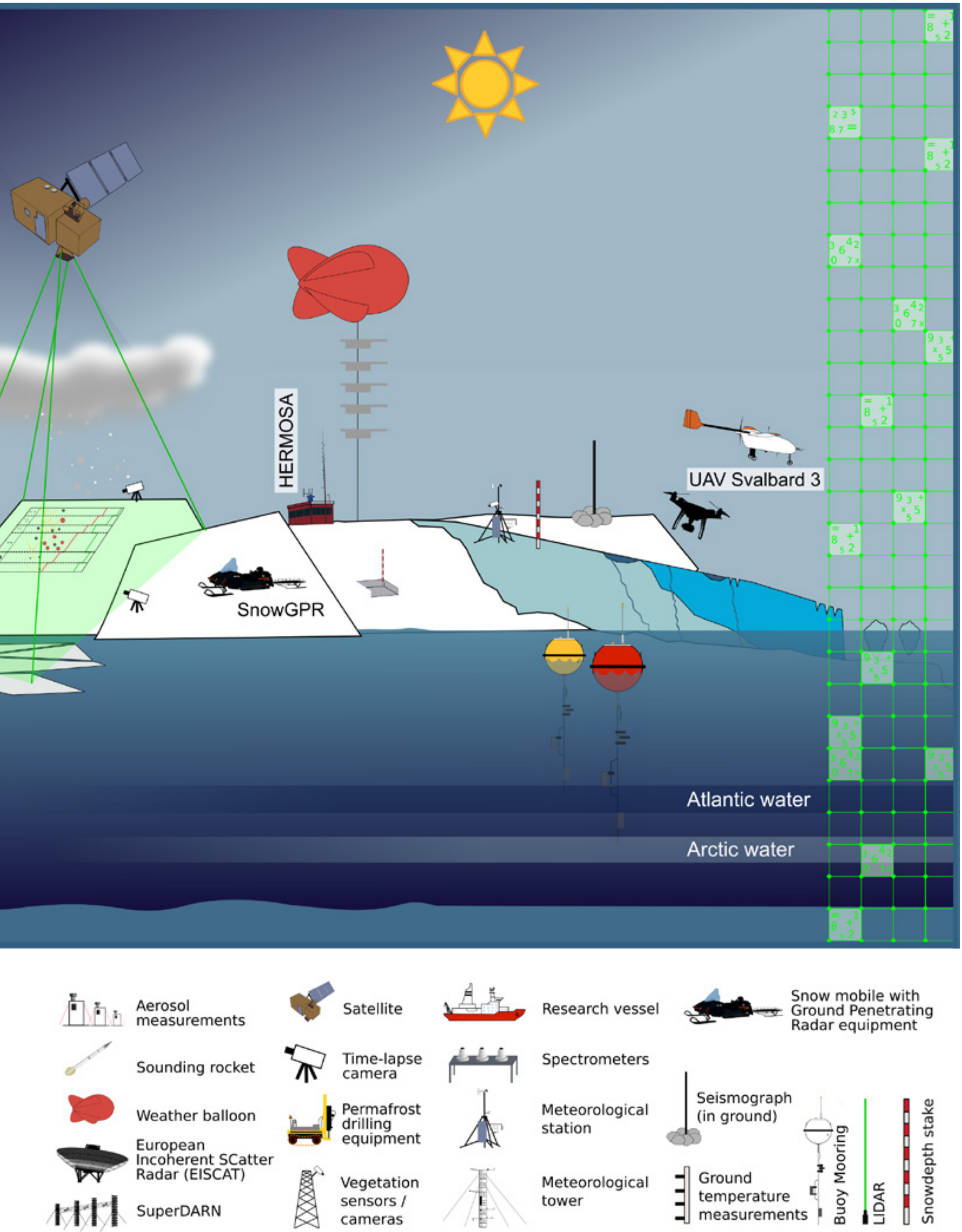
Furthermore, the concluding remarks[4] by the editorial board sets the content of this years' report in the context of previous reports and reflects upon the bigger interdisciplinary picture of environmental research in Svalbard.

At the end of the report, the authors have provided answers to Frequently Asked Questions[4] (FAQ) from the general public, as a contribution to the growing SIOS reference book for environmental science facts.

The editors would like to thank the authors for their valuable contributions to the SESS Report 2022.

4 Only included in the full report: https://sios-svalbard.org/SESS_Issue5


SATS
LOAD-RIS
SVALDUST
Legend
Climate model
Svalbard grazers
Plastic litter
Seabirds
Snow covered land
Sea ice and land fast sea ice
Glaciers
Partly ice-covered lake
Coastal erosion
Permafrost degradation, ground instability and ice wedges
Zoo- and Phytoplankton
Uncrewed Aerial Vehicles
Air sampling station
Sun Precision Filter Radiometer
Hydrological monitoring station
Snow model
Gas emission measurements
Snowpit



Earth system science in Svalbard as described in the SESS report series. Acronyms of the chapters in the current report are shown. (Figure: Floor van den Heuvel).

CHAPTER 1

The EISCAT radar at Breinosa, Svalbard. This radar provides profiles of ion and electron temperatures in the altitude 100-1000 km. (Photo: Christer van den Meeren, Creative Commons)

Seasonal asymmetries and long-term trends in atmospheric and ionospheric temperatures in polar regions and their dependence on solar activity (SATS)

Click here for full chapter

HIGHLIGHTS

1. On ground and in the lower atmosphere we observe a trend towards higher yearly average temperatures, and less difference between winter and summer temperatures.
2. We observe an increasing asymmetry between temperatures and season over the last decades; the day with maximum temperatures tends to occur later in the year.
3. While there is a significant phase shift between season and temperatures on ground and in the troposphere, there is little or no phase shift above the tropopause.
4. We do not find any strong relation between the temperatures on ground or in the sea and solar activity.
5. In the higher parts of the thermosphere, in particular the ionosphere, but to some extent also the mesosphere, there is a pronounced correlation between solar input energy and temperatures.

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We have used temperature measurements from a number of observatories in and above Svalbard to study temperature variations, and their relation to solar activity. Sea temperatures from the mouth of Isfjorden, several ground stations as well as weather balloon measurements were used to study long-term trends of temperatures on ground and in the atmosphere. Radar and optical measurements were used to infer temperatures in the mesosphere and ionosphere.

The measurements show a trend towards higher temperatures and less difference between summer and winter over the last decades. An increasing seasonal asymmetry between temperatures and season over the last decades is also observed; the day with maximum temperatures tends to occur later in the year.

RECOMMENDATIONS

- Enhance cooperation between science disciplines: space science, meteorology, oceanography and glaciology.
- Promote cross-disciplinary studies and modern data assimilation techniques like machine learning to identify couplings between processes.
- Make sure long-term measurements from space, from the atmosphere, from ground and in the sea/ice are easily available.
- Continue to promote open access to observations, and make sure measurements are well calibrated and contain sufficient metadata.

Ground and atmospheric temperatures were also compared to solar input energies, but no clear correlation between solar activity and temperatures on ground or in the lower atmosphere was found. We attribute the observed trends in the ground and atmospheric conditions to a combination of climate warming and local conditions such as sea currents and changes in the extension of the ice shelf.

At higher altitudes, in the mesosphere and in the ionosphere, we observe a clear correlation between solar activity and temperatures, suggesting that a significant transfer of energy from the Sun and its solar wind to the upper part of the thermosphere takes place. This coupling can be explained by electromagnetic processes and enhanced Joule heating due to collisions between neutrals and ions.

Ground based temperature measurement station near Longyearbyen airport (Photo: Antonia Radlwimmer)

1m ‘Silver’ Ebert-Fastie Spectrometer mounted at the Kjell Henriksen Aurora Observatory (KHO). This instrument uses measurements of airglow to provide mesospheric temperatures from ca 90 km altitude during the dark season. (Photo: Antonia Radlwimmer)

Sun Precision Filter Radiometer (PFR) operated by NILU and PMOD/WRC at Sverdrup, Ny-Ålesund. (Photo: G. Hansen)

Long-term observations of aerosol optical depth and their relation to in-situ aerosol properties in the Svalbard region (LOAD-RIS)

Click here for full chapter

HIGHLIGHTS

Aerosols are an important element of the climate system and can lead to both heating and cooling in the polar regions. In Svalbard, Arctic haze, aerosols from anthropogenic pollution at lower latitudes, has decreased significantly in the last 2 decades, while aerosols from biomass burning events in spring and summer increase in number and severity.

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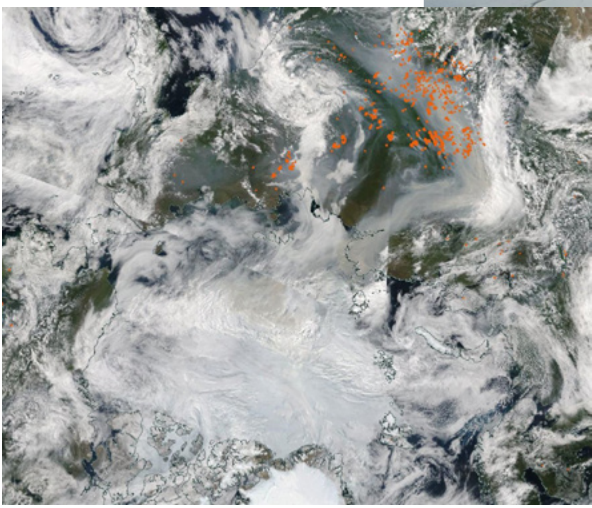
Aerosols are an important constituent of the atmosphere both influencing the climate system and contributing to increasing pollution of the Arctic. At the same time, their adequate monitoring is a big challenge, as instruments on the ground only can sample aerosols in the lowermost atmosphere. For this reason, these measurements are complemented with observations of aerosol optical depth (AOD) which quantify the total amount of aerosols throughout the atmosphere from the attenuation of direct sunlight (and moonlight). This procedure requires extremely careful instrument calibration and removal of cloud contaminated data. In Svalbard, such measurements have been performed by several research groups with different instruments, mostly in Ny-Ålesund and in Hornsund, but also on research vessels offshore. In the framework of the SSF Strategic Grant project ReHearsol, all AOD data from the Svalbard region since

2002 have been collected and made available to the SIOS research community. They indicate that number and intensity of Arctic haze episodes occurring in late winter and spring have decreased consistently and significantly in the two decades, while pollution events in summer/early autumn, caused by boreal biomass burning, are on the rise, though not as consistently. Comparison between in-situ measurements at Gruvebadet Atmosphere Laboratory in Ny-Ålesund and AOD measurements indicate that most (more than 65%) of the episodes with high aerosol load are not captured by surface measurements. This finding does not change when one includes in-situ measurements at Zeppelin Observatory (475 m a.s.l.). Studying extensive high-AOD episodes such as those in summer 2019 requires a multi-tool approach including in-situ and remote-sensing measurements combined with model tools.

RECOMMENDATIONS

- Sun AOD measurements should continue at both Hornsund and Ny-Ålesund as at present, while a third station in eastern Svalbard connected to a meteorological station should be considered.
- An observation capacity for in-situ aerosol measurements on board a mobile platform (uncrewed autonomous vehicle, aircraft) to be used during periods of elevated AOD measurements should be developed.
- More emphasis should be put on collecting data during the polar night, possibly through the establishment of a star photometer and further development of lunar AOD observations.

View from Zeppelin Observatory to Ny-Ålesund and Kongsfjorden during the high-pollution episode in April/May 2006. (Photo: Webcam Zeppelin Observatory)



Satellite image of the Arctic (Aqua/MODIS, corrected true reflectance) on 10 August 2019. Greenland is at the lower edge in the centre, Svalbard to the right of Greenland, and Siberia in the upper half of the image. Red dots: forest fires in central and eastern Siberia, releasing large plumes of smoke spreading towards the North Pole. The image is produced by NASA's EOSDIS Worldview tool.

CHAPTER 3

Mine 7 near Longyearbyen (Breinosa mountain). Note the dark coal dust deposits on surface snow. (Photo: Alia Khan)

Dust in Svalbard: local sources versus long-range transported dust (SVALDUST)

Click here for full chapter

HIGHLIGHTS

- Dust has an impact on both the atmosphere and the cryosphere in Svalbard.
- In the Svalbard archipelago, dust can have both local and long-range sources.
- Dust can lower snow albedo and trigger a melting feedback.

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Dust consists of fine and coarse particles that travel in the atmosphere and are deposited on the Earth's surface. Dust particles deposited on snow and ice can cause snow darkening and contribute to melting. In this chapter, we summarise existing knowledge on local and long-range dust sources in Svalbard, and describe current methodologies for studying dust from both an observational and modelling perspective. Dust science in Svalbard is still in its infancy; future research will help to disentangle the complex role of dust in the Svalbard environment.

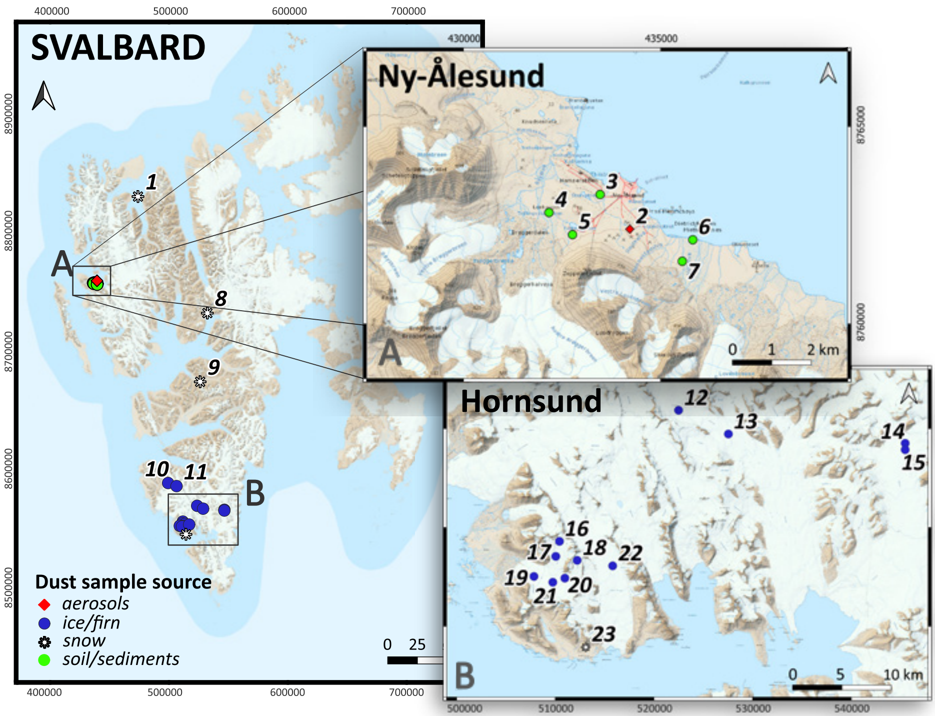
Coal and other local dust from melted snow samples collected in Adventdalen. (Photo: Alia Khan)

RECOMMENDATIONS

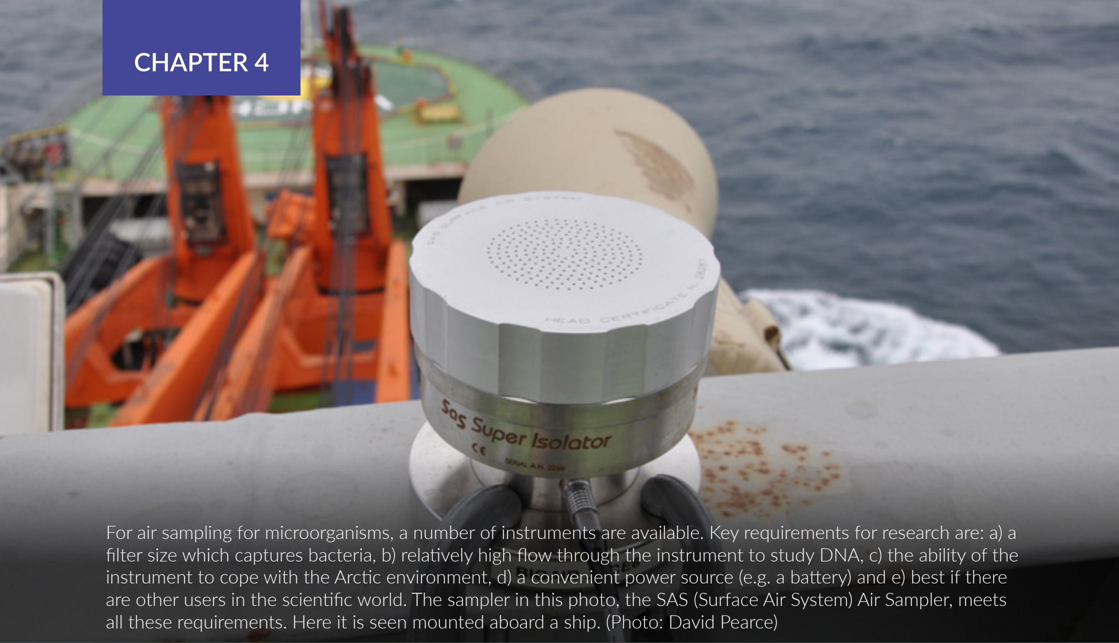
We propose following recommendations for future dust research in Svalbard:

- Identify and characterise dust sources in Svalbard.
- Systemise the observation and remote detection of dust emission/uplift and dust storm events on Svalbard by means of adequate monitoring systems.
- Investigate the influence of local sources in the lower troposphere and long-range transport at higher altitudes by continuous measurements and devoted campaigns.
- Establish an inventory of the long-range dust sources by source profiling in order to cooperate with the modellers for the quantification of the dust load from different sources.
- Attribute the role of dust, black carbon and living organisms (e.g. algae) to snow albedo reductions and melt.

Sampling sites locations described in the SVALDUST chapter. 1 – Woodfjorden; 2 – Gruvebadet; 3-7 – Ny-Ålesund; 8 – Pyramiden; 9 – Breinosa; 10-11 – Recherchebreen; 12-13 – Storbreen; 14-15 – Hornbreen; 16-21 – Werenskioldbreen; 22 – Hansbreen; 23 – Ariekammen. Coordinate Reference System: WGS84 / UTM 33N. Map made based on the NPI S100 Topographic Raster Data for Svalbard. © Norwegian Polar Institute. (Maps by: Adam Nawrot)



CHAPTER 4



For air sampling for microorganisms, a number of instruments are available. Key requirements for research are: a) a filter size which captures bacteria, b) relatively high flow through the instrument to study DNA, c) the ability of the instrument to cope with the Arctic environment, d) a convenient power source (e.g. a battery) and e) best if there are other users in the scientific world. The sampler in this photo, the SAS (Surface Air System) Air Sampler, meets all these requirements. Here it is seen mounted aboard a ship. (Photo: David Pearce)

Harmonising environmental research and monitoring of priority pollutants and impurities in the Svalbard atmosphere (HERMOSA)

Click here for full chapter

HIGHLIGHTS

- Air impurities, from sulphur to pollen, were measured in Svalbard already before 1980s.
- Air quality monitoring is spatially uneven – the Ny-Ålesund hub needs to be supported by other regular sites.
- Methods of impurity measurement show similarities which can be exploited for better problem solving.

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Many characteristics of atmospheric air are measured in Svalbard, including levels of chemical pollution, dark dust connected to soot, and living organisms, but most of these studies happen in Ny-Ålesund. Air monitoring was initiated as early as the 1970s, and multiple atmospheric components have been added to the monitoring over time (especially since 2010; in the early 2000s a few parameters measured at Hornsund joined the regular programme). New types of contaminants are being discovered and measured in Svalbard. Methods for detecting simpler substances and particles have been established for a long time, while certain complex chemicals and small living organisms are more difficult to capture and study. Laboratory and field equipment upgrades help improve understanding of the Svalbard environment. In this chapter, we find that collecting information on many characteristics of the air at the same time helps solve long-standing scientific questions in Svalbard, such as the origins of pollution in the Arctic air and the future of the Arctic atmosphere in a changing world. This is especially important since the Arctic is changing fast, both due to global warming and to the shift in local people's activity from mining to services, e.g. tourism.

RECOMMENDATIONS

- Researchers should agree on important parameters of the atmospheric composition to be measured in at least three places across Svalbard (we propose Ny-Ålesund, Longyearbyen and Hornsund as site, and black carbon (soot), the greenhouse gas methane, inorganic ions, pollen and novel organic chemicals as parameters).
- Change over time (between seasons and years) of a few such parameters should be measured simultaneously to better study the influence of human activity and climate change. This would be easier to study in the future if organic chemical analyses were saved for future searches for novel chemicals (that is, if an electronic sample bank was founded).
- Ny-Ålesund is the best place to study how such parameters change between sea level and mountaintops, but the effects of altitude should be tested in other places too, with shorter experiments. Methods at various locations need to be harmonised and laboratories compared for robust results.

The environmental chamber of the Polish Polar Station in Hornsund also has a few instruments sampling the air on its roof. Regular measurements of aerosol in Hornsund started in 2002. (Photo: Krystyna Koziol)

A collection of instruments monitoring air composition (and pollution) atop Gruvebadet Atmosphere Laboratory roof in Ny-Ålesund. Ny-Ålesund is the main place in Svalbard for air monitoring, with two main sites – Gruvebadet near sea level and Zeppelin Observatory near the mountain top. (Photo: Marco Casula)

CHAPTER 5

Example of the GPR system configuration: A – snowmobile with navigator, B – sledge with GPR operator, C – pulkas with antenna(s) in a waterproof cover (Photo: Mariusz Grabiec)

Ground penetrating radar measurement of snow in Svalbard – past, present, future (SnowGPR)

Click here for full chapter

HIGHLIGHTS

- Snow thickness surveys by ground penetrating radar (GPR) have been conducted in Svalbard for over 25 years, thus permitting assessment of long-term changes.
- More than 5000 km of GPR profiles have been collected in Svalbard.
- Standards for the metadata of the GPR snow measurements have been proposed.

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Snowpack covers 60-100% of all land in Svalbard, depending on the season, and it is very sensitive to changes in climate. Knowledge about the snowpack is important not just in itself, but also to understand how snow cover affects other components of Svalbard's natural environment – land, sea, permafrost, glaciers, and the ecosystems that they support. Monitoring the evolution of Svalbard's snow cover will be crucial as the world's climate continues to warm.

Ground-penetrating radars (GPRs) towed by snowmobile across glaciers and snowfields provide vital information about snowpack thickness and structure. Ideally, such surveys should be repeated annually for continuous monitoring of climate-induced change. Three decades ago, a GPR programme catalogued regional variations in snow accumulation. This should be repeated and expanded to cover all of Svalbard. The GPR method should also be further developed e.g. by mounting GPRs on drones, giving access to parts of glaciers that are too dangerous for researchers to visit. Lastly, women are encouraged to join the field of GPR-based research on snow.

Most of the GPR data collected so far are not currently available in any data repository. The comprehensive compilation of available studies presented in this report, and the recommendations for metadata and data quality, are important first steps to making GPR data more accessible.

RECOMMENDATIONS

- Repeated measurements in successive years should be made along the same tracks whenever safety conditions allow.
- GPR results should be validated with data from snow pits (snow depth, stratigraphy, snow water equivalent (SWE)) or shallow coring (snow depth, SWE).
- The shared GPR data should be accompanied by a full metadata description as proposed in this report.
- UAVs should be adapted to perform autonomous GPR measurements of snow cover.
- The programme conducted in the late 1990s to chart regional variations of snow accumulation in W–E and N–S transects should be repeated for all of Svalbard.

GPR measurements during a blizzard, Hansbreen (Photo:Dariusz Ignatiuk)

GPR measurements on Longyearbreen for the SIOS Access Project in 2018. The screen shows a raw, unprocessed radarogram recorded in real time. Reflections of horizons in the snow cover at the snow/firn/ice border can be seen. (Photo: Bartłomiej Luks)

CHAPTER 6

Off-the-shelf commercial drone in Adventdalen (Photo: Richard Hann)

Practical guidelines for scientific application of uncrewed aerial vehicles in Svalbard (UAV Svalbard 3)

Click here for full chapter

HIGHLIGHTS

1. Recommendations for data storage and data accessibility for drone-based data.
2. Framework for planning drone-based fieldwork in Svalbard.
3. Practical guidelines and recommendations for conducting fieldwork in Svalbard.
4. Recommendations on how to strengthen and expand scientific drone applications in Svalbard.

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Uncrewed aerial vehicles (UAVs), or drones, have become an established tool for a wide range of scientific applications. Today, UAVs are used for example for mapping geomorphic features, glaciers, and heritage sites, counting reindeer, atmospheric measurements, sea ice monitoring and in many other ways.

However, the technology is still relatively new and there is a substantial untapped potential for using UAVs for scientific goals. This report's main focus is to highlight practical issues related to planning and conducting fieldwork in Svalbard, as well as storing and sharing drone-based datasets. One of the key challenges in the field is related to a lack of standardised data storage and metadata requirements. This means that many datasets are not adequately described and/or archived so they are publicly available This means that drone-based data can often not be reused, for example for long-term monitoring studies. The practical recommendations about planning and conducting fieldwork with UAVs in Svalbard is intended to help and guide scientists to become more successful in conducting drone missions. Svalbard has several special challenges related to its remoteness, high latitude, and fauna.

Recommendations are given on how SIOS can strengthen and expand scientific drone applications in Svalbard. The recommendations are intended to make it easier to conduct more complex missions in Svalbard and to train and fund new users. Furthermore, it is recommended to create a forum for scientists to discuss drone-related issues, e.g. to develop community standards for data.

RECOMMENDATIONS

1. Efforts to lower barriers for advanced and complex operations with drones in Svalbard.
2. Develop community standards for data storage and data accessibility for drone-based data.
3. Develop and provide an interdisciplinary forum for scientific drone users in Svalbard.
4. Provide training and funding for basic and advanced scientific drone missions in Svalbard.

Off-the-shelf commercial drone in Adventdalen (Photo: Richard Hann)

Fixed-wing UAV operations in Ny-Ålesund (Photo: Alexander Peuker)

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