SESS REPORT 2019

SUMMARY FOR STAKEHOLDERS

The State of Environmental Science in Svalbard – an annual report

SIOS

SVALBARD INTEGRATED ARCTIC EARTH OBSERVING SYSTEM

SESS REPORT 2019

SUMMARY FOR STAKEHOLDERS

The State of Environmental Science
in Svalbard – an annual report

Floor van den Heuvel, Christiane Hübner,
Malgorzata Błaszczyk, Martin Heimann,
Heikki Lihavainen (Editors)

SESS report 2019 – Summary for Stakeholders
The State of Environmental Science in Svalbard
– an annual report

ISSN 2535-6313 (printed)
ISSN 2535-6615 (pdf)
ISBN 978-82-691528-4-5 (printed, stapled)
ISBN 978-82-691528-5-2 (pdf)

Publisher: Svalbard Integrated Arctic Earth Observing System (SIOS)
Editors: Floor van den Heuvel, Christiane Hübner,
Malgorzata Błaszczyk, Martin Heimann, Heikki Lihavainen
Editor popular science summaries: Janet Holmén
Layout: Melkeveien designkontor, Oslo

The report is published as electronic document, available from
the SIOS web site www.sios-svalbard.org/SESSreport

Contents

Foreword

The Svalbard Integrated Arctic Earth Observing System (SIOS) is an international multidisciplinary research infrastructure for observing the Arctic Earth. SIOS concentrates on long-term observations important for global environmental and climate change, to observe, attribute and describe the effects of the change. The central instrument for developing SIOS, guiding the next years' work within SIOS and reporting the achievements during the last year is this annual SESS report.

The integrating theme of SIOS is to understand the processes in the interfaces between different earth system science disciplines and their dependencies on each other in the changing environment. As a holistic multidisciplinary research infrastructure, SIOS has huge potential to improve our understanding of the sweeping changes in our Arctic environment. Huge potential often also entails huge challenges. We as SIOS together are challenged but strive incessantly towards attaining the SIOS goals. International and multidisciplinary also means multilingual in a scientific environment. Finding a common language is a challenge indeed, but facilitated by strong common interests towards Arctic research. The science and research in different spheres have matured in different manners and directions, and to align them to the shared SIOS goals we need this common language. The SESS report is one integrative tool to improve the communication between spheres.

To be able to attain the potential described above, SIOS has defined the first set of core data, which in a broad sense are state variables important for global environmental diagnostics, describing energy and mass exchange and the combined effect of human perturbations and environmental change on organism, populations and ecosystems. Core data will be produced over time such that scientists can plan experiments leaning on a trustworthy source of the core data streams. This backdrop of data produced by SIOS is a vital enhancement in making Svalbard an even better research platform for the international research community. The SESS report is instrumental to exploring, developing and defining the next generation of core data and thus the proliferation of Svalbard research.

The SESS report is a way to develop the observing system; the recommendations in the SESS reports are used as prioritising instruments in developing and optimising the research infrastructure. This year's report includes reviews of existing data and activities, data summaries and updates from last year's chapters. It is a unique description of current activities and collaboration, as well as recommendations for the future in Svalbard research.

Without the voluntary work of the editorial board (Floor van den Heuvel, Martin Heimann, and Malgorzata Błaszczyk) this report would have never seen the light of day. We deeply appreciate their invaluable devotion towards this report. The help of Janet Holmén in turning the scientific language into understandable popular science form is appreciated. The anonymous reviewers made an important contribution to the chapters with their constructive suggestions: the scientific world relies on scientists' willingness to act as reviewers. Finally, thanks to the authors of the SESS report 2019; your contribution to science in Svalbard is indispensable. Now the task lies with us, SIOS and the SIOS Knowledge Centre, to take your recommendations to the SIOS consortium to discuss feasibility, set priorities, and strive for timely implementation.

Longyearbyen, December 2019

Prof. Heikki Lihavainen Director, SIOS	Kim Holmén Chair of Board of Directors, SIOS	Christiane Hübner Information Officer, SIOS

Authors from following institutions contributed to this report:

AARI	Arctic and Antarctic Research Institute, Russia
AMU	Adam Mickiewicz University, Poland
ASC	Andøya Space Center, Norway
AU	Aarhus University, Denmark
AWI	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Germany
Bates College	Bates College, USA
CIRA	Cooperative Institute for Research in the Atmosphere, Colorado State University, USA
CPR-Survey	Continuous Plankton Recorder Survey, Marine Biological Association, U.K.
CPS	Centre for Polar Studies, University of Silesia, Poland
CU	Clemson University, USA
DC	Dartmouth College, USA
GFZ	German Research Centre for Geosciences, Germany
Hampshire College	Hampshire College, USA
IGF PAS	Institute of Geophysics, Polish Academy of Sciences, Poland
IGRAS	Institute of Geography, Russian Academy of Sciences, Russia
IIM	Italian Navy Hydrographic Institute, Italy
IMR	Institute of Marine Research, Norway
INAR	Institute for Atmospheric and Earth System Research, University of Helsinki, Finland
Insubria Univ	Insubria University, Italy
IOPAN	Institute of Oceanology Polish Academy of Sciences, Poland

ISP-CNR	Institute of Polar Sciences, National Research Council of Italy, Italy
JAXA	JAXA Institute of Space and Aeronautical Science, Japan
JB Hyp Devices	JB Hyperspectral Devices, Germany
JHI	The James Hutton Institute, UK
Lund Univ	Lund University, Sweden
MET Norway	Norwegian Meteorological Institute, Norway
NASA	NASA Goddard Space Flight Center, USA
NCSR	National Center for Scientific Research, Greece
NGI	Norwegian Geotechnical Institute, Norway
NINA	Norwegian Institute for Nature Research, Norway
NIPR	National Institute of Polar Research, Japan
NORCE	Norwegian Research Centre AS, Norway
NORSAR	NORSAR, Norway
NPI	Norwegian Polar Institute, Norway
OGS	National Institute of Oceanography and Applied Geophysics, Italy
SLU	Swedish University of Agricultural Sciences, Sweden
SU	Stockholm University, Sweden
U IOWA	University of Iowa, USA
UAF	University of Alaska, USA
UiO	University of Oslo, Norway
UiT	UiT, The Arctic University of Norway, Norway
UNIMiB	University of Milano-Bicocca, Italy
UNIS	University Centre in Svalbard, Norway
Univ Bolzano	Free University of Bozen-Bolzano, Italy
UP	University of Perugia, Italy
UU	Uppsala University, Sweden

Executive Summary

Floor van den Heuvel[1], Christiane Hübner[2], Malgorzata Błaszczyk[3], Martin Heimann[4], Heikki Lihavainen[2]

1 Ecole Polytechnique Fédérale de Lausanne, Environmental Remote Sensing Laboratory, Lausanne, Switzerland; 2 SIOS Knowledge Centre, Longyearbyen, Norway; 3 University of Silesia, Faculty of Natural Sciences, Sosnowiec, Poland; 4 Max-Planck-Institute for Biogeochemistry, Jena, Germany

The Arctic constitutes a key "hotspot" in the global Earth System. It is currently warming faster than the rest of the Earth due to several critical feedback processes of global importance, e.g. the land and sea ice albedo effect. This warming promotes a host of changes in interconnected environmental parameters, from the oceans, ice and ecosystems at the surface, past the clouds to the stratosphere. Understanding, quantifying and ultimately predicting changes in these interactions using complex Earth system models constitutes a critical challenge in Earth system science. Meeting this challenge requires comprehensive observations in the Arctic domain.

Due to its location at the crossroads of major atmospheric and oceanic currents, as well as its accessibility and the presence of important international research infrastructures, Svalbard constitutes a perfect location for observing and studying Arctic climate change and its impacts on high latitude terrestrial and oceanic ecosystems. The chapters in this report document the current status of the Arctic environment as observed in Svalbard in 2019, and highlight research conducted within SIOS.

In Svalbard, conditions during the 2017/18 hydrological year were markedly warmer than the previous year. Despite a longer freezing season, mean air temperatures were higher at all measurement locations in Svalbard.

This continued warming has had repercussions on the terrestrial system through a decrease in the depth and duration of snow cover, as well as an increased frequency of rain-on-snow events. These changes have led to increases in plant productivity, permafrost active layer thickness and ground temperatures.

While enhanced vegetation growth has positive effects on the population sizes of grazers in Svalbard, such as reindeer and geese, rain-on-snow events and the resulting thick layer

of ice raises herbivore mortality rates by blocking their access to food. Enhanced grubbing by grazers in search of food extends the exposure of permafrost to warming, while changes in the snow- and vegetation cover affects the amount of solar radiation reflected back into the atmosphere. Thus, changes within the terrestrial system can both affect other parts of this system and feed back into the atmosphere.

Increased monitoring of permafrost at different locations and greater depths, as well as enhanced use of remote sensing techniques to monitor both ground instability and vegetation growth are necessary for better quantification of the observed changes. The complex interactions between climatic variables and the Arctic tundra ecosystem and species, require long-term, adaptive food-web based monitoring.

Glaciers and ice caps are among the most eye-catching indicators documenting changes in the global climate. Svalbard holds only a tiny fraction of the glacier area in the Arctic, but represents a wide range of glacier types. All reported pan-Svalbard estimates show a decrease in glacier mass balance, likely as a result of atmospheric and oceanic warming. Fast glacial retreat in Svalbard causes expansion of fjords and proglacial areas, and increases freshwater input into marine environments, influencing regional albedo and energy balance.

Collaborative research programmes across (and outside) the glaciological community are required to better assess the future evolution of glacier cover. Long-term *in situ* measurements and models focus on surface ablation. Frontal ablation, however, is understudied. Estimates of ablation processes at the glacier front – calving and submarine melting – have hitherto been forced to rely on outdated information and low-resolution methods. Long-term trends and changes in seasonal calving patterns can be now observed in near real-time with cryoseismological monitoring. Expansion of the seismological network and integration of seismic observations with other monitoring methods are expected to provide a more accurate and more complete quantification of the global warming footprint on Svalbard's cryosphere.

Currents from both the Atlantic and the Arctic Oceans strongly influence the climate in Svalbard through input of warm or cold water. More frequent warm water inputs from

the Atlantic in combination with higher ocean and air temperatures impact sea ice extent, thickness and duration, as well as the snow cover on the sea ice. Reduced ice cover diminishes the amount of solar radiation reflected back into space, as the darker water absorbs solar radiation and warms up, further accelerating sea ice melting. Loss of sea ice, oceanic warming and freshwater inputs from glacier melt also affect marine ecosystems, for example by changing species' ranges and increasing phytoplankton productivity.

Extending the established *in situ* sea ice monitoring at Svalbard with autonomous technology and remote sensing tools would provide a robust suite of complementary monitoring methods. An integrated observation system and enhancement of monitoring activities with additional biogeochemical and molecular sensors is recommended. This would give us a more comprehensive overview of the biological and chemical changes in oceans and fjords.

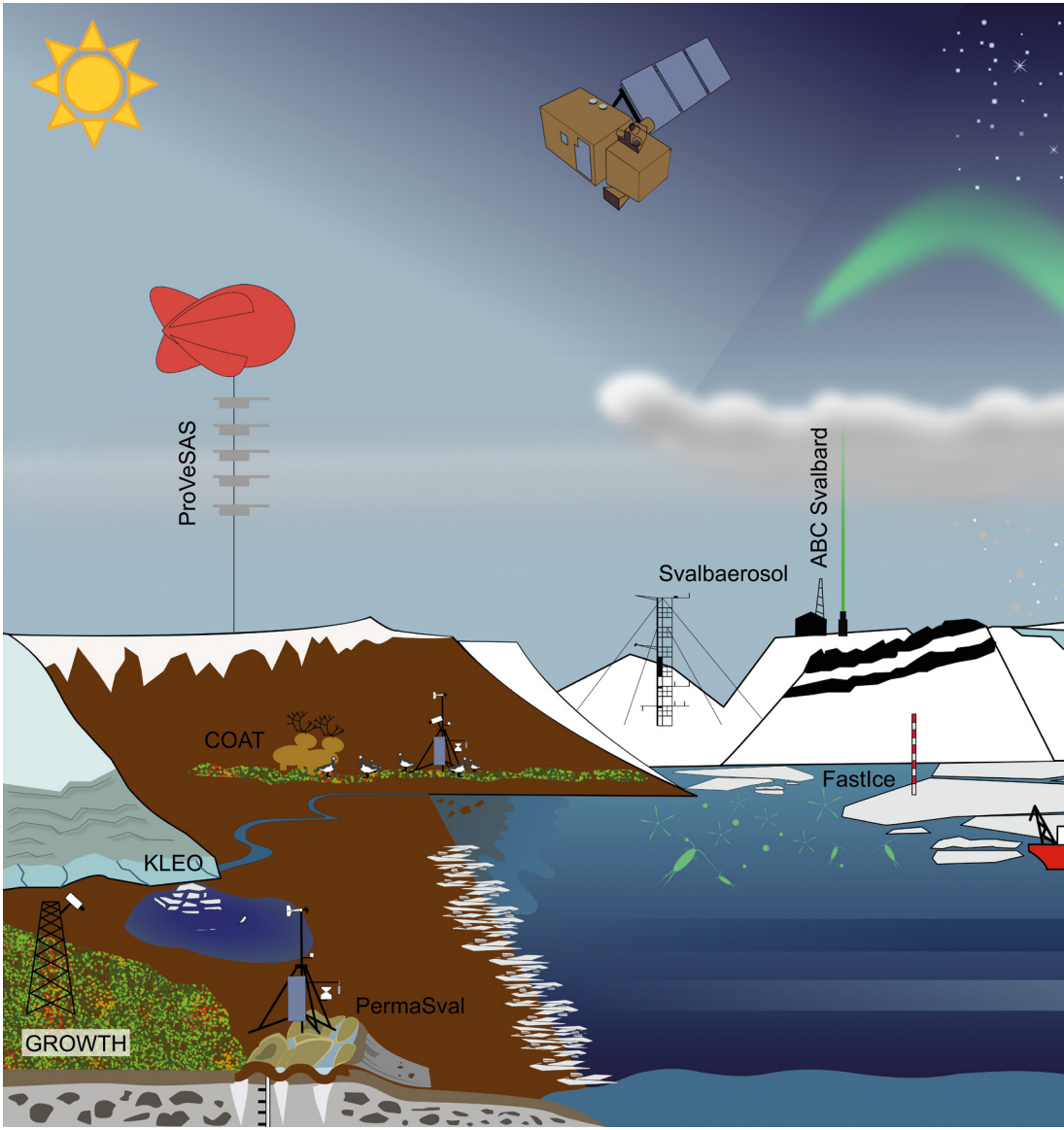
The characteristics of natural and anthropogenic aerosols are fundamental for our understanding of changes in the Arctic system as the impact of aerosols and their various feedback mechanisms are still very uncertain. Aerosols are solid or liquid particles suspended in the air. Oceans and sea ice are sources of natural cloud condensation nuclei; aerosols that can act as a seed for cloud droplets. Among these are aerosols released from sea spray, secondary aerosols originating from phytoplankton-emitted dimethyl sulphide and iodine emissions from sea ice. More open water and increased phytoplankton activity may impact the chemical composition of the aerosols and thus cloud formation. In addition, natural cloud condensation nuclei may originate from emissions of biogenic vapours from plants and animals as a result of increased terrestrial primary production on land.

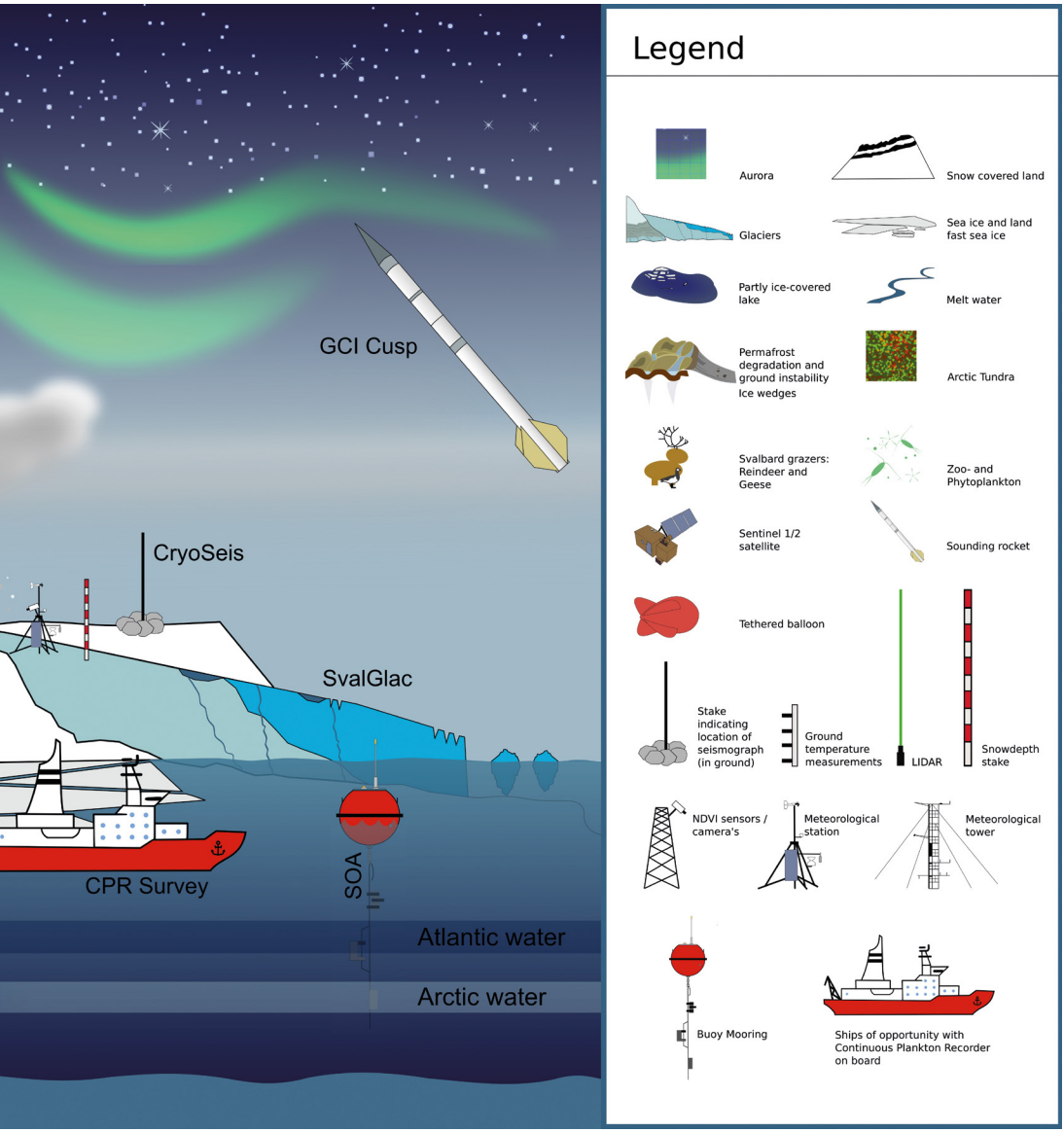
Black carbon aerosols, mostly of anthropogenic origin, warm the atmosphere through their capacity to absorb solar radiation while suspended in the atmosphere or in clouds. Black carbon may also affect the physical and radiative properties of clouds or, when deposited on the ground, impact the regional radiation balance by reducing snow and ice surface albedo.

Extension of the current instrumentation for aerosol detection in the atmosphere to other locations in Svalbard, and improved comparability among different measurement techniques, would improve our understanding of how aerosols of both natural and anthropogenic origin end up in the Arctic atmosphere. Supplementing the infrastructure for the vertical probing of atmospheric variables with drones, unmanned aerial vehicles, and balloons will not only enhance our understanding of the Arctic atmosphere, but also facilitate the use and interpretation of remote sensing observations.

The upper polar atmosphere is strongly influenced by solar winds, which heat and structure the thermosphere. During 2018/19, five Grand Challenge Initiative – Cusp rockets were successfully launched through daytime auroras over Svalbard. Unique data sets were collected to explore solar wind forcing of particle acceleration, turbulence, atmospheric heating and outgassing that may influence the upper boundaries of the polar atmosphere.

The editors thank the many researchers who have contributed articles for the SESS Report 2019. Reading about how the SIOS projects have advanced has been a rewarding experience.


ProVeSAS
ABC Svalbard
Svalbaerosol
COAT
FastIce
KLEO
PermaSval
GROWTH


GCI Cusp
CryoSeis
SvalGlac
CPR Survey
SOA
Atlantic water
Arctic water
Legend
Aurora
Snow covered land
Glaciers
Sea ice and land fast sea ice
Partly ice-covered lake
Melt water
Permafrost degradation and ground instability
Ice wedges
Arctic Tundra
Svalbard grazers: Reindeer and Geese
Zoo- and Phytoplankton
Sentinel 1/2 satellite
Sounding rocket
Tethered balloon
Stake indicating location of seismograph (in ground)
Ground temperature measurements
LIDAR
Snowdepth stake
NDVI sensors / camera's
Meteorological station
Meteorological tower
Buoy Mooring
Ships of opportunity with Continuous Plankton Recorder on board

CHAPTER 1

Automatic phenology cameras (phenocams) capture the timing of plant green-up, growth and senescence in Adventdalen. (Photo: Stein Rune Karlsen)

Sentinel satellite-based mapping of plant productivity in relation to snow duration and time of green-up (GROWTH)

HIGHLIGHTS

Annual plant production provides food for wildlife and plays a key role in the global carbon budget. With new SIOS data and existing data from Adventdalen, close to Longyearbyen, we have a unique possibility to measure plant production at different scales.

AUTHORS

SR Karlsen (NORCE)
L Stendardi (Univ Bolzano)
L Nilsen (UiT)
E Malnes (NORCE)
L Eklundh (Lund Univ)
T Julitta (JB Hyp Devices)
A Burkart (JB Hyp Devices)
H Tømmervik (NINA)

Svalbard's climate is undergoing dramatic changes, but how this will influence plant productivity is largely unknown. Understanding these changes at the ecosystem level requires that we use data from different sources – including satellites – to assess climate-induced effects on plant vitality and productivity. However, measuring plant productivity is a challenging task. For the Adventdalen area we use radar satellite data to map snow and ice in the melting season and optical satellite data to map the start and peak of the growing season. The satellite data can be related to plant productivity, but must be interpreted based on measurements done in the field.

An observation system for continuous field monitoring of vegetation was established

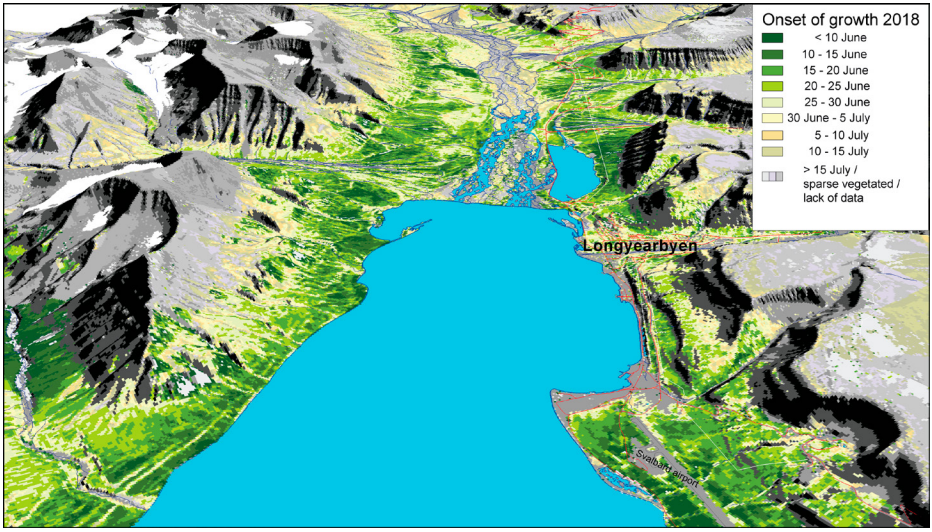
in Adventdalen in Svalbard in 2015. This system consists of field-based racks with various sensors and cameras, which are placed in different vegetation types. The system has successfully recorded the timings of green-up, plant growth and senescence since its establishment.

To further increase the usefulness of the observation system, we need to develop methods to validate the satellite data with data from the sensors and cameras on the racks in Adventdalen. This would allow more accurate estimates of plant productivity over broader regions and scaling up to all of Svalbard. The most advanced instrument in this observation system is a state-of-the-art spectrometer that measures radiances and sun-induced fluorescence; it was deployed in Adventdalen in the summer of 2019. This expensive instrument can give even better estimates of plant productivity and can also be used to calibrate the other measurements and the satellite data. However, the observation system as currently configured in Adventdalen does not provide sufficient data on bryophytes (mosses).

RECOMMENDATIONS

There is a need to develop methodologies that combine field-based measurements and near-ground sensors of plant productivity with data from Sentinel satellites in order to validate satellite data and provide more accurate estimates of plant productivity at large spatial scales. The plant observation system in Adventdalen should be expanded to include more measurements on mosses.

Longyearbyen – Adventdalen. Onset of growing season 2018. (NORCE – Norwegian Research Centre)



CHAPTER 2

COAT has five food web monitoring modules. The Svalbard reindeer is the focus of one of them. (Photo: Tore Nordstad/NPI)

Climate-Ecological Observatory for Arctic Tundra (COAT)

HIGHLIGHTS

COAT is a scientifically robust observation system that enables long-term, real-time detection, documentation, understanding and predictions of climate impacts on Arctic tundra ecosystems. COAT aims to be an ecosystem-based, long-term, adaptive monitoring programme, based on a food-web approach.

AUTHORS

ÅØ Pedersen (NPI)
J Stien (NINA)
S Albon (JHI)
E Fuglei (NPI)
K Isaksen (Met Norway)
G Liston (CIRA)
JU Jepsen (NINA)
J Madsen (AU)
VT Ravolainen (NPI)
AK Reinking (CIRA)
EM Soininen (UiT)
A Stien (NINA)
R van der Wal (SLU)
NG Yoccoz (UiT)
RA Ims (UiT)

COAT is a response to the urgent international calls for establishment of observation systems that make it possible to gain insight into how climate impacts Arctic tundra. COAT Svalbard is an essential component of SIOS and serves to optimise and integrate the ecosystem-based terrestrial monitoring.

Variations from year to year and differences from place to place make long-term monitoring essential to support the complex decisions involved in conservation, management and policymaking. The COAT approach is holistic, covering entire ecosystems by integrating information about living and non-living factors over time

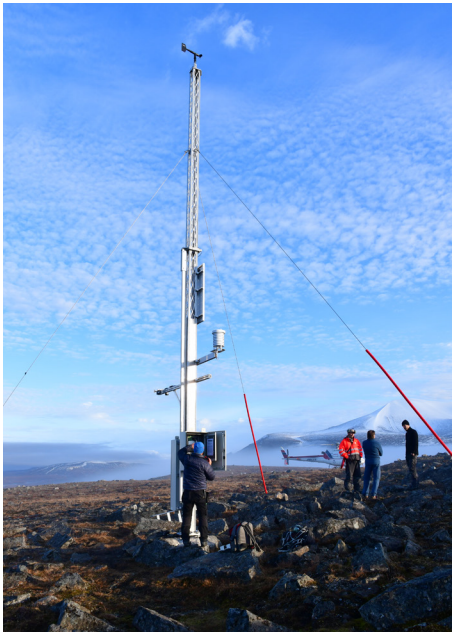
and space, with clearly defined monitoring goals.

Monitoring modules within COAT Svalbard track five key climate-sensitive food web pathways as well as climate parameters that determine how those pathways function (www.coat.no). Each module is described in terms of expected direct and indirect relationships between organisms in the food web pathways, and how climate and management interventions might influence these interactions. The programme is implemented according to a peer-reviewed Science Plan with a solid foundation in the scientific literature. COAT Svalbard focuses on two contrasting Arctic regions: Nordenskiöld Land and Brøggerhalvøya and surrounding areas. The vertebrate populations being monitored in these areas currently appear to be stable or growing. However, the lack of long-term monitoring of the vegetation communities on which these animals rely hinders understanding of bottom-up processes within the food web. COAT aims to fill these gaps and provide new insight into how climate change impacts High Arctic tundra ecosystems.

RECOMMENDATIONS

We recommend coordinating research infrastructure and observational measurements at similar spatial and temporal scales to predict and understand climate impacts on Svalbard tundra. Specifically, we recommend increasing the number of full-scale automatic weather stations, developing high-resolution physically based snow models from joint data sources, and developing more relevant variables to describe ecosystem functioning and processes.

Integrated data from SIOS and COAT will demonstrate in practice how coordinated monitoring can help answer crucial research questions about the ecosystem.



Researchers check an automatic weather station, newly established at Janssonhaugen, Nordenskiöld Land, Svalbard. (Photo: Ketil Isaksen/MET)

A researcher carrying out the annual Svalbard reindeer population abundance census in Adventdalen to provide information on total number of animals, mortality and reproduction. (Photo: Elin Vinje Jenssen/NPI)

CHAPTER 3

Water column monitoring on Linnévatnet. (Photo: Michael Retelle)

Environmental Monitoring in the Kapp Linné-Grønfjorden Region (KLEO)

HIGHLIGHTS

1. Regional temperatures in Kapp Linné–Grønfjorden have risen
2. Lake ice formation in the fall has recently been delayed to as late as December
3. Peak river flow in six of the last eight years is due to late-season rain
4. AARI has done intensive hydrologic and precipitation studies

AUTHORS

M Retelle (UNIS, Bates College)
H Christiansen (UNIS)
A Hodson (UNIS)
A Nikulina (AARI)
M Osuch (IGF PAS)
K Poleshuk (AARI)
K Romashova (AARI)
S Roof (Hampshire College)
L Rouyet (NORCE, UiT, UNIS)
S Strand (UNIS, UiO)
I Vasilevich (AARI)
T Wawrzyniak (IGF PAS)

The Kapp Linné–Grønfjorden region is an ideal and strategic location for an interdisciplinary long-term environmental observatory in the coastal region of western Spitsbergen at the mouth of Isfjorden. The regional climate is greatly influenced by its maritime setting with higher mean annual air temperature and greater precipitation than the more continental interior regime in central Spitsbergen. With the recent intensified Atlantification of the northern Barents Sea, environmental monitoring studies along the west Spitsbergen coast may serve as an early warning system in a changing climate.

The Kapp Linné Environmental Observatory (KLEO) was formulated as an international collaborative site within the Svalbard Integrated Arctic Earth Observing System (SIOS) as a regional centre with a research focus on hydroclimate, snow and ice cover, permafrost, ecology and paleoclimate. KLEO research sites extend from the west coast of Spitsbergen at the mouth of Isfjorden, to the eastern shore of Grønfjord.

The Kapp Linné Environmental Observatory provides an ideal training ground for the next generation of arctic scientists who will take on the challenges of the 21st century. The proximity to the University Centre in Svalbard (UNIS) and the AARI Barentsburg Research Station provides a highly motivated and well-trained workforce for addressing critically important environmental research issues.

RECOMMENDATIONS

The network of environmental monitoring installations and environmental sampling in the Kapp Linné–Grønfjorden region should be maintained and improved in this period of changing climate. In addition, we encourage an increase in interdisciplinary research, including long-term studies of both terrestrial and aquatic ecology.

Understanding regional variability in hydroclimate will be an increasingly important issue in Svalbard in the 21st century. Regional precipitation gradients, water storage in glacier ice and groundwater, and the role of groundwater as a water source and a factor in shaping the bio-geosphere are significant but poorly understood issues that must be addressed.

Linnédalen (Linnéelva, Linnévatnet and Linnébreen) looking south across the outlet of Linnévatnet. (Photo: Michael Retelle)

Physical limnological monitoring on Linnévatnet. (Photo: Margaret Holzer)

The calving front of Paierlbreen terminating in the Hornsund Fjord (Photo: Dominik Cyran)

New data, new techniques and new challenges for updating the state of Svalbard glaciers (SvalGlac)

HIGHLIGHTS

- We assess the mass balance of all Svalbard glaciers since year 2000
- Glaciers over all of Svalbard are losing mass, at rates depending on location
- Updated quantification of calving and better understanding of surges are urgently needed

AUTHORS

TV Schuler (UIO, UNIS)
A Glazovsky (IGRAS)
JO Hagen (UIO)
A Hodson (UNIS)
J Jania (CPS)
A Kääb (UIO)
J Kohler (NPI)
B Luks (IGF PAS)
J Malecki (AMU)
G Moholdt (NPI)
V Pohjola (UU)
W van Pelt (UU)

Glacier mass balance is the budget between snow accumulation and melting of snow and ice. Where glaciers terminate in the ocean, calving of icebergs constitutes an additional mechanism of mass loss, though it is more difficult to assess than snow accumulation and surface melting. The SvalGlac report reviews new technologies and new data that have become available in the past 20 years to update previous assessments. We find that glaciers all over Svalbard are losing mass, with rates depending on geographical location and glacier size. Smaller glaciers in southern Spitsbergen experience highest rates of mass loss while large ice caps in Northeast Svalbard are closer to a balance situation. However, variations from year to year are large and long-term observations are needed to recognise trends. These

Close-up of Basin-3, a surging outlet glacier from Austfonna, Nordaustlandet. (Photo: T.V. Schuler)

RECOMMENDATIONS

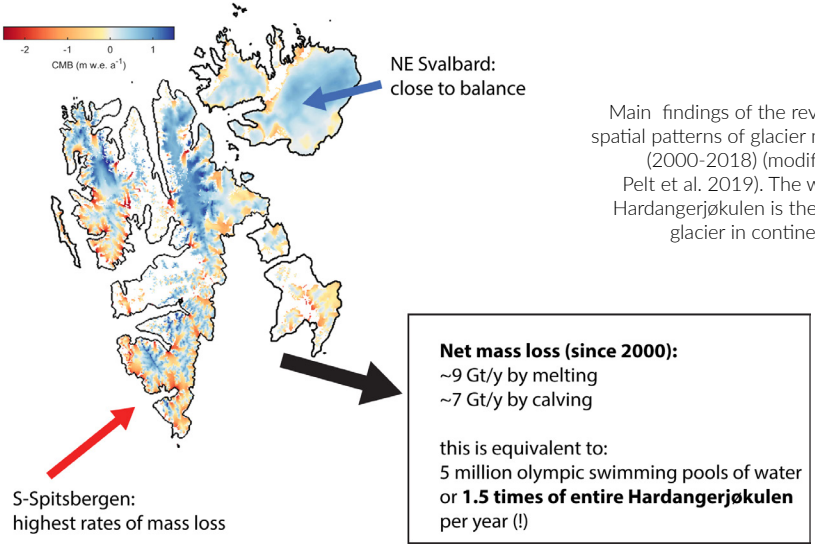
- To close the knowledge gaps, we recommend further development of Svalbard as a glacier laboratory by
- investing in instrumentation and data sharing to overcome lack of crucial data
- supporting pilot projects that can provide missing information where appropriate methodology already exists, and
- strengthening the glaciological community to collaboratively develop research programmes to improve process understanding.

spatial patterns and temporal evolution are also supported by modelling studies that calculate surface mass balance based on meteorological data, and by studies applying satellite remote sensing.

The only available estimate of calving needs updating, especially with regard to year-to-year and seasonal variations. Several large surges have occurred in the past few years, strongly influencing the amount of ice discharged into the ocean. A glacier surge is a switch from a slow to fast flowing mode, sometimes happening periodically. The mechanisms responsible for surges are not well understood but several Svalbard-based studies shed new light on these processes.

The most important gaps are:

- our incomplete understanding of surging, both the process itself and its implications for Svalbard glacier mass balance
- incomplete basic data coverage for quantification of calving and
- imited information about glacier mass balance and meltwater runoff in a future climate.



Main findings of the review showing spatial patterns of glacier mass balance (2000-2018) (modified after Van Pelt et al. 2019). The widely known Hardangerjøkulen is the sixth largest glacier in continental Norway.

CHAPTER 5

Fieldwork on Holtedalfonna where a temporary seismic station was deployed in April 2016. (Photo: A Köhler)

Seismological monitoring of Svalbard's cryosphere: current status and knowledge gaps (CRYOSEIS)

HIGHLIGHTS

Cryoseismology can track changes in seasonal patterns of glacial seismicity and sub-surface properties over decades, allowing us to assess the effects of climate change in the cryosphere. Better seismic station coverage in Svalbard would enhance use of cryoseismology in environmental research.

AUTHORS

A Köhler (NORSAR)
W Gajek (IGF PAS)
M Malinowski (IGF PAS)
J Schweitzer (NORSAR)
M Majdanski (IGF PAS)
W Geissler (AWI)
M Chamarczuk (IGF PAS)
A Wuestefeld (NORSAR)

The new research field of cryoseismology studies ground shaking (seismic waves) generated in the frozen part of our planet. The shaking is caused by processes such as icequakes related to the movement of glaciers, glacier calvings, and flowing meltwater. Climate change affects processes at glaciers such as calving and causes changes in the permanently frozen ground (permafrost) in polar regions. Cryoseismology can measure these changes using seismic waves.

Accessibility and well-developed logistics mean that Svalbard is much easier to work in than other regions in the Arctic or the Antarctic, and make Svalbard a natural laboratory to study changes in the cryosphere induced by climate change.

Continuous seismic data collection in Svalbard (going back as long as decades) allows us to observe long-term trends and changes in seasonal patterns of glacial seismicity or sub-surface structures (permafrost). High temporal resolution of seismic data provides much more detail, e.g. about the calving process, than satellite images and helps us estimate the mass of ice that glaciers lose due to calving. Strong calving in Svalbard can be registered at great distances (up to 100 km) and measurements are fully independent of visibility, which allows for observation of calving regardless of polar night or bad weather conditions. This report briefly presents cryoseismology, its capabilities and methods within a global context, highlights recent research activity in Svalbard and suggests directions for future research and development of seismological infrastructure.

RECOMMENDATIONS

- The permanent seismic station network in Svalbard should be extended to improve detectability and location of glacier seismicity.
- A continuous automatic near-real-time detection system for seismic events (calvings, surges, etc.) should be implemented.
- Using resources of a common instrument pool for cryosphere research in Svalbard, multi-disciplinary, integrated field experiments with direct observations of cryosphere processes should be carried out.
- New technologies and methods (such as fibre-optic cables, noise interferometry, machine learning) that have just started being employed in seismology should be adopted in Svalbard to foster the cryoseismological research.

Extracting data from a temporary seismic station close to Ny-Ålesund in April 2016. (Photo: A Köhler)

Hansbreen terminus. (Photo: W Gajek)

CHAPTER 6

View from the observatory on Zeppelinfjellet near Ny-Ålesund over the northern part of inner Kongsfjorden, in April 2018. From here, regular sea ice observations are performed. In the picture, sea ice is recognisable in the distance to the right. (Photo: M Semmling)

Long-term monitoring of landfast sea ice extent and thickness in Kongsfjorden, and related applications (FastIce)

HIGHLIGHTS

Systematic monitoring of landfast sea ice in Kongsfjorden, Svalbard, since 2003 improved understanding of its variability and long-term changes. After 2006, the ice cover was less extensive in space and time, and thinner than earlier. Results have also contributed to process and validation studies.

AUTHORS

S Gerland (NPI)
O Pavlova (NPI)
D Divine (NPI)
J Negrel (NPI)
S Dahlke (AWI)
AM Johansson (UiT)
M Maturilli (AWI)
M Semmling (GFZ)

Landfast sea ice (ice anchored to the shore) covers the inner parts of Kongsfjorden, Svalbard, in winter and spring, and is an important feature for the physical and biological fjord systems. Systematic fast-ice monitoring for Kongsfjorden, as a part of a long-term project at the Norwegian Polar Institute (NPI), started in 2003. It includes ice extent mapping and in situ measurements of ice and snow thickness. The permanent presence of NPI staff at Ny-Ålesund Research Station enables regular in situ fast-ice thickness measurements as long as the fast ice is accessible. In addition, daily visits to the observatory on the mountain Zeppelinfjellet close to Ny-Ålesund allow regular ice observations (weather, visibility, and daylight permitting). Monitoring of the sea ice conditions in Kongsfjorden can be used to demonstrate and investigate phenomena

related to climate change in the Arctic.

Fjord ice begins to form in the inner part of Kongsfjorden between December and March. After that the ice grows in thickness and extent, and then decreases until it melts or breaks off and drifts out of the fjord between April and June. Before 2006, ice often stretched from the interior to the central fjord parts, but in later years the ice has mainly been restricted to the inner fjord. Moreover, the ice was usually at least 0.6 m thick, in contrast to recent years with thickness often only about 0.2 m. The snow cover thickness on the ice in spring has also decreased, which can be partly explained by shorter fast ice seasons. The reason for less ice in Kongsfjorden after 2006 is considered to be a combination of the influence of warmer water and higher air temperatures in winter.

RECOMMENDATIONS

- Continue the monitoring as a robust and affordable initiative. While keeping consistency in the methods, consider introducing modern and autonomous technology
- Continue developing tools based on satellite remote sensing to support the monitoring
- Continue refining sea ice model components to improve the understanding of changes and variability observed

This monitoring has contributed to a number of process and validation studies, for example to improve satellite remote sensing techniques and the understanding of atmosphere–ice–ocean interaction.

Monitoring of sea ice thickness and freeboard (the vertical distance between ice and water surfaces) in Kongsfjorden is done from drill holes, usually drilled with an auger 5 cm in diameter, here from spring 2015. In addition, snow thickness is measured. (Photo: S Gerland)

Sea ice loss leads to increased emission of compounds from phytoplankton and other living organisms, including dimethylsulphide and iodine, which can then form cloud condensation nuclei. (Photo: Mikko Sipilä)

Multidisciplinary research on biogenically driven new particle formation in Svalbard (SVALBAEROSOL)

HIGHLIGHTS

Sea ice loss accelerates formation of cloud condensation nuclei (CCN) in the Arctic, leading to feedbacks to Arctic climate. We propose upgrades to aid resolution of mechanisms of CCN long-term monitoring of how relevant quantities change with warming Arctic environment.

AUTHORS

M Sipilä (INAR)
CJM Hoppe (AWI)
A Viola (ISP-CNR)
M Mazzola (ISP-CNR)
R Krejci (SU)
P Zieger (SU)
L Beck (INAR)
T Petäjä (INAR)

Climate change in the Arctic is reflected in decreased snow cover, thawing permafrost, increased productivity on land, and especially loss of sea ice. The latter accelerates climate warming and further sea ice decline. However, it may also increase phytoplankton productivity, thus increasing concentrations of cloud "seeds", cloud condensation nuclei (CCN), which in turn largely determine how clouds interact with light and affect Earth's energy balance. Therefore, change in CCN concentration may speed up or slow down climate warming in the Arctic. However, the mechanisms leading to CCN production over ice-covered and open Arctic waters are not known in detail. In addition, increasing emissions of vapours from plants and animals as a result of increased primary production on land may affect natural CCN production.

Gruvebadet laboratory in Ny-Ålesund filled with mass spectrometers and other instrumentation relevant for resolving and monitoring the formation of aerosols and cloud condensation nuclei. (Photo: Mikko Sipilä)

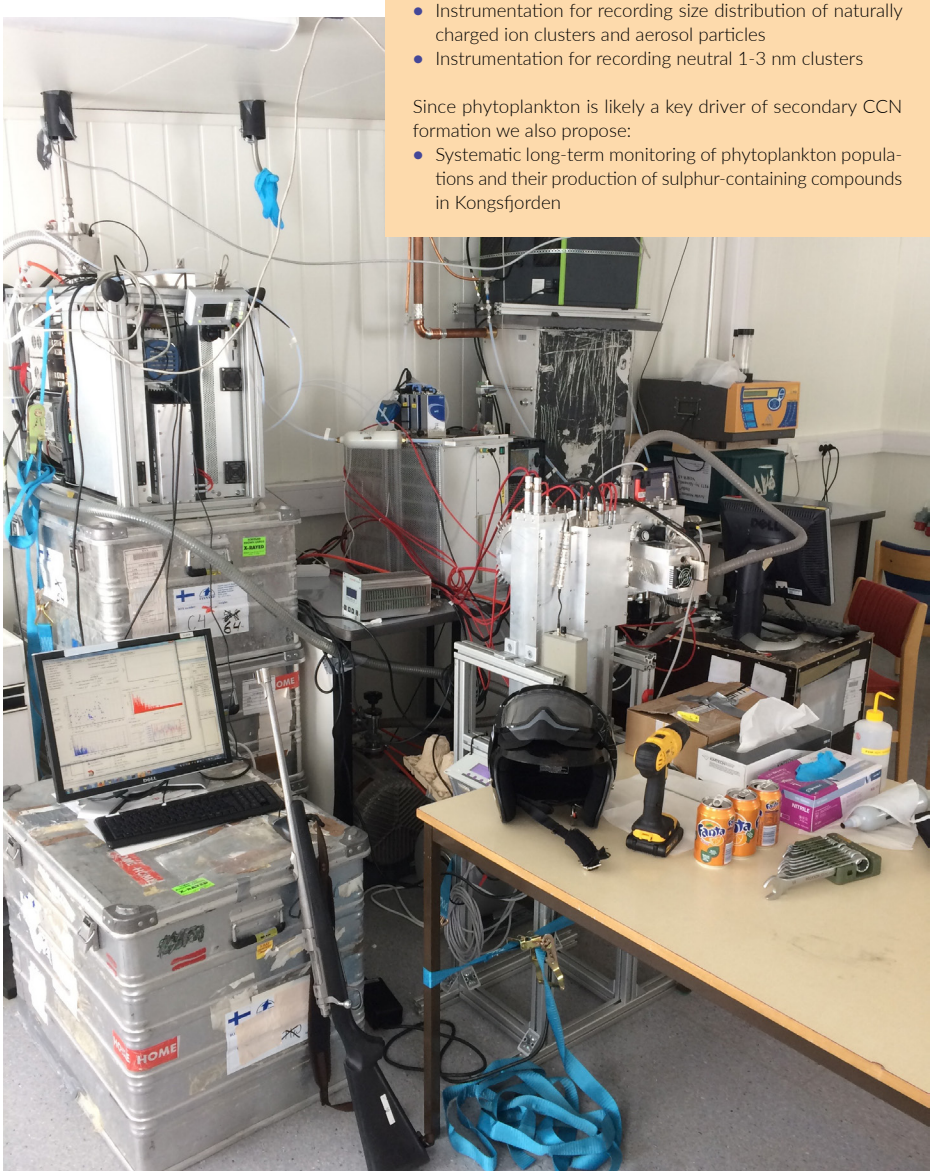
RECOMMENDATIONS

To resolve the details of CCN production and to monitor changes in the process chain from emissions to CCN formation we recommend upgrading the SIOS observation system. The following upgrades in Ny-Ålesund (Gruvebadet laboratory and Zeppelin observatory) are proposed:

- Mass spectrometer systems capable of measuring aerosol precursor vapours and naturally charged ion clusters
- Instrumentation for recording size distribution of naturally charged ion clusters and aerosol particles
- Instrumentation for recording neutral 1-3 nm clusters

Since phytoplankton is likely a key driver of secondary CCN formation we also propose:

- Systematic long-term monitoring of phytoplankton populations and their production of sulphur-containing compounds in Kongsfjorden



CHAPTER 8

Zeppelin observatory (near mountain top) from Gruvebadet (foreground). (Photo: Mauro Mazzola)

Atmospheric black carbon in Svalbard (ABC Svalbard)

HIGHLIGHTS

Black carbon in Svalbard has been monitored continuously for more than 10 years at two adjacent sites at different altitudes, and during short research campaigns in various parts of the archipelago. The complexity of atmospheric dynamics promotes variable vertical profiles of black carbon.

AUTHORS

S Gilardoni (ISP-CNR)
A Lupi (ISP-CNR)
M Mazzola (ISP-CNR)
DM Cappelletti (UP)
B Moroni (UP)
L Ferrero (UNIMiB)
P Markuszewski (IOPAN)
A Rozwadowska (IOPAN)
R Krejci (SU)
P Zieger (SU)
P Tunved (SU)
L Karlsson (SU)
S Vratolis (NCSR)
K Eleftheriadis (NCSR)
AP Viola (ISP-CNR)

Black carbon particles are emitted into the atmosphere during combustion and reside in the air for days. Once emitted, they can be transported across thousands of kilometres and reach remote locations, like the Arctic. In the polar regions, black carbon has extremely important impacts on climate and environment. Because of its dark colour, it absorbs incoming solar radiation and can warm the atmosphere. Furthermore, black carbon that settles on the white surface of snow and ice favours their melting.

Black carbon has been measured for decades in Svalbard, continuously at the high-altitude Zeppelin observatory, and during the warm seasons at the low-altitude Gruvebadet observatory, both near Ny-Ålesund village. Although the data show matching seasonal oscillations, the concentrations are generally higher at Gruvebadet, suggesting an impact of local emissions and demonstrating the complexity of vertical dynamics in the atmosphere. In 2018, unlike previous years, the two sites registered very similar concentrations. In Svalbard, the long-term records of black carbon measurements are complemented by short-term observations, performed during intensive experiments, cruises along the coasts, and vertical profile measurements. Such measurements reveal a large spatial variability of local black carbon sources and the impact of ship emissions. Vertical profiles clearly show the presence of black carbon layers at high altitude (above 1 km) during spring, likely due to long-range transport of pollution from lower latitudes during conditions of Arctic haze.

RECOMMENDATIONS

- Improve comparability among different techniques currently used to measure black carbon.
- Develop a correction algorithm for optical measurements specifically designed for the Arctic environment.
- Increase spatial and temporal coverage of black carbon vertical profile measurements.
- Promote measurement of carbon flux in dry and wet deposition (dry=as particles; wet=with precipitation).
- Favour integration of atmospheric and cryospheric measurements by establishing joint discussion platforms and integrated databases.
- Improve understanding of black carbon's properties as cloud condensation nuclei (cloud seeds).

Hornsund 2006 cruise.
(Photo: Anna Rozwadowska)

Measuring black carbon vertical profiles.
(Photo: David Cappelletti)

CHAPTER 9

Aerial view of Ny-Ålesund, as seen from a drone. (Photo: Rune Storvold)

Probing the vertical structure of the lower atmosphere over Svalbard (ProVeSAS)

HIGHLIGHTS

- Interest in using tethered balloons and drones to study the vertical structure of the lower atmosphere over Svalbard is growing.
- Most studies of Svalbard's lower atmosphere are done in Ny-Ålesund or during cruises.
- Most measurements are done in spring/summer.
- About 60 papers on this topic have been published.

AUTHORS

M Mazzola (ISP-CNR)
AP Viola (ISP-CNR)
DM Cappelletti (UP)
C Ritter (AWI)
R Storvold (NORCE)

Understanding the causes and mechanisms of climate change requires an enormous number of continuous and accurate measurements. To measure atmospheric parameters along the vertical profile, one must either fly the instrumentation or infer such information at a distance from the emissions or reflections of components in the atmosphere (remote sensing). Techniques that use one of these approaches have been developed since the 1940s. However, both approaches suffer from limitations on the accuracy of the measurements and the amount of information that can be obtained. Recent technological development has enabled production of small, low-cost sensors with capabilities similar to those used in the laboratory. These sensors can be installed on balloons or small unmanned aerial

vehicles, allowing direct measurements in the lower atmosphere. With more accurate information on the status of the atmosphere, researchers can refine their mathematical data interpretation techniques.

The research station in Ny-Ålesund is already well equipped for a number of standard vertical profile measurements. Fewer activities are performed at other stations in Svalbard. This is clear from the studies we cited in our contribution: about 60 papers. Half were based on remote sensing, 22 on balloons (tethered or free), 5 on dropsondes and 5 on drones. Although we do not claim that this list is exhaustive, it may represent the status of activities in Svalbard. The limited air traffic in the Arctic means that carrying out measurements with balloons and small radio-controlled airplanes is easier than elsewhere.

RECOMMENDATIONS

- Studies of the lower atmosphere should be encouraged by simplifying the process of obtaining flight permits, and by creating specific infrastructure, such as hangars for the recovery of vehicles, runways dedicated to take-off/landing of drones, sites dedicated to the launch and recovery of balloons, and compressors for helium recovery.
- Activities during the dark season should be increased, despite the logistical challenges, as most campaigns are currently performed during spring and summer.
- We recommend improved coordination between the different groups involved in this type of research. Data visibility and availability should also be increased.

Tethered balloon and LIDAR beam during the January 2019 campaign in Ny-Ålesund. (Photo: Gregory Tran)

Permafrost drill site on pingo in Adventdalen. (Photo: Ulrich Neumann, Kolibri Geo Services)

Permafrost temperatures and active layer thickness in Svalbard during 2017/2018 (PermaSval)

HIGHLIGHTS

During the 2017-2018 hydrological year mean annual ground temperatures observed in Svalbard ranged from -1.2°C to -5.1°C. The duration of active layer freeze-back varied from 2 to 151 days. Active layer thickness at the observation sites varied in summer 2018 between 64 cm and 463 cm.

AUTHORS

HH Christiansen (UNIS)
GL Gilbert (UNIS, NGI)
N Demidov (AARI)
M Guglielmin (Insubria Univ)
K Isaksen (MET Norway)
M Osuch (IGF PAS)
J Boike (AWI)

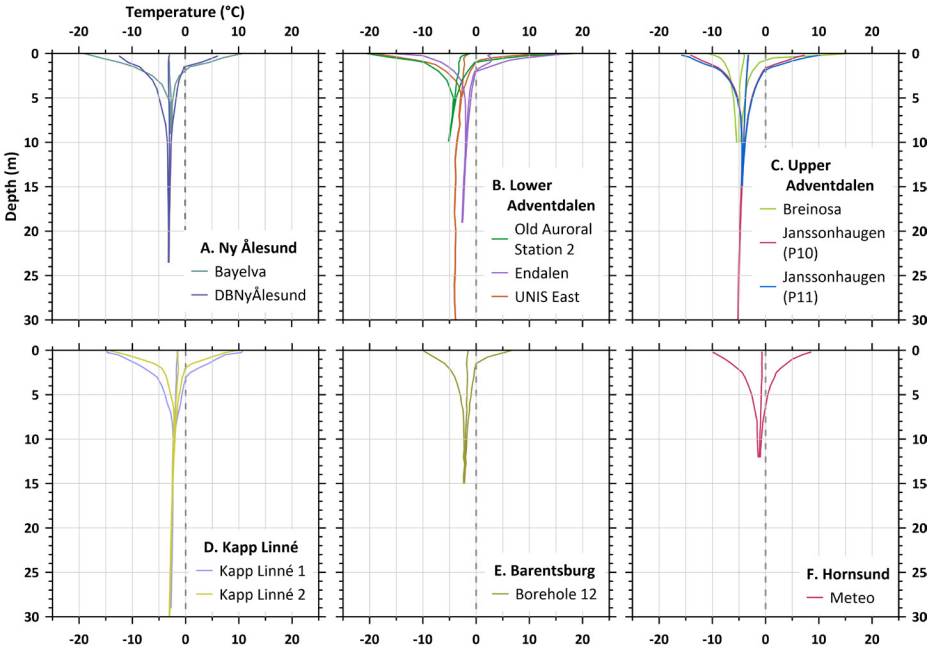
Permafrost temperature presented in this report, including the first full year of ground temperature data from the Hornsund area, indicate that the north-south gradient present in air temperatures is also present in ground temperatures in Svalbard. Permafrost temperatures are warmest in Hornsund in the south, intermediate in Barentsburg and Kapp Linne in the central part, and lowest around Ny-Ålesund in the northern part and in the centrally located Adventdalen area. The ground is warmest near the coasts (e.g. Kapp Linne and Hornsund) and in areas with thicker snow cover during winter (e.g. Endalen and Bayelva). Mean annual ground temperatures measured at the depth of zero annual amplitude or lowermost sensor

varied from -1.2°C (Hornsund, 12 m depth) to -5.1°C (Breinosa and Old Auroral Station, 10 m depth). During the 2017-2018 hydrological year, the duration of active layer freeze-back in Svalbard varied from 2 days at Breinosa to 151 days at Endalen. Active layer thickness ranged in summer 2018 between 64 cm (Breinosa) and 463 cm (Hornsund).

RECOMMENDATIONS

- Maintain existing permafrost and active layer monitoring networks and instrumentation.
- Expand the permafrost monitoring network and make the data on this essential climate variable available online.
- Assess the response of permafrost landscapes to changes in climate by obtaining more knowledge about the ground ice content.
- Investigate avenues to increase the time-scale of permafrost observations.
- Continue to develop remote sensing tools for monitoring permafrost conditions and landscape response.
- Improve interdisciplinary networking on permafrost-related issues.

Ground thermal snapshot (minimum, mean, and maximum temperatures) measured in the upper 10–30 m of the permafrost observation boreholes in Svalbard during the 2017-2018 hydrological year.



CHAPTER 11

Operations at the stern of RV *Alliance* during mooring deployment west of Svalbard. (Photo: Fixed GoPro camera)

Spitsbergen Oceanic and Atmospheric interactions (SOA)

HIGHLIGHTS

Observations gathered in the deep sea west of Svalbard reveal oscillations in temperature and salinity during winter months. Longer time-series collected in the Arctic Ocean are essential to identify and analyse anomalies and events that can affect global circulation and climate.

AUTHORS

M Bensi (OGS)
V Kovačević (OGS)
L Langone (ISP-CNR)
S Miserocchi (ISP-CNR)
M Demarte (IIM)
R Ivaldi (IIM)

Off the Svalbard archipelago, in the eastern Fram Strait, at 1000 m depth along the continental slope, we observed temperature and salinity fluctuations that were more prominent between October and April. Data were acquired employing an oceanographic mooring deployed at 76°N 013°E from June 2014. Since then, the most noteworthy episode lasted more than 15 days in December 2016/January 2017 when the temperature rose from the typical value of -0.9°C to over 2°C. At the same time, bottom currents increased significantly, to 85 cm/s. Normally, these bottom currents flow around 10-15 cm/s. This region is characterized by the passage of Atlantic Water flowing northward in the upper layer, bringing relatively warm water to the Arctic Ocean. Below 800 m depth, the Norwegian Deep Sea Water, colder and less salty, also flows northward.

Thanks to the scientific community that carries out measurements both in the ocean and in the atmosphere, we know that the Arctic is progressively warming up; we see this in the gradual melting of sea ice and ice on land. However, it is not clear how much of this warming is caused by human activities and what consequence it will have. In order to record and to study environmental changes and anomalies, we need time series. To provide robust climate data, such series must span decades. Achieving this goal requires great effort in terms of international collaborations, both economic and scientific.

RECOMMENDATIONS

Many processes must be taken into consideration when studying oceanographic time series from the area west of Svalbard. These include atmospheric phenomena such as wind, evaporation and air pressure oscillations at the sea surface, but also the ocean's internal oscillations induced by tides and formation of dense water plumes. Possible implications for biogeochemical aspects, e.g., the carbon cycle and the marine food web, also need further attention. Lastly, it will be important to probe how global ocean circulation might be affected by changes in oceanic heat content associated with the variability in the properties and volume of inflowing Atlantic water and/or with vertical mixing processes that extend into the deep ocean. How much these processes will affect global circulation is still an open question.

Buoys of the oceanographic mooring before deployment. The researchers will not see them again for an entire year. (Photo: Manuel Bensi)

Drone flying over sea ice during the High North 2018 cruise. (Photo: Manuel Bensi)

CHAPTER 12

Planktonic crab larvae.
(Photo: Martin Edwards)

The Continuous Plankton Recorder Survey – Monitoring plankton in the Nordic Sea (CPR Survey)

HIGHLIGHTS

The Pacific diatom *Neodenticula seminae* (an indicator of trans-Arctic migration) was recorded off Svalbard in 2016, the easternmost observation of this diatom in the Nordic Seas.

AUTHORS

M Edwards (CPR-Survey)
P Helaouet (CPR-Survey)
C Ostle (CPR-Survey)
D Johns (CPR-Survey)
M Wootton (CPR-Survey)
E Strand (IMR)
E Bagoien (IMR)

The Continuous Plankton Recorder (CPR) survey monitors plankton in the waters around Svalbard and south to northern Norway. Within this region of the Nordic Seas, the CPR survey adds to and complements other monitoring methods by providing a broader spatial and temporal perspective. Most other surveys are coastal or are sporadically sampled through time. The CPR survey also adds value by providing data covering several decades at the Atlantic basin scale that can help disentangle and interpret changes observed in the Nordic Seas and help predict changes over coming decades. For example, regions that currently support Arctic ecosystems will instead support sub-Arctic systems within the next 10 to 20 years (if not sooner). The biological signals of change we see further south in Atlantic sub-polar systems now can be used to detect the early warning signs of change in the Arctic.

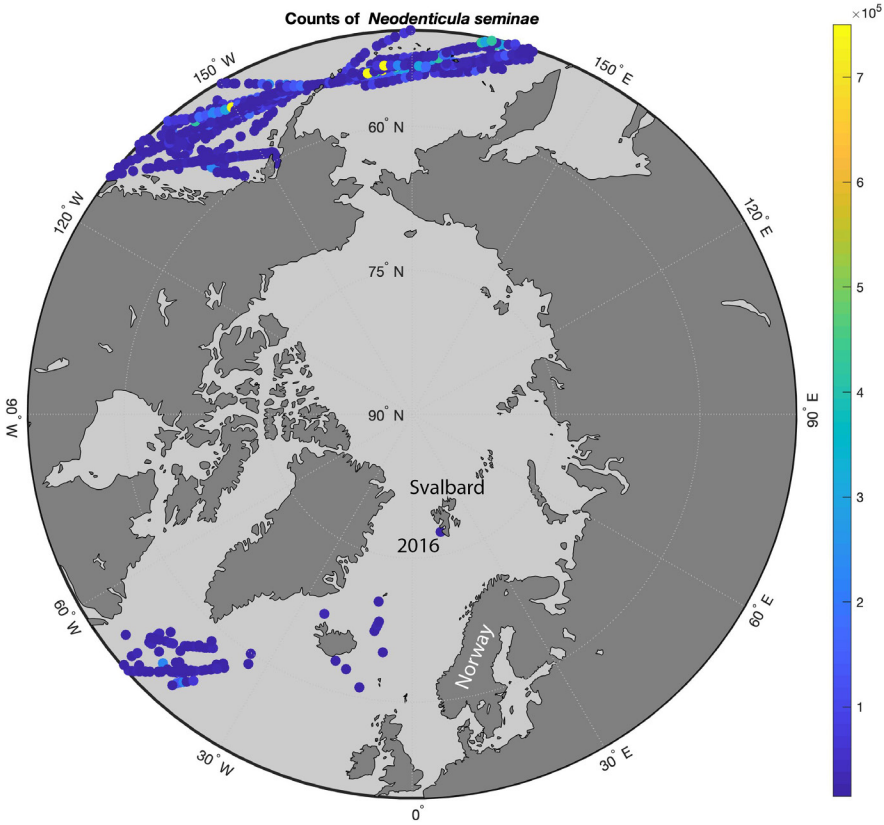
To develop the observation system further, the CPR survey currently works closely with Norwegian scientists to coordinate its sampling on board "ships of opportunity". These are often cargo vessels that regularly ply the same route. They are outfitted with instruments that automatically and routinely collect a range of data on oceanographic parameters. The Norwegian FerryBox system is one such ship of opportunity.

RECOMMENDATIONS

The CPR survey, by coordinating its sampling programme with the FerryBox system, can obtain valuable complementary information such as pCO_2 in the waters where the sampling was done.

It is envisioned that in the near future the CPR survey will form part of a more integrated observation system within this region and enhance its monitoring with an additional suite of biogeochemical and molecular sensors. It will also endeavour to explore possible synergies between other oceanographic monitoring and the biological monitoring conducted by the CPR survey. Although commercial shipping in the Arctic is sparse, CPR monitoring could be expanded by using other ships of opportunity that operate in this region, such as tourist vessels.

The distribution of the Pacific diatom species *N. seminae* in the Northern Hemisphere from CPR records in the North Pacific and records from the North Atlantic from 1998. The species was recorded off Svalbard in 2016, its most easterly observation in the North Atlantic.



CHAPTER 13

Svalbard is the only place in the world where we can explore the daytime Northern lights (cusp aurora) with sounding rockets. ICI-5, equipped with two 4DSpace modules, each carrying six daughter payloads as big as ice hockey pucks, is a first attempt at 3D measurement of ionospheric turbulence. (Illustration: Trond Abrahamsen, Andøya Space Center)

Grand Challenge Initiative – Cusp: observational network for solar wind-driven dynamics of the top atmosphere (GCI-Cusp)

HIGHLIGHTS

In winter 2018/19, five Grand Challenge Initiative – Cusp rockets were successfully launched through energetic daytime auroras over Svalbard. Unique data sets to explore solar wind forcing of particle acceleration, turbulence, atmosphere heating and outgassing were collected.

AUTHORS

J Moen (UiO, UNIS)
A Spicher (UiO)
T Takahashi (UiO, NIPR)
DE Rowland (NASA)
C Kletzing (U IOWA)
J LaBelle (DC)
M Larsen (CU)
M Conde (UAF)
Y Saito (JAXA)
K Blix (ASC)

The Grand Challenge Initiative – Cusp (GCI-Cusp) is a strategic research coordination between Norway, Japan, and the US. Eight sounding rockets were successfully launched during winter 2018/19, and three more are scheduled in December 2019. Polar cusps are two funnel-shaped regions in the Earth's magnetic field, where solar wind particles can directly enter the polar atmosphere. Collisions between these particles and the atmosphere produce the Northern lights. Cusp aurora is the scientific term for the Northern lights in daytime. Svalbard is a world-class laboratory for studying the cusp.

The polar atmosphere is strongly influenced by the solar wind. The GCI-Cusp questions are related to the physics of how the solar

wind couples the top of the atmosphere at the poles and the effects it has: how auroral particles are accelerated by waves along magnetic field lines in the cusp, and how these energy inputs lead to heating, upwelling and outgassing of Earth's atmospheric gasses into space. The Norwegian rocket, ICI-5, launched 26 November 2019, equipped with 12 daughter payloads for 3D imaging of turbulent vortices within the Northern lights. This turbulence sometimes causes severe disturbances/black-out of radio signals. Unfortunately, due to roll rate anomaly the daughters did not spin out. Efforts will be made to redo this novel experiment.

The initial processing of the GCI-Cusp data is ongoing and looks very promising. Some data suggest a new method of remotely detecting the cusp using VLF waves. As a world first for sounding rocket experiments, data collected within the GCI-Cusp programme will be made openly and easily available to all users through the SIOS data management system.

RECOMMENDATIONS

For the future, the SIOS partners should invest in a high-resolution 4D (time and space) all-sky imaging system to enhance the cusp-observational network. Key parameters derived from routine ground optical and radar instruments should be given status as SIOS core data.

Strategic efforts should be made to become a central partner in the GCI-Mesosphere Lower Thermosphere rocket initiative. Together, GCI-Cusp and GCI-M/LT will contribute to optimizing an ESS programme that monitors the vertical coupling of atmospheric layers from sea surface to space and provides knowledge crucial to weather and climate prediction models.

ICI-5 rocket lift-off from SVALRAK Ny-Ålesund 07:43 UT on 26 November 2019. The near-vertical green trace is the LIDAR beam. (Photo: Helge Markussen)

Would you like to be part of the SESS report?

SIOS frequently publishes calls for contributions to the SESS report. Visit our web portal and follow us on twitter/facebook to stay updated.

www.sios-svalbard.org
twitter.com/sios_kc
facebook.com/SIOSKnowledgeCentre

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

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

SIOS
SVALBARD INTEGRATED ARCTIC EARTH OBSERVING SYSTEM

ISSN 2535-6313 (printed)
ISSN 2535-6615 (pdf)
ISBN 978-82-691528-4-5 (printed, stapled)
ISBN 978-82-691528-5-2 (pdf)