SESS REPORT 2023

SUMMARY FOR STAKEHOLDERS

The State of Environmental Science
in Svalbard – an annual report

SIOS
SVALBARD INTEGRATED ARCTIC
EARTH OBSERVING SYSTEM

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The State of Environmental Science in Svalbard – an annual report

Marjolaine Verret, Dariusz Ignatiuk, Renuka Badhe, Christiane Hübner, Heikki Lihavainen (Editors)

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The State of Environmental Science in Svalbard
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Foreword

It is a privilege for me to provide the foreword for the 6th State of the Environment Science in Svalbard (SESS) report. This year it contains six updates to previous years' contributions. The synthesis report from the first four SESS reports' contributions has been published. The first four optimisation projects are based on these recommendations and are ongoing. The upcoming optimisation call will incorporate new recommendations, including those presented in this SESS report.

Year 2023 brought changes among SIOS' human assets. Shridhar Jawak, our remote sensing officer since 2018, embarked on new career challenges. His contributions to SIOS and remote sensing services have been both valuable and a pleasure to witness. May the force be with you! The Board of Directors (BoD) of SIOS also experienced what is probably the most significant change in its history, as Kim Holmén, Vito Vitale, and Piotr Glowacki concluded their terms. They were on the BoD right from the start of the operational phase of SIOS in 2018, and their work has built solid foundations for SIOS. Their legacy will be challenging to surpass. I am confident that the new BoD members will respond to this challenge.

The work we have done together in SIOS has been also noticed. SIOS has solidified its role as a prominent actor in Svalbard and the Arctic landscape of observing systems. But there is still work to be done. Improvements in our research infrastructure and continued harmonization of both the observation strategies used to obtain SIOS core data and the data themselves will be part of the prioritized core activities in coming years. Currently SIOS core data includes 51 variables from different spheres; however, they are very unevenly distributed between the themes. Proposals for new SIOS core data variables are welcomed, with the SESS report being one channel for their introduction.

The SESS chapters this year again reflect the comprehensive approach of SIOS. The updates deal with topics from high in the atmosphere through lower atmosphere to snow and plastic in seawater, sediment, algae, and walruses. To the editorial board, which has worked diligently to ensure the timely publication and high quality of this report: thank you for your efforts. The reviewers are the backbone of scientific work, too often left unnoticed. I thank them for the invaluable time they have dedicated to SESS contributions. Finally, to our team at SIOS Knowledge Centre, it is truly a privilege to be part of such a supportive team. It's great to work with you!

Longyearbyen, December 2023

Heikki Lihavainen

Director, SIOS

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Executive Summary

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The annual State of Environmental Science in Svalbard (SESS) report has established itself as a main driving force in the science-based development of the earth observing system in Svalbard. The SESS reports have collated more than 30 unique chapters with the first 5 reports since 2018. Chapters have ranged across all Earth system environments. An integral mission of the SESS reports is to highlight unanswered questions and provide future recommendations. As such, it reflects the iterative, ongoing nature of science, in a world where technology, particularly artificial intelligence (AI), and scientific infrastructure are fast evolving.

The SESS report is an overview tool that conveys scientific development to the scientific community, as well as stakeholders and the public. As such, the scientific chapters are preceded by the summaries for stakeholders, which provide an overview of each chapter.

The 6th State of Environmental Science in Svalbard Report reflects over past editions and offers six updates of chapters from previous editions. These update chapters are essential in showcasing the state-of-the-art research being conducted in Svalbard, especially at a time when the archipelago and the Arctic in general are being transformed by climate and environmental changes. Chapter 1 deepens our understanding of long-term air temperature forecasts for Svalbard, while chapters 2, 3 and 4 describe snow cover studies ranging from satellites to ground measurements. Lastly, chapters 5 and 6 discuss atmospheric and oceanic pollution respectively.

SATS23 is an update of chapter 1 in the SESS report 2022 "Seasonal asymmetries and long-term trends in atmospheric and ionospheric temperatures in polar regions and their dependence on solar activity" which investigates the intricate interplay between space, atmosphere, sea and land in long-term trends of atmospheric temperatures. Along with datasets of solar activity and ground temperatures, this year's chapter also includes sea temperatures and global atmospheric CO_2 content, enabling us to model ionosphere and mesosphere temperatures. Additionally, the chapter offers a preliminary outlook on how to use machine learning in processing large datasets with complex interactions.

Snow 23 is an update of chapter 11 in the SESS report 2020 "A multi-scale approach on snow cover observations and models". It summarises the state of art in snow science in Svalbard, namely the essential climate variables and SIOS Core Data: snow covered area, snow depth and snow water equivalent. The chapter describes how SIOS aims to create a supersite for snow parameter monitoring in Svalbard and discusses new and upcoming satellite sensors from NASA and Planet which will improve snow measurements in the near future. The chapter also proposes emerging AI-based coupling of models and observations as a tool to reduce model uncertainty.

PASSES 3 complements the previous chapters 10 in the SESS report 2020 "Terrestrial photography applications on snow cover in Svalbard" and 3 in the SESS report 2021 "Improving terrestrial photography applications on snow cover in Svalbard with satellite remote sensing imagery". PASSES has established the Svalbard network of time-lapse cameras to bridge the gap between automated snow stations, ground-based data collection and satellite remote sensing. This year, the chapter presents the design of the data processing chain based on open-source libraries and potential synergies offered by time-lapse cameras during the melt season.

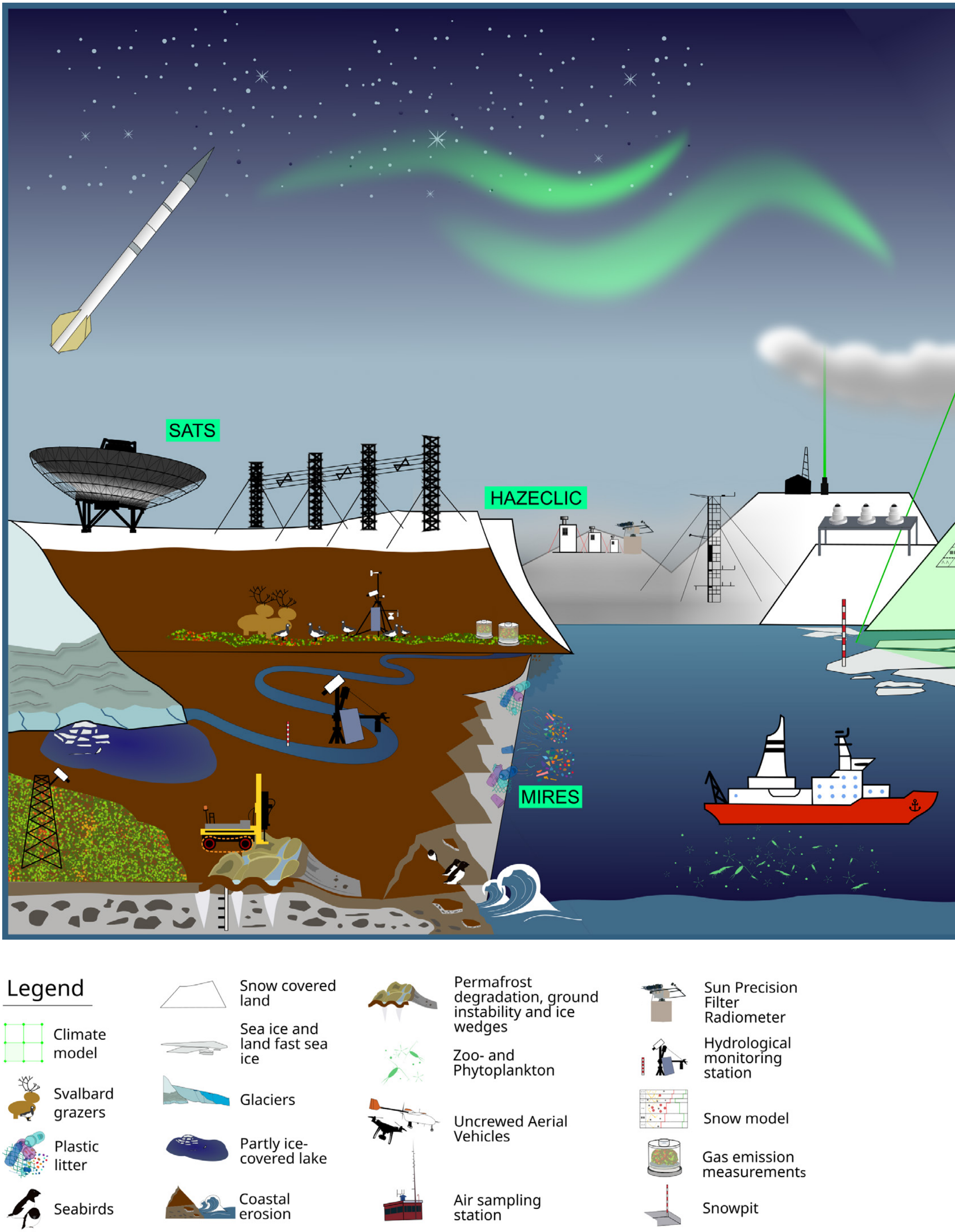
SATMODSNOW 2 is an update of chapter 8 in the SESS report 2020 "Satellite and modelling based snow season time series for Svalbard: Inter-comparisons and assessment of accuracy". The project aims to develop accurate, complete and consistent snow cover datasets in Svalbard using remote sensing observations and snow models. It builds on the previous chapter by utilising additional years of snow cover data from remote sensing and models to examine inter-sensor and inter-model differences.

HAZECLIC 2 is an update of chapter 4 in the SESS report 2020 "Arctic haze in a climate changing world: the 2010-2020 trend". The chapter studies the temporal evolution of Arctic haze, in the form of anthropic sulphate, during the last decade in Ny-Ålesund. It presents promising results of decreasing sulphate concentrations in the atmosphere, which are likely due to air pollution mitigation strategies.

MIRES II is an update of chapter 5 in the SESS report 2020 "Microplastics in the realm of Svalbard: current knowledge and future perspective". The chapter aims to understand the sources, impacts, and interactions with the ecosystems. It highlights that microplastics are widespread in the Svalbard ecosystem and stresses the importance of mitigation strategies.

The authors of each chapter have identified knowledge gaps and unanswered questions. While the first four chapters address essential climate variables and SIOS Core Data that are crucial to understand future climate change in Svalbard, the two last chapters provide insights on the impacts of anthropogenic activity on the fragile Svalbard environment. The SESS reports are a bottom-up process where leading experts in Svalbard science are invited to make recommendations about future research infrastructures and societal needs in Svalbard. However, it is clear that research and observations conducted in Svalbard are essential players in pan-Arctic research. Each chapter has a strong focus on interdisciplinarity and also this year, all update chapters focus on topics that are relevant on a global scale.

Photo: Christiane Hübner


SATS
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Seabirds
Snow covered land
Sea ice and land fast sea ice
Glaciers
Partly ice-covered lake
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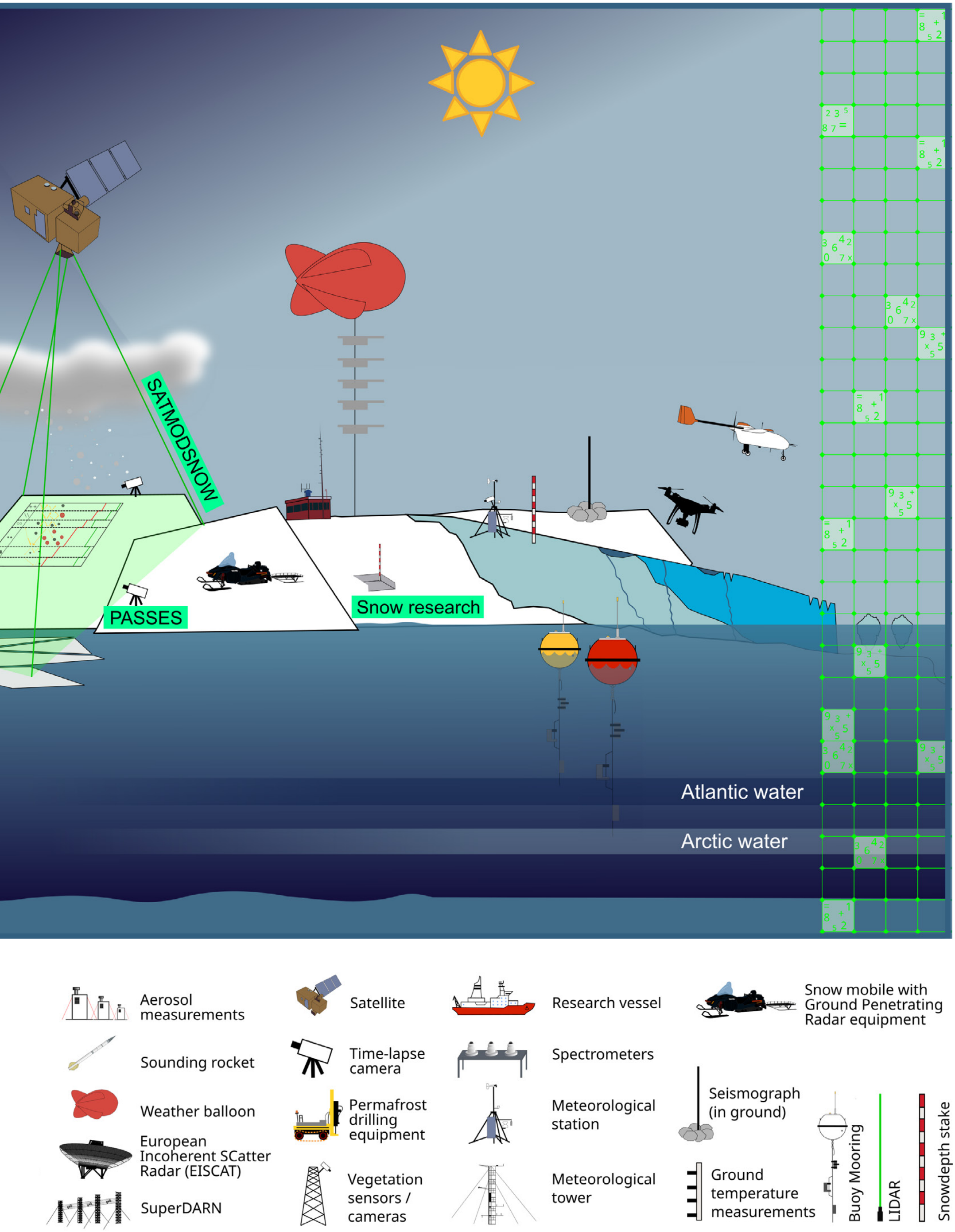
Permafrost degradation, ground instability and ice wedges
Zoo- and Phytoplankton
Uncrewed Aerial Vehicles
Air sampling station
Sun Precision Filter Radiometer
Hydrological monitoring station
Snow model
Gas emission measurements
Snowpit



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

CHAPTER 1

Aurora over Longyearbyen seen from the Kjell Henriksen observatory near Longyearbyen. Aurora is one of the most spectacular manifestations of coupling between space and Earth's upper atmosphere. (Photo: UNIS media)

Seasonal asymmetries and long-term trends in atmospheric and ionospheric temperatures in polar regions: an update (SATS 23)

Click here for full chapter

HIGHLIGHTS

- Arctic annual average temperatures are increasing at ground level and in the lower atmosphere. Temperature differences between winter and summer are decreasing.
- Ground temperatures now follow the seasons less closely. Notably, the warmest day comes later in the year. At the top of the atmosphere, incoming solar energy and temperature correlate well.
- Machine learning modelling helped clarify interactions between processes in the upper atmosphere and ground temperatures.

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During the last decades, temperatures in the Arctic have risen faster than in other parts of the globe. The cause of this rapid temperature increase remains elusive, but likely several factors are in play. Global warming due to the greenhouse effect, in which certain gases in the atmosphere trap heat, is one important factor. Cyclic changes in sea currents and ice coverage also probably play an important role. Moreover, high-latitude Svalbard faces more direct exposure to electromagnetic energy from the Sun; the converging geomagnetic field in this region concentrates electromagnetic energy into the atmosphere – sometimes manifested as spectacular aurora.

Comprehending the relative contributions of these factors, and the intricate interplay between space, atmosphere, sea, and land, remains a challenge. Therefore, an interdisciplinary team of scientists initiated a project to collect as much data from the Svalbard region as possible, to investigate and better understand these interactions. Their findings were presented in the SESS-2022 report.

This chapter updates the original SATS chapter in 2023 with additional data and new methodology. In addition to incremental updates to the existing data set, we include new measurements of sea surface temperatures from several regions around Svalbard, as well as global atmospheric carbon dioxide measurements.

Our recent measurements continue to show rising ground temperatures and reduced temperature differences between summer and winter. We also observe increasing seasonal asymmetry, with peak temperatures shifting towards later parts of the year.

To effectively process and make sense of the growing volume of data, we also explored the use of machine learning. As a proof of concept, we created a simple machine learning model that used upper atmospheric measurements, solar activity indices, and global CO_2 levels as input variables to predict ground temperatures.

This modelling exercise showed that ground temperatures could be predicted quite accurately, suggesting that machine learning could be used for filling data gaps or forecasting temperatures in places where measurements are not feasible. Second, and in contrast to our SESS-2022 results, the machine learning model unveiled discernible, albeit small, correlations between ground temperatures and those in the middle layers of the atmosphere. The causal relationship remains unknown, but it is possible that ground (and sea surface) temperatures influence the upper atmosphere, rather than the other way around.

RECOMMENDATIONS

- Decisions to address challenges arising from the observed warming trend should be based on scientific data.
- Interdisciplinary studies and cooperation across many fields of science should be encouraged.
- Machine learning combined with use of cross-disciplinary data sets should be explored to address the complex interaction between processes in the sea, the atmosphere and space.

The European Space Agency Sentinel-3 mission provides a comprehensive set of environmental parameters, including measurements of sea surface temperatures. (Image: ESA Medialab)

CHAPTER 2

Drone measurements of snow in Adventdalen April 2021. (Photo: Eirik Malnes)

A holistic approach to snow observations and models in Svalbard (Snow 23)

Click here for full chapter

HIGHLIGHTS

- SIOS is in the process of developing a super site for snow parameter monitoring in Svalbard that will improve our ability to assess the snow cover significantly.
- New and upcoming satellite sensors will allow measuring snow depth and snow water equivalent in the coming decade. These sensors need support from ground observations and aerial sensors to obtain desired quality.
- Snow models need development and capacity to assimilate all types of observations.
- A digital twin for the snow cover in Svalbard – AI based coupling of models and observations could potentially solve some of the assimilation issues related to snow models.

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The chapter gives joint recommendations from the two updated SESS chapters SATMODSNOW and PASSES in this SESS report and set them into a wider context on snow research in Svalbard where SIOS now develops supersites for snow parameter monitoring in several projects such as Crios, SIOS Snow Pilot and SnowInOpt. The chapter also gives a brief overview over upcoming satellite sensors allowing for measurements of snow depth and snow water equivalents, which previously have been unavailable from satellites. The chapter also reviews the snow observations provided in the SIOS Data Management System, and advises improvements. We also highlight the importance of snow models and their ability to assimilate different in situ and earth observations to accurately represent the snow cover. At the end of the chapter, we look forward to new possibilities for a holistic approach where models (from past data and future climate scenarios) and observations are merged in a digital twin based on AI techniques for pattern recognition, allowing for detailed prediction of the future snow cover.

Preparations for field campaigns in Longyearbyen. The use of avalanche transceivers is mandatory during field work. (Photo: Markus Eckerstorfer)

RECOMMENDATIONS

- Intercomparisons (and intercalibrations) of snow products from coarse scale (4 km, AVHRR), via medium scale (500 m, MODIS) and detailed (10–20 m, S2-MSI) to sub-meter scale (time-lapse cameras) should continue and be used to improve products.
- The SIOS supersite for remote sensing of snow must be continued as a reference for upcoming satellite products and snow parameter retrieval methods. Funding of snow water equivalent transects using GPR and web-camera operations should be sought from available sources.
- Attempts should be made to map, harvest and maintain (if possible) all kinds of Earth Observation products of snow over the archipelago and validate/quantify errors in each of the datasets.
- The assimilation of Earth Observation data in snow hydrology and snow process models needs to be further investigated.
- A digital twin framework for the snow cover in Svalbard should be implemented to assimilate data in models using AI-concepts, and possibly make future predictions about the snow cover.

Aerial photo of snow cover in Longyearbyen April 2021. (Photo: Eirik Malnes)

CHAPTER 3

The IG PAS time-lapse camera view at Hornsund. (Photo: Bartłomiej Luks)

Terrestrial photography applications on the snow cover: developing a data service for monitoring extreme events in Svalbard (PASSES 3)

Click here for full chapter

HIGHLIGHTS

- The Svalbard time-lapse camera network focused on snow cover monitoring has been established.
- Three focal sites have integrated previously established and novel camera systems, and conceptualizing a shared data service.
- Earth observations provided by the infrastructure assist in describing emerging phenomena occurring in Svalbard.

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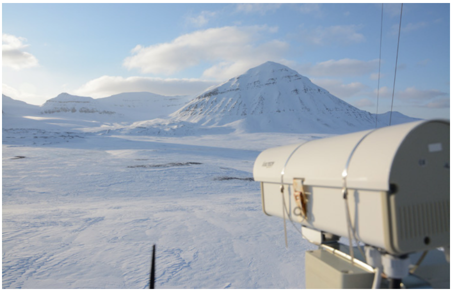
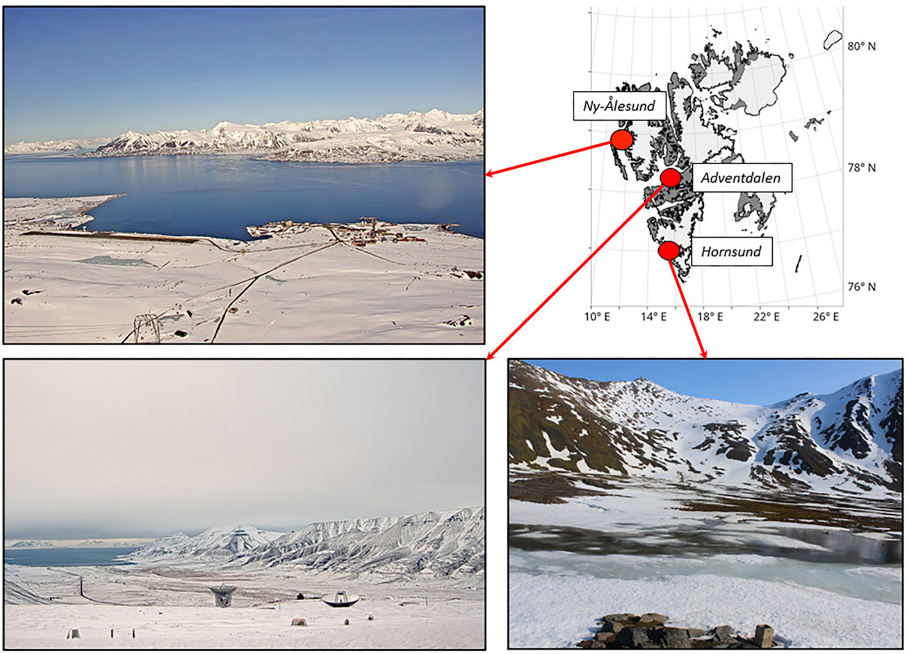
The PASSES initiative has matured within the framework of SIOS activities, resulting in the establishment of the Svalbard network of time-lapse cameras. The primary objective of this network is to monitor the evolution of the snow cover during the melting season. A survey of available applications served as a valuable tool for identifying scientific priorities and potential opportunities. By optimizing the operation of these applications through a collaborative approach, we supported the design of the network architecture and the development of a data service, including a product prototype. The continuity of Earth Observation (EO) data obtained through terrestrial photography is invaluable for describing emerging phenomena in the changing Arctic. These observations primarily serve to bridge the gap between automated stations, ground-based data collection, and satellite remote sensing. Moreover, they enable continuous observation, facilitating the integration of data from various sources.



The CNR time-lapse camera at the Amundsen-Nobile Climate Change Tower. (Photo: Riccardo Cerrato)

RECOMMENDATIONS

1. Promote projects involving use of the time-lapse cameras, particularly in the more remote areas of Svalbard. Utilise distributed computing systems to facilitate the use of systems built into the "internet of things", aiming to overcome data transfer limitations.
2. Support the maintenance of the Svalbard camera system network and advocate for the establishment of a dedicated data service for processing images captured by various devices for snow cover applications.
3. Enhance the understanding of snow dynamics and processes by combining high-resolution terrestrial images and large-scale satellite data with advanced machine learning and artificial intelligence methods.
4. Encourage the use of time-lapse cameras across disciplines where high-resolution temporal information can be harnessed for various purposes, including glaciology, hydrology, plant and animal ecology, coastal processes, sea ice tracking, and satellite imagery calibration and validation (Cal/Val).



The three selected sites of the Svalbard camera network. (Photos: Roberto Salzano)

CHAPTER 4

Snow cover has significant impacts on terrestrial and marine ecosystems. (Photo: Hannah Vickers)

Satellite and modelling based snow season time series for Svalbard: Intercomparisons and assessment of accuracy (SATMODSNOW 2)

Click here for full chapter

HIGHLIGHTS

- Snow models produce patterns of later snow melt and snow onset compared to remote sensing (RS) observations.
- Snow cover derived from remote sensing datasets is very dependent on the retrieval algorithm used.
- Methods exploiting artificial intelligence (AI) are needed to extract finer detail from low-resolution remote sensing observations and for combining remote sensing observations with snow models to obtain accurate snow cover time series.

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Climate change is taking place at a much faster pace in the Arctic and polar regions compared to the global average. Across the Norwegian archipelago of Svalbard, a warming climate is impacting where and when there is snow cover, which in turn has consequences for the physical environment, terrestrial and marine ecosystems. Remote sensing observations and snow models represent valuable tools for large scale monitoring of snow cover and provide historical data spanning several decades. These approaches provide complementary data that can contribute to filling important gaps in both datasets. However, we must first understand the how and how much the datasets differ. Only then can we use these complementary datasets to develop accurate, complete and consistent snow cover time series for Svalbard. The research in this update chapter builds on the SESS report 2020 chapter SATMODSNOW by utilising additional new years of snow cover data from remote sensing and models to examine inter-sensor and inter-model differences. Our results highlight some systematic differences in the temporal characteristics of snow cover onset and disappearance between models and remote sensing, as well as the significance of cloud cover masks and retrieval algorithms on the snow cover fraction derived from identical remote sensing datasets.

RECOMMENDATIONS

- Develop methods using remote sensing data to improve hydrological models for better representation of snow cover distribution.
- Increase measurements of snow temperature and liquid water content for use in validation/ ground truthing for models and remote sensing datasets.
- Utilise wet snow cover datasets obtained with Synthetic Aperture Radar (SAR) in combination with optical snow cover fraction maps to improve snow cover detection during the melting period, especially on overcast days when optical sensors cannot provide snow cover data.

The current availability of ground truthing data in Svalbard is sparse. (Photo: Hannah Vickers)

The spatial distribution of snow cover in Svalbard can be highly inhomogeneous and vary over small scales. (Photo: Hannah Vickers)

CHAPTER 5

Close-up of Zeppelin observatory (Zeppelin Mountain), continuously operated by NILU since 1989. The village of Ny-Ålesund can be seen at the left. (Photo: Ove Hermansen)

Arctic haze in a climate changing world: the 2010–2022 trend (HAZECLIC 2)

Click here for full chapter

For this update of the HAZECLIC chapter in SESS report 2020, we studied the temporal evolution of the Arctic haze over the past decade in Ny Ålesund (at Gruvebadet and Zeppelin observatories) through data on atmospheric sulphate, which is the most reliable marker of Arctic haze. By using other source chemical markers, we managed to quantify the solely anthropic sulphate and study its behaviour between 2010 and 2022. Although detecting a trend was not straightforward, we observed decreasing levels of anthropic sulphate when the haze is present (April) while no trend could be observed when the haze is not present (September). These results have various implications: first, they suggest that atmospheric sulphate arising from anthropic activities and present during non-haze months has reached a bottom threshold, a sort of "background level" which is

HIGHLIGHTS

- Source apportionment method applied to atmospheric sulphate from two sites in Ny-Ålesund to quantify anthropic contribution.
- Anthropic sulphate used to study the evolution of Arctic haze from 2010 to 2022.
- Air pollution mitigation strategies appear to be improving air quality.

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probably difficult to reduce further. Second, it appears that atmospheric sulphate is still slowly decreasing during haze months, likely due to a persistent long-term effect of stricter air quality policies.

Aerosol sampling devices operated at Gruvebadet observatory since 2010 by University of Florence in close cooperation with CNR-ISP. (Photo: Mauro Mazzola)

RECOMMENDATIONS

1. Continue with the experimental observations at the Gruvebadet and Zeppelin observatories. two highly strategic sites. The continuous long-term aerosol measurements at both observatories will allow constraining the impact of the haze at ground level and above the atmospheric boundary layer.
2. Define the "natural Arctic baseline". The natural aerosol emissions are progressively changing due to the environmental impact of anthropic activities. Since natural aerosol plays a key role in the radiative balance of Arctic regions, a more accurate assessment of the "moving natural baseline" would represent an asset in understanding and forecasting the impact of human activities in the Arctic.
3. Upgrade the Gruvebadet facility with measurement of trace gases. Gruvebadet observatory has been acknowledged in the last years as a relevant facility to accomplish several atmospheric studies. The instrumental set-up has been successfully used to measure the chemical composition of aerosols, but so far the gas phase has only been investigated during spot campaigns. A systematic measurement array for key gas species acting as aerosol precursors (such as dimethylsulphide), possibly via on-line instruments, would yield an expanded overview of the gas–aerosol–cloud interaction.

Overview of the two observation facilities mentioned in the report: Gruvebadet - GVB (at left in the foreground) and Zeppelin - ZEP observatories (right, near the top of the mountain), Ny-Ålesund. (Photo: Mirko Severi)

CHAPTER 6

Plastic litter in Svalbard. (Photo: Norwegian Polar Institute)

Microplastics in the realm of Svalbard: current knowledge and future perspective (MIRES II)

Click here for full chapter

HIGHLIGHTS

Plastic pollution in Svalbard is an increasing environmental issue. Despite Svalbard's remote location, microplastics are infiltrating this pristine environment. Understanding their sources, impacts, and interactions with the ecosystem is crucial for mitigation strategies.

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Microplastics, tiny plastic fragments (<5mm), have emerged as a global concern, infiltrating even the most remote regions such as Svalbard. The surge in plastic production has led to widespread contamination. Svalbard, like the broader Arctic region, is already contending with issues related to climate change, pollution, and invasive species, and it now faces an additional risk in the form of microplastics. Recent studies conducted in Svalbard have advanced our understanding of microplastics in seawater, sediment, algae, fulmars and walruses. Ongoing monitoring indicates that microplastics could potentially be harmful to the Svalbard environment over extended periods. It is imperative to maintain a comprehensive grasp of the status of microplastics and adopt a proactive approach. This is crucial for assessing and conveying the significance of prevention and reduction efforts targeting plastic pollution in the Arctic. It serves as a rallying call for all of us to reduce our plastic consumption and seek sustainable alternatives whenever feasible. Each small effort we make can contribute significantly to a reduction in microplastic pollution.

Taking a snow profile in a mountain slope. (Photo: Eirik Malnes)

RECOMMENDATIONS

- **Harmonization:** Organize a workshop with experts on microplastic, to reach agreements on microplastics monitoring on Svalbard.
- **Collaboration:** Establish a Svalbard plastic task force. Its members should meet regularly to develop methods and monitoring recommendations to ensure a concerted effort to fulfil knowledge gaps.
- **Mapping:** Microplastic has not been mapped properly in Svalbard. This knowledge gap includes biota both from the terrestrial and marine ecosystems. In depth mapping studies should be done to enable reliable risk assessment for both the environment and human consumers.
- **Long-term monitoring:** A monitoring programme should be designed to include societal needs. Scientists working on microplastics can provide advice regarding plastic use in Svalbard, wastewater treatment, effects of recreational (cruises/tourists) and fishing activities.
- **Experiments:** Experimental studies on microplastics effects in Arctic key species should be promoted and the possible trophic accumulation of microplastics under Arctic conditions should be investigated.

Plastic litter in Svalbard. (Photo: Geir Wing Gabrielsen)

You can find this and previous SESS reports on our webpage:
https://sios-svalbard.org/SESSreport

Visit the SIOS data access portal to find metadata and datasets described in this report: https://sios-svalbard.org/metadata_search

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