INTERACT

International Network for Terrestrial Research and Monitoring in the Arctic

Stories of Arctic Science II

2020

INTERACT is a network of friends.

ACKNOWLEDGEMENT

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INTERACT TRANSNATIONAL ACCESS

Transnational Access is a way to support international research conducted at research stations and other research infrastructures. Researchers are selected to receive Transnational Access through scientific evaluation to ensure high quality. The researchers then have free access to conduct research at the site, including travel and accommodation costs and the use of research facilities and instruments. To facilitate international scientific collaboration and more efficient use of research infrastructures, support is only provided to stations and facilities located in another country than where the researchers live.

INTERACT's Transnational Access programme has been funded by the EU-H2020. By autumn 2020, approximately 1,000 scientists from over 20 countries have received awards from INTERACT to work at 43 research stations located throughout the Arctic.

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INTERACT
Stories of Arctic Science II

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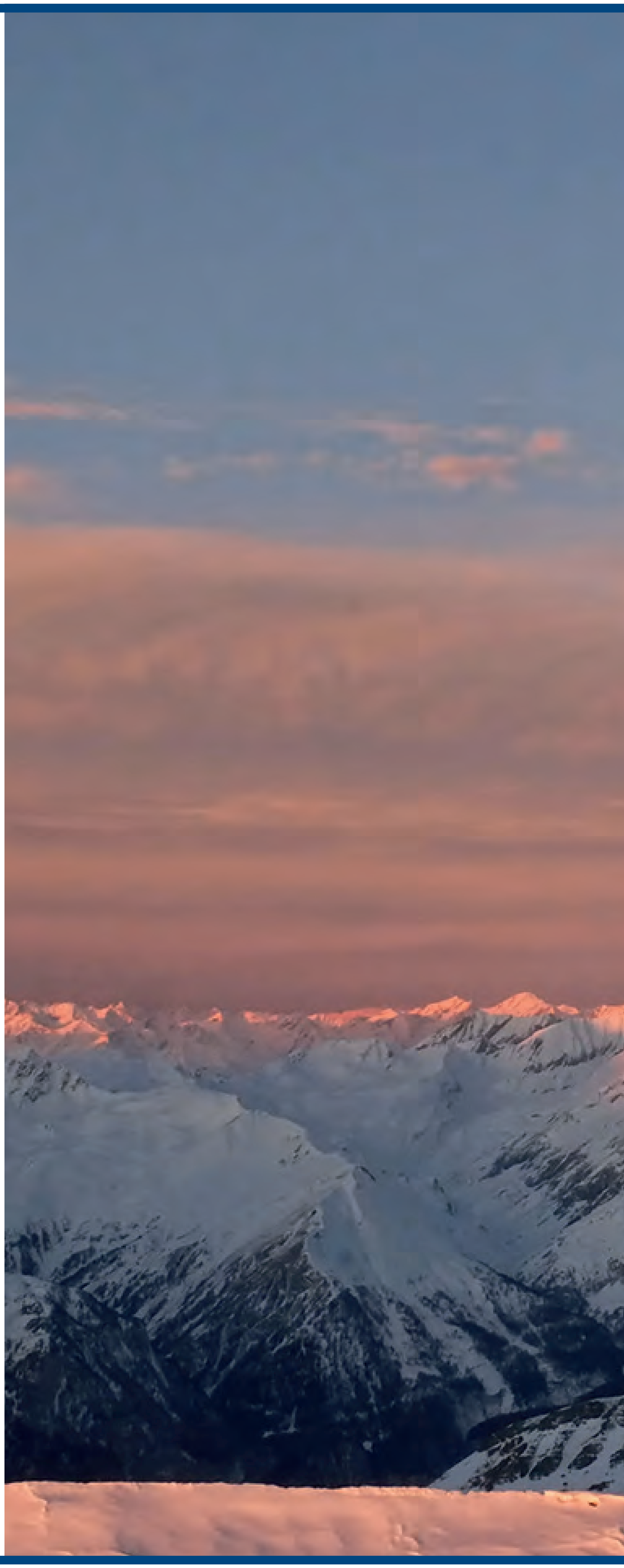

Grant Francis

Her Royal Highness Crown Princess Victoria of Sweden and INTERACT Science Coordinator Terry V. Callaghan pictured at Abisko Scientific Research Station in Sweden (Peter Rosén).

Her Royal Highness Crown Princess Victoria of Sweden

When I was a child, my father took our whole family hiking in Abisko up in Swedish Lapland. He introduced us to the beauty and the unique natural environment of the Swedish Arctic.

Ever since, the Arctic has held a very special place in my heart. And I have come back on several occasions to visit the research stations in Tarfala and Abisko, where data series dating back more than a century now provide a unique source of information for scientists and decision makers all over the world.

On site in Abisko, I have had the opportunity to see with my own eyes how climate change can be expected to affect the environment, and how rapidly rising temperatures threaten the delicate balance of vulnerable ecosystems.

These experiences have given me a deeper appreciation of the importance of understanding and protecting the Arctic. Research is critical for providing solutions to how to predict, prevent, adapt to and mitigate the dramatic environmental changes that are taking place in the Arctic, and that will affect all of us. The need for research has never been greater, nor more urgent.

"INTERACT Stories of Arctic Science" was published in 2015. Since then, the INTERACT Network has grown and even more compelling evidence of environmental change in the Arctic has become available.

This new book, "INTERACT Stories of Arctic Science II", contains new, short research stories from around the Arctic. I hope that you will find it as interesting as I do, and that it will inspire new generations of Arctic scientists.

Peter Rosén

Content

Minimising surprises for society


Lars Holst Hansen

Foreword

The vast, cold northern region of our planet – the Arctic – is changing dramatically and rapidly. Scientists and Indigenous and local people are seeing changes in the Arctic's landscapes, vegetation cover, animal populations, snow and frozen ground and pollution that affect the ecosystem services for people who live there. Most of the changes are imposed on the Arctic and its relatively small population by the rest of the world: rapid climate change caused by the ever increasing release of greenhouse gases, pollution from dirty industries and plastic waste. However, the Arctic is no longer distant and isolated. It is closely connected to the rest of the world and the changes to its surface and permafrost below amplify global warming that affects the rest of the world and contributes to sea level rise that will affect low-lying cities, communities, agricultural lands and island nations. Changing snow and ice and invasion of tall vegetation affects the ability of the Arctic's surface to cool the Earth by reflecting heat from the sun while thawing permafrost is mobilising ancient carbon stored in Arctic soils to increase greenhouse gases in the atmosphere. At the same time, melting glaciers and ice caps pour ancient water into the ocean and increase sea level.

Documenting and understanding these changes so we can mitigate and adapt to them is a huge challenge as the Arctic is not only vast, but it is surprisingly diverse. In contrast, the number of scientists and residents are low and our observing power on the ground is insufficient. Consequently, INTERACT, a network of 88 research stations in 20 countries is operating a programme whereby scientists from around the world are funded to visit Arctic research stations: so far, more than 1,000 have been sponsored. Working with INTERACT, the Siberian Environmental Change Network (SecNet) has stimulated research collaboration into the varied landscapes of Siberia, the largest, yet under-studied, land-mass in the Arctic.

As access to the rich resources of the Arctic improves, more tourists visit the Arctic and new transport routes open-up, there is a danger that tensions among nations will spill over into the Arctic. The access to research stations awarded by INTERACT is "Transnational" so that scientists must work at a station belonging to a country other than their own. This establishes a greater awareness of cultural differences among nations and cements collaboration. It is an important way of achieving "Science Diplomacy" that is further enhanced by working closely with many national and international institutions and networks.

Five years ago, INTERACT published the popular science book "Stories of Arctic Science" that was well received. However, the rapid changes in the Arctic require new stories to be told. This book "Stories of Arctic Science II", tells 41 new stories by scientists and Indigenous People of the Arctic. Although novel in its approach and information, the format of the book is traditional. To provide a more accessible on-line format, and to increase the contents to add educational material for students and school children, we have worked with the UK education charity "Wicked Weather Watch" and the IT department of Tomsk State University to produce an e-version of the book available by scanning the bar code on the back cover.

We sincerely hope that you will appreciate both versions of the book, learn important new stories, and be stimulated to be kinder to our planet and the Arctic.

It is a pleasure to thank all those who were involved in the production of the book.

On behalf of INTERACT

Terry V. Callaghan[1,2], Founder and Science Coordinator of INTERACT
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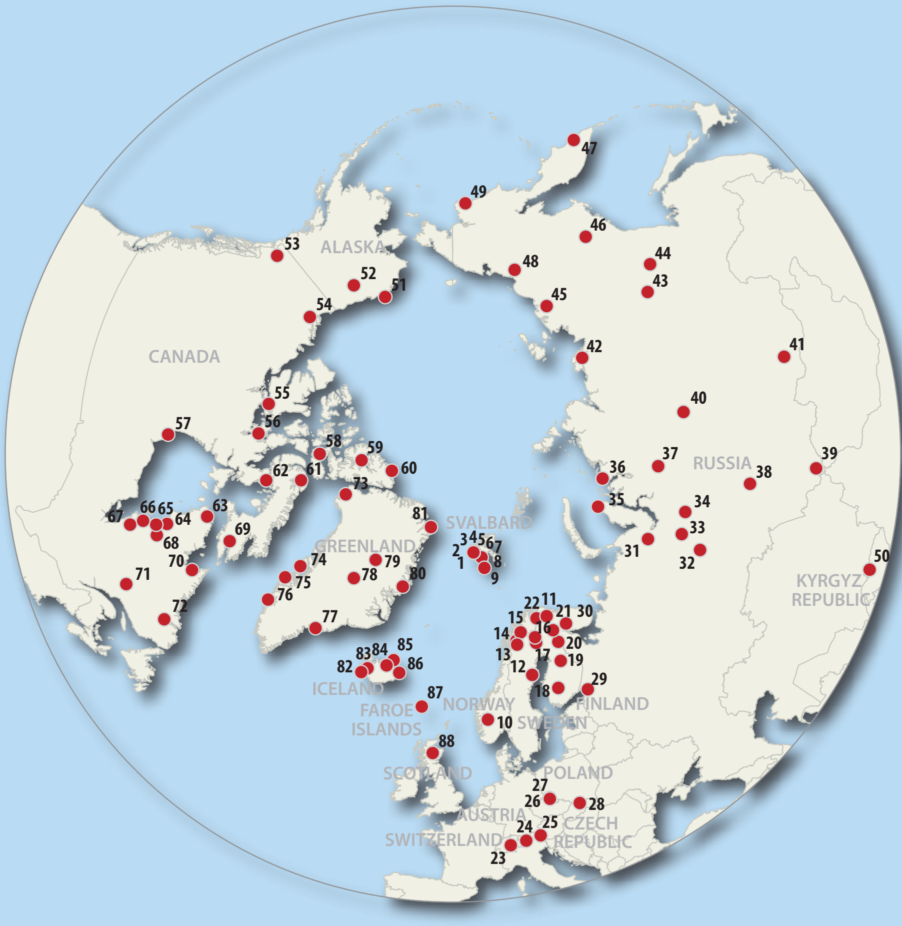
Telling stories about the changing Arctic

INTRODUCTION

Terry V. Callaghan, Hannele Savela & Margareta Johansson

Five years ago, INTERACT which is a network of 88 terrestrial research stations throughout the Arctic and neighbouring territories, published the book "Stories of Arctic Science" (Callaghan and Savela, 2015). The book gave information on research that was mainly carried out by scientists from around the world working at INTERACT research stations. We adopted a format to tell stories of Arctic science in a simple and highly illustrated way to provide resources for education, outreach and policy makers. The inspiration of using stories to pass on information is based on the traditions of Indigenous Peoples who ensure knowledge is available to younger generations by telling stories. This knowledge has various forms and the knowledge related to changes in environment and biodiversity is being increasingly recognized as an important addition to science understanding.

The book became highly successful as it appeared at a time when the Arctic was changing dramatically and received global attention. The reasons for this were based on the amplification of global warming at high latitudes and the numerous impacts that affected local and Indigenous Peoples and potentially the global community. This is through feedback loops from the Arctic's environment to the Earth's climate system and sea level increases. Five years later, the changes in the Arctic have accelerated not only environmentally but also geopolitically.



Living in the Arctic, Uummannaq, West Greenland.
(Terry V. Callaghan)

INTERACT stations. The key to the research stations numbers can be found on the inside of the cover.

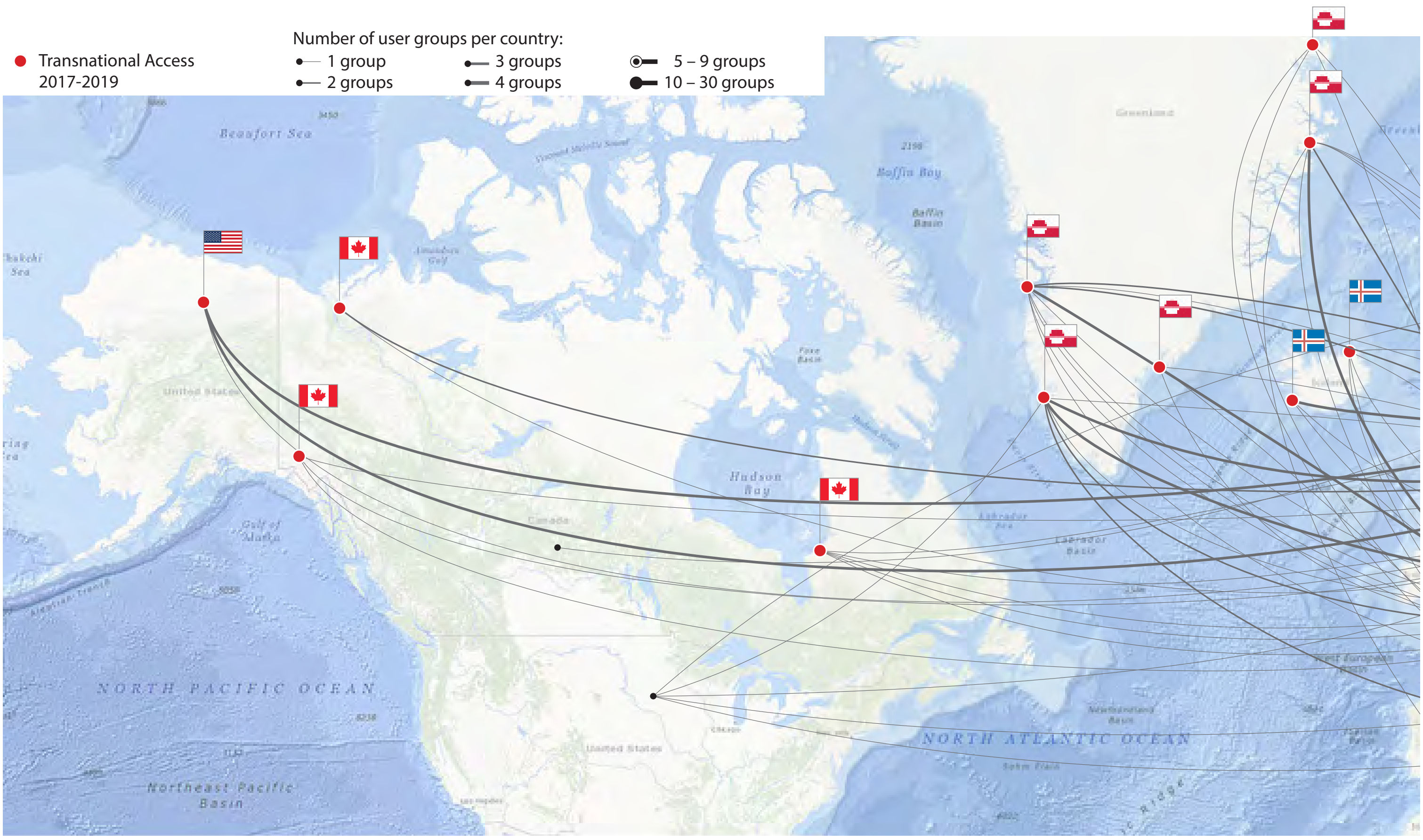
ENVIRONMENTAL CHANGES

If we look at environmental changes, the previously reported long term trends of warming, decrease in snow duration and ice extent, and ecosystem changes have continued. However, the previous trend of "greening" of vegetation (increased growth) has been replaced by a trend of browning (damage to vegetation and decreased growth). Some of the browning has been caused by extreme weather events both in winter and summer. New records of temperature have been experienced and the importance of specific weather events has been recognized far more than previously. Recent examples include the record temperature of 38 °C in Verkhoyansk, Siberia in June 2020, and an earlier seasonal start of wild fires. Turning to the cryosphere (ice, snow and permafrost), since the 2015 book was published, a glacier in Iceland and the St. Patrick Bay ice caps in Canada have disappeared. Furthermore, the southern distributional limit of permafrost has moved northwards by 25 km along the Alaska Highway in southern Yukon and northern British Columbia.

Direct impacts of people on the Arctic environment have continued but with a new recognition of the accumulation of plastics in the Arctic environment – and even in Arctic animals – and observations of how suddenly biodiversity and species' distribution ranges can change. The deposition of industrial pollutants such as "black carbon" on snow and ice is altering the micro-climate and, for example, accelerating the melt of glaciers. While the Arctic is impacted in these and many other ways by the rest of the world, the changes in the Arctic environment also have the potential to change global climate through a series of feedbacks. Since the publication of the 2015 book, research has proliferated on feedbacks such as emissions of carbon from areas of thawing permafrost in which vast amounts of carbon are stored. However, different stories are emerging: some researchers are revising their estimates of carbon emissions downwards whereas others maintain that carbon emissions will greatly exceed the ability of plants to capture carbon from the atmosphere. A continuing significant loss of sea ice, reduced glacier area, reductions in the length of the snow season and the polluted surfaces of snow and ice affect the ability of Arctic surfaces to reflect heat from the sun and lead to an amplified warming. Changes in the Arctic's environment also affect the rest of the world, particularly low-lying coastal areas including cities, through sea level rise largely resulting from increased melt water from ice caps and glaciers: since the publication of the 2015 book, estimates of the contributions of Arctic glaciers to sea level rise have been refined.

Transnational Access projects: home bases and research sites of funded projects.

Transnational Access projects are those funded via INTERACT where researchers can access facilities only outside their national bases.

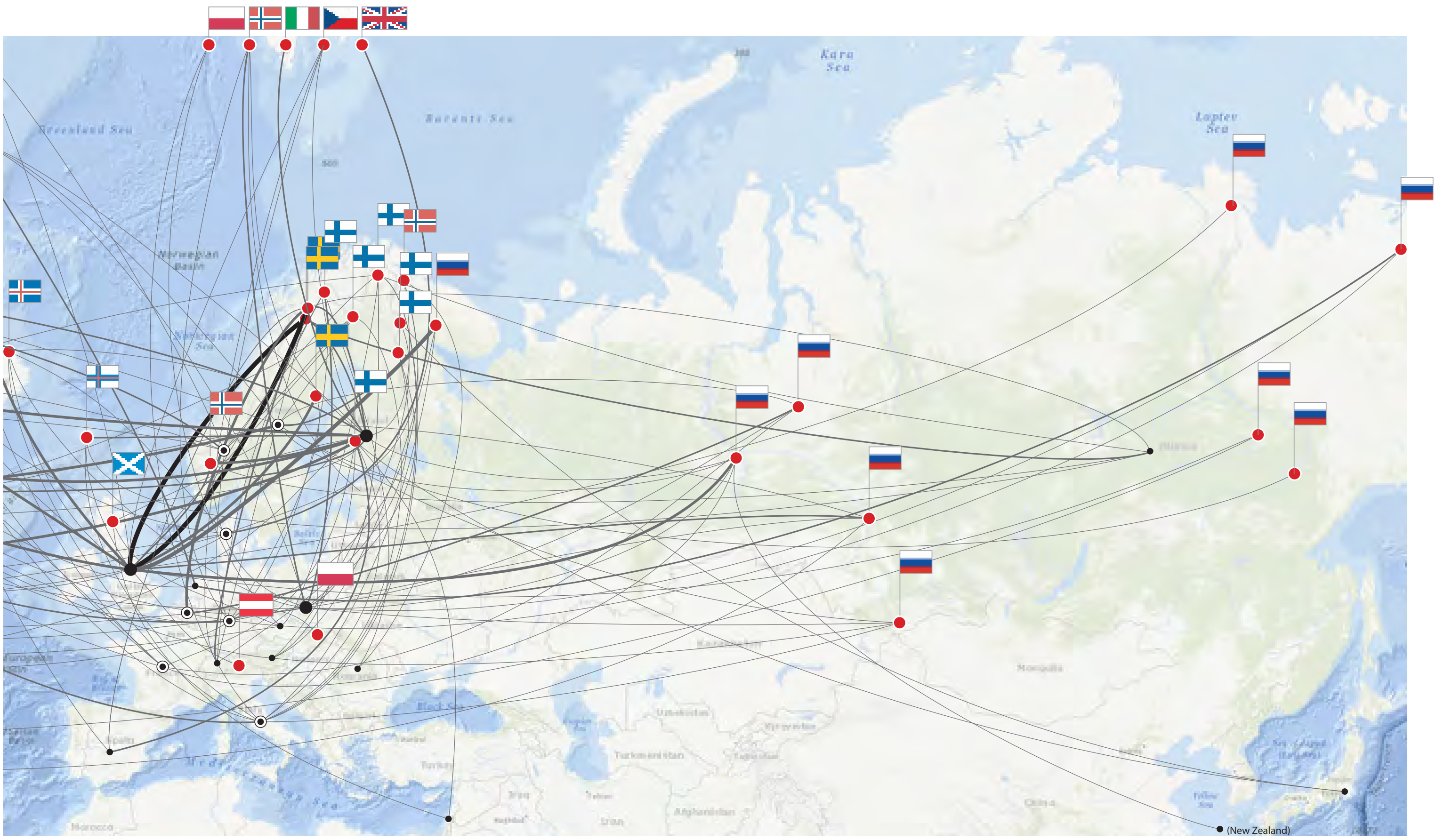


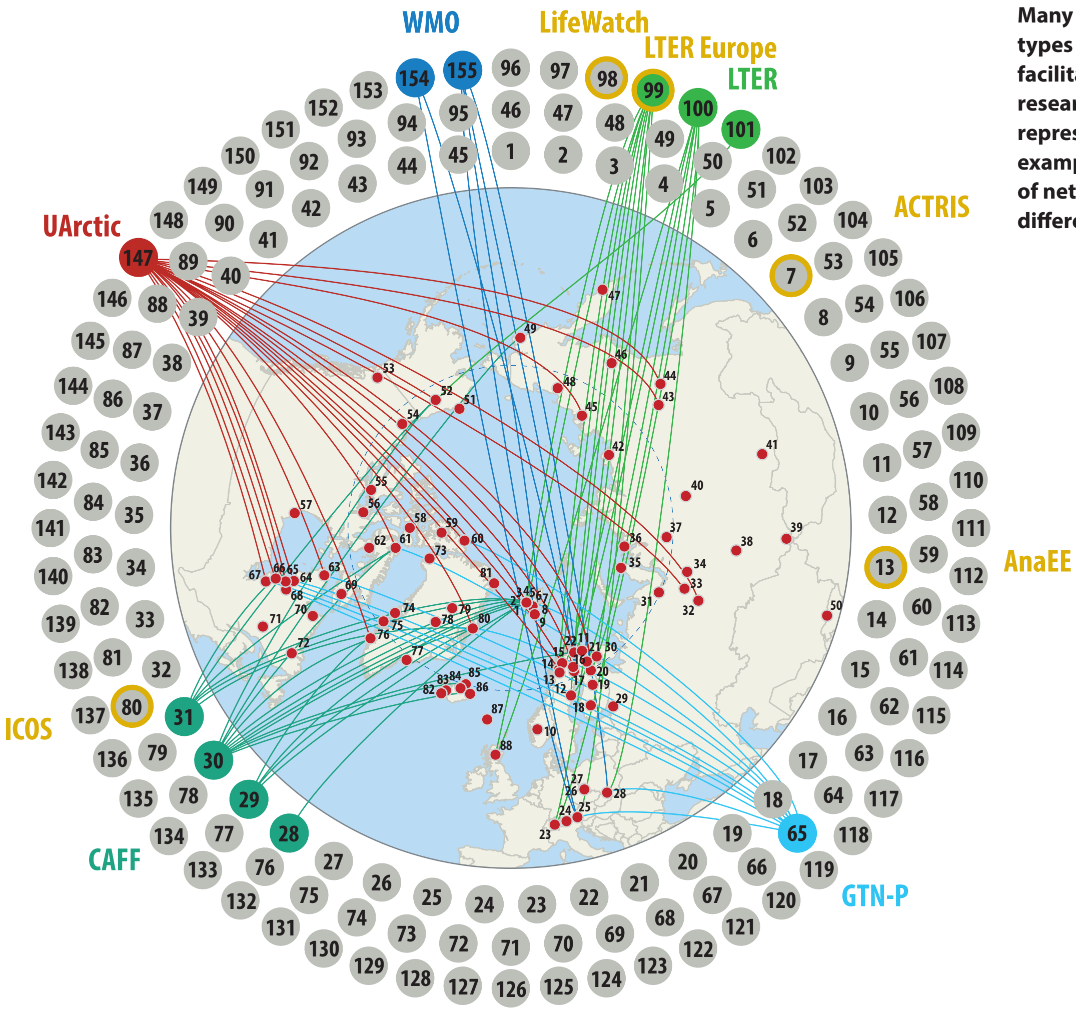
GEOPOLITICAL CHANGES

The Arctic has become a focus for global attention due to its vast resources, increasing ease of access to them and the opening-up of new transport routes. Geopolitically, there have been advances in diplomacy. For example, the Arctic Council has signed an agreement to enhance international cooperation in science. Importantly, it maintains a dialogue among the Arctic nations and other nations with Arctic interests at a time of growing tensions. These tensions can be seen in a greater militarization of the Arctic and political maneuvering for influence in Arctic territories as well as failure to agree on, and recognize the importance of climate change impacts on the Arctic. There are also steps forward and backwards in national political situations. Examples are mainly from the way people use the Arctic, by damaging ecosystems through extracting resources as opposed to conserving sensitive environments, and non-compliance with regulations over pollution that have recently led to major pollution events. On the other hand, there has been increasing recognition of the rights of some Indigenous Peoples, for example in fishing and hunting.

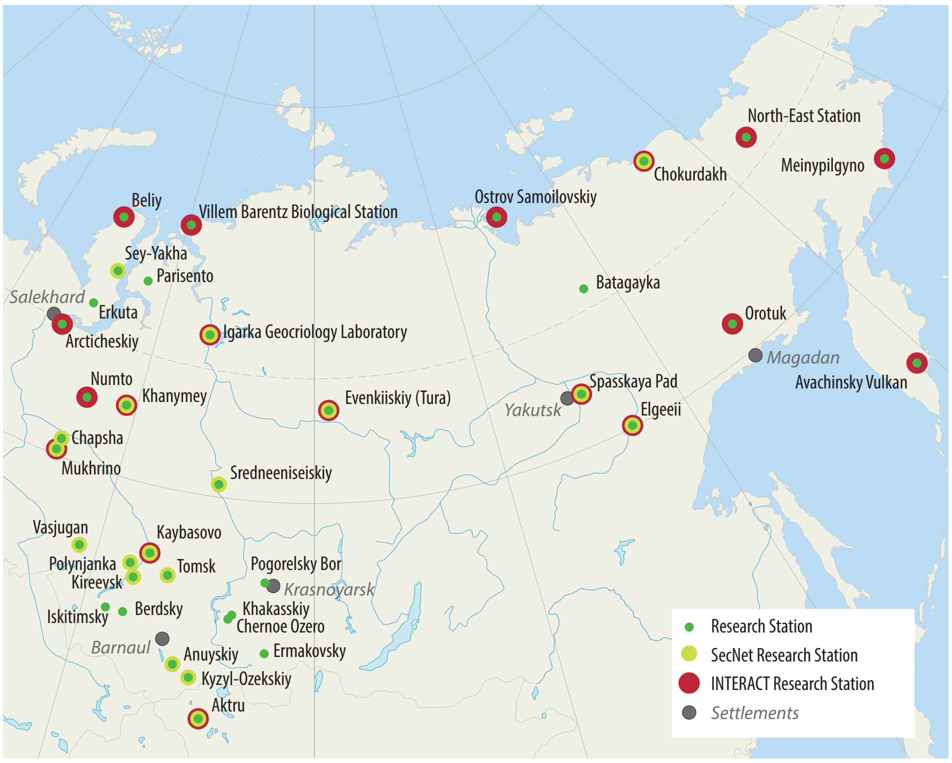
SCIENCE DIPLOMACY AND NETWORKING

At this unprecedented time, it is extremely important to unite international scientific effort not only to increase our understanding of change, but also to help diffuse political tensions. By reaching out to all sectors of society over the years through various INTERACT activities, we found a general interest and concern but the focus by many stakeholders and decision makers remains firmly on economic values rather than on environmental protection. As the INTERACT network annually hosts more than 5,000 scientists, has facilitated research by more than 1,000 scientists from around the world, has underpinned the work of more than 150 global, regional and thematic networks and has extensive outreach, it has an enormous possibility – and responsibility – to increase awareness and mutual understanding of how to collaborate internationally to respond to Arctic change.





Many networks, and different types of networks, are facilitated by INTERACT research stations. Each circle represents a network. Some examples of different types of networks are presented in different colours.



INTERACT inspired and facilitated the establishment of the Siberian Environmental Change Network and stimulated science diplomacy.

The research station staff work closely together to understand and share experiences of ways of operating and to explore ways of collaborating internationally. To improve international cooperation even further, INTERACT offers Transnational Access whereby scientists from around the world can apply for funding to visit research stations in countries other than their own. This immediately improves the potential for international collaboration and gives a greater understanding of the cultures in different countries. An important improvement in diplomacy between East and West was achieved by opening up many Russian research stations to western scientists and by enabling Russian scientists to visit western research stations. In addition, INTERACT helped to form the Siberian Environmental Change Network (SecNet). Together, these two networks have brought decision makers, Indigenous and Local Peoples and researchers together to improve their interactions and dialogue on environmental change (Callaghan et al., 2019). This science diplomacy has been recognized by government ministers, Ambassadors, and Embassies.

NEW STORIES OF ARCTIC SCIENCE

Without the research stations in INTERACT and the Transnational Access projects, we would know far less about the dramatic changes occurring in Arctic environments, biodiversity and ecosystem processes. Many of the stories in this second edition of "Stories of Arctic Science" for the 2020s give examples of new developments over the past five years and present projects, the results from which will inform us of changes over the next decade. We tell stories of how new knowledge is discovered – "Different ways of knowing", how people are directly impacting Arctic environments, how ecosystem services to people are changing, how local and global societies can be impacted by often "surprising" changes, and finally how we should work together and "INTERACT". We add to many of the stories in this book by publishing an e-book version with many extra resources for all readers. The e-book is available at eu-interact.org and by scanning the QR code on the rear covers of this printed book. All of this information is freely available to everyone, including the world's leaders. By providing educational resources to students from primary schools to universities, we actively support the next generation who can be empowered to act in the future.

Based on the rapid developments in the last five years, it is timely to tell new stories of Arctic science!

1 Different ways of knowing

SECTION OVERVIEW

For tens of thousands of years, human populations have survived by observing their environment and accumulating local knowledge and wisdom. For the past ten thousand years, evolving urban centres developed numeric approaches and measuring to add to observations. Today, in the digital age, measurement and technology not only allow us to observe current environmental features but also to look back into the distant past and predict future environments. However, the Traditional Indigenous Knowledge of Arctic Peoples gained and handed-down over many generations plays an invaluable role alongside hi tech developments.

In "Different ways of knowing", we provide stories that show how Indigenous Knowledge tells us how climate and topography are changing and how this affects Arctic ecosystems while we learn how ice cores tell us about climate change over the past 130,000 years. Another story analyses sediments with microscopic animals and plants to explore if an ancient sea or lake occurred where we now have land. The remaining stories show how new hi tech methods can be used to measure physiology of leaves from satellites, measure waves under lake ice and look inside melting glaciers.

Development of technology adds to a range of different ways of knowing about our environment.
Rocket launched from Ny Ålesund, Svalbard, into an aurora at the same time as a laser was fired into the atmosphere.
(Gregory Tran)

A Siberian indigenous knowledge system for understanding climate change

Alexandra Lavrillier & Semen Gabyshev

Evenki nomadic reindeer herders and hunters ("Evenki") have observed climate change for several decades in East Siberia and are frontline witnesses of the profound effects of global and local climate changes. They want their knowledge and observations to be heard: they have noted several steps marking new abrupt increases in severe and unprecedented abnormalities in the local climate from 2005 and in the cryosphere and biodiversity from 2012.

During the summer, the Evenki nomadise every 3-7 days to provide fresh pasture to the reindeer. (© V. Gabyshev)

AIMS OF THE PROJECT

Aiming to bridge Evenki Indigenous observation and the environmental sciences, we first had to reach a deeper understanding of the former's poorly-documented complex knowledge system. Evenki and natural social scientists joined forces in forming observatories. We respected all contributors' authorships and involved Indigenous co-researchers in all stages of the research (project design, data gathering, analysis and writing).

WHAT DID WE DO?

From 2013 to 2020, our co-production methodologies were daily monitoring by the Evenki (meteorological measurements and Indigenous observation of the fauna, flora, sky, and cryosphere), collaborative fieldwork by the Evenki and the anthropologist in order to document knowledge in the native language, and participant observation. The Evenki and the anthropologist co-analysed abnormal winters and summers, including events the Evenki consider "extreme". These have become increasingly frequent from 2015, and include phenomena such as ice embedding pastures, repeatedly thawing and freezing snow, rivers which fail to freeze, long summer heat waves and droughts, and overly shallow or deep snow.

WHERE DID WE WORK?

The studied area contains a large nomadic community that lives across the frontier between the Amur Region and Sakha-Yakutia: it is administratively divided between 5 villages. 70,000 km^2 in size, the area contains around 15,000 reindeer led by 200 reindeer units. These Evenki live off a combination of reindeer herding and the sustainable hunting of various species, which implies a deep knowledge of biodiversity, landscape specificities, climate and microclimates (at scales from cm to km).

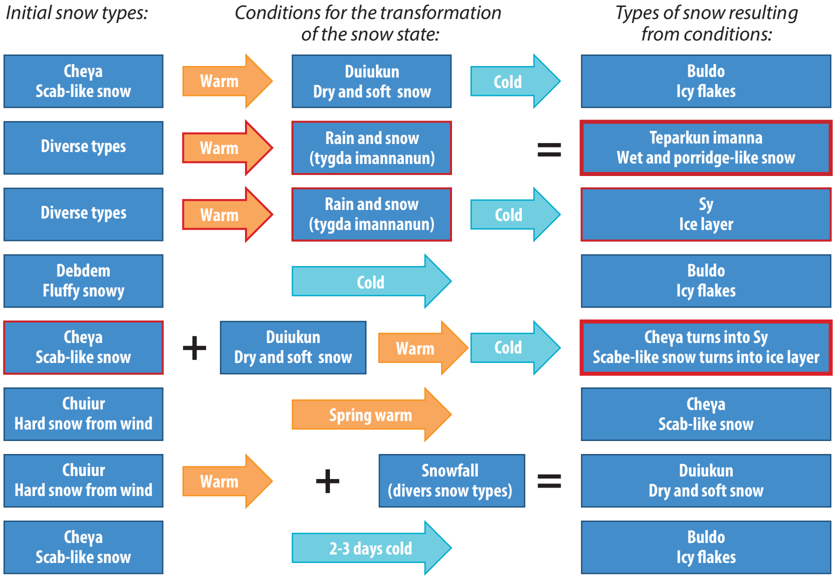
WHAT DID WE FIND?

Evenki ecological knowledge is a vast and sophisticated system of knowledge attached to complex processes of cognition. It is not a set of practical "knowledge packs", but a theoretical system containing a great deal of "know-how", hypothesising and predictions, including some "modelling".

It is not only passed down through generations: it questions existing knowledge, performs experiments, produces new knowledge, takes measurements, forms theories and uses specialised terminologies shared by a part of the community. Like in science, the notion of authorship of innovation exists.

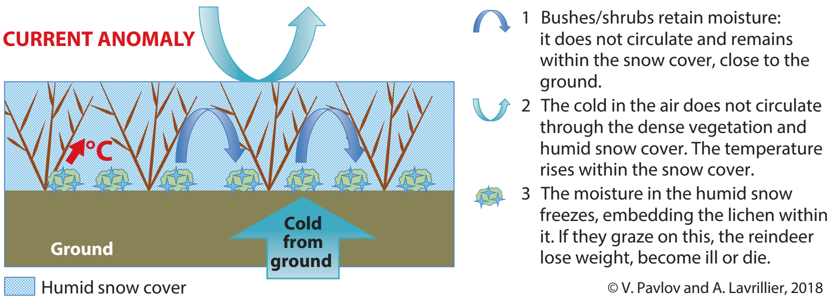
Evenki hypothesising about the climate and environment after observing an abnormal winter.

The Evenki Physics of the Snow examples



© Lavrillier A. and Gabyshev S. 2016, published in Lavrillier A. and Gabyshev S. 2017, p. 283.

Diagram showing indigenous knowledge about the current abnormal interactions between climate change, disruptions in the vegetation cover and reindeer health. The norm would be sparse vegetation: this allows the snow to be dry and for a cold snow cover thanks to the circulation of air and the escape of humidity. The lichen is then dry and good for reindeer.



© V. Pavlov and A. Lavrillier, 2018

We identified several Evenki classifications ("typologies") of topography, vegetation cover, fauna, and a "climate science". The latter comprises a complex typology of warm and cold air, a typology of wind, a typology of clouds and precipitation (20 types) and a typology of snow and ice (8 ice types, 25 snow types). The latter forms an Indigenous "physics" of snow and ice. The Evenki articulate their typologies for analysing norms and abnormalities of the past and present or for hypothesising about the future. These are crucial tools for successful adaption. The elements of these typologies are thought to interact with each other.

The Evenki conceptualise norms (admitting variations), abnormalities and, due to the recent acceleration of climate change, various "degrees of extreme event" (relative to the extent of their adaptive capacity). They struggle with unprecedented and accumulated abnormalities in the snow cover and river ice, the intensification of shrub growth, increasing humidity, an overabundance of predators, changes in insect reproductive cycles, huge changes in biodiversity, such as the disappearance of animal species and the appearance of insects and birds unknown to them, and, from 2017, changes in the landscape's topography.

WHY ARE THE RESULTS IMPORTANT?

All this local-scale Indigenous knowledge about the ongoing transformation of the Earth has compelled the Evenki to state: "The environment is broken!". This knowledge also complements the assessment reports of climate and biodiversity on a global scale, including contributions to IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) and IPCC (Intergovernmental Panel on Climate Change).

This demonstrates that Indigenous knowledge and observations contain key information and many common points with the sciences. We have raised new research perspectives and projects with climatologists, geographers, biologists, atmospheric physicists, geomorphologists and hydrologists. This contributes to the ongoing official recognition of the scientific value of Indigenous knowledge.

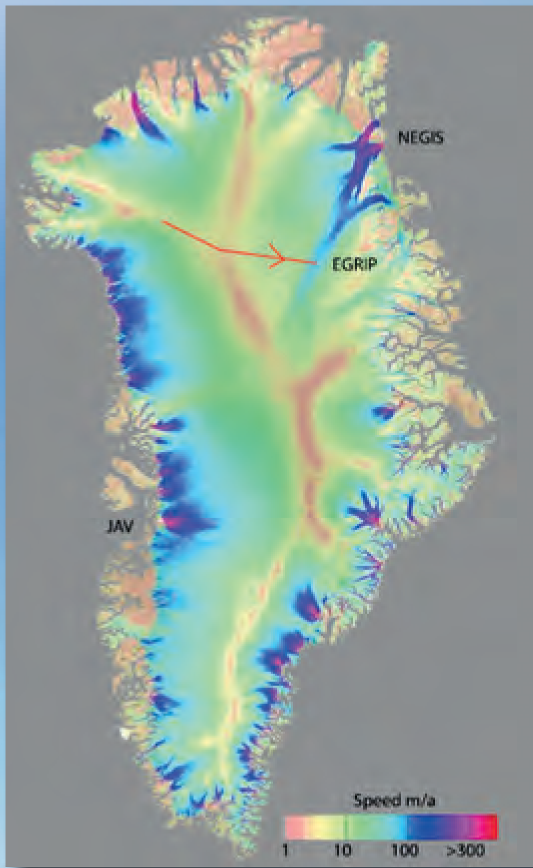
THE ADVENTURE

Crossing hundreds kilometres of harsh cold landscape by snow mobile or reindeer is normal for the Evenki, so the anthropologist had to adapt. Lavrillier felt as if she had undergone years of intensive courses at a "nomadic university", with the Evenki as professors. Gabyshev appreciated the intensive practice and enhancement of his native knowledge through observation, co-writing and meeting with scientists; he enjoyed their interest in his knowledge.

Using climate records preserved in ancient ice to understand modern climate change and its impact

Dorthe Dahl-Jensen

During the current global warming, sea level is increasing, mainly because of the thermal expansion of the sea water and input of melt water from warming glaciers and ice sheets. Rising sea levels are predicted to have profound effects on low-lying coastal areas and cities — including megacities, with impacts on many millions of people.



Surface velocities on the Greenland Ice Sheet.

AIMS OF THE PROJECT

The Greenland Ice Sheet is losing mass as the climate warms in the Arctic. Together with the Arctic glaciers and ice caps, the melting ice accounts for approximately half of the global mean sea level rise. How can we make good estimates of the future sea level rise so low-lying coastal cities and communities all over the World can prepare?

WHAT DID WE DO?

To understand the response of ice to the warming climate, I look into the past, leading projects where international teams drill ice cores through the Greenland Ice Sheet from the top to the bedrock, 2,500-3,100 m below the surface. The ice cores consist of layers of annual snowfall that become older and older with depth and can thus be used to learn about the past climate. Near the bedrock, the ice layers are more than 150,000 years old.

WHERE DID WE WORK?

We establish camps that can house around 30 scientists during the summer months on very cold and remote sites on the Greenland Ice Sheet. At present we are drilling the EGRIP (East GReenland Ice core Project) ice core in the center of the NEGIS (North-East Greenland Ice Stream) both to understand the past climate but also to learn how an ice stream flows as they are so important and yet badly understood contributors to sea level rise. In 2015, we moved the camp 440 km from the previous camp pulling the 55 ton heavy main building, the "Dome", on skies over the ice sheet at 10 km per hour. The ice core drilling and the first measurements on the ice cores are done in subsurface snow trenches where the temperatures are cold and not influenced by the surface weather. In these trenches, international teams measure ice and climate properties and cut samples for further climate analysis in more than 100 laboratories around the World.

WHAT DID WE FIND?

The deep ice cores contain ice layers from the Glacial Period, 115,000 years to 11,700 years before present, and ice from the Last Interglacial 130,000 years to 115,000 years ago. During the last Glacial Period, we experienced 25 events of very rapid warming of the climate over Greenland. The Arctic temperatures abruptly changed from –30 °C to –15 °C warmer than now in just 100 years. These events are called "Dansgaard-Oeschger" events, named after Professors from Copenhagen and Bern. They are not caused by human activities, but by internal feedback mechanisms within the Earth system itself. These periods caused global sea level rise of 5-10 m showing strong loss of mass from the glacial ice sheets over Greenland, Antarctica, North America and Eurasia. Increases and decreases in sea level are thus common and a natural component of land-sea interactions. During the Last Interglacial, more than 115,000 years ago, Arctic temperatures became very warm and the temperatures were 5 °C warmer than present over the Arctic. Investigations of the ice cores show that the ice sheet lost around 20% of its volume corresponding to 2 m of global mean sea level rise. During this last warm Interglacial Period, sea level was 5-9 m higher than at present.

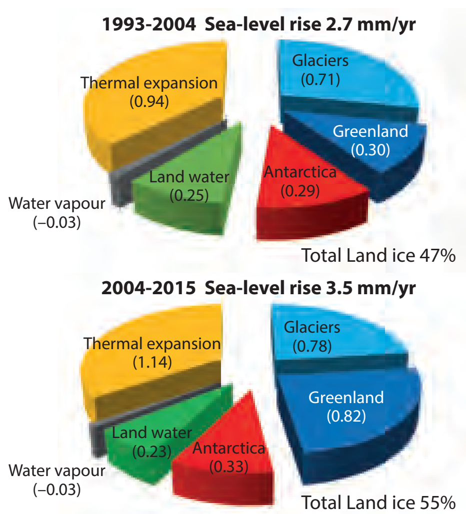
WHY ARE THE RESULTS IMPORTANT?

The results are important because they show that the climate system can have instabilities resulting in abrupt changes. If we change the climate system — will we risk abrupt changes again? The climate models we are replying on for future predictions do not contain the physics to generate abrupt changes. In addition, the research shows that when the Arctic is warmed by 5 °C — corresponding to a global warming of 2 °C — we can expect 5-9 m sea level rise — but probably over thousands of years. Using palaeodata to constrain what can happen in our future helps us to prepare, particularly as even small increases in sea level will have profound impacts on a modern world with vast coastal populations.

THE ADVENTURE

The ice camp, EGRIP, is placed on the middle of NEGIS and is moving with the ice stream at 50 m/yr. The camp is more than 1,000 km from the nearest airport and we need ski-equipped airplanes to reach the camp. Once a month we exchange team members. Between the flight periods we are truly isolated and enjoy the friendship and international spirit on the middle of the Greenland Ice Sheet.

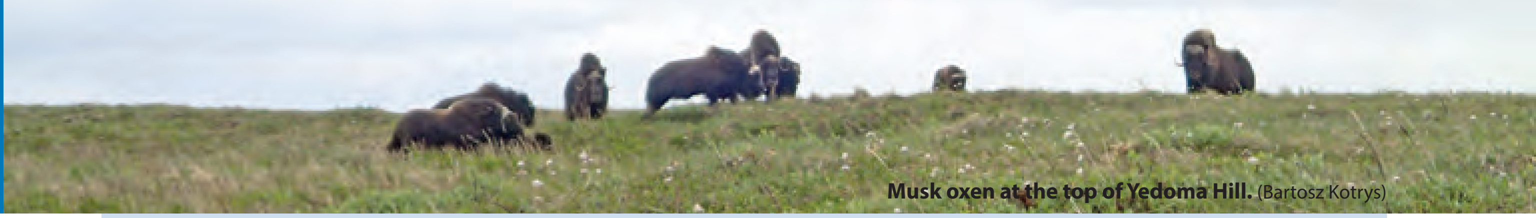
Pie chart insert of sea level rise, showing increasing contribution from the Greenland Ice Sheet.



Pictures from the deep ice core drilling program.
Top left: moving the Dome 440 km over the Greenland Ice Sheet to EGRIP in 2015. (Bartosz Kotrys)
Bottom left: The subsurface science trench. (Bartosz Kotrys)
Bottom right: Cutting an ice core. (Piotr Kittel)

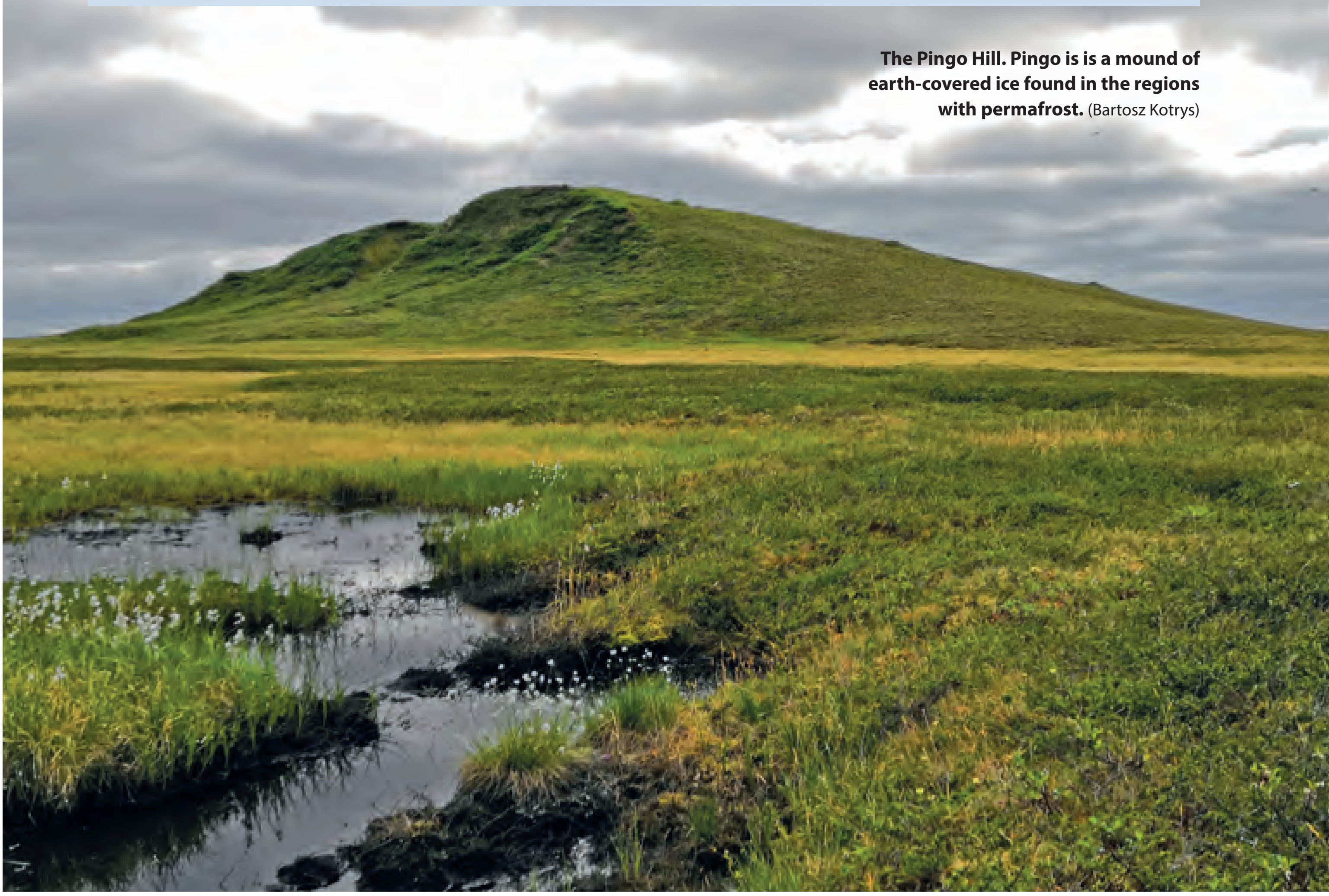
How inland waters have changed over many thousands of years in north-eastern Russia

Piotr Kittel, Bartosz Kotrys, Mateusz Płóciennik & Trofim Maximov



Musk oxen at the top of Yedoma Hill. (Bartosz Kotrys)

Polar landscapes are very sensitive to global climatic fluctuations. When temperature decreased for many thousands of years in Europe, a large part of the continent was covered by ice caps, but when temperature sharply rose during interglacials (periods between ice ages), landscape changes were much more dramatic. In north-eastern Russia, there were no ice caps during the Quaternary (last 2,590,000 years), but glacial-interglacial cycles caused pronounced landscape changes including the formation of large water bodies. A large body of inland water or an East Siberian Sea lagoon reaching even 200 km south of the current sea coast may have existed in the Kytalyk Federal National Park during the previous interglacial period, called the "Eemian Interglacial" (about 132,000 – 115,000 years ago). This would result from tectonic movements or from warm climatic conditions which would cause large scale permafrost thawing, higher precipitation and sea level rise. During accumulation of lake and shallow marine sediments, micro- and macrofossils of small aquatic plants and animals were also deposited. Specialised analysis of the sediment's chemistry along with fossil diatoms (single-celled aquatic plants) and invertebrates (midges and water fleas) tell us if the water body was saline or freshwater and what past temperatures probably were. Radiocarbon dating of biotic (living organisms) remains indicates the approximate age of the sediment layers while pollen fossils reveal how plant communities changed.



The Pingo Hill. Pingo is is a mound of earth-covered ice found in the regions with permafrost. (Bartosz Kotrys)

AIMS OF THE PROJECT

There are three main project goals: 1) determination of the character of a large water body in the region during the previous interglacial (freshwater *versus* saline), 2) reconstruction of palaeoclimatic (past climate) conditions based on the invertebrate and plant subfossils deposited in local palaeolakes (ancient lakes) and mires, and 3) determination of biota diversity of local peatlands in the Holocene using ancient DNA.

WHAT DID WE DO?

To achieve these aims, we collected three short sediment cores of the active layer above permafrost within different basins of palaeolakes as well as three profiles of silts and loams from the Yedoma Hill and Berelekh River banks. We also cut a 70 cm long peat core from the permafrost.

WHERE DID WE WORK?

We visited the Chokurdakh Scientific Tundra Station in the Kytalyk Wildlife Reserve (North-East Siberia). It is around 480 km north of the Arctic Circle on the Berelekh River bank. This site was chosen because there are many lakes and palaeolakes as well as Arctic mires in the close vicinity of the station. We were also curious about the geological structure of those parts of hills in the region that could have been formed by sediments of a large ancient water body in northern Yakutia.

WHAT DID WE FIND?

The sediments that form the local hills consisted of loam and silts that could have been deposited in a large water body that might have existed in the previous interglacial period. We have found deposits of this large water body that were not very disturbed by permafrost structures on the slopes of Yedoma Hill and in some places on exposed stretches of the Berelekh River banks. Further analysis of the sediment content (chemistry, micro- and macrofossils) will allow past landscapes and climates to be reconstructed. The analysis should also reveal if sediments of palaeolakes that developed later in the Holocene consist partly of materials redeposited from the past ancient large water body discussed above and therefore, temperature reconstructions for the past 10,000 years may be blurred.

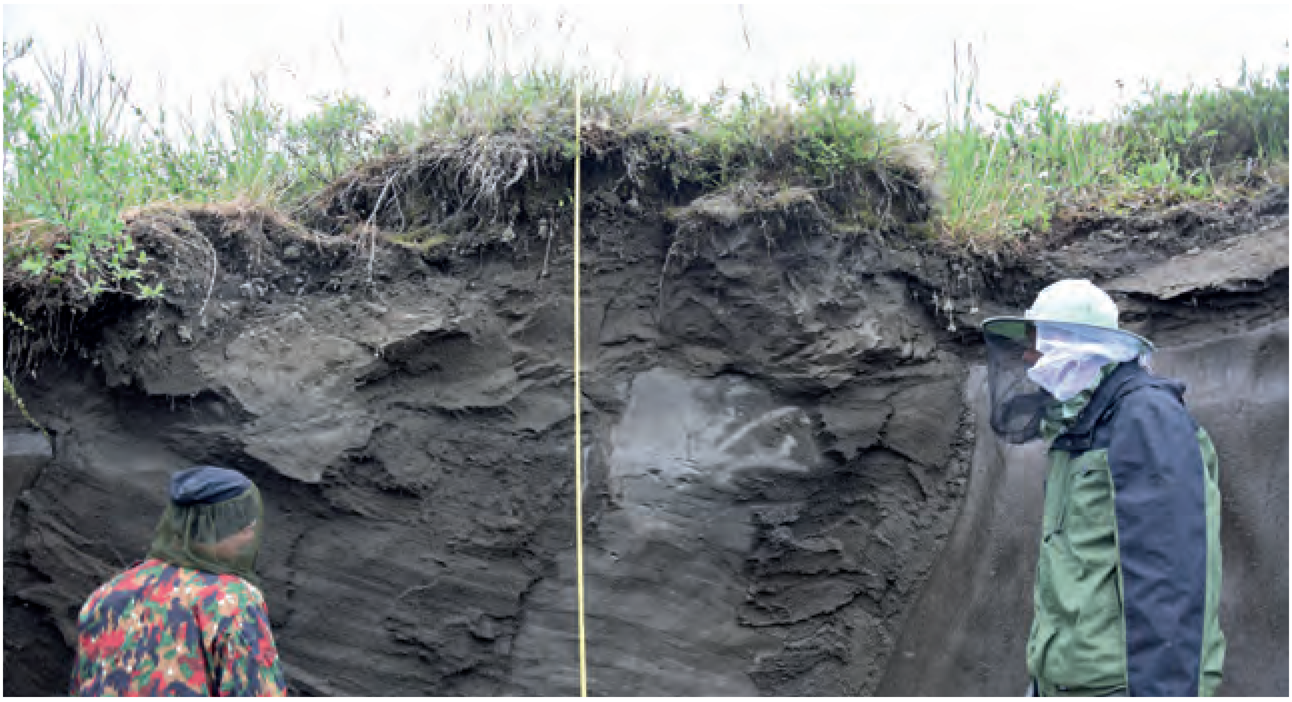
WHY ARE THE RESULTS IMPORTANT?

Currently we are experiencing global warming, but the previous (Eemian) interglacial was warmer than the Holocene (present interglacial period). Global climate change in the past caused wide-ranging landscape transformations. If we are correct that there was inundation of large areas of northern Siberia during warm phases, this study may contribute to regional spatial planning and may make people more aware of the importance of current warming for the Arctic's environment.

THE ADVENTURE

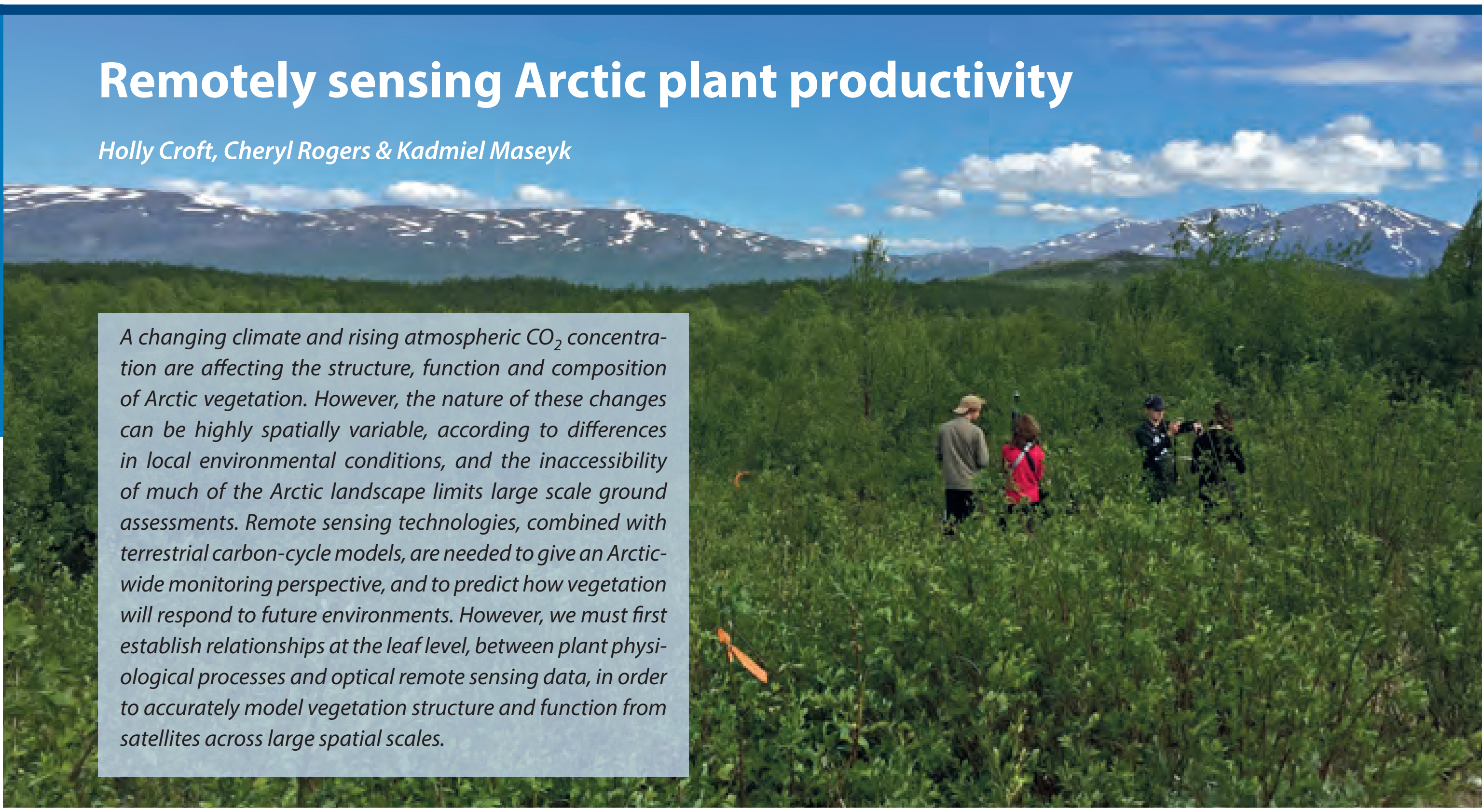
The whole expedition was a great adventure. There was a logistic and physical effort, but perhaps the most exceptional episode was cutting a peat core from the permafrost with a motor saw. First, we removed the active soil layer (uppermost 15 cm), and then we waited for the frozen peat to thaw during quite warm weather at that time but that strategy failed. So, we used a motor saw to cut a small outcrop in the permafrost, block by block. Finally, we had a core which was later cut gently into 1 cm thick slices at the station.

Taking samples from the slope of Yedoma Hill. Here you can see the exposed old sediments that we define as accumulated from the past large lagoon situated in the Kytalyk Region. (Piotr Kittel)



Remotely sensing Arctic plant productivity

Holly Croft, Cheryl Rogers & Kadmiel Maseyk



A changing climate and rising atmospheric CO_2 concentration are affecting the structure, function and composition of Arctic vegetation. However, the nature of these changes can be highly spatially variable, according to differences in local environmental conditions, and the inaccessibility of much of the Arctic landscape limits large scale ground assessments. Remote sensing technologies, combined with terrestrial carbon-cycle models, are needed to give an Arctic-wide monitoring perspective, and to predict how vegetation will respond to future environments. However, we must first establish relationships at the leaf level, between plant physiological processes and optical remote sensing data, in order to accurately model vegetation structure and function from satellites across large spatial scales.

Dwarf shrub – *Betula nana, Salix* spp. (Cheryl Rogers)

AIMS OF THE PROJECT

Our research aimed to investigate the relationships between leaf physiology, leaf biochemistry and remote sensing measurements across different Arctic species.

WHAT DID WE DO?

We carried out simultaneous measurements of: i) leaf photosynthesis, ii) solar-induced chlorophyll fluorescence (SIF) which is an optical measure of light re-emitted from chlorophyll molecules, and iii) photochemical reflectance (PRI) which is a spectral index that provides information on the thermal dissipation of excess energy by leaves. These measurements, which represent the different possible pathways for light once it is absorbed by a leaf, were collected at 1 minute sampling intervals, for different Arctic plant species. Additional sampling surveys were also conducted, for leaf chlorophyll content, leaf nitrogen content, "Pulse Amplitude Modulation" (PAM) fluorescence (which measures the efficiency of photosynthetic machinery) and leaf photosynthetic capacity measurements. Using a combination of gas exchange, biochemical and optical methods will give us a better understanding of how plants are acclimated to different environments, and whether remote sensing techniques can be used to directly or indirectly estimate plant photosynthesis.

Wetland – *Rubus chamaemorus, Vaccinium vitis-idaea*. (Cheryl Rogers)

WHERE DID WE WORK?

The fieldwork took place at Abisko, Sweden, about 200 km north of the Arctic Circle. We sampled at three field sites, representing different vegetation types close to the Abisko Scientific Research Station, a wetland site at the Stordalen Mire flux tower, a deciduous broadleaf site and dwarf shrub site. The facilities at the research station enabled us to process our leaf samples and keep on top of ensuring that the equipment batteries were fully charged.

WHAT DID WE FIND?

There has been considerable interest in using SIF as a direct proxy for photosynthesis, with strong, linear results reported at coarse spatial and temporal scales. However, results from this study demonstrate that at minute time-steps, the relationship between SIF and leaf-level photosynthesis is non-linear, as excess light that is not used in photosynthesis is variably partitioned to both fluorescence and heat dissipation pathways. Results also showed a consistent, strong relationship between leaf chlorophyll content and the maximum leaf photosynthetic capacity, across all species and vegetation types. This finding has significant implications for improving modelled estimates of photosynthesis by using leaf chlorophyll as a proxy for photosynthetic capacity, a key parameter in terrestrial biosphere models.

WHY ARE THE RESULTS IMPORTANT?

Plants take up a large proportion of CO_2 from the atmosphere through photosynthesis. Any climate-induced changes in photosynthesis could either modulate or amplify increasing atmospheric CO_2 concentrations. Recent developments in both remote sensing methods and satellite technologies have opened up exciting new opportunities to improve modelled plant photosynthesis over large areas. Optical narrowband satellite sensors (e.g. ENVISAT Medium Resolution Imaging Spectrometer; MERIS, and Sentinel-2), that measure reflected radiance in red-edge wavelengths (~705-740 nm), have improved our ability to spatially map leaf chlorophyll content, which is a key component of plants' photosynthetic machinery, over regional to global scales. Over the last decade, several satellite sensors that were originally designed for atmospheric research have been used to measure the extremely small fluorescence signal that is emitted by plants (e.g. Global Ozone Monitoring Experiment-2; GOME-2 and Tropospheric Monitoring Instrument; TROPOMI). Advances in both SIF and leaf chlorophyll satellite retrieval methods may allow a more refined approach for targeting more precisely how vegetation function is changing across Arctic plant communities, and improve estimates of the terrestrial carbon budget, under current and future climate scenarios.

Sentinel-2 satellite.
Photo source: ESA/ATG medialab (European Space Agency https://www.esa.int/Enabling_Support/Operations/Sentinel-2_operations)

THE ADVENTURE

We decided to drive from the UK to Abisko, which included two ferries, four countries, 3,400 km and two overnight stops. Driving the length of Sweden was an incredible journey. The entire fieldtrip was one big adventure and made all the more enjoyable by four good-spirited and hardworking team members from the University of Sheffield undergraduate programme — a big thanks to Nathan Howard, Hannah Shreeve, Charles Kenny and Katherine O'Connor.

Broadleaf forest – *Betula pubescens*. (Cheryl Rogers)

Exploring waves under the ice of Arctic lakes

Georgiy Kirillin, Andreas Jechow & Ilya Aslamov

Lakes are important features of the Arctic landscape, while the lake ice is one of the most dynamic components of the cryosphere (the frozen regions of planet Earth). Not surprisingly, the timing and duration of the winter lake ice cover is a highly sensitive indicator of climatic changes. Physical processes involved in the formation and melt of lake ice are complex and are not yet fully understood. The water movement and the heat transport in the lake water under ice remain particularly obscure.

AIMS OF THE PROJECT

We aimed at acquiring the first detailed observations of ice cover formation and melting in a polar lake over the entire several months' long ice period in an Arctic lake. Key aspects were to work with time intervals of seconds and measure heat transport processes at scales of centimetres. A fundamental scientific question was to understand the effect of small-scale physical effects on ice properties produced by under-ice waves.

WHAT DID WE DO?

We installed an automatic measuring station consisting of a 5 m long "chain" of sensors frozen into the lake ice. It recorded the continuous temperature profile in the air, ice and water every 1-10 cm. The station was equipped with an echo-sounder measuring ice thickness with 1 mm accuracy. A high-resolution pressure recorder below the surface measured oscillations of the ice cover.

To measure under-ice waves, we used a remote-operated vehicle equipped with a custom-built sensor platform and acoustic current profilers for registration of water movements under the ice. Lake-wide surveys of under-ice water properties were performed in addition.

Installation of station on the ice cover and underwater. (Georgiy Kirillin and Anreas Jehow)

The remote-operated vehicle "VideoRay" with a sensor platform under the ice. (Georgiy Kirillin)

Panorama of Kilpisjärvi. (Ilya Aslamov)

WHERE DID WE WORK?

Kilpisjärvi is a glacial lake located in Lapland at the border between Finland and Sweden. Several features make Kilpisjärvi a particularly attractive field site for investigations of lake ice cover. The relatively small area of several tens of square kilometres is covered by lakes with the longest ice-covered period in Western Europe. Kilpisjärvi is the largest of these lakes (the lake surface area is 37.1 km^2, the average depth is 19.5 m and the maximum depth is 57 m).

WHAT DID WE FIND?

We discovered highly turbulent conditions under the ice. The source of the turbulent mixing was identified as whole-lake ("barotropic") standing waves driven by strong wind events over the ice surface. The waves transported heat from the deep waters to the ice base making a stronger contribution to the melt of ice cover than was commonly assumed.

WHY ARE THE RESULTS IMPORTANT?

The decline of the seasonal ice cover in the Arctic is currently gaining recognition as a major indicator of climate change. The transfer of heat at the boundary where ice and water meet remains the least studied mechanism controlling the growth and melting of winter ice. The field results could be used generally to improve computer models of winter ice dynamics. Hence, the outcomes of the study find application in the heat budget estimations of winter ice on inland and coastal waters.

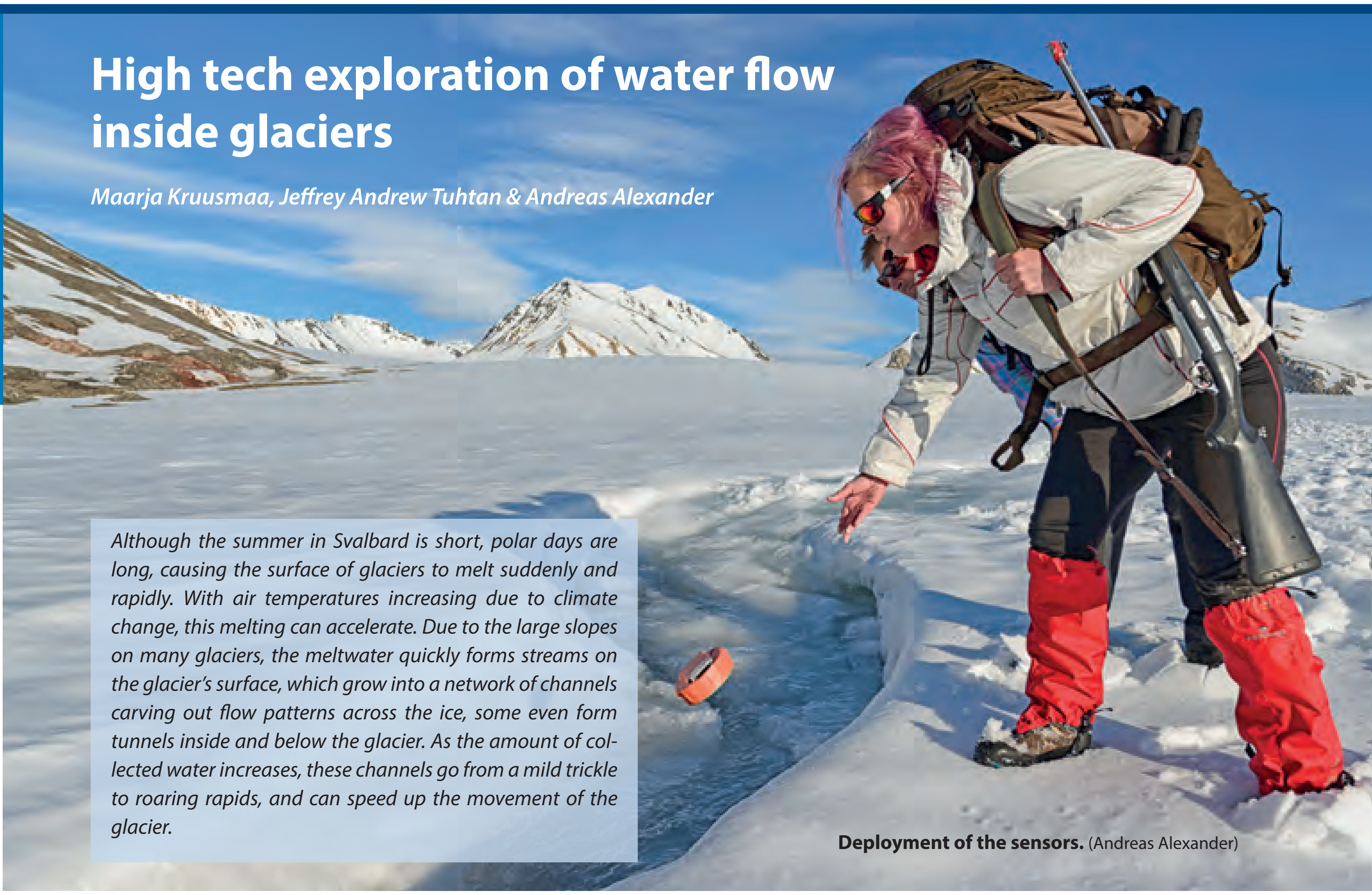
THE ADVENTURE

The Arctic Peoples know it: the flat lake ice is perfect for walking, skating, driving a snowmobile or even a car. So it is for installing instruments and doing measurements through ice holes. However, the warmer is the weather the more intense are the water motions under the ice, the more valuable are the data, and — the more adventurous becomes the ice walking! Our last survey with 40 holes drilled along a 4-km long lake-wide transect was performed on 25th May 2018 —snowmobiles could not be used anymore and even walking was a challenge. Thanks to Finnish kicksleds provided to us by the staff of the Kilpisjärvi Biological Station, the journey across the wobbly ice was successful. Three days later the ice disappeared. It was the earliest ice break on Kilpisjärvi since the start of observations in the 1950's.

A Finnish "kick-slegde" on the Kilpisjärvi ice. (Ilya Aslamov)

High tech exploration of water flow inside glaciers

Maarja Kruusmaa, Jeffrey Andrew Tuhtan & Andreas Alexander



Although the summer in Svalbard is short, polar days are long, causing the surface of glaciers to melt suddenly and rapidly. With air temperatures increasing due to climate change, this melting can accelerate. Due to the large slopes on many glaciers, the meltwater quickly forms streams on the glacier's surface, which grow into a network of channels carving out flow patterns across the ice, some even form tunnels inside and below the glacier. As the amount of collected water increases, these channels go from a mild trickle to roaring rapids, and can speed up the movement of the glacier.

Deployment of the sensors. (Andreas Alexander)

AIMS OF THE PROJECT

Our aim was to make detailed maps of how glacial channels evolve over time and space. These maps will help glaciologists to improve their hydrological models. We aimed therefore, to measure the physics of water flow in glacial meltwater channels, using drifting sensors. The sensors measure the water temperature, pressure, geomagnetic field, water stream rotation rate and acceleration. Using this data, we can create maps of the flow velocity, acceleration, pressure and temperature of the glacial water. Current methods rely on collecting field data at various points and require large and expensive equipment. The drifters are a new way to measure continuously along the whole channel, and provide new kinds of data.

WHAT DID WE DO?

Previously, we developed and tested smart sensor systems for hydrological measurements, with a focus on alpine rivers. Since the environments are physically similar, we were certain that the sensors would be reliable enough to survive Arctic conditions. Deploying them is very easy. We hiked out to the glacier, activated the sensors, said "Goodbye", and tossed them into the meltwater channel on the glacier. There is a small caveat: you need to recover the sensors to read the data! So, the hardest part was figuring out how to catch these small, rapidly drifting gadgets when they emerge from the englacial (exit) channels. After returning from the field experiments, we recovered a treasure-trove of data. The last and least exciting bit is downloading, storing and processing all that.

WHERE DID WE WORK?

INTERACT granted us access to the Norwegian Polar Institute Sverdrup Research Station in Ny-Ålesund (Svalbard). Near the Ny-Ålesund settlement there is the easily accessible Austre Brøggerbreen Glacier. The test site was about two hours hike away and as such we were able to return to the base station for overnighting. We found meltwater channels on the surface of the glacier, and were lucky enough to have hit the peak ablation period (period of melt) for our target site. We also found a relatively large supraglacial (surface) channel that disappeared into a moulin (hole in the glacier eroded by water) and resurfaced at the glacial front about 1 km downstream.

WHAT DID WE FIND

While travelling downstream, the drifting sensors recorded the magnetic field, rotation rate, acceleration, pressure and temperature of the water. We can combine the sensor signals to reconstruct the stream's profile. For example, we are able to answer important questions related to the melt rate such as what are the maximum velocities and accelerations in the channels? Also, we got a good look at the channel morphology (shape and structure), which is often very difficult to measure in the field, or remains entirely inaccessible to humans and their measuring instruments. For example we can detect and quantify if there are any falls, knickpoints, chutes or slides, even under the ice.

Entrance of the englacial channel: the stream of meltwater disappears inside the glacier where directly observing and measuring the water flow is no longer possible. (Andreas Alexander).

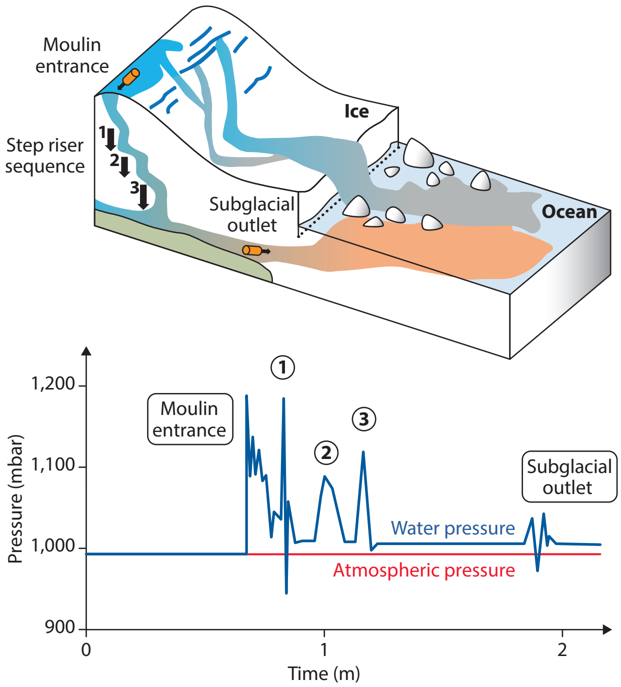
Sensor retrieval after it reappears from the englacial channel at the glacier front. (Andreas Alexander)

WHY ARE THE RESULTS IMPORTANT?

The meltwater channels in and under the glaciers have an impact on how glaciers are moving. Essentially, water moving under the ice lubricates the contact surfaces and increases the motion of the glacier. If the channels get pressurised, then they might lift up the glacier from the base and the glacier can start surging (rapidly "flowing"). Rapid water flow also means increased warming of the ice. Previously it was however almost impossible to measure inside those channels. With our results we are now able to show detailed flow patterns of glacial channels. This will help to improve our understanding and models of glacier dynamics.

THE ADVENTURE

Every day in the field was a reminder of how dependent we are on weather and that fieldwork on glaciers can be rather unpredictable, in particular when the ice is melting. The most challenging part was the retrieval of the sensors by standing in the glacier outlet in a survival suit but also coordinating the deployment of sensors via a radio communication between the entrance and outlet of the englacial channel. A day before our last planned field test we had to pack out our equipment because the channel streams had become too fast and dangerous. It did not help that the pawprints of a mother polar bear with two cubs were spotted along the edge of the glacier. It was always good to return to the Ny-Ålesund station every evening, to get warm food and a warm bed.



Conceptual overview: mapping subsurface channels with multisensory drifters. As an example, the pressure sensor readings show clearly a cascade of 3 waterfalls near the moulin entrance.
(Diagram after Rennermalm et al., 2013)

2 Human impacts on Arctic environments

SECTION OVERVIEW

Until recent times, there was a widely held view that the Arctic had a pristine environment with little impact from land use. However, we are constantly learning that the environment we see today has been shaped by land use over hundreds of years and by long-range impacts from growing global activities.

In "Human impact on Arctic environments", we learn how pollution, particularly black carbon (soot), from industrialised countries reaches the Arctic snow pack and changes the surface which can affect the quality of drinking water for local settlements. In addition, the global problem of plastic pollution has reached the Arctic and we learn how concentrations of micro-plastics in sea food can be higher than in Europe. Vegetation is also changing: a 60-year study shows decreases due to the impact of land-use pressure and changes in climate. At the same time, people walking in northern mountains are introducing southern species. We end this section by learning how pollution from light may affect the navigation cues used by night flying birds and insects.

2

People impact Arctic environments in many ways including sometimes inadvertently creating new habitats.
Black-legged Kittiwake nesting on buildings in the abandoned town Pyramiden, Svalbard.
(Anne D. Jungblut)

Airborne delivery versus surface accumulation of microbes, mineral dust and black carbon onto the Greenland Ice Sheet

Liane G. Benning & Chris Trivedi

The cryosphere (the world of frozen water) plays a critical role in the global water cycle and is strongly related to global climate change, ocean circulation, and sea level. The unprecedented rate of melting of the Greenland Ice Sheet (GrIS), a major component of Earth's cryosphere, is partly driven by surface darkening linked to a decrease in surface albedo (reflection of the sun's rays). This change is closely linked to the increase in amount of light-absorbing particles (LAP) on snow and ice surfaces. Often called 'impurities', they are natural materials made up of a combination of aerosol-delivered black carbon (soot), mineral dust, sea salts and microbes. When these particles land, they interact with the snow and ice crystals and with the coloured algae that bloom during the summer melt season. Together they contribute to reducing the albedo and speeding up melting. We do not know however, how many of each type of airborne particle are delivered to the GrIS surface and we do not know what happens to them once they land and interact with inorganic materials and the quickly changing pigmented algae already on the surface during a melt season.

AIMS OF THE PROJECT

We aimed to assess the fluxes, composition and activities of chemical and biological components in such 'impurities' delivered through aerosol inputs to the GrIS surface and quantify the changes they are undergoing and the role they play in triggering the surface algal bloom during the summer melting.

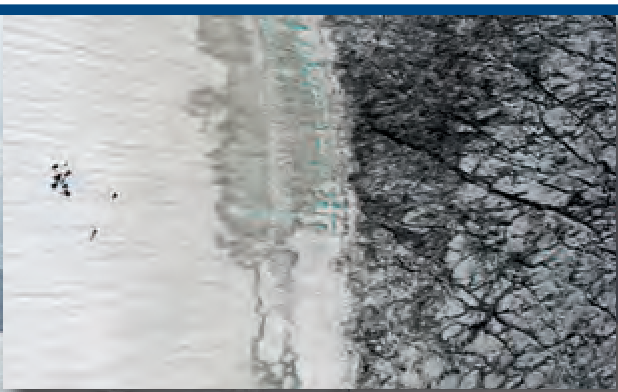
WHAT DID WE DO?

We sampled air as well as surface snow and ice and through combined microbial, geochemical and mineralogical analyses we evaluated their composition and the potential of aerosol vs. surface colonising microbes to use the nutrients from "impurities" through "bio-mining".

WHERE DID WE WORK AND WHY THERE?

In July 2019 we sampled air and surface snow/ice on Mittivakkat Glacier (a maritime, Subarctic, low altitude glacier accessed from the INTERACT Sermilik station). We also flew across Sermilik Fjord onto the Greenland Ice sheet and collected similar sets of complementary air and surface samples to add the SE Greenland component to our existing aerosol and surface data from several other locations around Greenland. All these data sets will ultimately be combined with year-round monitoring data about climatology, local climate gradients, snow depths, and albedo at stations around Greenland.

Site on the Greenland Ice Sheet with researchers setting up for collecting an air sample far upwind from the helicopter and any other team members.
(Laura Halbach)



Clean snow to dirty — mineral and algae laden — ice transition melt zone in the upper part of the Mittivakkat glacier in July 2019. At left, on the white snow, are people for scale. (Laura Halbach)

One of the 'field-labs' we set up in a 'bedroom' in Sermilik Station for processing our samples. (Matthias Winkel)

WHAT DID WE FIND?

Our work is ongoing and we have in part been disrupted by COVID19. Nevertheless, our analyses of the mineralogy, geochemistry and DNA sequences of our air and snow/ice surface samples so far revealed "impurities" from both air-delivery and local sources. There were clear differences between the chemical composition and microbial diversity of air-delivered inorganic and primarily bacterial 'impurities' compared to the local minerals and the snow and ice surface microbiomes (microbial communities) dominated by pigmented snow and ice algae.

WHY ARE THE RESULTS IMPORTANT?

We aim to use the air and surface data sets to combine with similar sets that we collected using the same methods at several other locations around Greenland. This will be a first Greenland-spanning data set on what types of 'impurities' are delivered via air or snow and what happens to them once they are changed on the surface through interactions, for example, with local biota during melting. Analyzing these components on the ever faster melting Greenland Ice Sheet surface will ground truth and help validate satellite observations for predictive numerical model development and improvement.

THE ADVENTURE

Our days usually consisted of a beautiful walk to the Mittivakkat Glacier, sampling and on-ice experiments and sample processing and returning with heavy backpacks with loads of samples to continue the work in the 'lab' that we set up in the Sermilik Station. Naturally, we had a lot of day chores like cooking, cleaning, getting water, 'toilet duty' etc. However, the most palpable excitement came when we had the opportunity to charter a helicopter and fly across the large Sermilik Fjord to sample air, snow and ice on the Greenland Ice Sheet. For many of the team members this was their first helicopter flight and although for several days we could not fly due to bad weather, eventually we got there and it was pure magic. The weather was glorious, the sample sets we collected were perfect and the 'hilo-ride' over the massive ice sheet and across the fjord absolutely magnificent. This is what many of us live for each summer. Unbelievable beauty, very hard work and loads of fun.

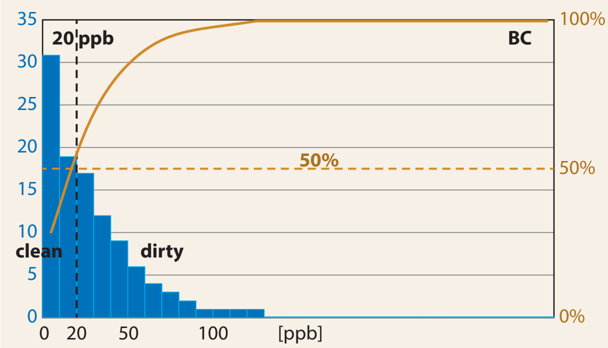
One of the few peaceful afternoons when 'fishing' in front of the station was possible; this resulted in a marvellous gourmet dinner extravaganza. (Laura Halbach)

Black carbon in snow and water in Iceland, the Faroes and Scotland

Outi Meinander

When light-absorbing aerosols (small particles suspended in air) such as soot (black carbon, BC), ash, wind-blown dust and the so-called brown-carbon fraction of organic carbon aerosols (OC) are deposited in snow and ice, they reduce the reflectivity of ground surfaces (albedo) and induce increased melt of a now darker surface, which further lowers albedo and increases melt. This is called the ice-albedo feedback mechanism. Albedo feedback is one of the mechanisms causing Arctic amplification, which refers to a stronger climate change in the Far North.

The OCEC analyzer of the aerosol laboratory at the Finnish Meteorological Institute, Finland, is used to detect BC in the filters of snow and water samples. (Outi Meinander)



Histogram of BC concentrations [ppb] in Arctic snow, where 20 ppb indicates clean seasonal surface snow. Increased BC can be due to snow melt enhancement or long-range transported BC. (Data from Meinander et al. 2020)

AIMS OF THE PROJECT

The aim of the project was to investigate and measure black carbon, organic carbon, and dust in the snow and ice, and natural water and drinking water in and around three INTERACT stations in Iceland, the Faroe Islands and Scotland, UK. These stations were chosen as they experience snow in the winter, they are located close to each other, and they are potentially influenced by the transport and deposition of Icelandic black dust and long-range transported black carbon. The project also aimed at filling geographical gaps in the current black carbon data collection.

WHAT DID WE DO?

In the field, we collected snow, ice and water samples. During the station visits, we melted snow and ice samples and filtered all of them. We then placed the filters in sterile petri slides, air-dried them, and carried them back to the aerosol laboratory at the Finnish Meteorological Institute, where the filters were analysed for their black carbon, organic carbon and dust contents.

For the Iceland investigations, the focus was on the seasonal and spatial variabilities of BC contents. The scientific question also asked where BC ends up when snow melts. We sampled snow and water in February during the cold season, natural water in April soon after the snow melt and later in July. Sea water samples were also taken. Reference materials included snow, ice and water samples from elsewhere in Iceland. In the Faroe Islands, we focused on the spatial variability of BC from metre to kilometric scales. We sampled snow from various altitudes on the highest mountain of Slættaratindur (Flat summit, 882 m asl), where we measured that snow depth was up to 50 cm, and from elsewhere around the Faroes. In Scotland, the samples taken at the ECN Cairngorm site and around Cairngorms National Park represented snow and water from spring, stream and lake, including the River Spey.

WHERE DID WE WORK?

The work was conducted in and around Iceland's Sudurnes Science and Learning Center, the Faroe Islands Nature Investigation FINI and the UK Environmental Change Network, ECN Cairngorms.

WHAT DID WE FIND?

The first results showed that we did not find any BC in the drinking water of the stations. However, we were able to detect not only BC and OC in our snow samples but also the amount of dust (or lack of dust). On the basis of earlier Arctic snow results elsewhere, we expect clean snow to contain less than 20 µg/kg BC and enrichment in melt to contain up to more than 60 µg/kg BC, i.e., an enrichment factor of about 3 due to processes occurring after the deposition of snow.

The ECN Cairngorms in March 2019, at the end of seasonal snow melt period. (Outi Meinander)

The Sudurnes Science and Learning Center pond at the Reykjanes Peninsula, Iceland, is an interesting natural water environment with, e.g., pond snails, ramshorns and water boatmen. (Outi Meinander)

WHY ARE THE RESULTS IMPORTANT?

Seemingly small amounts of BC in snow, of the order of 10–100 parts per billion by mass (ppb), decrease its albedo by 1–5%. BC deposition in snow and ice can therefore strongly contribute to their darkening and melt via black-carbon-on-snow reduced albedo. The impurity results for snow in Iceland, the Faroes and Scotland are needed to fill in the geographical gaps in the current black carbon data collection. Critical questions also include the role of BC in the carbon cycle budget and where the BC ends up when snow melts. Our results can be used to study the origin of BC and deposition estimates of black carbon and dust, as well as to assess their impacts on climate and the cryosphere (snow and ice) in the cold climate regions at high altitudes and in Arctic latitudes. Such assessments are made, e.g., by the Arctic Council's Arctic Monitoring Assessment Programme (AMAP) and the Intergovernmental Panel on Climate Change (IPCC).

THE ADVENTURE

Our field work took place in winter when various kinds of weather extremes and snow could be expected. In Iceland, a yellow alert for extreme weather and strong winds in many (most) parts of Iceland occurred during all the visits. In the Faroe Islands, almost 80% of the Islands have an Arctic climate, and previously, some avalanches have occurred there, too. Our field work there included hard climbing up the highest mountain with up to 50 cm of snow on the slope. The ECN Cairngorm, Scotland, in turn, is the coldest and snowiest plateau of the UK.

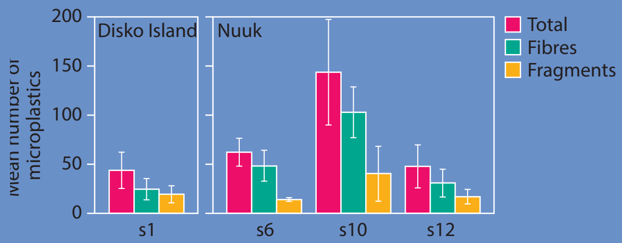
Snow around the mountain Slættaratindur, the highest mountain of the Faroes. (Outi Meinander)

Biodiversity changes and microplastics on Arctic beaches

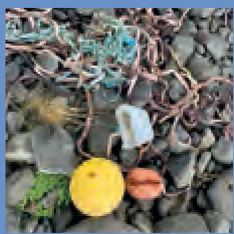
Catherine L. Waller, Huw J. Griffiths & Stephen J. Roberts

Changes in climate and their impacts on the Arctic intertidal zone are likely to have dramatic impacts on the species that live there. In lower latitudes, the intertidal zone (the beach) is the marine 'canary in the coal mine' with changes in species ranges and establishment of invasive species, due to climate change, being observed here first. The invasive brown algae Fucus serratus *that has previously only been recorded from South-West Iceland was recorded at three northern locations and may be an indicator of climate change.*

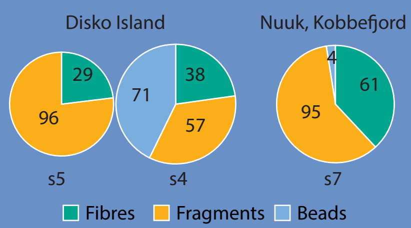
A selection of periwinkles from the beaches of Raufarhöfn, Iceland.
(Huw J. Griffiths)



Mean number of particles per 50 g of sediment from Greenland samples (labelled s1 to s12).

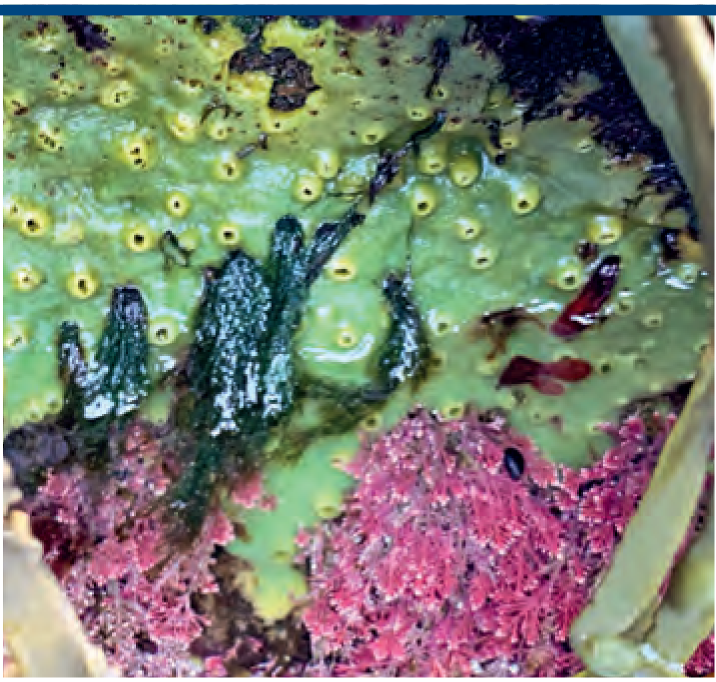


Plastic waste on a beach in north-eastern Iceland.
(Huw. J. Griffiths)



Example results showing the average number of microplastic particles found per *M. edulis* at sites on Greenland.

One of our research sites in Qeqertarsuaq, Greenland.
(Huw J. Griffiths)



A green sponge and calcareous pink seaweed on Sandvík Beach, Iceland. (Huw J. Griffiths)

A raspberry and orange sea star, a young *Henricia sanguinolenta* on Sandvík Beach, Iceland. (Huw J. Griffiths)

AIMS OF THE PROJECT

Our objectives were to understand and predict the response of the Arctic's intertidal environment to ongoing and future climate changes. We also wanted to assess the impact of microplastic pollution both in sediments and in intertidal animals and plants.

WHAT DID WE DO?

Overall we sampled and recorded the biodiversity and zonation of 21 beaches by sampling 189 quadrats. A multispectral drone, which takes photographs using wavelengths of light not visible to the human eye, was used to map 12 beaches and we took 44 sediment samples for microplastic analysis. We wanted to establish a baseline understanding of the intertidal in the Arctic and Subarctic and to compare this with historic records. In Iceland, we used drone technology and infrared imaging to map seaweeds, sediments and macroplastic pollution across whole beaches.

WHERE DID WE WORK?

We sampled beaches on the west coast of Greenland (Arctic Station, Disko Island and Kobbefjord) and the south-western and north-eastern Iceland (Sudurnes Science and Learning Center and the Rif Field Station).

WHAT DID WE FIND?

Biodiversity at the Greenland sites was low, especially when compared to a German study undertaken in 1998. The number of species in the current study ranged from 0-6 algal species and 3-9 invertebrate species across all sites, compared to 42 faunal and 32 algal species in the previous study. Currently, we have processed 70% of the samples collected for microplastic analysis from Greenland. Analyses have shown that all samples of intertidal sediment and *Mytilus edulis* (common mussel) from all of these sites contain microplastic fibres, beads and fragments.

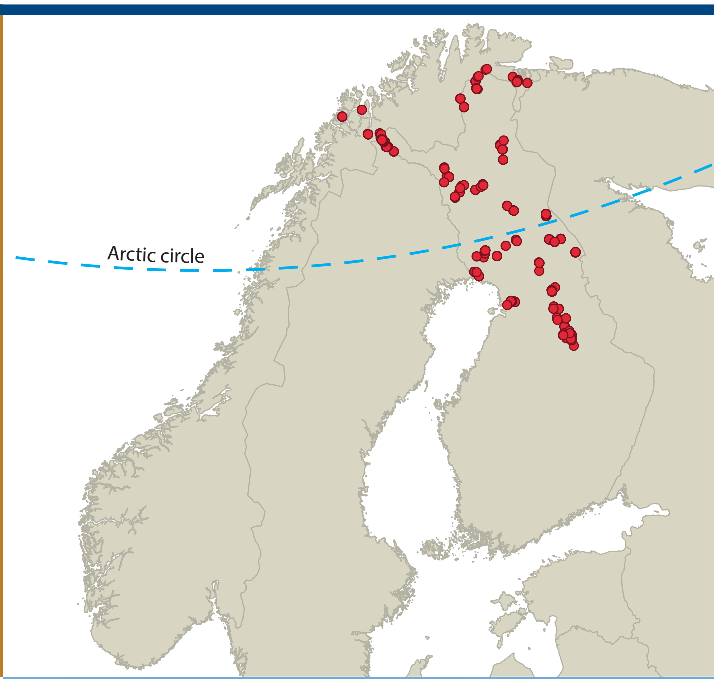
WHY ARE THE RESULTS IMPORTANT?

In these times of increasing awareness of plastic pollution, it was not surprising to find macro and microplastics in every location we have examined so far. However, we were shocked to see levels of microplastic pollution in West Greenland mussels that were as high as those found in China and higher than the same species in Germany. The levels in intertidal sediments were an order of magnitude higher than at populated sites across the globe.

The samples and data generated by our work are contributing to several PhD, MSc and undergraduate studies.

THE ADVENTURE

Working in Greenland and Iceland was an adventure every day. When travelling to our sampling locations we saw ice sheets, fjords, icebergs, waterfalls, volcanos and thermal springs. Working on beaches in both regions meant that we were treated to beautiful views of the sea and were surrounded by nature, including fearless seabirds and feeding humpback whales! One of the nicest parts of working in remote regions with small human populations is meeting the locals. In both countries, the people were warm, friendly and welcoming. Not only were we welcomed onto private land to do our work, but also we were then invited into their homes and given tea and cake when the work was done. We met their children, favourite dogs and even a one eyed pet lamb called Odin. For those of us who usually work in the unpopulated South Polar Region, working in the Arctic was particularly special for the warm welcome we received.



During our study projects, we have resurveyed a total of over 700 vegetation plots in Finland and northern Norway that include treeless heath and tundra sites (about 260 sites), boreal forests (c. 380 sites) and mountain birch forests (about 60 sites).

Vegetation changes in the Fennoscandian tundra over 60 years

Jutta Kapfer & Tuija Maliniemi

Resurveying historical vegetation data has become a widely applied method for studying long-term vegetation changes in relation to environmental change. Because of the remoteness of high latitude environments, long-term monitoring of vegetation sites in such areas is rare. Old studies of vegetation structure are unique sources of data that can be utilised to detect vegetation changes in these environments that are facing rapid climatic warming.

Reindeer is an important driver of vegetation change. In areas with high grazing intensity, lichen grounds are affected strongly resulting in changes in the structure (height), composition, and diversity of species. (Jutta Kapfer)

AIMS OF THE PROJECT

The aim of the project was to describe and better understand long-term vegetation changes and what causes them in boreal treeless heath and Subarctic tundra habitats in northern Fennoscandia (the northernmost parts of Norway, Sweden and Finland).

WHAT DID WE DO?

In 2017, we resurveyed tundra vegetation about 60 years after the first survey by Matti Haapasaari in the 1960s. To allow the comparison of changes over time in species composition and diversity we used the same methods as in the original sampling: we relocated vegetation plots of 2 m × 2 m size in the same vegetation types and noted the abundance (ground coverage) of all vascular plant (flowering plants and ferns), bryophyte (mosses and liverworts) and lichen species.

WHERE DID WE WORK?

Staying in Kilpisjärvi Biological Station and in Sodankylä Station in northern Finland allowed us to study treeless heath and tundra communities that varied from having many species (Kilpisjärvi area) to being species poor (Sodankylä area). The data from the 2017 survey fed into the dataset of a larger project on vegetation changes across the boreal and Subarctic Fennoscandia.

The dwarf-shrub crowberry (*Empetrum hermaphroditum*) has become more frequent in the study site, especially in habitats that previously were dominated by bilberry (*Vaccinium myrtillus*). (Tuija Maliniemi)

The main vegetation types resurveyed in the Fennoscandian tundra were those dominated by crowberry (*Empetrum hermaphroditum*; top) and bilberry and dwarf-birch (*Vaccinium myrtillus, Betula nana*; bottom). Vegetation plots of 2 m × 2 m size were used to study species diversity and composition. (Jutta Kapfer)

The abundance of several lichen species with N-fixation functions (e.g. *Peltigera aphthosa*, top) have decreased across the study area, in some cases substantially. Many cup-bearing Cladonia-species (bottom) decreased in the more continental and species-poor Sodankylä area. (Tuija Maliniemi)

WHAT DID WE FIND?

The most conspicuous change was the pronounced increase of crowberry (*Empetrum hermaphroditum*). Crowberry increased primarily on sites that previously were dominated by bilberry (*Vaccinium myrtillus*) or dwarf birch (*Betula nana*). Surprisingly, we did not observe a general increase in taller shrubs as is reported for circumpolar tundra by other studies. This is most likely because our sites were more controlled by reindeer grazing. Decade-long grazing has deteriorated lichen grounds, whose cover and diversity had diminished substantially across the study area.

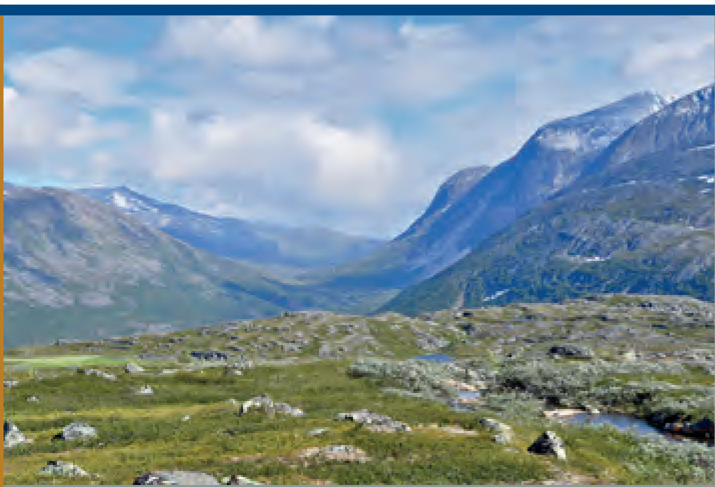
WHY ARE THE RESULTS IMPORTANT?

Our results together with the wider survey show that the vegetation in high-latitude habitats across the North European tundra has responded to changes in climatic conditions and land use pressure over the past decades. Increasing crowberry abundance and intensive reindeer grazing may further lead to less diverse and more similar plant communities. However, larger scale species turnover within and between communities is yet to be studied.

THE ADVENTURE

The most exciting experience was to see the Great grey owl (*Strix nebulosa*) for the first time. Unfortunately, the pleasure of seeing this rare bird alive was rather short as it got hit and killed by a car only seconds later, obviously driving too fast. The Great grey owl, with its huge head and incredible abilities, like flying totally silently to hear mice under the snow, should still have lived there near its secret nest and given rise to new generations of these beauties. The car that killed it may be a symbol of how humans behave towards nature: We move too fast to see what is there, and our speed harms the diversity of our environment.

Great grey owl, the largest owl in the Northern Hemisphere, killed by a car. (Jutta Kapfer)



Roads bring lowland plants to high elevation areas such as the Skjomen Valley in northern Norway.
(Adapted from Lembrechts et al. (2017))

Plants moving along mountain roads and trails

Jonas Lembrechts

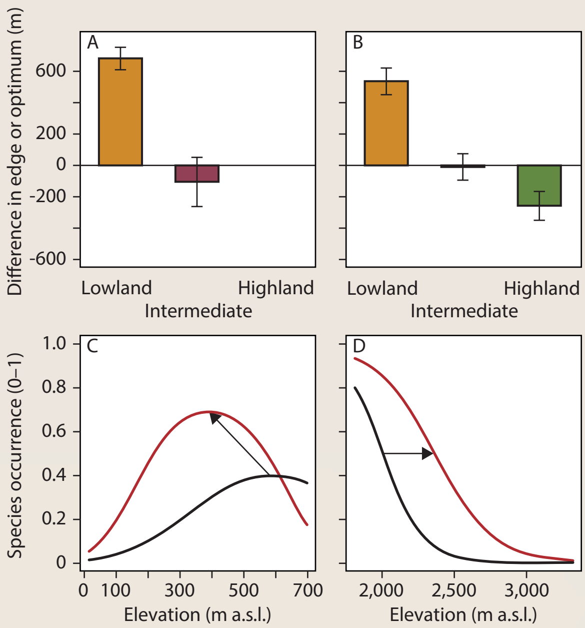
Disturbances such as roads and trails have a major impact on all aspects of the environment, and thus consequently on the distribution of plant species living there. This impact is so direct and so intense that the plant communities in road- and trailsides differ fundamentally from the natural vegetation a few metres away from the road or trail.

AIMS OF THE PROJECT

We aim to show how climate and land use changes initiate major reshuffling of plant species distributions along road and trail-sides.

WHAT DID WE DO?

We track the movements of native and non-native plant species along mountain roads and trails, which plants extensively use to travel up and down the mountains. Since the summer of 2012, we have been observing a series of long-term biodiversity monitoring transects (observation sites along a gradient of altitude) along three roads and ten hiking trails in the northern Scandes (Scandinavian Mountains along the border of Sweden and Norway). These transects are used to monitor vegetation both in the disturbed road- and trailsides and in the natural adjacent vegetation. We make these surveys, every two to five years and measure microclimate, soil conditions and root-colonising fungi.



Non-native lowland species (A) have moved on average more than 600 meters higher along mountain roads. Similarly, native lowland species (B) have moved up close to 600 m higher, while native alpine species have moved 200 meters lower along mountain roads. C and D show examples of an upward (C) and downward (D) elevational shift (black line = natural vegetation, red = roadside). (Adapted from Lembrechts et al. (2017))

Tough hiking through a snowstorm in late August in Laktatjåkka Valley, northern Sweden. (Jonas Lembrechts)

WHERE DID WE WORK?

While our research has a global scope, with similar monitoring sites installed in a network of more than twenty mountain regions across the world, our INTERACT-related research focusses on the northern Scandes. We use the beautiful ANS Research Station in Abisko as our home base, and wander from there along the trails and roads of northern Sweden and Norway.

WHAT DID WE FIND?

Roads dramatically change the local microhabitat: more extremes of cold and heat in roadsides, acidity of the roadside soils is a lot less than in the typical tundra vegetation and nutrient and moisture regimes are disrupted. These changes inevitably result in a massive change in plant species distributions. But there is more: roads and trails also provide the perfect transport system for plants up and down the mountains, as seeds hitchhike in the mud under our shoes or attached to our cars. Lowland species use these linear disturbances to move uphill, and alpine species travel down to the valleys, creating a unique community along these roads and trails of species that have never seen each other before.

WHY ARE THE RESULTS IMPORTANT?

These results show that the direct impact of us humans on mountain vegetation can be several magnitudes more intense than what is seen as a result from climate change, albeit much more local. Yet with those two major global changes (land use and climate change) acting together, the effect on mountain plant communities is truly devastating. The main outcome of our research is thus a call to all who want to hear: help reduce the human impact on our vulnerable mountain regions to save its biodiversity. That means less road building and less economic activities. On a smaller scale, you can contribute as well: please stay on the trails when hiking through the mountains, to limit further impact on the vegetation around you.

THE ADVENTURE

Our fieldwork included a lot of beautiful mountain hiking in the northern Scandes. From the smooth hills on the Swedish side to the steep cliffs and fjords of northern Norway, our days outside were always blessed with beautiful views. From blazing hot days of Arctic summer that required cooling down in a Norwegian fjord, over endless depressing hours spent with frozen fingers surrounded by somber grey low-hanging clouds, to brave plant identification adventures in gushing snow storms, we have seen it all over the past 7 summers. What have we learned from this? The rainbow is often only one valley away, and nothing beats a good piece of Swedish chocolate after a long hike (but its taste is highly temperature dependent).

Plant seeds hitchhike uphill, attached to the clothes or shoes of hikers, here on a trail in Laktatjåkka Valley, northern Sweden. (Jonas Lembrechts)

Recording communities of tiny alpine plants in northern Sweden (Abisko Village in the background). (Jonas Lembrechts)

Arctic night skies show effects of light pollution on nocturnal orientation

James J. Foster & Marie Dacke

For night-time navigation, nocturnal animals such as many night-active bird and insect species must rely on the positions of the moon and the stars, as well as the faint pattern of polarised light (light that vibrates at a narrowed range of angles) produced as moonlight scatters in the upper atmosphere. These cues are being investigated around the world but the Arctic night skies are important because of phenomena such as the northern lights and anticipated lack of light pollution by urbanisation and industry.

AIMS OF THE PROJECT

We aimed to understand the cues in the night skies that animals use to navigate. We measured starlit and moonlit skies between new moon and first quarter, as skylight shifts from a brightness-pattern dominated by the Milky Way to a pattern of brightness and polarisation driven by scattered moonlight.

WHAT DID WE DO?

The long Arctic winter nights and low air pollution allowed us to conduct repeated measurements of night skies, using a high-sensitivity calibrated camera system to measure the starlight and polarised lunar skylight visible over Sodankylä. We recorded high-dynamic-range images of starlit and moonlit skies that could be converted to estimates of spectral radiance (photons per second in the red, green and blue regions of the spectrum) and polarisation. By arranging our fieldwork for March, we were able to exploit the long nights and clear skies to collect repeated measurements with a range of exposures and conditions. Back at Lund University, we used custom software to combine these images into spectral radiance maps across the sky, revealing the brightness, colour and polarisation patterns that help nocturnal animals to find their way. We then simulated the information available at different resolutions — as seen through the eyes of nocturnal animals. In other work, we compare these images with ones recorded in other biomes to determine how they vary across the globe.

Night-time temperatures ranged between –21°C and –17°C during our fieldwork.
(Therese Reber)

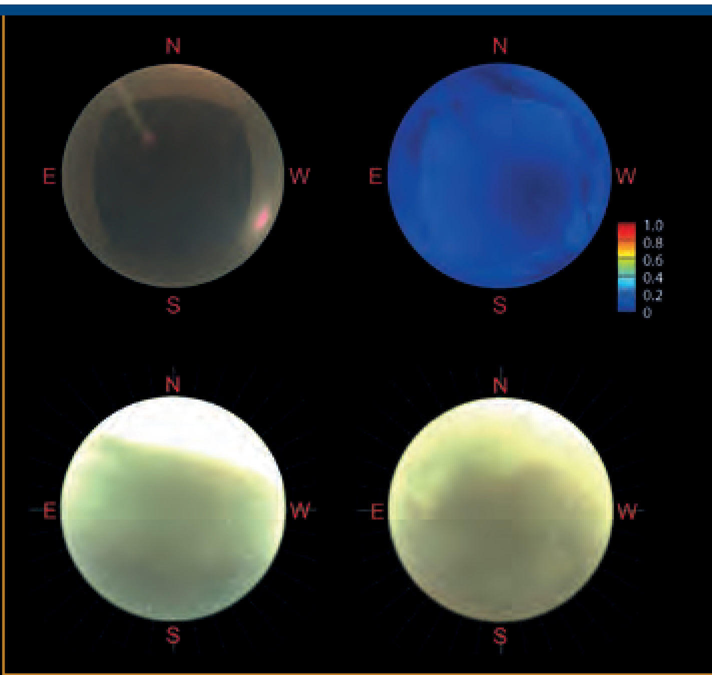
Aurora Borealis over the FMI Arctic Research Station, captured from the top of a 16 m meteorological tower.
(James J. Foster)

WHERE DID WE WORK?

We performed our measurements at the top of a 16 m tower at the Finnish Meteorological Institute (FMI) Artic Research Station in Sodankylä, normally used for meteorological measurements. This tower provided an excellent vantage point above the surrounding boreal forest and allowed us to compare lunar skylight polarization with solar skylight polarisation previously measured during midsummer at the same location. As a ground-level alternative, we also set up our tripod at the centre of the frozen Kitinen River.

WHAT DID WE FIND?

While one of our aims was to measure the brightness-pattern produced by the Milky Way across the clear sky, nature had other plans. Our fieldwork coincided with a period of intense solar activity that produced stunning Auroras, far outshining the dim Milky Way. Our measurements suggest that Auroras may also act as reliable orientation cues for night-active animals, since they create a North–South brightness-gradient across the sky not unlike that produced by the Milky Way. More concerningly, on Aurora-free nights the skylight polarisation pattern we measured was nearly 60% weaker than predicted, which may indicate that light pollution from nearby industry and urban areas is beginning to dilute some of the dimmer cues in the low Arctic night sky.



Patterns in a clear night sky lit by a quarter moon (West South-West): normalised spectral radiance (left) and degree of polarisation (right). We expected modal degrees of polarisation of ≈0.30, but recorded only 0.11, most likely as a result of encroaching light pollution. Foster et al., 2019.
(James J. Foster)

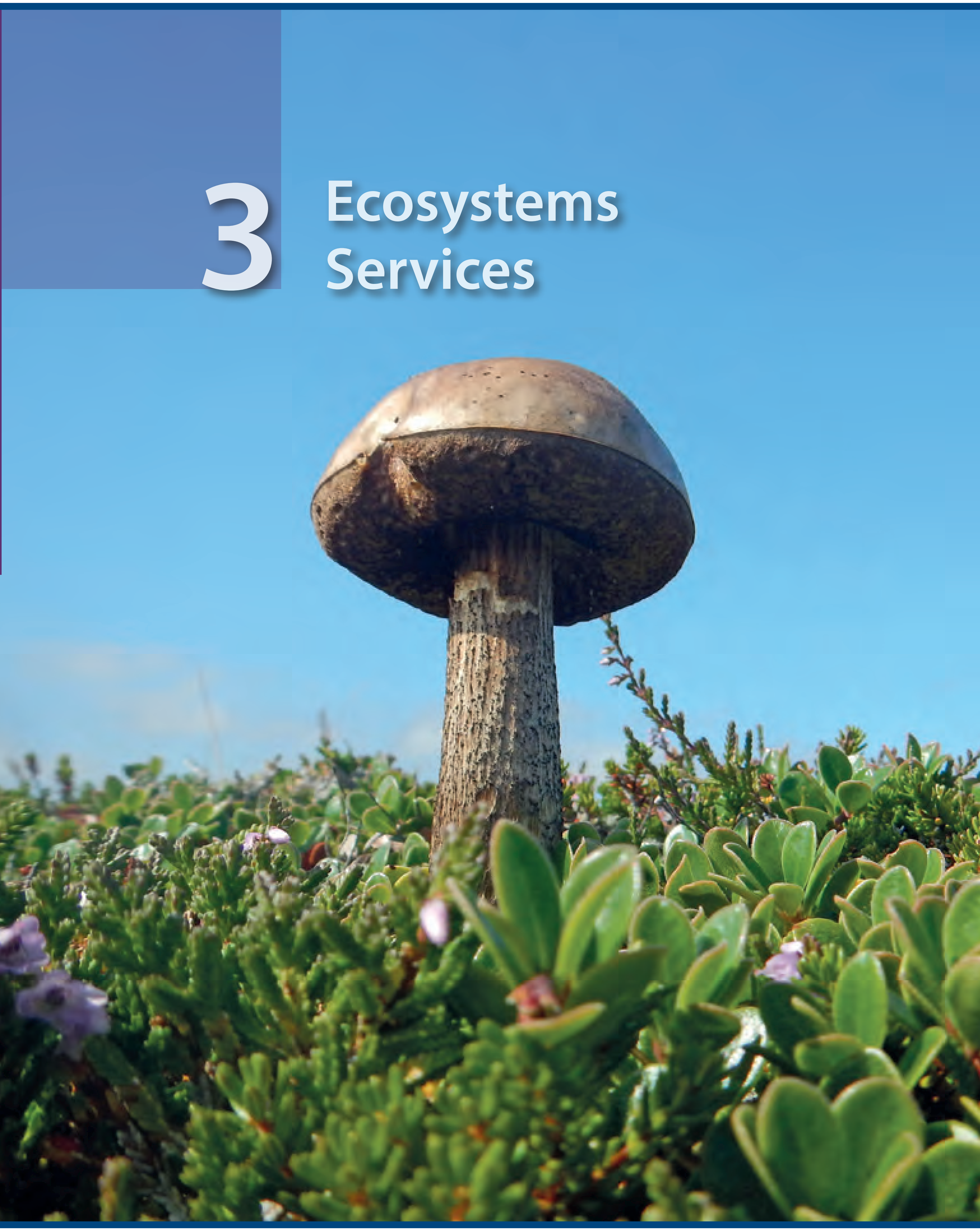
WHY ARE THE RESULTS IMPORTANT?

To mitigate the loss of animals' natural habitats to human encroachment and climate change, we need to understand what conditions animals require to travel reliably between their homes, feeding grounds and breeding sites. The loss of clear, dark nights to air and light pollution may affect biodiversity in ways that are hard to predict or quantify. By measuring the night skies around the world and estimating the information available to animals viewing those same skies, we can take the first steps towards understanding what features of natural skies are important in guiding the animals' night-time journeys, and how best to preserve these features. Uniquely, during the Arctic winter, the majority of animal activity is in darkness or twilight.

THE ADVENTURE

In addition to being long and dark, Winter nights in Sodankylä can be bitterly cold, with temperatures dipping to –21°C during our stay. We had to be vigilant to stop the camera lens from frosting up, but, when working on the Kitinen River, the nearby sauna allowed us to warm up between measurements. The tower provided us with spectacular views of the forest and river, and, since we were working at night, we had time to explore the area on skis during the day, following a track along the river's surface. Seeing the Aurora for the first time was absolutely unforgettable, but it remained every bit as astonishing even after six hours at the top of a tower in the cold night.

3 Ecosystems Services

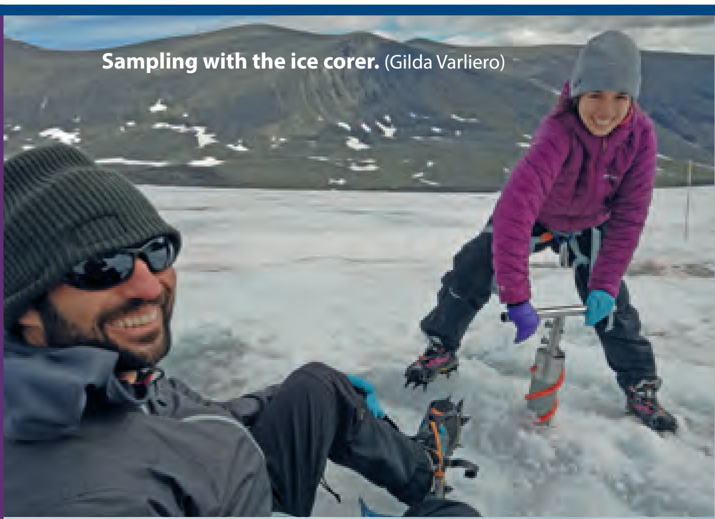


SECTION OVERVIEW

Life on Earth depends on fully-functioning ecosystems. These ecosystems provide numerous services for mankind. In the Arctic, where land use and urbanization are far less developed than in other latitudes, ecosystem services are particularly important for local communities and also for the global community through feedbacks to climate.

In "Ecosystem Services", we learn how biodiversity is changing by looking at how microbial communities develop and thrive inside glaciers. We also learn how lichen and moss communities are changing at the top of mountains and warmth-loving species are increasing in northern Sweden. Although many studies around the Arctic show that shrubs are increasing their extent in the tundra, a story from Siberia shows how some shrubs are "drowning" due to permafrost thaw while analyses of wood tell us how resilient trees will be to other aspects of climate change. Where trees are moving north and upwards at the treeline, they are squeezing the tundra between the forest and the coast in many places. Animal populations are also changing. Faster development of many insect species affects migrating bird species that depend on them for food. Bees provide essential ecosystem services as pollinators, but some bee species are particularly sensitive to the warm summers and heat waves that the Arctic is now experiencing.

Arctic ecosystems provide various services for local people and the wider community.
Mushrooms and berries provide important food for people and animals throughout the Subarctic.
(Lucrezia Hunterholzner)



Sampling with the ice corer. (Gilda Varliero)

Understanding glaciers as a biome (i.e., a large-scale ecosystem with distinct biological communities) has started only in the past few decades. This biome is dominated by microbes and is usually divided into three different habitats: the glacier's surface (supraglacial), its interior (englacial), and its base where glacial ice is in contact with the bedrock (subglacial). The englacial environment remains the most poorly understood of the three glacial habitats due to the technical challenges involved with sampling there. Yet, this environment covers most of the glacier realm and it has been suggested to host viable and active microbial communities. The water that flows in the englacial fractures could be potentially an important active portion of the glacial biome.

Microbes inside glaciers

Gilda Varliero, Andrew Fountain & Alexandre M. Anesio

AIMS OF THE PROJECT

The clear ice bands visible on the surface of the glacier "Storglaciären" are the product of the slow freezing of water within fractures deep in the glacier. The fractures are uplifted to the surface of the ablation zone (zone where ice melt is faster than ice accumulation) due to the normal flow of glaciers. The slow freezing of water, particularly when flowing, can exclude air bubbles. Therefore, ice sampled from these clear bands is bubble-free (clear ice) compared to glacier ice formed from the compaction of snow (meteoric, cloudy ice). The aim of the project was to characterise the diversity and structure of microbial communities of the clear ice band and to compare these communities to those found in the meteoric glacier ice.

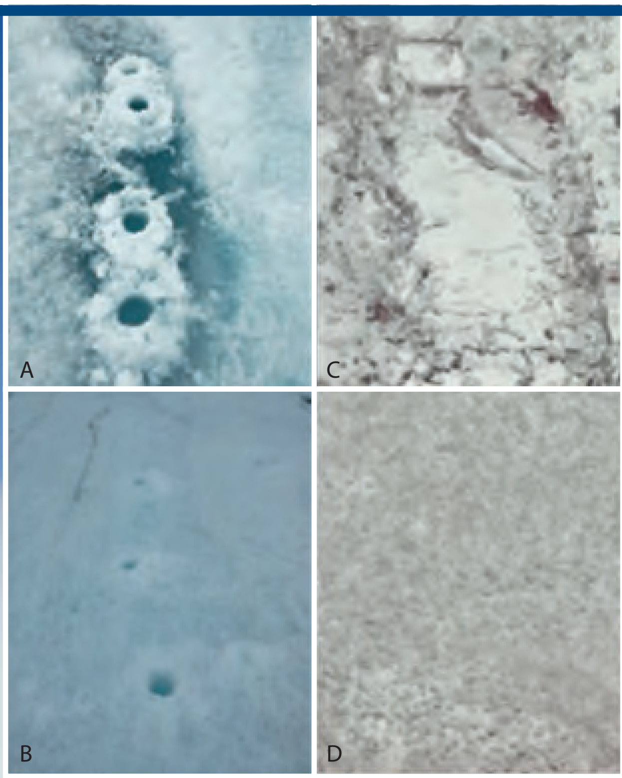
WHAT DID WE DO?

In July 2017, we collected over 60 ice cores from nine different sites in the Storglaciären ablation zone. All the cores were divided into clear and cloudy ice subsections and processed for further geochemical and microbial analyses.

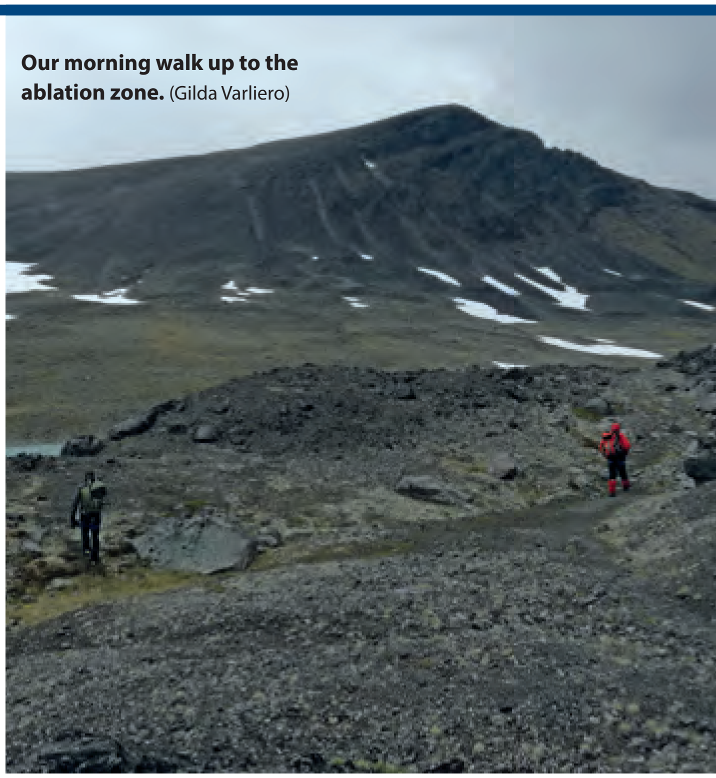
WHERE DID WE WORK?

We were based at the Tarfala Research Station, which is in walking distance from the Storglaciären, a small polythermal glacier (i.e., where the ice is wet at the base and in some areas of its interior) in northern Sweden. We processed all the samples in the research station labs where we melted, filtered and stored samples for DNA extraction and sequencing (to identify the microbes), cell counting (to look at the abundance of the microbes) and geochemical analyses (to look at carbon and nutrient recycling).

Overview of the ablation zone, the zone where glacier melt exceeds accumulation. (Gilda Varliero)



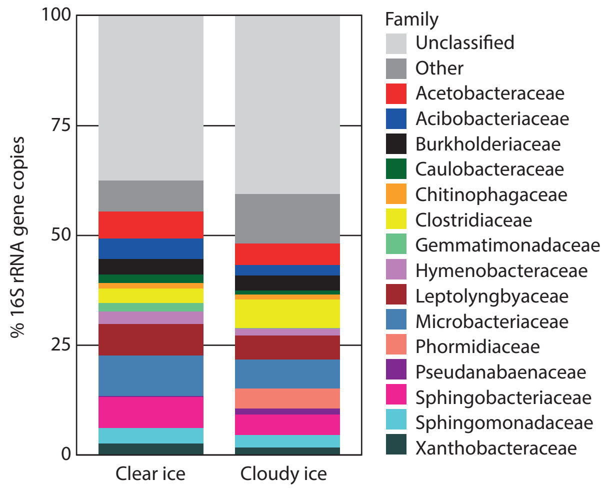
Differences between A) clear band ice and B) normal glacier meteoric ice formed from snow and firn (granular snow, especially on the upper part of a glacier, where it has not yet been compressed into ice). C) and D) show the clear ice matrix and the meteoric ice matrix respectively. (Gilda Varliero)



Our morning walk up to the ablation zone. (Gilda Varliero)

WHAT DID WE FIND?

Microbial communities showed variation in diversity and structure between cloudy and clear ice cores. Furthermore, variations in nutrient concentrations could explain those variations in the microbial community, suggesting recycling of nutrients by an active microbial community within the wet fractures of the ice interior. In one area of the glacier, the cloudy meteoric ice showed a unique microbial community, different from that in the clear englacial ice, suggesting a strong isolation of this community, while cloudy and clear ice microbial communities were very similar in another glacier area. Thus, there is a clear spatial variability of microbial communities in the englacial habitats of the glacier. Different phenomena could have shaped the different glacier areas suggesting that water flow in englacial fractures and consequent microbial dispersion are highly affected by the environmental conditions at the time of the ice formation and the opening of the englacial fractures.



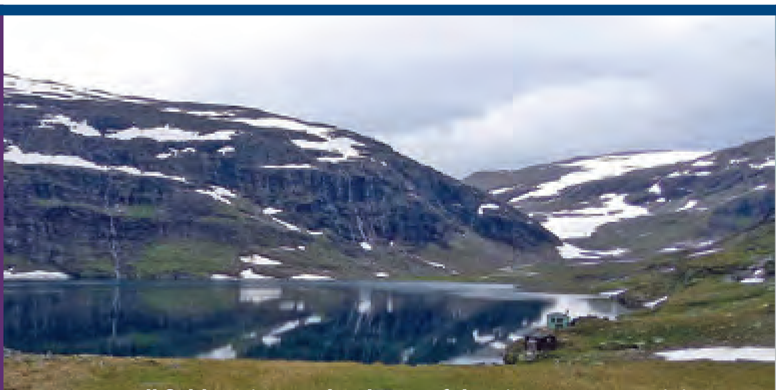
The bar plot shows the % for each group relative to all the bacteria found in the samples.

WHY ARE THE RESULTS IMPORTANT?

These results provide some first insights into the microbial communities inhabiting englacial waters. They will help improve our understanding of glacial biogeochemical processes, such as nutrient recycling and carbon transformation, from a 2 dimensional perspective (surface and/or the subglacial habitat) to a 3 dimensional view of microbial processes in glaciers. Much of the surface melt, along with carbon, flows through the englacial system, which often contains an extensive water-filled fracture system. We have demonstrated that this fracture system is inhabited by active microbial communities that transform nutrients and organic carbon.

THE ADVENTURE

We had an amazing time at the Tarfala Research Station. Storglaciären is just almost at the doorstep of the station (40 minutes of a very pleasant hike). Our sampling trip was blessed with great weather conditions making all the sampling activity very nice and enjoyable. Every morning we walked to the glacial ablation zone through its moraine, we collected the ice cores, and with our backpack full of ice, we started our descent to the lab in the afternoon. With good support from the station, nice facilities, nice people and excellent food, all felt much more like a very relaxing experience.



Small field station on the shores of the picturesque Latnjajaure Lake (about 15 km to the west of Abisko). (Liyenne Hagenberg)

Vegetation is changing on mountain-tops in northern Sweden

Liyenne Wu Chen Hagenberg, Thomas Vanneste, Øystein Hjorthol Opedal, Hanne Torsdatter Petlund, Håkon Holien, Juul Limpens, Bente Jessen Graae & Pieter de Frenne

High-mountain environments are experiencing some of the highest rates of warming under contemporary climate change. At the same time, these ecosystems are considered highly sensitive to climate change since their species are adapted to low-temperatures. Over the past decades, vegetation monitoring has shown an upslope migration and increasing number of species of vascular plants (mainly flowering plants, conifers and ferns) in montane regions across the globe. Furthermore, high-mountain plant communities have shifted towards an increasing ground cover of deciduous shrubs and graminoids (grasses and grass-like species such as sedges), at the expense of lichens and bryophytes (mosses and liverworts). These changes may have important implications for the overall functioning of high-mountain ecosystems, and may even influence the global climate system.

Researchers performing a detailed vegetation analysis on the second highest summit (Latnjachorru). (Thomas Vanneste)

AIMS OF THE PROJECT

We wanted an insight into the ecological effects of global warming on high-mountain and high-latitude vascular plants, lichens and bryophytes. The project merges long-term observations of vegetation patterns on mountain summits with climate data recorded at the sites.

WHAT DID WE DO?

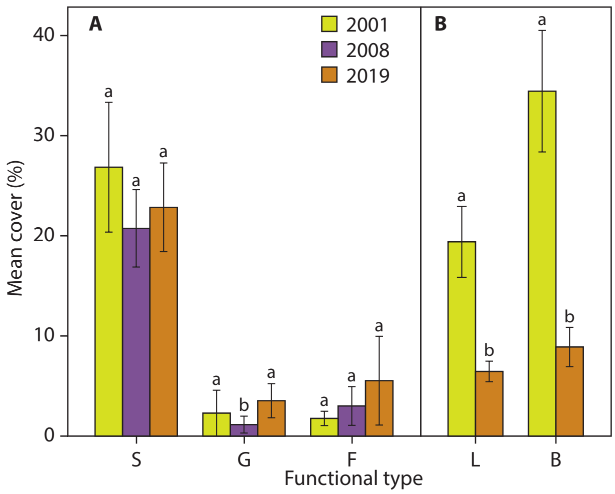
We performed the third resurvey of the vegetation on four mountain summits near the Latnjajaure Lake, northern Sweden. These summits were chosen to represent a gradient of altitude from the treeline up to the high alpine zone. Each summit was divided into eight summit area sections: two (an upper and a lower) for each slope direction (corresponding to the four main cardinal directions). Within small areas of each, we recorded for the occurrence and ground covered by all of the vascular plant, lichen and moss species following the "GLORIA Multi Summit Approach" (Global Observation Research Initiative in Alpine Environments; www.gloria.ac.at) and previous observations in 2001 and 2008. Finally, we compiled long-term climate records from weather stations in Abisko and near the Latnjajaure Lake to detect potential warming trends and changes in precipitation.

WHERE DID WE WORK?

We are working on four mountain summits close to the Abisko Research Station in northern Subarctic Sweden. One summit is easily accessible from the main road (30 minutes walking) but is botanically most challenging because of the higher number of shrubs and herbaceous plants, moss and lichen species. The three other summits are in the vicinity of Latnajaure, a research station also managed by the Abisko Research Station.

WHAT DID WE FIND?

Our results showed relatively few and minor changes over time in terms of species richness and the cover of the shrubs, graminoids and forbs. However, both lichen and moss community composition changed significantly as their diversity and cover decreased substantially during the 19-year study period. We also found an increase of species that love warmth and a decrease of cold-adapted species due to warming. This process is referred to as 'thermophilisation'.



***Betula nana* (dwarf birch, thermophilic species) encroaching on a patch of lichens.** (Thomas Vanneste)

WHY ARE THE RESULTS IMPORTANT?

Biodiversity is changing as a result of the impacts of people on the planet. In high-mountain ecosystems, especially in the Subarctic, temperature is a main limiting factor and climate warming thus can have potentially large effects on the ecosystem. Loss of species is resulting in composition change and this might have repercussions on the functioning of the ecosystem, for instance via changed albedo (how much of the incoming radiation is reflected or absorbed), changed carbon stocks in the vegetation and soil (important for carbon storage) and increased cover (important for carbon drawdown). This work contributes to the GLORIA network, that is a long-term monitoring program with 69 sites spread across mountain regions on six different continents.

THE ADVENTURE

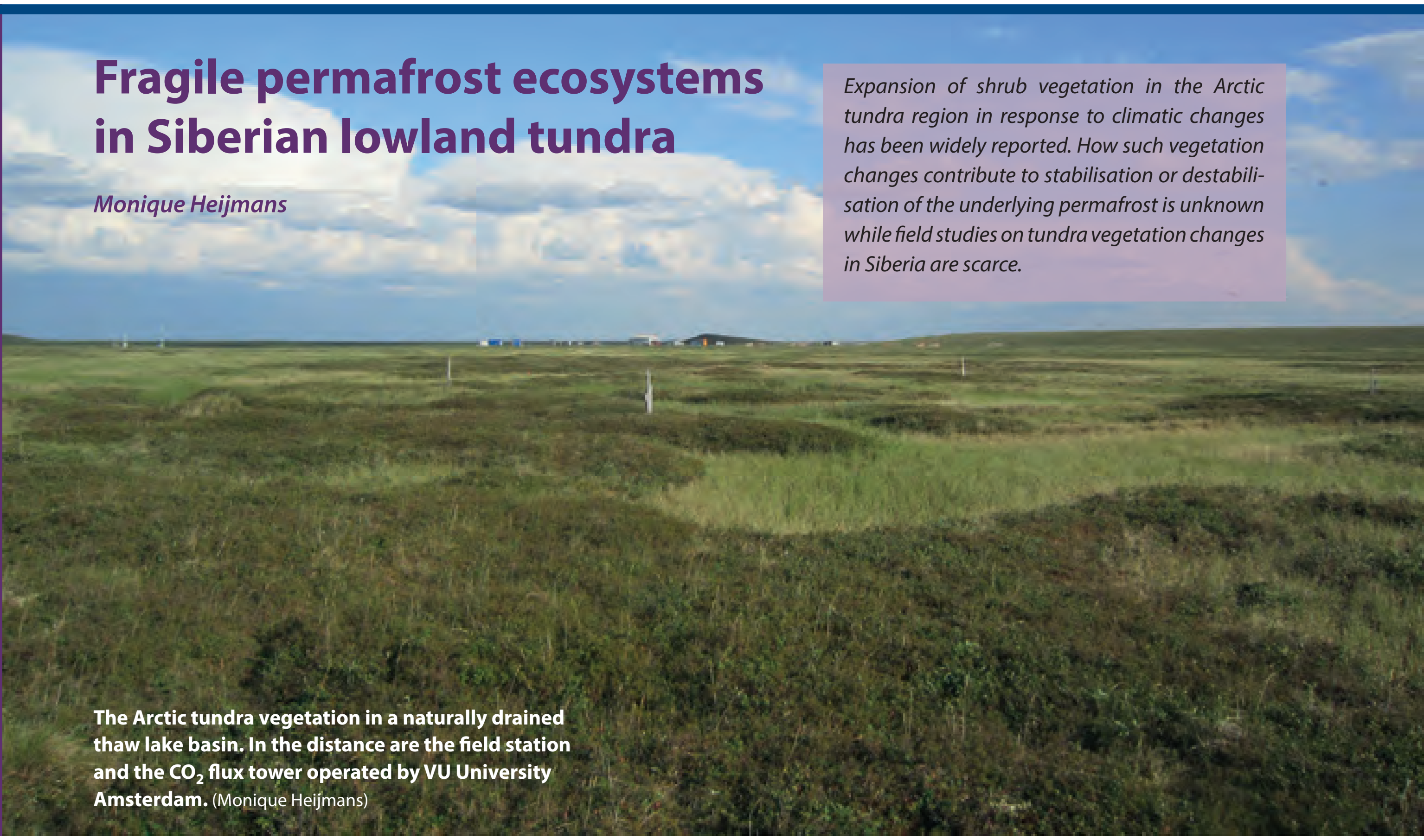
Abisko and its surroundings truly are a magical place to work in, with the majestic peaks of Lapporten in the background, the deep blue Torneträsk Lake and picturesque alpine flora. During the first week, we recorded the vegetation of the lower summit, which was easily accessible. Next, we took a heavily loaded helicopter to a small field station on the shores of the Latnjajaure Lake (about 15 km to the west of Abisko). Finally, we embarked on an adventure to the highest (and most remote) summit. After a long day's hike (with some challenging river crossings), we installed our basecamp at the foot of the mountain. The next day, the climb was difficult and dangerous as recent melting of snow patches had turned quietly babbling brooks into swirling mountain rivers. After an eleven-hour hike, we finally returned to our tents, unfortunately without successfully reaching the summit.

Percentage cover of (a) dwarf shrubs (S), graminoids (G), forbs (F), and (b) lichens (L) and bryophytes (B) in all 1-m^2 quadrats of the four study summits combined for 2001, 2008 and 2019. Line bars represent the standard error of the mean (SEM) an estimate of variation in the measurement. Different letters indicate significant differences among the sampling years.

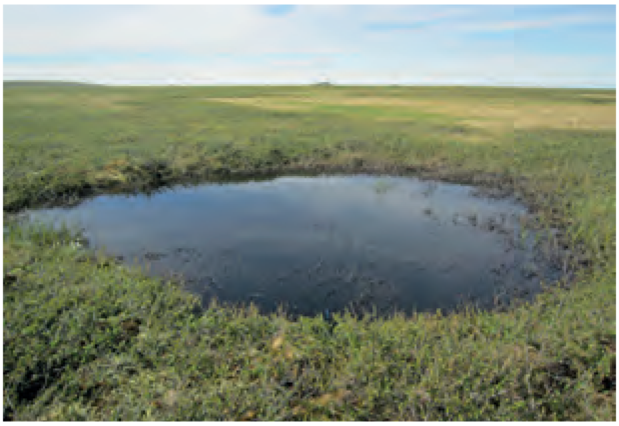
Fragile permafrost ecosystems in Siberian lowland tundra

Monique Heijmans

Expansion of shrub vegetation in the Arctic tundra region in response to climatic changes has been widely reported. How such vegetation changes contribute to stabilisation or destabilisation of the underlying permafrost is unknown while field studies on tundra vegetation changes in Siberia are scarce.



The Arctic tundra vegetation in a naturally drained thaw lake basin. In the distance are the field station and the CO_2 flux tower operated by VU University Amsterdam. (Monique Heijmans)



A young thaw pond with drowned shrubs and open water resulting from local abrupt permafrost thaw. (Monique Heijmans)

AIMS OF THE PROJECT

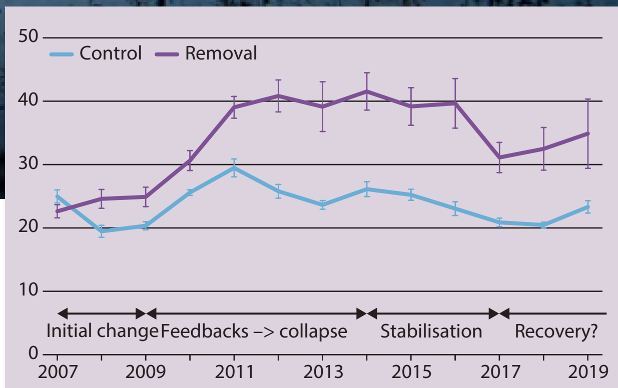
The original aim of our research was to investigate the impacts of Arctic shrub vegetation on the seasonal thawing of permafrost. However, over time we learned that the shrub vegetation at this Siberian tundra site is declining due to abrupt permafrost thaw. The research focus is shifting to understanding permafrost degradation (abrupt thaw) and the following recovery by vegetation succession (natural changes in vegetation).

WHAT DID WE DO?

In 2007, a shrub removal experiment was set up in which the aboveground biomass of the shrub species *Betula nana* (dwarf birch) was clipped off in plots of 10 m diametre. We have been monitoring thaw depths and plant species abundances since then. After a few years it became clear that the plots in which we had removed the *B. nana* shrubs were subsiding whereas the plots with intact shrubs were not.

Sampling air inside flux chambers for analysis of methane fluxes in a thaw pond with drowned shrubs and colonising cotton grasses. (Monique Heijmans)

Midnight view of the flooded tundra in summer 2017.
(Monique Heijmans)



Late-July thaw depth (cm) 2007-2019 in Control and Removal plots.

WHERE DID WE WORK?

We have been working at the Chokurdakh Scientific Tundra Station in North-East Siberia (Yakutia). The field station is located in the lowlands of the Indigirka River. From Chokurdakh, it is a 2 hour ride by speedboat to the research site, which is also known as the Kytalyk Field Station. Kytalyk is the sound and the local name for the highly endangered Siberian crane, which has its breeding grounds in this area. Despite the high latitude, the summers are relatively warm (10.3 °C mean July temperature for 1981-2010), but the winters are freezing cold (mean January temperature –34.0 °C) in the extreme continental climate there. Most of our studies are in an old, naturally drained thaw lake basin.

WHAT DID WE FIND?

As novices in tundra research, we did not know about abrupt permafrost thaw at the start of the experiment and yet it was taking place to a smaller or larger extent in our plant removal plots. One year after clipping of the aboveground biomass of the dwarf birch, we measured a larger thaw depth in these removal plots than underneath the intact shrub vegetation in the control plots. This led us to conclude that the low shrub vegetation has a soil cooling effect in summer. The experiment also showed that damaging the tundra vegetation can trigger abrupt permafrost thaw. Outside the experiment, but in the same drained thaw lake basin, we found 'natural' thaw ponds with drowned shrubs, but it is unclear what has triggered the abrupt permafrost thaw there. At the same time as we witnessed abrupt permafrost thaw, we also saw recovery of vegetation and permafrost, probably assisted by the establishment of Sphagnum mosses.

WHY ARE THE RESULTS IMPORTANT?

The results of the well-documented *B. nana* removal experiment show how important the tundra vegetation cover is for protecting the permafrost. Removal of a part of the vegetation resulted in a literal collapse of the ecosystem. It demonstrates how fragile the Arctic tundra ecosystem is. Despite the short Arctic growing season, the landscape appears highly dynamic. The results are also important as most studies of Arctic vegetation show increasing shrub growth, but data for the area where we worked are few and provide an additional dimension.

THE ADVENTURE

It is indeed an adventure. First, the flight from Yakutsk to Chokurdakh in an old Antonov airplane. In the beginning it is a bit scary, but that is compensated by the great view over the Arctic landscape. Then we experienced the reception by the local people in Chokurdakh sometimes with vodka and frozen fish, which tastes really good. Then the boat ride on the Indigirka and Berelekh rivers with muskox and new north-ward moving brown bears. Last summer, for the first time a bear foot print was sighted.

The crucial role of the forest in the resilience of boreal ecosystems to global warming is now under investigation but a question arises: "how could these changes influence tree growth and forest stand productivity in the Northern Hemisphere?" Tree growth (i.e. wood formation) at high latitudes could benefit from global warming as a result of a lengthening of the growing season but on the other hand a rapid warming could increase tree mortality from carbon starvation or hydraulic failure. The studies on wood formation can contribute to the clarification of the evolution of forest stands as well as of the carbon cycle at landscape level in cold environments.

The forest at the Hyytiälä Forestry Research Station. The plots were characterised by a managed, mixed-coniferous boreal forest dominated by Scots pine. (Maria L. Traversi)

Wood formation and carbon balance in forest trees growing in cold environments

Alessio Giovannelli & Maria Laura Traversi

AIM OF THE PROJECT

We wanted to understand if the lengthening of the growing season due to climate warming increased tree growth because of higher annual carbon capture. We explored if a greater amount of carbon in the form of soluble carbohydrates would lead to more carbon being fixed during the warmest summers in the structure of latewood cells (cells produced within annual growth rings late in the growing season). This would make wood more dense.

Taking wood cores with a) the Pressler increment borer for studies of dendrochronolgy (time series of annual, wood growth rings), b) homemade puncher sampling for biochemical analysis. c) microcores collected by a Trephor puncher sampling for anatomical observation of the cambium. (Alessio Giovannelli)

WHAT DID WE DO?

We collected many wood microcores from stems of mature Scots pine *(Pinus sylvestris)* trees growing in two contrasting habitats (a wet/high fertility site, the 'wet' site vs a dry/low fertility site, the 'dry' site). A set of microcores was used for anatomical analyses, and measurements of wood density and soluble carbohydrates content whilst a second set was used to measure widths of annual rings formed during the last 5 years. The morphology and density of the wood rings gives us information about the effect of environmental variations on stem growth and carbon fixed into cell walls.

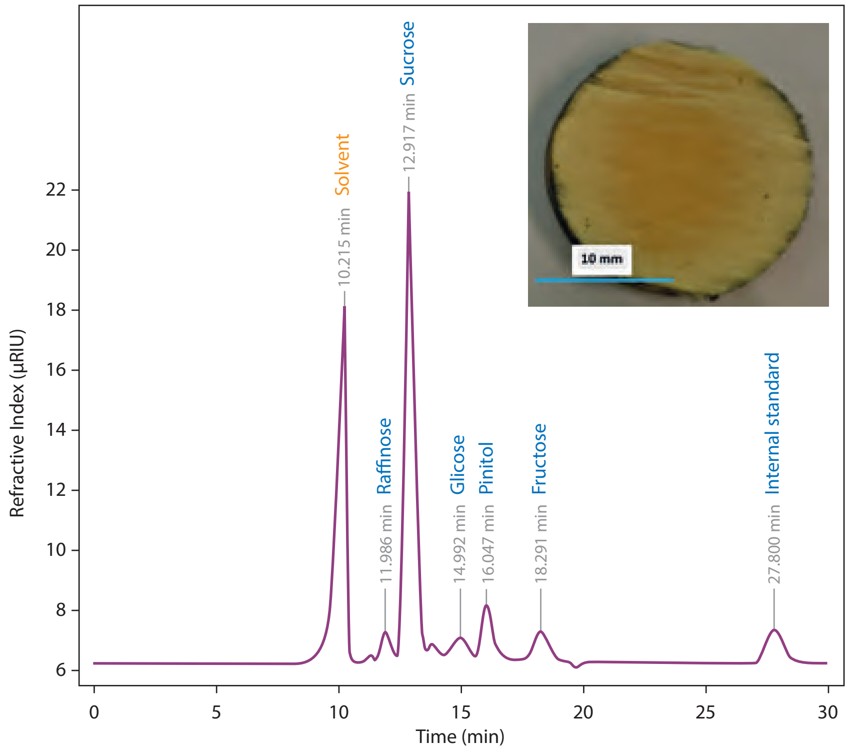
WHERE DID WE WORK?

The field campaign and sampling were carried out at the Hyytiälä Forestry Research station in Finland. The station hosts an ICOS (International Carbon Observing System) site which is located in southern Finland and characterised by a managed boreal mixed-coniferous forest with Scots pine as the dominant species. We used an open access weather dataset (https://avaa.tdata.fi/web/smart/smear/search) that included among others meteorology, gas fluxes, soil moisture content, and radiation.

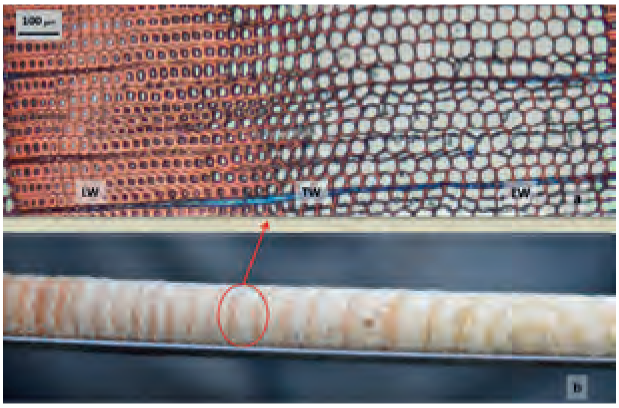
WHAT DID WE FIND?

The lengthening of the growing season did not induce an increase of the soluble carbohydrates within the wood and cambial region. (The cambial region is the outer area of the stem where cells divide to create the annual rings). During hot summers (for example the year 2018), the high temperatures caused the cambium to become inactive for a period during the growing season in some trees growing in the 'wet' site. This resulted in the formation of 'anomalies' in the pattern of woody ring density (i.e. a few earlywood-like cells are present

Separation of soluble carbohydrates by HPLC-RID (High Performance Liquid Chromatography — Refractive Index) extracted from xylem (the wood cells within the inset) of Scots pine trees (Maria Laura Traversi). HPLC is a technique that allows the separation of very complex chemical mixtures like soluble carbohydrates contained in a alcohol/water solution of wood powder. It is possible to determine composition and quantities of substances analysed and their chemical nature. The grey numbers represent the amounts of each soluble carbohydrate. The names of each soluble carbohydrate are included in blue on the x-axis.



within the latewood). As annual rings are identified by the difference between early season and late season cells, the abrupt transition between early and latewood cells, followed by a new earlywood production within the same growing season, allowed us to record anomalies in cambium activity due to environmental stresses.



a) Cross-sectional images of an annual growth ring (magnified 10×) of Scots pine. LW (Latewood), wood produced in late summer with thick cell walls (in brown) and narrow lumen tracheid (white holes); TW (Transition wood), wood produced in early summer with intermediate size of cell walls; EW (Earlywood), wood produced in spring with thin cell walls (in brown) and wide lumen tracheid (white holes). b) Each wood core was 2 mm in diametre and contained from 54 to 57 rings. (Maria L. Traversi)

WHY ARE THE RESULTS IMPORTANT?

Our results showed that the trees that grew in the 'dry' site were acclimated (i.e. acustomed) to their habitat and were more resilient to the warming than trees growing at the 'wet' site. Acclimated trees maintained their usual growth rate and ring anatomy pattern under the environmental constrains of hot summers so the early to latewood boundary was emphasised. These results highlight the importance of phenotypic plasticity (non-genetic changes) and growth responses that will enhance the resilience of the forest trees to global change.

THE ADVENTURE

The Hyytiälä Forestry Field Station is situated along the small lake Kuivajärvi, surrounded by forest in a typical Finnish atmosphere. There, the forest dominates with its colours, scent and silence. Pine and birch stand above the landscape and the blueberry, with its purple colour, offer a carpet for our feet and a gluttony for our palate.

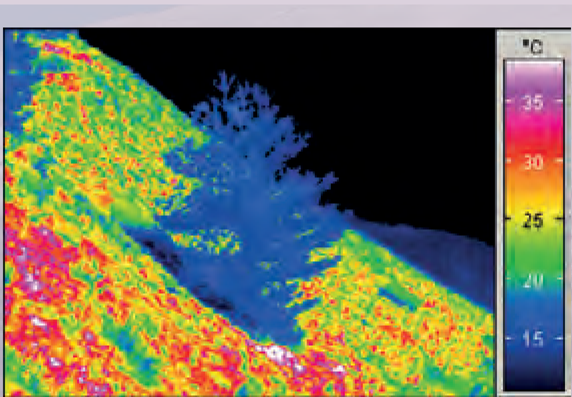
We enjoyed all of this because we had two bicycles for our sample collection in the forest. Nothing more suitable!

Environmentally friendly vehicles for forest sampling. (Maria L. Traversi)

Is the Subarctic treeline moving under global warming?

Christian Körner

A line connecting the northern-most lowland or uppermost high elevation groups of trees at least as tall as an adult person is termed the treeline, provided a site or region has not been disturbed in the recent past. Fire, logging, a high water table, windthrow (trees blown down) avalanches on slopes, browsing, grazing, and pathogens may cause a local absence of trees from treelines caused by climate. In other words, the treeline is a concept related to the biological potential of trees to grow under certain climatic (physical) contraints. It delineates a growth form, and no species representing the growth form "tree" can grow beyond that limit, which also means that the 'Arctic' or 'alpine' world is, by definition, naturally treeless. The low temperature treeline is a global phenomenon, with the Arctic treeline near sea level and the equatorial treeline at around 4,000 m elevation connected through the common isotherm of growing season mean air temperature of about 6 °C. As climate is changing, particularly in the Arctic, we would expect the location of the treeline to change as well.



Thermal image of a 'cool' tree (and its cool shade) surrounded by 'warm' short stature tundra-like vegetation. (Christian Körner)

AIMS OF THE PROJECT

What is it that confines the growth form "tree" to such a climatic boundary, while many other Arctic and alpine species and life forms thrive beyond that boundary? What are the implications of a warmer Arctic for treeline movement into the alpine or tundra vegetation?

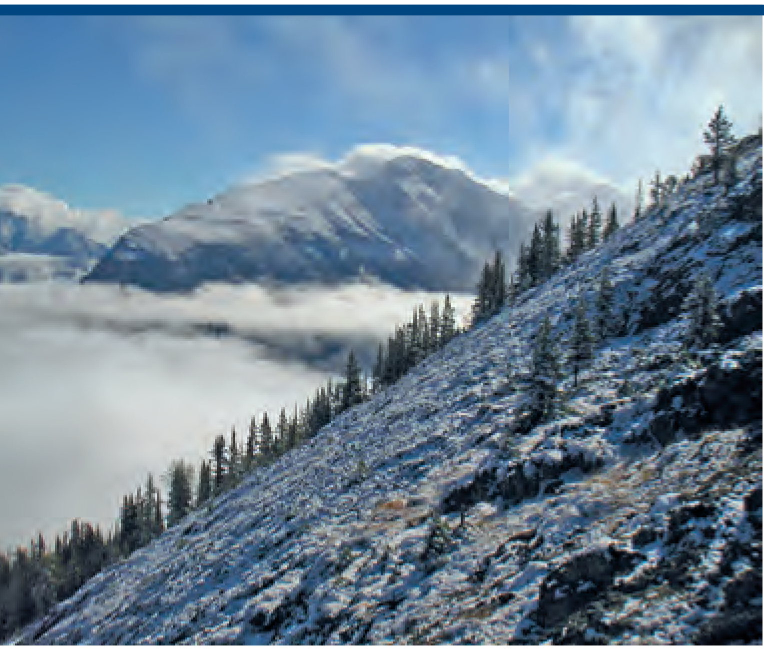
WHAT DID WE DO?

We studied trees at treelines and recorded temperatures.

WHERE DID WE WORK?

At the cold limit of trees around the world.

The Arctic treeline as formed by birch and pines in northern Sweden (Abisko). Note, the treeline becomes compressed, and thus sharp, on slopes but spreads out in flat terrain. Small shrubby pines in the foreground became victims of moose browsing in winter. (Christian Körner)



Where the boreal forest meets Arctic life conditions: the low temperature treeline near Banff (Alberta, Canada). Note, how rapidly trees become small and the forest thinned. (Christian Körner)

Viewed from above, it becomes clear why the Arctic treeline often does not resemble a sharp line: the water table controls tree distribution (an autumn view near Kiruna, northern Sweden). (Christian Körner)

WHAT DID WE FIND?

The driver of the treeline phenomenon is simple and physical, rather than related to biological shortcomings specific to trees, compared to herbs and shrubs. Trees evolved for their competitiveness for light. To over- and outgrow a neighbour translates into greater reproductive success. The "cost" of the stem is close to zero, because it largely represents a delayed recycling of annual investments in mechanically supporting structures and a conduit system that would otherwise be wasted in herbaceous or grass-like species every autumn. As a result, the annual productivity of a forest and adjacent grassland or shrubland does not differ. It is only the duration of the tissues produced that differs. So why not retain this strategy over the entire Arctic and alpine zone? This is where physics come in: being tall means being cold. Because of their size, trees are inevitably tied to surrounding air temperature. Air moves through the canopy and prevents any heat accumulation. Trees track the atmospheric climate, while shrubs, grasses, sedges and herbs inhibit free heat exchange with surrounding air, by dense, low stature growth, and thus, 'engineer' a warmer micro-climate when the sun is out. So the transition from the boreal forest to the treeless Arctic or Arctic-alpine world is driven by the physics of upright versus prostrate structures. We also found that trees are limited by a 6 °C seasonal mean temperature: why? There is clear evidence that plants hardly grow new tissue below 4-6 °C, while photosynthesis may reach half of full rates at such temperatures. Activity of apical meristems (buds that cause branches to extend) and the cambium (that causes stems and branches to thicken) become extremely slow below 6 °C and thus represent the most likely action of low temperature. Because of the intimate linkage of trees to atmospheric temperature, a warming climate could facilitate a northward or upslope shift of the treeline.

WHY ARE THE RESULTS IMPORTANT?

Will the Arctic treeline move into current Arctic tundra in a warmer future? If trees will track climatic warming, this will have major implications for biodiversity, land use and impacts of vegetation on climate (feedbacks). Models that assume that the treeline keeps pace with climate, predict massive northward and upslope forest encroachment but field observations do not support such pace-keeping. In a circumarctic survey, including 151 observation sites, it was recently found that only half of the sites showed any shift over the past century, and the ones that shifted northward did so very little. In contrast, treelines on Arctic mountain slopes moved roughly as predicted (1 m per year). This delay of treeline movement could result from limits of seedling establishment and the 50 to 60 years it takes for a successful recruit to become a tree.

So it is a matter of time for the Arctic treeline to achieve a new equilibrium with the climatic environment. For the time being, many factors influence trees at the current treeline position in both positive and negative ways. Together, these influences make it highly unlikely that the Arctic treeline will advance in a uniform way.

THE ADVENTURE

Visiting the world's treelines, leaving little automatic temperature sensors beneath trees, and seeing the uniform temperatures coming in from the 600-800 m treelines in the Brooks Range of Alaska and Abisko northern Sweden, and the 4,800 m tree limit in Bolivia was eye opening.

Low resistance to high temperatures of cold-adapted bumblebee species unveils a global threat for Arctic pollinators

Baptiste Martinet & Pierre Rasmont

Current global warming is impacting ecosystems by modifying species geographic ranges and fostering local extinctions. While most studies focus on the consequences of gradual modifications of climate, impacts of extreme events such as heat waves (hyperthermic stress) have been poorly investigated. The Arctic regions experience extreme warming events, and these will cause major continuing problems such as the dramatic decline in both diversity and abundance of wild, pollinating, bees.

Bumblebee sampling in Nickel creek (Kluane Lake Research Station, Yukon, Canada). (Baptiste Martinet)

AIMS OF THE PROJECT

We focus on the bumblebees, a diverse group of important pollinators in temperate and cold areas. Bumblebees *(Bombus)* are social insects like honeybees and ants. They are the most important pollinator group in mountains, Arctic, Subarctic and boreal regions. They are robust and hairy warm-blooded bees well adapted to cold climates. However, their populations have been strongly declining and shifting in altitudinal and latitudinal ranges, at least partially triggered by climate change. To conserve these wild bees, we need to know their current population status, and also how they respond to heat stress.

WHAT DID WE DO?

We sampled 2,386 bumblebee specimens, across three continents and twenty regions with latitudinal and continental gradients. We assessed heat stress resistance for 39 different bumblebee species from different eco-climatic regions in relation to body mass. We investigated the relationship between heat stress resistance and population trends. We used only males because (i) they display simple and constant behaviour contrary to females; (ii) they do not take shelter in thermoregulated underground nests as the females do; (iii) they are more exposed to meteorological events while collecting nectar and making their nuptial behaviour in open areas; and (iv) to reduce sampling effects on bumblebee populations. Our sampling allows comparison of the genetic diversity to identify potential refuge zones in bumblebee distribution.

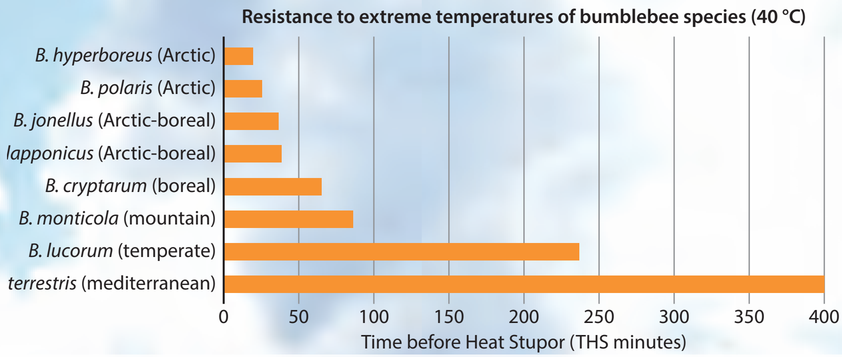
WHERE DID WE WORK?

With support from INTERACT, we have sampled different Arctic, boreal and mountain regions such as northern Sweden

Bombus polaris **on** ***Potentilla palustre*** **in Chokurdakh (Siberia).** (Pierre Rasmont)

Arctic landscape in Abisko (Sweden). (Pierre Rasmont)

Simplified results of heat stress resistance of bumblebee species. The time before heat stupor corresponds to the time spent by the specimen at 40 °C before falling into a "heat coma". (Martinet B., 2020)



(Abisko Scientific and Tarfala research stations), West Siberia (Khanymey Research Station), North-East Siberia (Chokurdakh Scientific Tundra Station), North Alaska (Toolik Field Station), West Canada (Kluane Lake Research Station), North-East Canada (Whapmagoostui-Kuujjuarapik and Salluit research stations). Moreover, we added data from Scotland (Hebrides), Norway (Narvik), Finland (Kilpisjärvi Biological Station), the Alps, the Pyrenees, the Apennine Mountains and the Lebanon Mountains.

WHAT DID WE FIND?

Our results show significant variability in heat stress resistance between species but low variability within species. This supports the concept that hyperthermic stress is a species-specific trait. Species associated with cold habitats (polar, boreal and mountains) are much more sensitive to heat stress than temperate or Mediterranean species. However, cold and temperate areas are likely to experience heat waves. We suggest that expansion or decline of bumblebee species and range changes can be impacted by their species-specific thermotolerance during heat waves. Limited local adaptations and low genetic variability in heat stress resistance represents a critical physiological mechanism making some species very sensitive to environmental changes.

WHY ARE THE RESULTS IMPORTANT?

While gradual changes in climate cause progressive shifts in the geographical distribution of species, heat waves can quickly induce local extinctions that drastically alter animal and plant communities. The genus *Bombus* is a vast group of more than 260 species worldwide, with a key role in maintaining the integrity of cold ecosystems. Our work allows us to assist in international bee conservation, particularly as we use criteria defined by the International Union for Conservation of Nature, IUCN. We showed the high sensitivity of bumblebees to heat stress which could play a key role in understanding their drastic decline worldwide. All species are not equal in the face of this threat. The ecological void left by declining species will not be filled by the minority of expanding species. We need an inclusive picture of the different threats to our pollinators which could ultimately contribute to safeguarding one of the most important players on our planet.

THE ADVENTURE

We have been able to experience the diversity and beauty of numerous Arctic and boreal landscapes and their bumblebee fauna. Thanks to the INTERACT project, we discovered a new bumblebee species and we decided to name it *Bombus interacti*. Compared to our highly urbanised western Europe, the Arctic still offers the possibility to study a nature less disturbed by humans. During our expeditions, we have encountered every possible weather condition (hot, cold, wind, snow, frost), and used no less than 10 different vehicles (boat, canoe, quad, bike, plane, helicopter, truck, train, etc.). The ambiance and working atmosphere of all the stations were very nice, organised by extraordinary people to coordinate the different teams of researchers. However, some scars from mosquito bites and other biting insects are likely to last a lifetime!

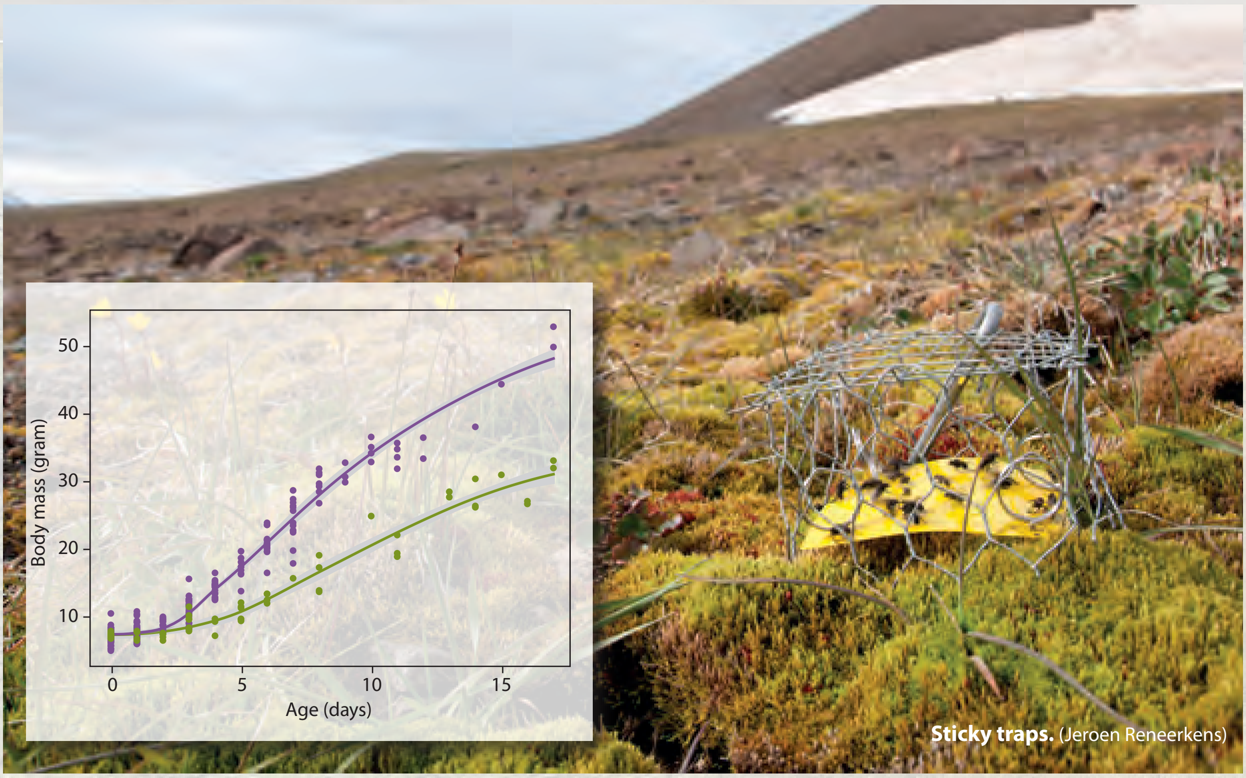
New bumblebee species discovered in Alaska (Toolik Field Station): *Bombus interacti nov. sp.* (Pierre Rasmont)

How an insect-eating shorebird may reduce the harmful effects of a warming Arctic

Tom S.L. Versluijs & Jeroen Reneerkens

As a consequence of Arctic warming, the phenology (seasonal development) of tundra arthropods (small invertebrate animals) has generally become earlier. Arctic shorebird chicks rely on the short and abundant supply of arthropods for their fast growth and survival. However, Sanderlings (Calidris alba) *have not advanced their breeding phenology and chicks now grow up after the general abundance of their prey has already peaked. Despite this phenological mismatch, chicks did not suffer from reduced growth in previous years (apart from 2019). Why?*

Sanderling forage. (Jeroen Reneerkens)



Sticky traps. (Jeroen Reneerkens)

Sanderling chicks forage for themselves after hatch and are guided by one of their parents (top photo). Sticky traps were used to catch arthropods and monitor their abundance at different locations on the Arctic tundra (bottom photo). Chick growth in 2019 was dramatically lower than in previous years (graph; lower green line). Sanderling families generally moved to wet areas close to meltwater streams (background photo).

AIMS OF THE PROJECT

We aim to investigate how chicks might mitigate the consequences of a mismatch with their prey. The phenology of Arctic environments can vary at small spatial scales. After hatching, shorebird chicks might thus be able to avoid mismatches with their prey by moving to areas with a later arthropod phenology.

WHAT DID WE DO?

We radio-tracked Sanderling families on the tundra to study how chicks moved around and used their habitat. In addition, we deployed traps along the foraging paths of chick families to catch and monitor arthropod abundance. We compared this with arthropod abundance measured at random locations on the tundra.

WHERE DID WE WORK?

We conducted our study at Zackenberg Research Station. This project is part of a four-year PhD project, of which 2019 was the first field season.

WHAT DID WE FIND?

The tundra was very dry in the first year of this study and arthropods seemed to be relatively scarce and appear early. Preliminary results indicated that Sanderling families moved to relatively wet areas close to meltwater streams. Sanderling chicks showed significantly reduced growth in 2019 compared to previous years. Thus, chicks seemed not able to fully mitigate the harmful effects of a mismatch with their prey. We suspect that this is because arthropods were generally scarce in this dry year. However, we found that Sanderling families considerably varied in their degree of movement across the tundra. In addition, chicks differed in their growth rates. In the near future, we will research whether these individual differences can be correlated with differences in the extent to which these individuals moved to areas with a later arthropod phenology. Radio-tracking of Sanderlings sometimes proved challenging as chicks can cover remarkable distances within the first few days after hatching. One family moved away from the field station 600 m up the slopes of a nearby mountain.

WHY ARE THE RESULTS IMPORTANT?

We hypothesise that heterogeneity within study areas might allow individuals to avoid local temporal mismatches with their prey. Such buffering capacity of individuals might translate into a higher resilience against climate change effects on the population level. Understanding such issues is globally important because millions of birds from Europe and Africa visit the Arctic each year to breed. Any reductions in their populations would reduce biodiversity in the South as well as in the Arctic.

THE ADVENTURE

To follow the single family that moved up the mountain, we had to make daily trips up to 600 m altitude. Trips often were extended well into the Arctic midsummer night, which resulted in beautiful scenes.

Meltwater landscape. (Peter Spierenburg)

4 Minimising surprises for society

SECTION OVERVIEW

Many of the changes that are occurring in the Arctic follow long term trends and much of the research is incremental, building on the findings of previous studies. However, relatively recently it has been found that short-term events such as warm winters and heat waves in summer often have very large impacts compared with those of the slower, longer trends. In addition, new discoveries are still being made and come as surprises to society.

In "Minimising surprises for society", we highlight events and surprises that we need to understand to be able to manage our life systems. We learn how just a few days in winter with warm weather can cover the tundra with ice which causes thousands of reindeer to die and southern scavengers to invade the Arctic. We also learn how thawing permafrost affects peoples' lives and wellness by releasing contaminants and aiding the spread of harmful pathogens. Some of the events are recorded in growth rings of shrubs which have been analysed to look at extremes in weather rather than just traditionally studied long term climate. Fires are a natural event in northern forests but from those we learn how the forests can recover. Following the fire, we learn how the resulting black carbon (charred wood) is an important source of nutrients for the forest soils. In the Russian tundra, a relatively recent surprise event has been discovered: mounds appear and then explode to scatter blocks of frozen ground around central craters which then become flooded.

Changes in weather and landscapes often occur as surprises, some of which challenge people.
Solar halo — sunlight and ice crystals — above the Greenland Ice Sheet.
(Maaike Weerdesteijn)

Unusual winter weather events cause rapid changes in tundra ecology

Aleksandr Sokolov

Many environmental changes are taking place in northern Yamal, Russia, as in other Arctic areas. We believe that by gaining a deeper understanding of such changes, we will be able to predict further changes. Hence, we can act accordingly by making management decisions in a wide range of cases, from actions toward conservation of particular species, to those for the wellbeing of Local and Indigenous Peoples of the Arctic.

(Aleksandr Sokolov)

40,000 reindeer died in the Yamalskiy District in winter 2013/2014 creating abundant carrion for new scavengers and predator. (Aleksandr Sokolov)

Crow chicks show that crows are now breeding much further north than previously. (Aleksandr Sokolov)

AIMS OF THE PROJECT

We are documenting and trying to explain changes in terrestrial tundra ecosystems caused by three main drivers: climate change, industrial development and reindeer herding. Our focus is on plants, mammals and birds — the major constructors of tundra ecosystem food webs on land.

WHAT DID WE DO?

Every summer we carry out systematic Arctic fox den surveys over a sampling area which has grown from 130 km^2 in 2007 to 230 km^2 now. In every den with signs of breeding, we place an automatic camera which allows us to determine the litter size. In addition to recording this Arctic predator, we now annually monitor scavengers in winter by a novel method of automatic cameras. Every calendar spring, we set up our 50 km long transect of 10 baited, automatic cameras taking pictures every 5 minutes.

WHERE DID WE WORK?

Our long-term tundra monitoring site "Erkuta" is a field station belonging to the INTERACT Arctic Research Station at Labytnangi. Erkuta is situated in the Yamalskiy District, south of the Yamal Peninsula, north-western Siberia, Russia. In the Nenets' language, Yamal means "end of the Earth". Nowadays we believe that zoogeographically, the field station is located "at the right time and in the right place". In "Erkuta" some Arctic resident animals (such as lemmings and Arctic foxes) are on the southern border of their breeding range. Contrariwise, some wide-spread, boreal species, rarely start to appear in the area (such as red foxes or hooded crows).

WHAT DID WE FIND?

Here we document when a catastrophic weather event, combined with the way of life of resident people — Nenets reindeer herders, led to a cascading effect on the entire terrestrial food web of the area. According to the Nenets People, a rather deep snow cover was established in the study area on 23 September 2013—about three weeks earlier than usual—during a three-day snowstorm. On 8 and 9 November, heavy rain fell on the snow-covered ground and led to the formation of a solid ice layer over large parts of the tundra. From satellite data, ground icing due to the rain-on-snow event was inferred for a large area that covered the whole southern part of the Yamal Peninsula and beyond. The ice layer did not melt until spring, blocking access by reindeer to their food in the field-layer vegetation for several months. According to official

Arctic fox posing for an automatic camera. (Aleksandr Sokolov)

Two Arctic foxes squabbling over carrion. (Aleksandr Sokolov)

Two new comers to Yamal: the magpie and red fox, attracted by abundant carrion. (Aleksandr Sokolov)

data, 40,000 reindeer died in the Yamalskiy District, about 10 times higher than usual. In the summer of 2014, for the first time since 1999, we registered breeding events of two species new to the area. Two dens of Arctic foxes were occupied by red foxes, and the automatic cameras recorded 12 cubs. The first nest of hooded crow ever recorded in the study site, was also in summer 2014. There were 3 chicks in the nest, and two adults were flying close by calling an alarm.

WHY ARE THE RESULTS IMPORTANT?

Whereas most studies address gradual ecological changes, for example responding to changes in resource levels, we documented the important way in which a weather-induced pulse of resources following an extreme weather event allowed a long-lasting and increasing range expansion of boreal/Subarctic predators. This continuing impact is despite recent low reindeer mortality and hence low carcas abundance. At present, such extreme weather events in the Arctic occur in addition to ongoing trends of change such as climate warming and changes in land use. In southern Yamal, the abundance of semi-domestic reindeer has increased considerably over the last decades. As rain-on-snow events are predicted to increase in frequency in the Arctic, reindeer herders will have to adapt to a more frequent risk of winter icing, and future management options may be the determinant for the expansion of boreal generalist predators. A combination of trend effects with stepwise changes due to specific events and over-arching management decisions are likely to be typical for ecosystem changes induced by global change. A possible lasting change in the composition of the predator species with more boreal generalists is likely to have a detrimental impact on many typical Arctic species, in particular ground-nesting birds, such as ptarmigan, waders, and Arctic foxes.

THE ADVENTURE

We visited the study area several times between November and May every year and met our friends and colleagues — the Nenets — the Indigenous People of Yamal. They still follow the nomadic way of life with their reindeer herds, in particular in our study area. And often they say “hello” through our automatic cameras.

Thawing permafrost and human health

Arja Rautio, Ulla Timlin, Anastasia Emelyanova & Khaled Abass

Permafrost thaw causes erosion of land, damages infrastructure and buildings, and increases pollution risks of drinking water and food safety in Arctic communities. The main concerns are that there might be a release of contaminants and heavy metals (such as mercury) and infective agents (especially anthrax from old burial places), that have been hidden for a long time, even hundreds of years, in frozen ground. All this is a serious risk for both human and wild-life health.

Our research is a part of the larger "Nunataryuk" project with the overall goal to determine the impacts of thawing land, coast and subsea permafrost on the global climate and on humans in the Arctic and to develop targeted and co-designed adaptation and mitigation strategies.

AIMS OF THE PROJECT

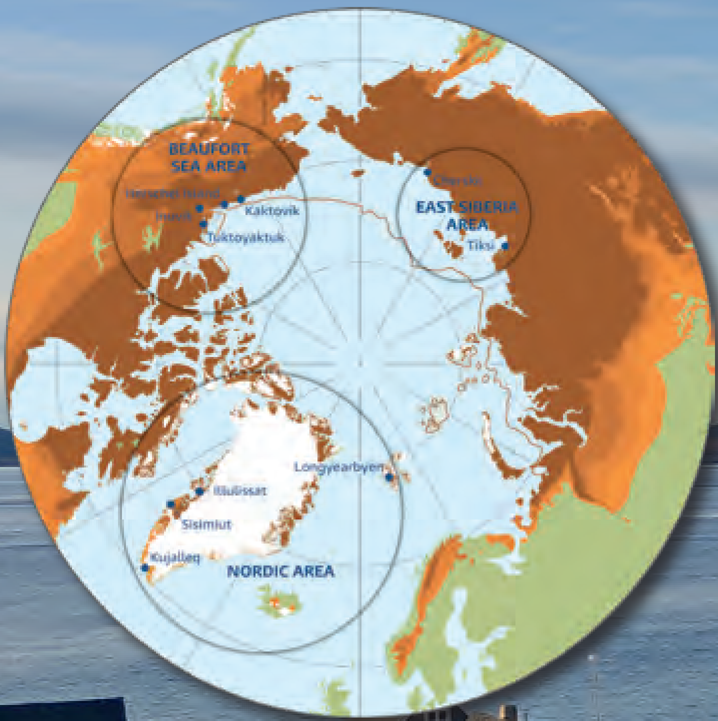
Our project "Health and pollution" concentrates on the effects of permafrost thaw on human health among people living in Arctic coastal communities.

WHAT DID WE DO?

During the first two years, we have focused on mapping levels of environmental contaminants and their health impact in the entire Arctic coastal human communities. We have also made systematic reviews of the impact of warming climate on infectious diseases and contaminants in human Arctic populations and the release of anthrax from permafrost thaw and possible impacts on coastal communities. We are continuing our research by studying effects of permafrost thaw on mental wellness, quality of life and risks on human health by using a community-based participatory approach.

WHERE DID WE WORK?

We have worked in all the Nunataryuk focal areas and sites in North America, Greenland, Svalbard and East Siberia.



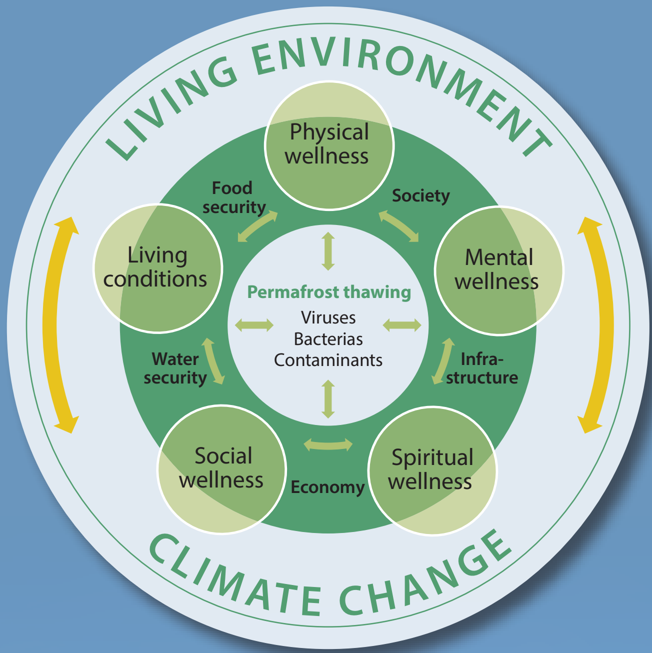
The Nunataryuk focal areas and sites (blue dots).

Arctic coastal communities such as Nuuk in Greenland face impacts of thawing permafrost on health and wellness.
(Khaled Abass)

4 • 2

WHAT DID WE FIND?

Our findings showed that international restrictions have decreased the levels of 31 contaminants in humans in the Arctic. However, the impact of climate change on temperature may be to increase the volatilisation and distribution of POPs (persistent organic pollutants) and consequently human exposure. Climate change has also been predicted to be the most influential factor in the emergence of infectious diseases. We found that tick-borne diseases, tularemia, anthrax, and vibriosis are the most likely diseases to be spread and moved northwards by climatic factors, and increased temperature and precipitation are predicted to have the greatest impact of those. We continue this work by writing a review of wildlife health. The epidemic modelling of anthrax disease under permafrost thawing and changing environmental variables is in progress. The research on mental wellness and quality of life are currently under investigation. Preliminary results support the evidence that life in Arctic coastal communities requires constant adaptation from people and thawing permafrost is affecting local peoples' holistic well-being through politics, economy, physical environment, water and food security and social life.



Holistic scheme for effects of thawing permafrost on human well-being in the Arctic.

WHY ARE THE RESULTS IMPORTANT?

Populations are living close to nature in the Arctic. The "One Health" approach recognises that human health is closely connected to the health of environment, plants and animals. Climate change and permafrost thaw have impacts on this connection. Mental, physical and social health and wellness are affected and challenged by permafrost thaw, but also in an indirect way, through socio-economical changes in the Arctic. It is also important to develop new suitable methodologies for understanding the dynamics of re-mobilising pollutants (contaminants, infectious agents) from permafrost thaw in the Arctic, and estimating their risks for human and wildlife health. These methodologies should combine social and physical science and Indigenous knowledge in multidisciplinary, culturally sensitive and community-based participatory research.

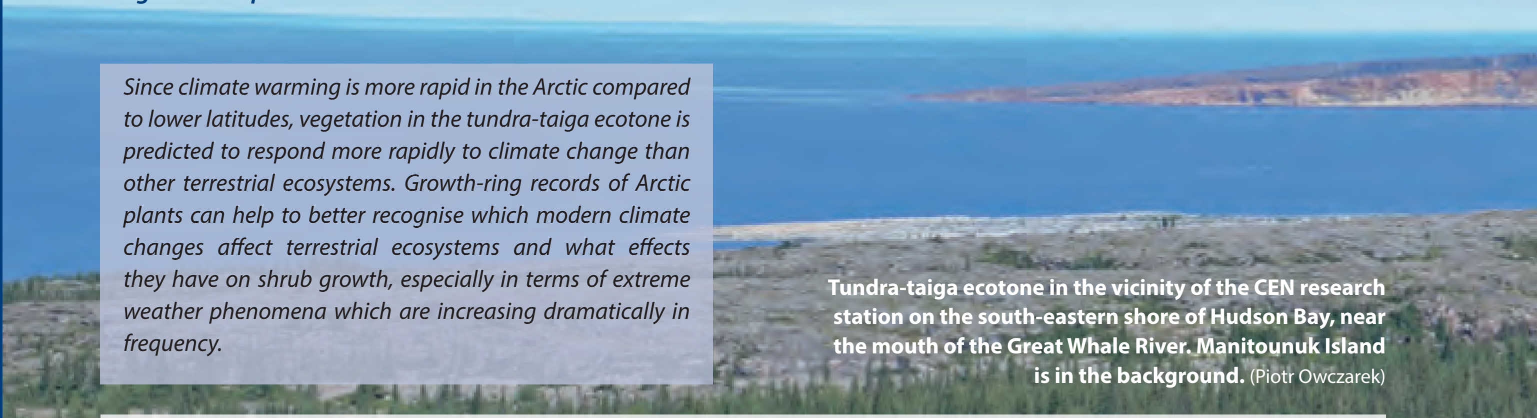
THE ADVENTURE

During the Nunataryuk project, we have already had the possibility to visit the Arctic Station, an INTERACT Station, in Greenland, which was a nice and pleasant place to concentrate on collaboration and multidisciplinary research.

Modern extreme weather in the low Arctic is recorded in growth-rings of shrubs

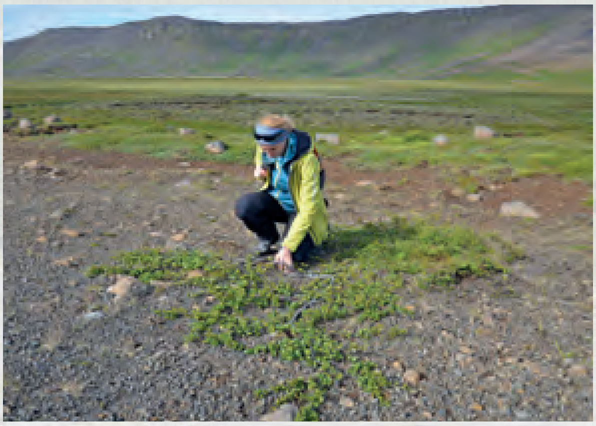
Magdalena Opała-Owczarek & Piotr Owczarek

Since climate warming is more rapid in the Arctic compared to lower latitudes, vegetation in the tundra-taiga ecotone is predicted to respond more rapidly to climate change than other terrestrial ecosystems. Growth-ring records of Arctic plants can help to better recognise which modern climate changes affect terrestrial ecosystems and what effects they have on shrub growth, especially in terms of extreme weather phenomena which are increasing dramatically in frequency.

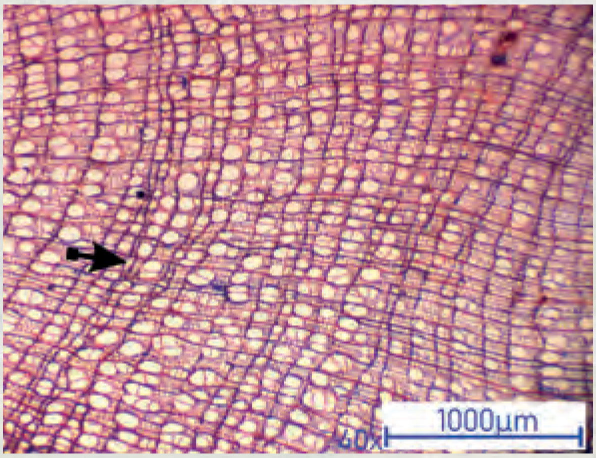


Tundra-taiga ecotone in the vicinity of the CEN research station on the south-eastern shore of Hudson Bay, near the mouth of the Great Whale River. Manitounuk Island is in the background. (Piotr Owczarek)

Collection of a *Betula glandulosa* sample from low rolling hills (150 – 200 m a.s.l.) and depressions built of Archean granito-gneissic basement, south-eastern shore of Hudson Bay. (Magdalena Opała-Owczarek)



One-hundred-year-old individual of *Betula nana* growing in the southern part of Melrakkaslétta (north-eastern Iceland). (Piotr Owczarek)



Growth ring pattern of *Salix uva-ursi* (bearberry willow). A very narrow ring in 1989 is marked by an arrow. In this year, the weather conditions were characterised by the coldest March in the entire meteorological series (dev –5.4 °C), long duration of snow cover (May 29th — last day of snow cover) and occurrence of 6 freeze-thaw cycles in late spring (June). (Piotr Owczarek)

Local transport during sampling on Manitounuk Island. (Piotr Owczarek)

AIMS OF THE PROJECT

We aimed to investigate if shrubs and dwarf shrubs, growing in the maritime and more continental climates of the Subarctic, reflect modern extreme weather phenomena. If "yes", is it possible to reconstruct extreme weather phenomena over the last hundreds of years by measuring annual growth ring variability?

WHAT DID WE DO?

We obtained a large collection of dwarf-shrub samples from the tundra-taiga ecotone. In Iceland. they were *Salix arctica, S. herbacea, Betula nana, Empetrum hemaproditum, Dryas octopetala,* and *Calluna vulgaris*. In Canada they were: *Salix uva-ursi* and *Betula glandulosa*. Additionally, we collected cores from the trees *Picea mariana,* and *P. glauca*. Next, growth-ring width chronologies (time series) were constructed for the different species. At the same time, we gathered general field observations and detailed meteorological information for dendroclimatic (tree ring) analysis. We investigated what climatic factors influenced the width and anatomical characteristics of annual growth rings. These climatic factors were rain-on-snow events, warm winters, and rapid changes of precipitation and temperature during the growing season.

WHERE DID WE WORK?

We worked at the CEN Whapmagoostui-Kuujjuarapik Research Station located on the south-eastern coast of Hudson Bay in Canada and the RIF Field Station in north-eastern Iceland. The results of studies in these two locations are important contributions to the longitudinal and latitudinal transects of other dendroclimatological research sites and will help to find teleconnections between the growth-ring chronologies from species growing in north-eastern Iceland, the coast of Hudson Bay and other parts of the Low Arctic.

WHAT DID WE FIND?

We developed one hundred years' dendrochronological records for different shrub species. One of the achievements was the construction of the first dendrochronological record for *Salix uva-ursi* (bearberry willow) from the east coast of Hudson Bay. Using daily meteorological data, we calculated different weather and climate indices, and found that the growth of Low Arctic willows is determined by changes in air temperatures as well as precipitation during the summer. In contrast to the previous studies that focused on a single factor, our research results also highlight the importance of multiple climatic drivers that interplay. Low growth can be associated with extreme low temperatures and thick snow cover shortening the growing season or temperature increases and reductions in amounts of rainfall that intensify drought stress. Detailed dendroclimatological analysis improved our understanding of the factors conditioning the growth of the other shrub species studied.

WHY ARE THE RESULTS IMPORTANT?

We have shown that growth-ring records of Low Arctic plants can help to better recognise modern climate changes affecting terrestrial ecosystems. The use of such a non-classical dendroclimatological approach using detailed climate indicators in addition to the standard monthly average temperatures and precipitation is now necessary in order to evaluate extreme climatic events in the past.

ADVENTURE

We were prepared for harsh climatic conditions, but the weather variability totally surprised us: from the stormy weather in northern Iceland to the constant rainfall or the cloudless blue sky over Hudson Bay. We used different modes of transport, including small local planes and to reach the research sites we traveled by quads on the wilderness of the Labrador Peninsula and by boat discovering the lost botanical worlds of the Manitounuk Islands. During the rain we often sheltered in tipi (teepee) which have been used during summer by the Indigenous Peoples of the Cree First Nation.

Forest recovery after fire

Heather D. Alexander, Jennie DeMarco, Brian Izbicki, Rebecca Hewitt, Michelle Mack, Alison Paulson & Valentin Spektor

Siberian larch forests are critical to the global carbon cycle. They occupy 20% of the world's boreal forests (northern coniferous forests) and contain half the carbon in Eurasian boreal forests. Much of the carbon in larch forests is found in 'yedoma' permafrost (perennially frozen wind-blown ancient organic sediment), which is rich in carbon (about 2%) and contains 30-50% ice. Larch forests also experience periodic wildfires during the growing season. These fires are a natural and important disturbance because they reduce competition from low-growing vegetation and expose mineral soil seedbeds, thereby promoting forest recovery. However, in recent decades, fire frequency, extent, and severity have increased with climate warming and drying. These fires expose vulnerable yedoma to thawing, which can release extra carbon into the atmosphere and cause ground subsidence. In addition, some larch forests fail to recover after these fires, resulting in forest loss and a change to grasslands and/or shrublands. This shift could impact climate because forests differ from grasslands and shrublands in their carbon storage, reflection of energy (i.e., albedo), and shading and protection of yedoma permafrost.

AIMS OF THE PROJECT

We aim to understand the causes and consequences of larch forest loss after fire in far eastern Siberia. We are looking at things that could cause forest loss, including larch seed availability, seedbed conditions, and interactions between trees, mycorrhizae (soil fungi that are symbionts of trees), and other vegetation.

WHAT DID WE DO?

In 2018, our team visited a forest near Yakutsk that burned in 2002. We sampled 25 groups of trees representing gradients in burn severity and recovery levels. In each stand (group), we measured species, diametre, height, and density of fire-killed and newly established trees to determine stand structure and composition prior to burning and to assess forest recovery after fire. We collected wood slabs to estimate average stand age at the time of burning and to detect fire scars on tree rings, which helps determine fire frequency. To characterise the belowground environment after a fire, we collected larch roots to quantify mycorrhizal community composition (fungal species) and soils for nitrogen analyses

Profile of burned forest soils showing distribution of char (partially burned plant material remaining after fire) throughout organic soils at the top into mineral soils below. (Valentin Spektor)

Larch forest stand near Spasskaya Pad Scientific Forest Station that burned in 2002. (Valentin Spektor)

Larch tree seedlings were abundant in stands that burned with high crown severity but had plentiful live trees nearby to provide seeds. (Valentin Spektor)

WHERE DID WE WORK?

To achieve our aim, we sampled burned forests near Yakutsk and Cherskiy, Russia. One study site was a short drive from Spasskaya Pad Scientific Forest Station located just north of Yakutsk. While most of our prior research centered on larch forests at their northern-most extent near Cherskiy. Spasskaya Pad and surrounding forests lie in the heart of the larch forest's geographical range. Both regions have yedoma permafrost, but the current fire return interval near Yakutsk (about 80 years) is around 3-times shorter than that near Cherskiy (about 200 years), and changes in the fire regime have been more pronounced in the Yakutsk Region. The forests near Yakutsk may provide a proxy for future forest dynamics at the northern end of the range as climate warming and fire activity intensify.

Fires ignited in 2018 cloaked the sky as we sampled the forests that burned in 2002. (Valentin Spektor)

WHAT DID WE FIND?

We found the greatest levels of larch forest recovery in forest stands that had the highest severity of crown fire (fire damage at the top of the trees). This is probably because increased light availability allowed new larch seedlings to grow tall fast and outcompete other vegetation. Also, higher crown fire severity probably indicates greater soil burn severity, which can improve seedbed conditions and promote tree seed germination. Also, larch recovery was highest in stands with more larch trees that survived the fire, probably because these trees provided a seed source.

WHY ARE THE RESULTS IMPORTANT?

Our results suggest that changes in fire severity are likely important for determining forest recovery and loss. Ultimately, our goal is to compare data from Yakutsk and Cherskiy to determine whether larch forest failure to recover after fire will increase dominance of shrubs or grasses and to assess consequences for carbon storage, albedo, and regional climate.

THE ADVENTURE

While the station is only 20 km from Yakutsk, the trip to get there and to our sites was a bumpy adventure. We travelled from Yakutsk into the upland, forested terrace in a small van. Our driver traversed the unpaved, forested roads with skill, as we bumped and rattled slowly, but safely, to the station and the burned forest nearby. We hiked through dense, shrubby vegetation to reach our sampling locations. While we sampled stands that burned 16 years earlier, the air was thick with smoke drifting in from nearby forests burning during 2018. The smoke reminded us of the immediacy of our research.

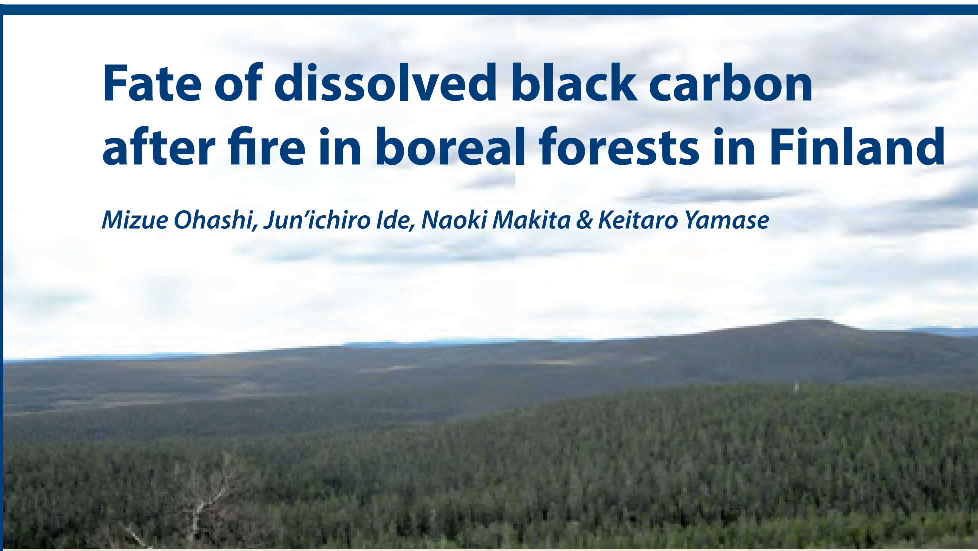
Forest roads we travelled to reach the stands that burned in 2002. (Valentin Spektor)

Hiking and navigating through the forest to reach stands that burned at different severities. (Valentin Spektor)

Fate of dissolved black carbon after fire in boreal forests in Finland

Mizue Ohashi, Jun'ichiro Ide, Naoki Makita & Keitaro Yamase

Nearly 1% of boreal (northern coniferous) forests are lost by fire every year. The charred remains called "black carbon" produced by forest fire is mineralised (broken down into simpler chemicals) slowly and thereafter dissolved in soil water. Global warming may result in changes of such dissolved black carbon at a molecular level, affecting the capacity of soils to store carbon, because decomposability of black carbon varies depending on its molecular structure. Therefore, it is urgent to clarify the behaviour of black carbon in forest soils after fire disturbance.



Värriö Strict Nature Reserve in eastern Finnish Lapland. (Mizue Ohashi)

AIMS OF THE PROJECT

The aim of this project is to study the formation and decomposition process of dissolved black carbon in boreal soil.

WHAT DID WE DO?

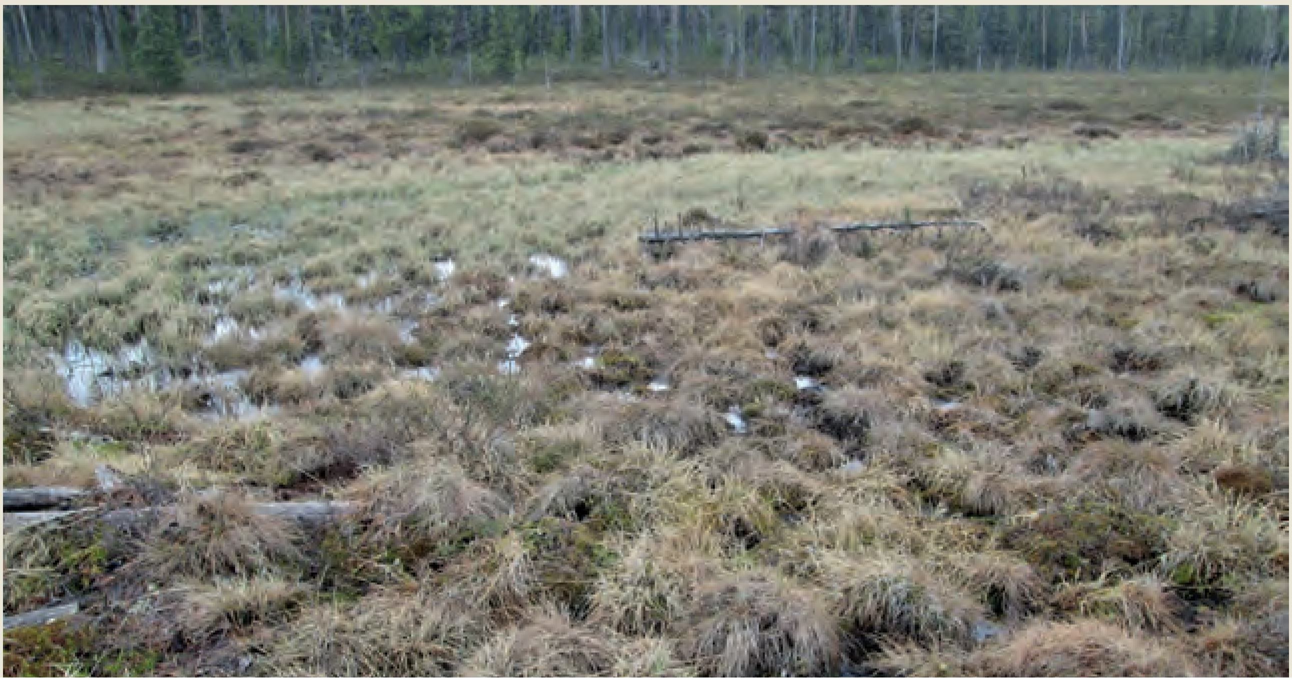
Soil water samples were collected from areas that had experienced fires at different times (which together make a "fire chronosequence"). We selected 160-, 60-, 50- and 9-year-old sites in Värriö and three to five samples were taken at each site. We sprinkled 2 litres of ultra-pure water at each location to collect more than 50 millilitres of soil water. In Hyytiälä, we sampled soil water from three biochar (previously burned) and three control (un-burned) sites. The samples were collected during spring and summer when biological activities are high in both places. The soil water samples were thereafter transported to Japan and their molecular compositions were analysed.

WHERE DID WE WORK?

Soil water samples were collected from the forest surrounding the Värriö Subarctic Research Station in Finnish Lapland and charcoal dispersal sites at the Hyytiälä Research Station in southern Finland where we artificially added biochar to the forest floor.

WHAT DID WE FIND?

Our preliminary results showed that hundreds of molecules existed in the samples from both Värriö and Hyytiälä. They were divided into seven classes of biological molecules, and one called condensed aromatic structures (CAS) was regarded as pyrogenic (created by fire) black carbons (BC). There was a big variation in the molecular composition between the sites, and nearly half of the average number of dissolved black carbon molecules in the recently-burned site were different from the site that had not been burned for a long time, nearly 160 years.



We had to cross the reindeer fence to go to the site. (Mizue Ohashi)

Short break after the long walk to the research plot. (Mizue Ohashi)

WHY ARE THE RESULTS IMPORTANT?

Black carbon is an important factor for controlling soil carbon sequestration, natural water quality and soil nutrient supply because it is decomposed into minerals very slowly compared to other organic materials, affecting the forms of carbon and nutrients retained in soil and water for a long time. The results of this study confirmed that dissolved black carbon is an important component in forest soil after fire disturbance and its quality changes with the forest's development. This information suggests that the sustainable management of forest ecosystems should take the changes in black carbon into account for promoting ecosystem services of forest soil and utilise the pyrogenic carbon produced by the burning of wood as natural nutrient sources for the long term during the establishment of boreal forests.

THE ADVENTURE

The fire chronosequence sites in this study were established in the Värriö Strict Nature Reserve in eastern Finnish Lapland. We walked more than 10 km to reach the sites from the Värriö Subarctic Research Station near the Russian boarder. We had to cross streams, peatlands and reindeer fences during the trip. We visited each site at least twice to bring soil sampling equipment and ultra-pure water to collect samples. It was a tough but exciting visit.

Large peatland on the way to our research plot in Värriö. (Mizue Ohashi)

The exploding tundra: from mounds to craters in permafrost

Marina O. Leibman, Alexandr Kizyakov, Artem Khomutov, Yury Dvornikov & Vladimir Melnikov

Climate fluctuations and air temperature extremes associated with the warming trend over the last decade have caused an activation of permafrost processes due to thaw of ground ice, as well as the appearance of never-before observed processes that dramatically change tundra land surfaces. One of these new processes is the formation of mounds, followed by deep craters, within permafrost.

Studying water chemistry in a crater flooded with snow-, rain-, and ice-melt water.
(Marina O. Leibman)

AIMS OF THE PROJECT

We aim to test our hypothesis of the origin of the formation of mounds and craters and to find what triggers the process. Our assumption is that mounds we call "mound-predecessors" (as they are the start of a process) form by pressure produced from dissociation of gas hydrates (release of methane from crystalline structures), then their "eruption" that ejects frozen ground to form hollows. We assume that gas from dissociation of methane hydrates accumulates beneath the layers of ground ice until a critical pressure is reached. That is why we call these hollows Gas Emission Craters (GEC).

WHAT DID WE DO?

A team of experts visited several known GECs in the field, measured their size, and surveyed geological sections, form and amount of ice layers, and gas emissions from the craters. We described terrain and environments around the GECs and we monitored their evolution using field and remote-sensing data. All the GECs were flooded with water very quickly, in a few years, and one in just a few hours, forming a lake we call a "lake-successor". We determined the chemical properties of lake-successors' water, and lake bathymetry (depth and shape). We use the word "successors" to denote that these lakes are formed only by the GEC creation process.

WHERE DID WE WORK?

All known GECs had formed in the north-western Siberia, in the Central part of the Yamal and Gydan peninsulas close to 70° North. All the GECs are located in the continuous permafrost zone of West Siberia, known for its natural gas resources and layers of ground ice.

We studied 3 GECs in detail whereas other GECs were studied using only remote-sensing data. All the GECs are located far away from each other, so field study is highly complicated. We visited no more than one or two craters at a time, GEC 1 (see map) was visited seven times since July 16, 2014, both in summer and in winter; GEC 2 three times (twice in summer and once in winter), and GEC 5 only once in summer.

WHAT DID WE FIND?

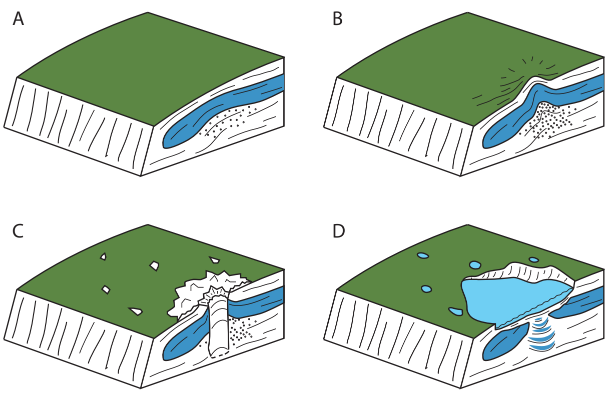
Through analysis of Digital Elevation Models around each GEC, we determined that all craters were preceded by mound-predecessors, 20 to 50 m in diametre and 2 to 6 m high. We established dates of formation of each GEC (see Table) and found that, in 4 years, the GEC diametre increased 4 to 7 times. Laboratory analyses of samples taken from ice in the crater walls, water in the lake-successor, and water and ice in other ice exposures and lakes taken as reference points, showed that lake-successor water contained very high concentrations of methane. Summarising our findings, we suggest that mound-predecessors "explode" when pressure due to the dissociation of gas hydrates finally exceeds the strength of the ground layer covering the growing gas reservoirs. At that moment, this cover of frozen deposits brakes into very icy blocks which are ejected out into the air, and thrown into the tundra where they melt leaving small hollows filled with water or pieces of ground. The central void that formed as a result of this explosion is then flooded, and at the same time, crater walls collapse, filling the void together with rain and melt water from snow. This mixture freezes up from the bottom. Thus, in a few years, a small diametre deep hollow turns into a big shallow lake.

WHY ARE THE RESULTS IMPORTANT?

Although there are different hypotheses of how the GECs form, our results over several years covering several GECs provide data needed to understand the mechanism and consequences of gas-emission crater formation. Our opinion is that GECs result from extreme summer temperature, and that a new mound-predecessor probably "explodes" in the fall or spring following extreme summer warmth. An unfortunate result of GECs turning into lakes is that there is little possibility of finding a good indicator of existing lakes that originate from GEC flooding. Yet we are now aware that this process is much more risky for local people travelling along pasture pathways than for infrastructure where growing mounds, if any, are easy to notice.

THE ADVENTURE

Travel to gas emission craters is a challenge because they are found in the most remote areas of the tundra where only helicopters can reach. Using off-road vehicles is limited for nature protection, and it takes many hours of driving through tundra with lots of unwanted adventures. A visitor will meet moist tundra, no wood for camp fires, and no drinking water in this water-logged area!

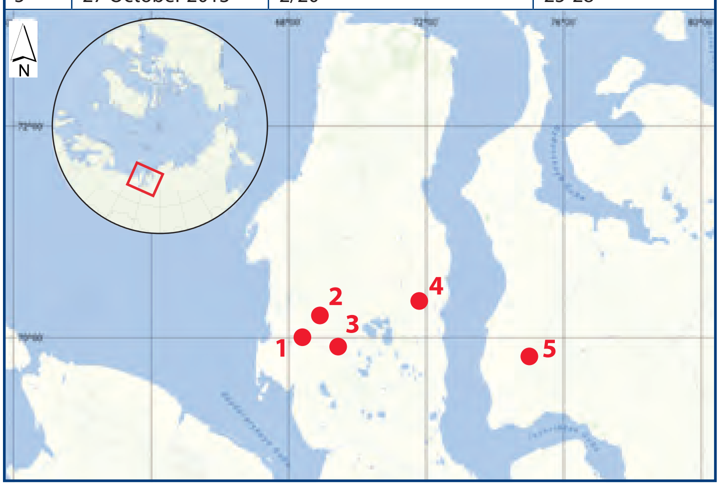


Three-dimensional model of GEC formation: A, stable; B, gas-inflated mound-predecessor; C, gas-emission crater; D, lake-successor. The dots represent methane hydrates and the dark blue colour represents ground ice.

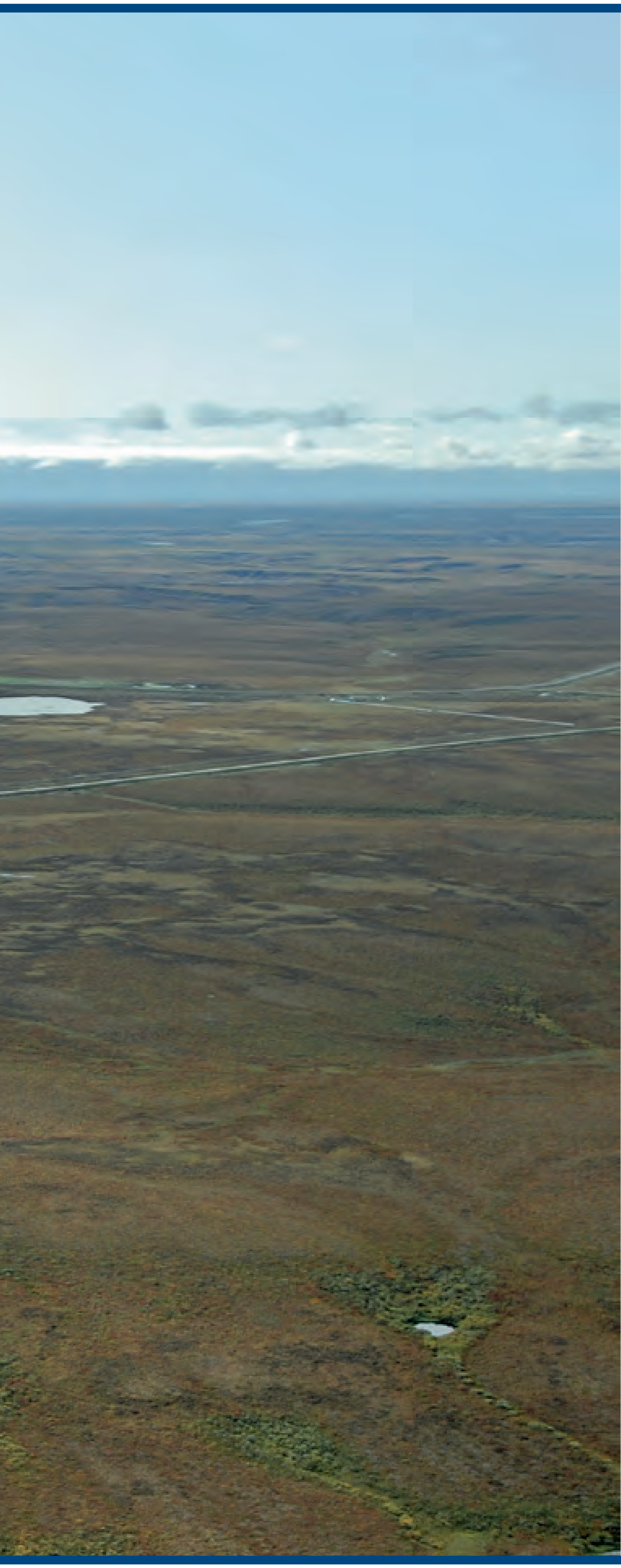
Sampling frozen crater walls with an axe while hanging on a rope.
(Marina O. Leibman)

Position of Gas Emission Craters in the north-western Siberia.
(Compiled by Alexandr I. Kizyakov)

GEC no.	When formed	Size (m)	
		Mound height/diametre	Crater diametre
1	October 2013	5-6/45-48	25-29
2	October 2012	4-6/40-55	32-35
3	2013 (?)	3/36-46	35-37
4	28 June 2017	1.7/55	76-88
5	27 October 2013	2/20	25-28



5 Impacts on local societies



SECTION OVERVIEW

Local societies, both Indigenous Peoples and other Arctic residents, are affected directly by changes in the Arctic environment caused by climate change, land use change and local regulations.

In "Impacts on local societies" we learn how increasing forest fires in Siberia produce smoke plumes that stretch over 1,000 km and affect air quality over large areas. When working with Arctic Peoples and particularly the Indigenous Peoples, it is important to show respect and one story emphasises the importance of guidelines on ethical principles. Using these principles, we learn how scientists and research stations in Greenland and northern Scandinavia should work far more closely with local and Indigenous Peoples to make their research more relevant, to do joint research and to improve education and awareness. Also, commercial enterprises such as tourism can benefit from working with Indigenous Peoples: working with reindeer herders can prevent possible conflicts of land-use. Surprisingly, one story shows how conservation measures and regulations can result in environmental damage when local economics of hunting, fishing and family farming cease to control previously protected animals and landscapes. A story based on an island community shows how despite developments in modern society, increased centralization leads to greater inequalities between the capital and the remote island settlements. The final story shows that along many Arctic coastlines, climate change and resulting coastal permafrost thaw are destroying cultural heritage and infrastructure.

Oil and gas extraction is one of the many human impacts on local ecosystems and societies.
Yamalo-Nenets Autonomous Okrug, near the city of Yamburg, Siberia.
(Andrey V. Soromotin)

5

SCIENCE STORY II

Forest fires are increasing in Siberia

Galina A. Ivanova, Aleksandr V. Bryukhanov, Andrey N. Romanov & Ilia V. Khvostov

Forest after a large forest fire. (Aleksandr V. Bryukhanov)

Siberia stretches over several climatic zones and ecosystem types, which present diverse conditions for forest growth and annual forest fires. According to the Federal Aerial Forest Protection Service, the annual area of fires varies between 5 and 15 million hectares just in one economic type of managed forest! Most of this area is in Siberia and the Far East. In 2018, fires covered 2.3 million hectares in Siberia and 6.3 million hectares in the Far East and in 2019, 4.1 and 5.9 million hectares respectively. Most of the fires occur in the southern taiga, where the majority of pine forests grow with a large number of logging sites that facilitate the quick spreading of fires. Surface fires of various intensities prevail over crown fires, accounting for more than 90% of the fires.

AIMS OF THE PROJECT

The aims of our research are to understand and predict the causes, extent and effects of forest fires in order to manage forests more effectively and prevent fires. One of the important, unsolved problems of "fire management" remains the problem of remote detection of areas of possible forest fires, as well as early detection of the foci of these fires.

Low-intensity surface forest fire. (Galina A. Ivanova)

Spring high-intensity surface fire. (Aleksandr V. Bryukhanov)

WHAT DID WE DO?

We surveyed forests for over 25 years to record the incidence and type of fire. We also used satellite images to estimate the geographical area covered by smoke and reduced air quality from fires, working with the visible, infrared and microwave ranges, supported by laboratory measurements of the relevant characteristics of grass and woody vegetation.

WHERE DID WE WORK?

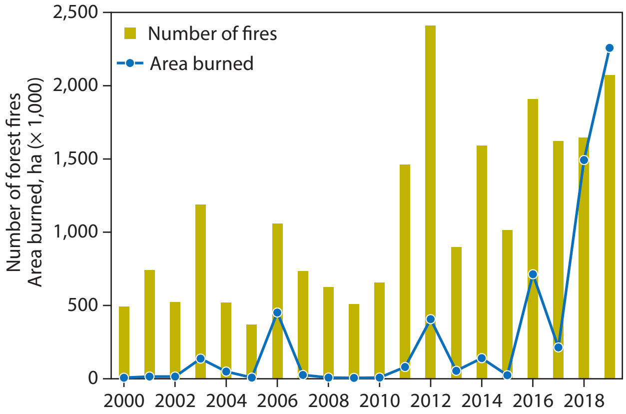
The investigations were conducted in an area of over 8,000 km^2 of Siberia. This area includes 9 Russian research stations within the INTERACT network.

WHAT DID WE FIND?

More than 85% of forest fires occur due to human activities, but in the northern regions "dry" thunderstorms are the main cause. The area of fires caused by humans is usually small, as they occur near settlements, where they are quickly detected and extinguished. In contrast, thunderstorm fires usually occur in remote forest areas, which are difficult or impossible to reach. The fire can advance several kilometres until it reaches a natural obstacle, such as a river or a swampy forest area. The area of one fire can be several thousand hectares. Therefore, while the number of fires caused by thunderstorms is small in comparison to those of anthropogenic origin, in terms of burned area they exceed the fires occurring near settlements.

The number and intensity of fires is increasing, mainly connected to increased anthropogenic pressure but also with climatic changes (increased storms) and problems related to fire protection. In the Krasnoyarsk Krai (administrative area), in 2019, there were more than 2,000 fires, including 335 each covering more than 200 hectares: some spread over ten thousand hectares. This is typical for all of Siberia.

An important characteristic of forest fires is their frequency, or the average interval between fires. The duration of the average fire interval decreases from the northern taiga zone to the southern forest-steppe zone. At 60 degrees latitude, the average fire interval in pine and larch forests varies between 20-40 years. In southern Siberia, the post-fire reforestation of these



The number and area of forest fires in the territory of Krasnoyarsk Krai.

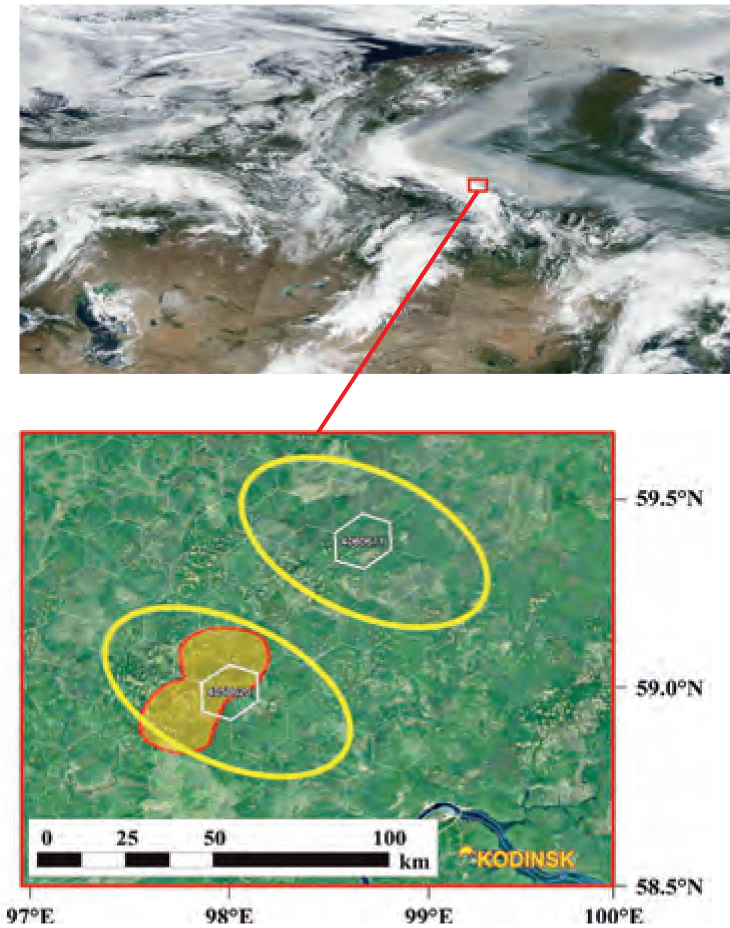
forests to technical maturity takes 60-70 years. However, even hundreds of years may not be enough to restore the forests of the northern taiga, where catastrophic fires have been taking place for many years. Frequently repeated fires affect fauna on the huge territory of northern Eurasia causing migrations of birds and animals of hundreds and thousands of kilometres and dramatically decreasing their populations.

WHY ARE THE RESULTS IMPORTANT?

Extensive and hazardous fire seasons result in loss of natural resources, and threaten the life and property of the population. Forest fires also affect all components of forest ecosystems. They release carbon into the atmosphere through the combustion of biomass, a significant part of which is located in the ground layer. In Siberian forest fires, 300-500 million tons of plant biomass combustion products enter the atmosphere annually in the form of gases (mainly carbon dioxide) and aerosol particles (smoke). In 2019, the smoke plume from the Krasnoyarsk forest reached the densely populated areas of southern Siberia 1,000 km away. Fires decrease the capacity of forests to capture CO_2, decrease albedo (reflection of energy from the surface), and reduce the quality of drinking water. Planning for the protection of forests from fires, as well as the use of fire for various forestry purposes, should be regulated with effective cooperation between scientists, practical specialists and decision makers.

THE ADVENTURE

Travelling and working in Siberian forests is a huge adventure, but we must all be careful of our actions and prevent fires.



Top: Smoke plumes from fires stretched for tens and hundreds of kilometres from the places of ignition, covering large areas of Siberia.
Bottom: The red box is 150 × 100 km square. The polygons represent the sources of the fires. Their plumes spread 1,500 km to the East and 900 km to the North.

The smoke plumes from fires stretched for tens and hundreds of kilometres from the places of ignition, covering large areas of Siberia and spanning the steppes (brown) taiga, (dark green) and almost reaching the tundra (and spanning the steppes covered in white cloud). At mid-day, hundreds of km from the fire at Barnaul, the sun was almost hidden by smoke. (Andrey N. Romamov)

There is growing awareness of the need to increase community 'voice' and participation in research that directly impacts people, as well as increasing global attention to the development and updating of formal protocols for the conduct of research with and about people. This is particularly important in regions where external review and oversight of community-based research has been limited.

Winter scene in the Sámi lands of northern Finland. (Rhonda Johnson)

Treating Arctic Peoples with respect: ethical principles for Sámi health research in Finland

Heidi Eriksen, Arja Rautio, Elizabeth Rink & Rhonda Johnson

AIMS OF THE PROJECT

The overall purpose of our project was to develop a set of useful guiding ethical principles for conducting community-engaged health research with members of the Sámi and researcher communities in northern Finland. This study sought to better understand the perspectives of Sámi community members and researchers in Sámi communities about research ethics and the process of engaging in collaborative research. Sámi communities working together with researchers is an example of "Community Based Participatory Research" (CBPR).

WHAT DID WE DO?

We used three types of methods to obtain a more complete analysis for interpreting the complexity of issues influencing health research studies with the Sámi in northern Finland. Data collection for Phases 1 and 2 included key informant interviews with researchers and Sámi community members; Phase 3 included focus groups, community presentations and discussions with both researchers from the University of Oulu in northern Finland and Sámi community members also dwelling in northern Finland. The meetings shared preliminary analyses from earlier phases and drafted recommendations for collaborative interpretation. These recommendations were also shared with the Sámi Parliament leadership and distributed through regional Sámi media outlets and circumpolar health meetings for further action.

All participants were asked the same set of questions in three broad topic areas including: 1) inclusion and partnerships; 2) ethics; and 3) trust, transparency and power.

WHERE DID WE WORK?

Our study took place primarily near the Kevo Subarctic Research Station in the Utsjoki region and in Oulu. The Utsjoki municipality is the only Finnish municipality with a Sámi majority. The Utsjoki region is located next to the Teno River and borders Norway. Oulu is a city of around 210,000 inhabitants ablout 150 km south from the Arctic Circle. Its university has 16,000 students and hosts the Giellagas Institute which has a nation-wide responsibility to organise, introduce and provide Sámi language and cultural studies and research at the academic level.

WHAT DID WE FIND?

Five key themes were identified: establishing trust, research preparation, research comprehension, research ethics, and inclusion in research. The differences in participant perspectives of these themes were compared based on participant role as community members or researchers. Our study demonstrated that Sámi community members and researchers often approach research differently based on their life experiences. These differences can have an impact on the research process including how research is conducted, what types of questions are asked and results generated. These different perspectives also affect how research results are shared and used which, unless acknowledged and addressed in meaningful ways up-front, may compromise the possibility for the research to be rigorous, credible and most beneficial to the Sámi community and others.

WHY ARE THE RESULTS IMPORTANT?

This study supports the continuing need for developing formal protocols for conducting research with the research community engaged with Sámi people and a negotiated research relationship that ensures the research conducted is mutually beneficial to researchers and the Sámi people. Since community members and researchers often approach research differently, it must be done together throughout the different phases of a research project.

THE ADVENTURE

Our research team enjoyed the beauty and warmth of northern Finnish landscapes over several seasons. After long days of conducting and discussing interviews, we particularly appreciated the beautiful hiking, "yummy" food and cosy sauna available at Kevo.

Sámi flag and pride in northern Finland. (Rhonda Johnson)

Hands-on practice with reindeer husbandry from local experts. (Heidi Eriksen)

Adapting reindeer husbandry to changes in vegetation and snow cover

Rosa-Máren Magga, Anders Oskal & Svein D. Mathiesen

Indigenous reindeer herding in the circumpolar North is threatened by multiple environmental and social changes that affect the sustainability of traditional family-based nomadic use of pastures. These impacts are exacerbated by Indigenous peoples' lack of voice in governance strategies, management and adaptation responses. In Utsjoki, Sámi reindeer husbandry has been facing increasing encroachments from other forms of land use, such as forestry, strictly protected areas and tourism, that change the vegetation. Added to these impacts are climate changes that will create challenges for reindeer herding, in particular due to their effects on snow cover over reindeer pastures.

View from Kevo Subarctic Research Station.
(Otso Suominen)

AIMS OF THE PROJECT

We aim to facilitate adaptation of reindeer husbandry to vegetation change and snow cover changes. We do this by producing a guide book for research station managers and local communities to develop a deeper mutual understanding of how to work together to build integrated local observation systems enabling local communities to respond to the challenges of present and predicted environmental change.

WHAT DID WE DO?

INTERACT facilitated a process to develop cooperation between the Kevo Subarctic Research Station and the local Indigenous community. We focused on research ethics, guidelines, traditional Indigenous knowledge combined with science, climate change adaptation and cooperation in a broader sense.

The Sámi concept of a reindeer herding siida is described as follows: "The siida is a Sámi local community that has existed from time immemorial. The reindeer herding siida has formed as an adaptation of ancient siida principles to large-scale nomadic reindeer herding. It is the prerequisite and basic organisational unit for carrying out large-scale herding. The main elements of the siida are the individuals (in Sámi siidda olbmot); the husbandry units (baikedoalut); the collective and the herding unit (siidadoallu); the siida territory, resources, and infrastructure (orohagat/siidavuoddu); and the semi-nomadic or nomadic lifestyle in accordance with the flow of the seasons (johtaladdan)."

WHERE DID WE WORK?

The work was based at the Kevo Subarctic Research Station, Utsjoki municipality and in surrounding areas. Sámi people are the majority of the population of 1,235 (2019) and one of the largest and most important economies and livelihoods is reindeer husbandry (an Indigenous economy). The reindeer are privately owned in Utsjoki, mostly by the Sámi people. Our work respected the siidas seasonal work, as the fall and winter until April is the busiest season in Utsjoki.

Community based INTERACT workshop in June 2019. (Svein D. Mathiesen)

WHAT DID WE FIND?

Some science topics, for example the study on autumnal moth, are not those that serve the local community and livelihoods the best. Some concerns for the local reindeer herders in Utsjoki are land use changes, shortening winters, difficulties to predict winter conditions as well as the changing tundra vegetation (more trees but less lichen cover). According to the local herders, the weather, especially in winter has changed drastically and prediction is very difficult. The winter has become shorter: the fall is longer and the spring starts earlier. Also, rain in winter makes grazing for the reindeer very difficult. However, the herders say they still have not faced the worst conditions yet.

The number of scientific articles about vegetation and snow change involving the Kevo Subarctic Research Station are vast. However, none include Indigenous reindeer herders' traditional knowledge in the studies' design, collection of data or analysis of results. At the station, there are no ethical guidelines and no system to include Indigenous Knowledge, and there is no organised cooperation about science between reindeer herders and the station. However, from the herders' perspective, it is important to increase the cooperation because the herders have much knowledge on the environment since they spend so much time ”out there.” This example of ”two ways of knowing” and a “co-production of knowledge” would ensure that the needs of the local reindeer herders would be better met. Such information and scientific knowledge are important for reindeer herders to adapt to on-going and future environmental changes.

WHY ARE THE RESULTS IMPORTANT?

Traditional knowledge is based on experience and has accumulated in people's memory and actions over multiple generations. Therefore, it is knowledge that is validated in the same way that scientific knowledge is found valid through trial and error. The mainstream community has today begun to demand the implementation of this traditional knowledge, and institutions such as the United Nations require and encourage that traditional knowledge be embedded into scientific research of the natural environment. We recommend all research stations to use Indigenous Peoples' needs and traditional knowledge in the planning of their work, in the design, collection and validation of data used, and in the discussion of the main findings.

THE ADVENTURE

After many sideways and getting lost we found the path again, meaning that traditional Indigenous knowledge needs to have a greater role in science. It is almost impossible to try to cooperate and fulfill a research project together with the scientists and traditional knowledge holders such as reindeer herders who are in the front line of the climate change effects in their daily working life if both sides are not seated at the table and their knowledge through their own voices is not heard.

Male castrated Reindeer. (Svein D. Mathiesen)

Male reindeer digging through layers of snow. (Ellen I. Turi)

Climate change and unpredictable sea-ice conditions bring changes to ecosystems and the traditional way of fishing/hunting. Knowledge of ecosystem change and processes is important to adapt to changes in local resource availability, regardless of the reason. These changes, their causes and their consequences, are sometimes perceived differently by the scientific community, the local community and the national political/administrative system.

Qeqertarsuaq town. (Morten Rasch)

Bridging knowledge systems in Greenland

Elmer Topp-Jørgensen, Morten Rasch, Ejner Grønvold & PâviâraK Jakobsen

AIMS OF THE PROJECT

Our aim was to increase the mutual awareness of changes in ecosystem and climate by bridging conventional scientific knowledge and local knowledge between the Arctic Station and the local community of Qeqertarsuaq, central West Greenland. This aim was to be achieved by strengthening the communication and cooperation between the scientific and local communities.

WHERE DID WE WORK?

We worked in the community of Qeqertarsuaq (about 850 inhabitants) located on the island Qeqertarsuaq (formerly Disko Island) in central West Greenland. The town of Qeqertarsuaq was founded in 1773. Fishing and hunting are very important for the subsistence of the town, with about 80 professional fishermen/hunters using boats, dinghies, snowmobiles or dog sledges. Implications of a changing climate are already seen with changes in sea-ice conditions and in the marine ecosystem. Scientific research in the area is led and facilitated by the Arctic Station which has been in operation since 1906.

WHAT DID WE DO?

The local administration of Qeqertarsuaq and the Arctic Station convened open community meetings where local stakeholders and staff of the Arctic Station met to discuss environmental and climate change-related challenges and to discuss potential for cooperation. Potential areas of cooperation were identified and discussed, and it was agreed to start up a number of specific joint activities.

Although in decline, dog sleds are still used in Qeqertarsuaq. (Morten Rasch)

Local fishermen heading out in icy waters. (Morten Rasch)

Scientists and station staff meeting with local community representatives at Arctic Station. (Morten Rasch)

WHAT DID WE FIND?

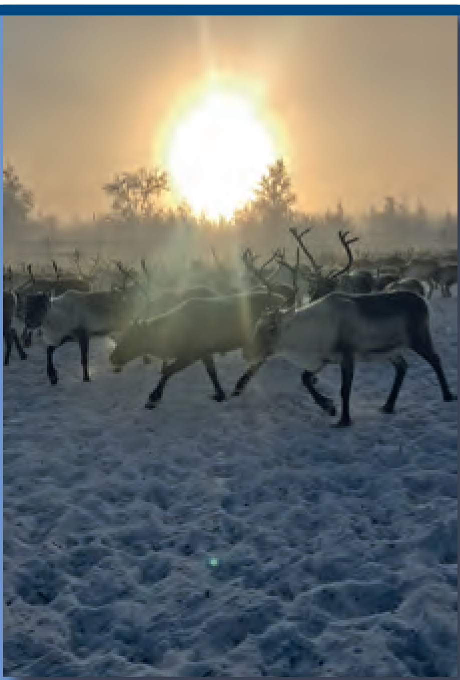
Participants expressed a wish to engage and increase collaborative activities related to, for example, (i) education and awareness, (ii) potential development of a citizen science or community-based monitoring programme for environmental change (i.e. Pisuna, a community run observation system focusing on the state of local fish and wildlife resources), (iii) bridging of knowledge systems by bringing together scientists and local knowledge holders and (iv) community use of the research station facilities. It was agreed to take an agile approach in which temporary and long-term activities are developed and possibly adjusted to remain relevant to the local context.

WHY ARE THE RESULTS IMPORTANT?

The dialogue we are achieving concerning environmental and livelihood issues across the different stakeholder groups can improve our understanding of what changes are happening, how they will affect ecosystems and livelihoods, and how we can best adapt. Hence the bridging of knowledge systems is important to ensure local adaptation and sustainability. The latter often necessitates linkages to decision makers at the local, municipal or national level, and that they are willing to use the information. Although settings change from location to location, the approach we developed is relevant in many other areas.

THE ADVENTURE

The lazy daylight of the polar night, with sprouts of *Aurora Borealis* to colour the night; experiencing a fishing/hunting community just waiting for the right weather and sea-ice conditions to be able to fish and hunt; the warm and welcoming smiles of local people and the setting of the town and the research station with glacier-covered mountain plateaus in the background and a sea full of icebergs in the foreground are all part of the adventure in Qeqertarsuaq.



Winter's day in a reindeer corral, Jarin Sweden. (Niklas Labba)

Ensuring tourism and Arctic Peoples cooperate for mutual benefit

Niklas Labba & Ann Eileen Lennert

Arctic tourism is growing rapidly, including in many of the North-Atlantic regions. The northern-most counties of Scandinavia and the Sámi parliaments have pointed to tourism as a developing area in political objectives, as well as national and local strategies. Such tourism development and planning today calls for proactive, holistic and responsible thinking that generates a greater awareness about Arctic Peoples and the Arctic landscape. Planning should address conceptual and contemporary issues during development including political trust, community engagement, innovation, networking, sustainability, moral encounters and education.

Gathering reindeer in the autumn in the Norwegian mountains. (Niklas Labba)

AIMS OF THE PROJECT

We aim to generate greater awareness of the sensitivity of the Arctic, with a focus on Sámi reindeer herders. We wish to emphasise how guidelines within the industry and education of visitors can contribute to sustainable tourism. We also wish to demonstrate that community engagement, identifying mutual benefits and understanding, as well as ensuring that local perspectives are considered in tourism management strategies, are the most important and essential tools meeting this task. The UNDP (United Nations Development Programme) publication "Tourism and the Sustainable Development Goals — Journey to 2030" concludes that knowledge sharing and mutual engagement is the best way towards a sustainable tourism development. Taleb Rafai (Secretary-General of the United Nations' World Tourism Organisation) captured the idea in his statement "There is no future for travel and tourism if you are not welcome and embraced by the local community".

Norwegian Championship in Reindeer Racing, Tromsø Norway. (Niklas Labba)

Sámi National Association, Annual Meeting, Stockholm. (Niklas Labba)

WHAT DID WE DO?

We gathered and summarised existing policies and regulations concerning Arctic nature-based tourism, identified their purposes and needs, and then suggested revisions based on the perspectives of local and Indigenous People. We looked to "best practices" across the Arctic to identify methods and tools for ensuring cooperation between tourism and Arctic Peoples. Our attention turned to The Association of Arctic Expedition Cruise Operators (AECO), that for many years has been dedicated to managing responsible, environmentally friendly and safe tourism in the Arctic with respect and consideration for local people, communities and cultural heritage. Their "best practices" implemented within Expedition Cruise tourism creates mutual understanding of values, needs and expectations on land, as well as to ensure development in accordance with local interests, culture, locality and capacity. We built collaboration between Indigenous and local communities, researchers, tourism businesses and research station managers, the latter approached via the INTERACT Station Managers' Forum which serves as a place for education, training and sharing best practices.

WHERE DID WE WORK?

Our focus areas were in the counties of Norrbotten in Sweden, Lappi in Finland and Troms in Finnmark, Norway. Relevant research stations were the Abisko Scientific Research Station (Sweden) and the Kevo Subarctic Research Station (Finland).

(continues)

WHAT DID WE FIND?

In central Europe, tourism businesses depending on the snow season are facing shorter seasons due to the warmer climate. Some of the foreign tour operators from Europe are therefore seeing the large potential in developing tourism outside their home by moving businesses to Scandinavia. Local communities, especially reindeer herders, are experiencing harmful effects from the growing tourist activity, mainly due to the tour operator's lack of knowledge about local and Indigenous communities and their businesses and culture. In contrast, where there is knowledge sharing and a mutual respect, harmful effects of the growing tourism activity have been mitigated and new business opportunities within the local and Indigenous communities created.

WHY ARE THE RESULTS IMPORTANT?

The results will be useful for tour operators, policymakers and local and Indigenous communities, who will be able to see the great potential and mutual benefit there lies within the notion of collaboration and engagement. The tourism industry needs guidelines and knowledge of how to conduct a respectful interaction with people and cultures in the Arctic. Policymakers need more information and knowledge to be able to ensure that Indigenous and local communities' benefit from tourism, and local suggestions are implemented,

Tourists taking a reindeer sledge trip with the "Tromsø Arctic Reindeer" company. (David Jensen) and concerns addressed, in tourism strategies and management. Local and Indigenous community guidelines based on internal values, needs and expectations, can be an important tool to maximise benefit and minimise harm from increasing tourism. Guidelines will give recommendations that help policymakers, research station managers, tourist operators and tourists to plan tourism to Arctic Indigenous and local communities in a respectful and considerate manner, as well as giving the communities control of their own representation.

THE ADVENTURE

Mutual understanding and sharing knowledge create a new dimension to Arctic tourism. It brings new possibilities and innovation. It brings local ownership into action. It has given an understanding of representation, consideration of cultural activities and use of land. Today young reindeer herders have started to cooperate with tour operators while pursuing their traditional Sámi activities.

New challenges for hunting, fishing, agriculture and conservation in the taiga

Olga Shaduyko (Morozova), Lidia Rakhmanova, Sergey Kirpotin & Terry V. Callaghan

Over the past decades many changes, both natural and social, occurred in the taiga. Examples are climate change; shifts in economic paradigms that are causing a tremendous movement of population and even total de-population of some regions; environmental changes driven by human land-use impacts that affect local communities; social and psychological changes that provoke conflicts between traditional knowledge, old official regulations, and the reality of daily life. These conflicts prevent people from adapting to the challenges and opportunities of a changing environment.

About 20% of former hayfields and pasture areas in the Krivosheinskiy District are abandoned now and turning to forest. In the Kaibasovo Village, only one resident remains, a bee-keeper. (Terry V. Callaghan)

The number of family, self employed farms in the Kajbasovo Research Station's administrative district decreased from 71 in 2011 to only 2 in 7 years! (https://depagro.tomsk.gov.ru/photoGallery/)

AIMS OF THE PROJECT

A main aim of this project is to provide the science background to help local people and decision makers to understand, predict and adapt to the changing life in the region near the River Ob and its floodplain. We focus on the stability of fishing resources, balancing conservation of biodiversity, hunting interests and safety, and also on the dynamics of land-use between agriculture and forestry.

WHAT DID WE DO?

Researchers at the station met and worked with local communities and local authorities to develop research that can be translated into regulations that enhance the sustainable use of natural resources essential to the wellbeing of local people while setting aside officially designated areas to conserve biodiversity. At the same time, the researchers cooperated with local people and authorities to implement projects that address global environmental challenges important to local people in the longer term. To optimise fish stocks, the station has studied fish populations for many years and works closely with fishing inspectors, local people and with other colleagues from Tomsk State University.

WHERE DID WE WORK?

The Kajbasovo Research Station in West Siberia is not situated in or near a village or community because it was specifically founded for basic environmental research activities in an area of minimal human disturbance. This location limits the direct contacts between the station and local communities. However, the station significantly interacts with the communities through contacts with local administrations that include settlement leaders. Often, and whenever possible, the station also has direct contacts with local communities.

WHAT DID WE FIND?

Some fish species have been introduced to local water bodies but the stocks of the most valuable fish are at a very low level. To restore the stocks of the most valuable fish for commercial and subsistence purposes, a range of measures should be undertaken. For example, limiting the number of specially introduced fish species (e.g. bream), trapping male fish in the spring period and cancelling fishery limits for less valuable species. This compromise among conservation regulations, subsistence needs and commercial exploitation is very difficult to negotiate.

Beavers have been protected for centuries but a combination of conservation measures and decreased economic interest in hunting have led to a large expansion of the beaver population. The results are a reduction in fish stocks and significant damage to the environment. Consequently, new conservation measures are required. The number of bears in the local forests also increases from year to year. The population peak was recorded in 2017, when the number of bears in the Tomsk forests was 9,500 individuals whereas the optimal number is only 6,500! Again, lack of economy interacting with outdated conservation measures and severe forest fires in the south-eastern taiga that drive bears westwards, is leading to population expansion with possible danger to humans.

There is now a strong long-term trend of depopulation of the area. The number of self-employed farms decreased from 71 in 2011 to only 2 in 7 years! About 20% of former hayfields and pasture areas in the Krivosheinskiy District are abandoned now and turning to forest which is good for biodiversity and carbon storage. In this case, the environmental changes are caused by social and political factors but the consequences are important for biodiversity and greenhouse gas capture.

WHY ARE THE RESULTS IMPORTANT?

The projects are important for science and important for communities. They show the complexities of change resulting from many interacting causes. It is important that the widespread and long-term observations of local hunters and fishermen became the basis for research projects, and the projects will result in the development of practical recommendations for the local and regional administrations with benefits for the local people.

THE ADVENTURE

The vast Siberian taiga offers many, mostly dangerous, adventures. Visitors can enjoy it and succeed with their work only if they are in a team of people with local knowledge who can help them to access the station and other places during the strong spring flood, can protect them against wild animals like bear, and who can cook delicious meals from what can be found in the forest.

Top. Increasing numbers of beaver dams result in environmental damage such as lack of oxygen in ponds (foreground water) that kills valuable fish. (Sergey N. Kirpotin)
Middle. TSU researchers sample fish, finding the only species (*Carassius* sp.) that can survive in winter with low oxygen levels. (Sergey N. Kirpotin)
Bottom. In 2017, the number of bears in the Tomsk forests was 9,500 individuals whereas the optimal number is only 6,500! (Terry V. Callaghan)

Faroe Islands' communities: social isolation or connectivity?

Lidia Rakhmanova & Evgeny Zarov

Globalisation and climate change impact isolated islands with their long traditions, causing changes in the geography of fisheries, routes of people's migration and transport mobility, and boundaries of settlements. Thus, the traditional way of life of island communities has to adapt. But is it possible to harmonise old traditions with the abruptly coming changes and what is the limit of the external impacts beyond which there is a cultural collapse?

AIMS OF THE PROJECT

We aim to reveal the changes in the traditional way of life under the pressures of globalisation and climate change. We chose semi-isolated (geographically and socially) communities of the Faroe Islands. Our societal component was to exchange knowledge and information not only within scientific networks and the academic community, but to discuss the results with representatives of the Islands' communities. We tried to merge visualising GIS (Geographical Information System) technologies with anthropological analyses in order to understand and explore the dynamics and structure of social phenomena.

WHAT DID WE DO?

In collaboration with local scientists and community representatives we focused on local changes in folk craft (fishing, hunting, gathering wild plants). We traveled around islands of the archipelago covering the central islands (Streymoy, Eysturoy and Vagar) and the remote ones. We tried to understand how life-support (food, pharmaceuticals and goods supply) and transport accessibility affect peoples' perception of climate change and lifestyle. We conducted 30 in-depth interviews with people of different backgrounds, from villagers and fishermen to experts from the Ministry of Transport Development, and we collected 50 questionnaires in Faroese and English.

WHERE DID WE WORK?

We carried out participant observation in the town of Miðvágur and the surrounding settlements. Here, we talked to the employees of shops and cafeterias, to the school staff, to the people at harbours, supermarkets, near town halls and churches, and at community meetings. Another central point for interviewing and observing was the capital Tórshavn, where we consulted colleagues from Jarðfeingi (Faroe Islands Nature Investigation (FINI)), interviewed fishermen, visited public places, analysed traffic, food supply and other aspects of everyday life. We visited many other settlements too.

WHAT DID WE FIND?

During the last decade, the number of immigrants and tourists have increased. This affects the Islands' infrastructure and development. At the same time, an archipelago poses the challenge of linking together all its settlements with tunnels and bridges. However, connectivity is not sufficient for those islands that are called 'The Other Islands' and villages in them are gradually dying.

The Faroe Islanders continue traditional land use such as sheep grazing on almost inaccessible land.
(Lidia Rakhmanova)

Communication among islands is difficult due to rugged coast lines. (Anastasia Zarova)

Saksun Village: historical heritage in a contemporary context. (Lidia Rakhmanova)

Thus there is a certain contradiction between the development of infrastructure hubs around the capital and important centers and the development of the archipelago's periphery. Therefore, some areas of the archipelago do not feel the constructive influence of globalisation and tourism. Although in the second half of the 20th century ferry crossings created technologically equal conditions for residents, today the technological and infrastructure gap is increasing between districts, cities and rural settlements of the Faroe Islands. Globalisation changes on the archipelago accelerate the pace of life of one part of the population, increases their comfort, and the unification of lifestyles with continental Europe grows. At the same time, for the other part of the population, the spectrum of opportunities remains the same as before or decreases.

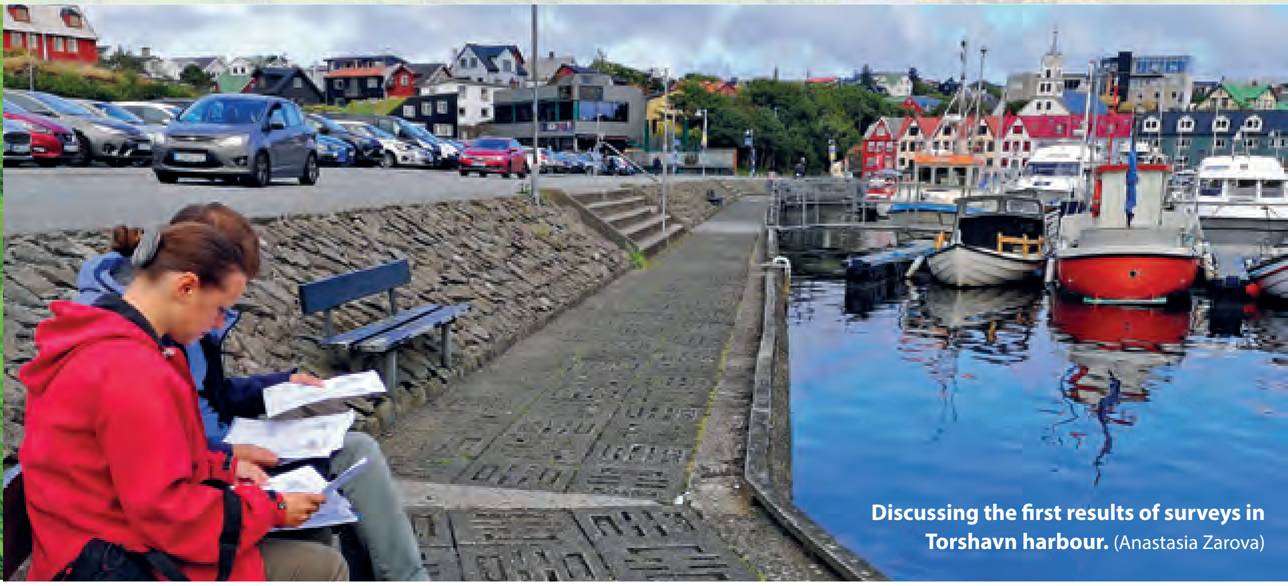
WHY ARE THE RESULTS IMPORTANT?

In our study, we have encountered two alarming issues that require further research and that need to be part of a general discussion about the natural and cultural transformation of Arctic island communities. Firstly, the anthropogenic and infrastructural pressures on the landscape and fragile ecosystems of the Faroe Islands exceed preventive measures including planning of tourism and decentralisation of settlements.

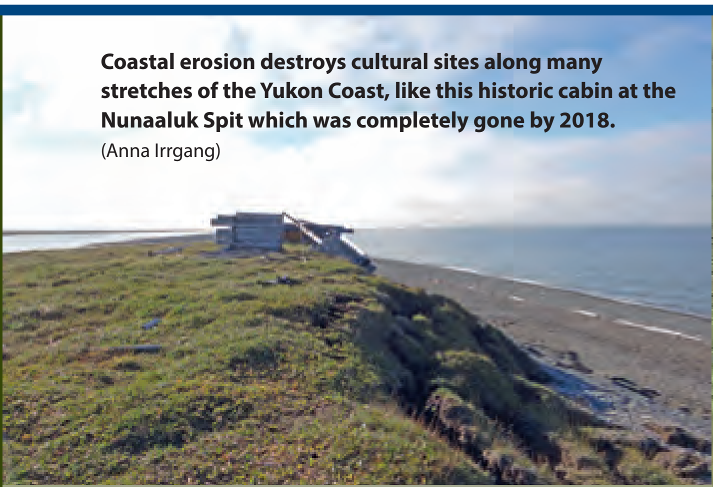
The second challenge is the increasing social and economic inequalities which are acute in remote territories. Infrastructural changes make the community more adaptable to the northern Island settings. However, the 'Other islands' develop in a reverse logic: while the transport systems are reduced and the change in quality of life of people is questionable, the pressure on ecosystems is reduced, and a former, more natural balance is maintained.

THE ADVENTURE

"Oh, it is SO incredibly awesome!" describes the journey. Everything on the Faroe Islands was so uncommon and attractive for the visitors from the continent. Everything, starting from the almost everyday drizzle and grass-covered roofs, to the traditional cuisines, dance-song parties and imperturbable quiet way of life of the islanders. It is something special to be and work on the Faroe Islands with its still carefully preserved traditional way of life in our globalised world.



Discussing the first results of surveys in Torshavn harbour. (Anastasia Zarova)



Coastal erosion destroys cultural sites along many stretches of the Yukon Coast, like this historic cabin at the Nunaaluk Spit which was completely gone by 2018.
(Anna Irrgang)

Infrastructure is being destroyed by coastal erosion. Here we see the landing strip of the DEW (Distant Early Warning) line station at Qamaqaaq which gets shorter each year.
(Anna Irrgang)

Coastal erosion threatens infrastructure and cultural sites in the western Canadian Arctic

Anna Irrgang & Hugues Lantuit

Arctic permafrost coasts make up 34% of the Earth's coasts and they are eroding at increasing rates. Decreasing sea ice extent, lengthening of the open water season, rising sea temperatures and thawing of permafrost all foster greater erosion of the coasts by waves. This erosion delivers large amounts of carbon-rich sediments to the coastal zone and threatens coastal infrastructure. The implications of this worrying trend are the focus of the EU H2020 NUNATARYUK project.

AIMS OF THE PROJECT

In this project, we looked at the impacts of increasing coastal erosion rates on infrastructure, navigation routes and cultural sites along the Yukon Coast, Canada.

WHAT DID WE DO?

We used an original approach based on remote sensing, mapping and engagement with local people to map threats to coastal infrastructure and cultural sites. Air photos from the 1950s, 1970s and 1990s were processed to create a full mosaic image of the Yukon Coast and compared to high resolution satellite imagery from 2011. Field work in the area is key to collect geodetic information about the accurate position of infrastructure and cultural sites and accurately pin-point the locations of the imagery. We then collected information on travelling routes, cultural sites and infrastructure using existing information from Parks Canada and the knowledge of local people. We combined the imagery with the locations of coastal sites to establish how many sites are under immediate threat. We also projected coastal erosion rates based on existing ones and mapped the potential loss of these sites to coastal erosion by 2100.

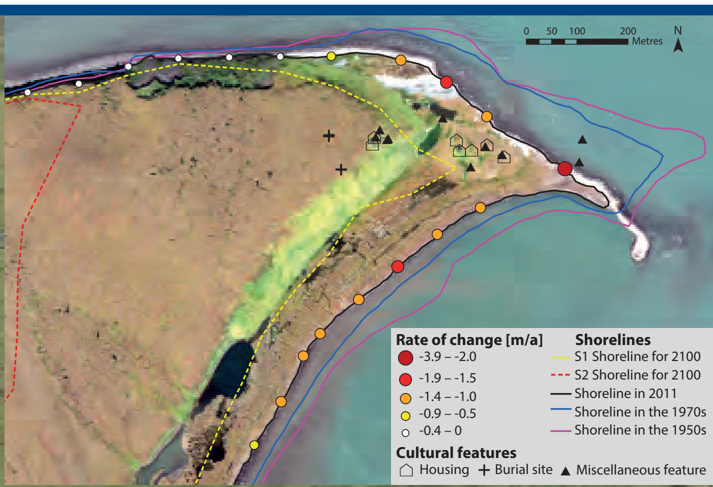
WHERE DID WE WORK?

Most of our work takes place on Herschel Island, Qikiqtaruk Territorial Park. Herschel Island has a vibrant heritage and spectacular landscape associated with permafrost degradation. The island provides access to sites along the Yukon Coast by boat or helicopter. We rely on the Park, the Aklavik Hunters and Trappers Committee and the Yukon Government to work in the area. Most of our field preparation and setup takes place at the Western Arctic Research Centre in Inuvik.

WHAT DID WE FIND?

On average, the coast was retreating by 0.5 metres/year (m/a) between the 1970s and 1990s. This retreat accelerated to 1.3 m/a between the 1990s and 2011. This acceleration in erosion was confirmed by field measurements that indicate increased erosion rates up to 8.9 m/a since 2006. Our projections show that as much as 2,660 hectares of land could be lost by 2100. Already, past erosion has led to the loss of 26% of all inventoried cultural features such as graves or cabins. An additional 35% are expected to be eroded under the most drastic erosion scenario, leading to a loss of 61% of the inventoried cultural features along the Yukon Coast by 2100. In contrast, several

A D-GPS survey along an actively eroding coastal site close to the Yukon-Alaska border. (George Tanski)



Coastal erosion and cultural sites at the former settlement of Niaqulik, along the Yukon Coast. Base image: WorldView-2 scene from August 2011. (After Irrgang et al. 2019)

cultural sites are built in areas in which the beaches have been widening through sand accumulation since the 1950s and are not directly threatened by erosion. The landing strips of the two DEW line stations (distant early warning stations which were built during the cold war to protect North America against potential attacks from the Soviet Union) of Ikpigyuk and Qamaqaaq are expected to be substantially shortened by 2100. Additionally, because of its low elevation, the landing strip at Ikpigyuk is in danger of becoming periodically or permanently flooded. The projections suggest that both landing strips near the Yukon mainland coast will be directly impacted by erosion and (or) flooding by 2100.

WHY ARE THE RESULTS IMPORTANT?

Coastal erosion will lead to the loss of hundreds if not thousands of cultural sites along the Arctic coastal rim, as well as important transportation nodes. The impacts of this process are manifold: The protection of vital coastal infrastructure is costly and is likely to increase in the near future. Our study shows the urgency of addressing this issue. The loss of sites is also a cultural challenge for the Inuvialuit, since most activities, oral history and travel takes place along the coast. These results will help to protect and document the living history of the sites that are most threatened and to prioritise action for local and regional stakeholders.

THE ADVENTURE

Traveling along the Yukon Coast is always an adventure. There are few people traveling there and conducting fieldwork means being alone with no one to reach in a 100 km radius, although the presence of wildlife monitors from Aklavik ensures that we anticipate changes in weather conditions and conduct field work safely in this nearly untouched wilderness. One time when we used the boat to get to a sampling site the winds picked up and changed very quickly and we could not go back to camp by boat. The strong winds evolved into a storm and we were several km away from our camp. It took several people to organise an exit strategy in order to get us, as well as our gear, safely back to camp — we secured the boat and picked it up a couple of days later.

6 Impact on global societies

SECTION OVERVIEW

While the local impacts of changes in the Arctic's environment and society are obvious, changes there do not stay local! Feedbacks from the changing reflection from Arctic land, snow, ice and water surfaces affect global climate; increased greenhouse gases from tundra landscapes and ponds where permafrost is thawing add to the global concentration of atmospheric greenhouse gases; meltwater from melting glaciers and ice caps add to increasing sea levels; and many aspects of biodiversity connect the Arctic with the rest of the world.

In "Impacts on global societies", we learn how "when the ice goes black", local climate is affected. This ice is melting and one story quantifies the important contribution this makes to global sea level. Carbon stocks in tundra and taiga soils are huge and are of concern because increased greenhouse gases from these areas could enhance global warming. We learn how significant the stocks of carbon are in taiga soils and how important the greenhouse gas emissions are from taiga wetlands while studies in both night and day time show how we may be underestimating methane emissions from thaw ponds in frozen peatlands. Despite many potentially harmful effects of thawing permafrost, the final story in this section shows how the specific conditions of the Arctic's permafrost is being used to conserve important elements of global biodiversity.

Changes in Arctic environments have global impacts.
Permafrost thaw leads to local ground disturbance and release of greenhouse gases.
(Lisa Broeder)

The margin area of the Mittivakkat Glacier (please pay attention to the drak surface filled with debris). (Sebastian H. Mernild)

When the ice goes black!

Sebastian H. Mernild

The Greenland Ice Sheet and mountain glaciers are independent recorders of climate change as surface air temperature above zero and snow accumulation control their surface mass balance (SMB: the difference between accumulation of snow and ablation of snow and ice loss through melt and other processes). The reflective nature of glacier surface conditions — the surface "albedo" — plays a role in the balance between the absorption and reflection of the sun's energy and the subsequent ablation processes that contribute to SMB. In Greenland, glaciers around the ice sheet have undergone rapid changes in area and volume over the last decades. Since the mid-1980's, some glaciers in South-East Greenland have lost about 27% of their area. The Mittivakkat Gletscher, the most recorded mountain glacier in Greenland, lost 17% in area, 15% in mean ice thickness, and 30% in volume. To understand such loses, it is important to measure the components of SMB such as changes in surface albedo.

AIMS OF THE PROJECT

For the Greenland Ice Sheet, the annual albedo dropped by 3% during the period 2000 to 2019, indicating that more of the incoming shortwave (heating) solar radiation was absorbed on the surface leading to increased surface ablation. Does a similar drop in albedo occur for glaciers around the ice sheet? If so, what is the specific impact from a changing albedo on the glacier ablation and SMB? Are the changes we see in albedo caused by an increase in temperature?

WHAT DID WE DO?

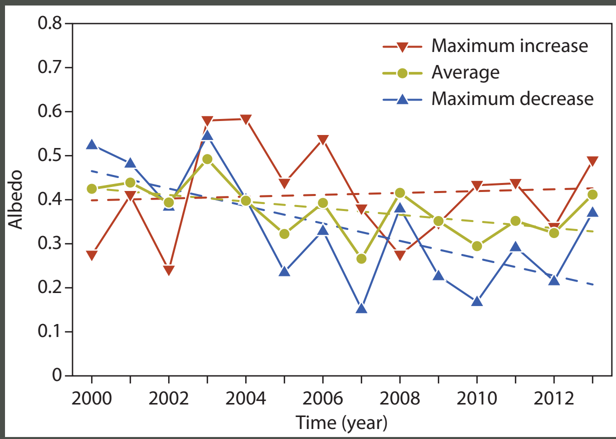
We measured variations in albedo over snow, ice, slush areas, algae, black carbon, and debris on Mittivakkat. Measurements were repeated to better understand how conditions change over time and space as changes in surface albedo can occur even over tens of centimetres. For the fieldwork campaign, we: 1) measured surface albedo on different surface debris types; 2) measured the surface energy balance components each hour to estimate albedo time-series; 3) took daily time lapse photos (at noon) to estimate changes in surface debris over the ice; and 4) estimated albedo changes since 2000 using satellite images (The MODerate Imaging Spectroradiometer (MODIS MCD43A3)).

WHERE DID WE WORK?

The Mittivakkat Glacier (26.2 km^2; near the Sermilik Research Station) is a temperate glacier located in South-East Greenland. Since 1931, Mittivakkat has been recorded at regular intervals by field observations, aerial photography, and satellite imagery. From 1931, the glacier's front (terminus) has retreated horizontally by about 1,700 m. Since 1995, the mean SMB was –0.99 ± 0.72 m of water equivalent per year, decreasing by 0.03 per year. This is also apparent at the ELA which has risen from around 500 to 750 m a.s.l. since 1995. The ELA is the elevation of the equilibrium line, defined as the set of points on the glacier's surface where the net mass balance is zero. In other words, above this elevation, the glacier faces net accumulation, and below net loss.

WHAT DID WE FIND?

We measured significant snow and ice albedo changes, even over small distances (tens of centimetres), and over time during the day. There was a clear link between changes in albedo and in air temperature near the surface. Mittivakkat's meteorological stations observed by the end of the mass balance year (EBY) that bare ice albedo reached around 0.3 which is low and only just exceeds values of around 0.2 observed for exposed bedrock. Also, the MODIS satellite albedo estimate was used to study Mittivakkat's snow and ice albedo by EBY. The analysis of MODIS estimates of EBY albedo reveals a significant decline in mean glacier-wide albedo of 0.10 since 2000, indicating that 10% more of the incoming shortwave solar radiation was absorbed on the surface and was therefore available for surface ablation. The greatest decline in EBY albedo of 0.25, occurred near the ELA, an important surface cover (between snow and ice) and albedo transitional zone.



Time series of Mittivakkat Glacier MODIS-derived albedo at the end of the mass balance year; average, maximum and minimum increase from 2000 to 2013.

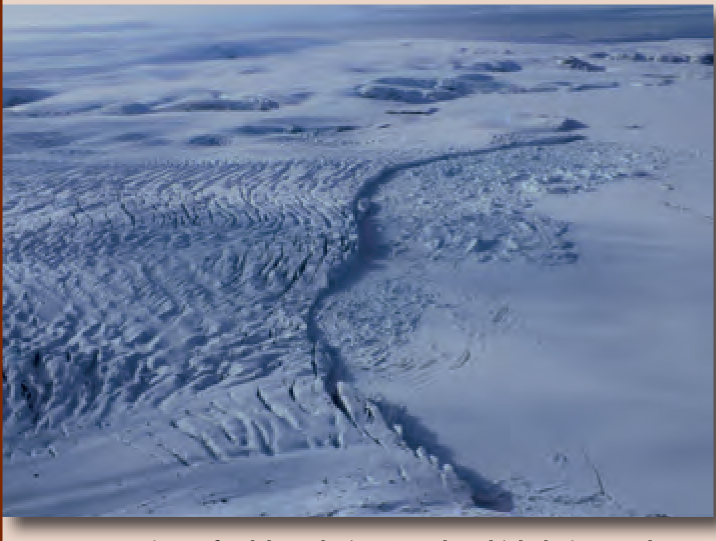
The Sermilik Fjord with Mittivakkat Glacier in the background.
(Sebastian H. Mernild)

WHY ARE THE RESULTS IMPORTANT?

As the end of the mass balance year albedo correlates significantly with the elevation of the ELA and net winter and summer glacier mass balance records, an increasing understanding of the glacier albedo conditions are important for our understanding of the surface energy balance and subsequent ablation processes that determine surface mass balance. The decline in albedo we saw indicates that the surface became darker and less reflective leading to more incoming shortwave solar radiation absorption, greater surface ablation, and increasing mass loss in the melt-albedo feedback.

THE ADVENTURE

Coming to South-East Greenland is like going to the Last Frontier. One is surrounded by alpine terrain, fjords, icebergs on the fjords, and glaciers, together with — very often — blue sky. From the Mittivakkat Glacier we saw the sunset over the Greenland Ice Sheet. Being on one glacier seeing the sunset over the biggest ice sheet in the Northern Hemisphere was amazing. When being on Mittivakkat — in this remote environment — I often think about the opposite, Times Square in NYC. Simply just to put the experiences into perspective.



Terminus of Belcher Glacier, Canada, which drains north from the Devon Island Ice Cap into Jones Sound. (Martin Sharp)

Aerial view of a melting glacier ice surface in Ellesmere Island, Canada (summer 2019). Note the dense network of meltwater channels on the surface that evacuate meltwater from the glacier, and the large number of small ponds between the channels. (Martin Sharp)

Melting of Arctic glaciers and ice caps and its impact on sea level

Martin Sharp, Gabriel Wolken & Bert Wouters

Arctic glaciers occur in areas with maritime (southern Alaska, Iceland, Svalbard, and Scandinavia), continental (interior Alaska/Yukon), and Polar Desert (Arctic Canada, Arctic Russia) climates. They form where snow accumulates faster than atmospheric heat can melt it. This balance between accumulation and melt is called "surface mass balance". Where a glacier ends in the ocean, ocean heat may melt the submerged part of a terminal ice cliff, or the underside of a floating ice tongue. Melt of all of the glacier ice in the Arctic would raise global mean sea level by 0.41 m. Complete melting of the Greenland Ice Sheet would add another 7.2 m.

6 • 2

AIMS OF THE PROJECT

To quantify rates of change in Arctic glacier mass and evaluate how they affect global sea levels.

WHERE DID WE WORK?

Annual field measurements of glacier mass change in the Arctic began in the late 1940s. By the mid 1990s, they were made annually on selected glaciers in Alaska, Arctic Canada, Svalbard, northern Scandinavia, and Iceland. For other areas, such as the Yukon and the Russian Arctic, episodic measurements are available of how glacier areas have changed over time, and there are some "snapshot" estimates of changes in glacier mass.

WHAT DID WE DO?

Satellite remote sensing is used to document rates and patterns of changes in glacier area/length. Repeat measurements of ice surface height track changes in ice thickness, mass, and volume. Such data come from aircraft surveys by programs like NASA's Operation "Icebridge", and from satellites, such as ICESat1/2 and CryoSat2, which monitor changes over time in the surface elevation and volume of ice masses. The GRACE satellites (2002-2016) and GRACE Follow-On Mission (2018-present) provide data to determine changes in regional scale glacier mass by tracking how these changes modify Earth's gravitational field.

WHAT DID WE FIND?

We used all *in situ* glacier mass balance time series from subregions of the Arctic (Alaska, Arctic Canada, Iceland, northern Scandinavia, Svalbard and Russia) to compute mean cumulative mass balance changes for each region over periods of about 30 (Iceland) to 70 (northern Scandinavia) years. These all show progressive loss of glacier mass over time, which is consistent with the fact that the Arctic was the most rapidly warming area on Earth from 1960-2019. Glaciers in Arctic Canada (–68 ± 14 Gt/yr) and Alaska (–53 ± 14 Gt/yr) had the most negative regional mass balances, followed by Arctic Russia (–11 ± 3 Gt/yr), Iceland (–10 ± 2 Gt/yr), and Svalbard (–7 ± 1 Gt/yr), while those in northern Scandinavia had a marginally positive net mass balance (+1 ± 11 Gt/yr). Among the regions with negative mass balances, only Svalbard shows no acceleration of mass loss since ~1990.

Melt channels incised into the surface fed by lakes that form in the early melt season. (Martin Sharp)

Meltwater channels incised into debris-covered glacier ice near a glacier margin. These feed into large channels that drain along the trench between the glacier margin and the valley wall. (Martin Sharp)

WHY ARE THE RESULTS IMPORTANT?

Measurements of glacier mass change allow us to assess how Arctic glacier shrinkage impacts global mean sea level. Data from the GRACE satellites suggest that the rate of glacier mass change across the Arctic from 2002-2016 was ~ –148.3 Gt/yr, equivalent to ~ 0.4 mm/yr of sea level rise. Approximately 46% of this came from glaciers in Arctic Canada (where melting slowed after 2014), 36% from Alaskan glaciers, and ~ 18% from glaciers in Iceland, Svalbard and Arctic Russia combined. Because of gravitational effects related to regional changes in ice mass (ice caps are gravitational attractors that draw ocean water towards them, an effect that decreases as they lose mass), glacier melt in the Arctic may cause more sea level rise in regions remote from the Arctic than it does in the Arctic.

THE ADVENTURE

Mass balance measurement teams needed strong mountaineering and winter survival skills, and the ability to evaluate and avoid avalanche risk, to navigate through or around crevasse fields, and to deal with less predictable hazards, like polar bears, that could be a threat to field teams, their supplies and equipment. They have also had to navigate less well-known hazards, like large slush flows, that became increasingly common in some areas as summer air temperatures rose after the mid 1990s.

Torrents from melt water are found on the Greenland Ice Sheet. (Terry V. Callaghan)

Soil organic carbon stocks in the Russian taiga

Juri Palmtag & Didac Pascual

Soils in the northern permafrost region are a key component in the global carbon cycle. Permafrost (perennially frozen) soils in the circumarctic region store enormous amounts of carbon — about twice as much as currently contained in the atmosphere. It is almost certain that increased global temperatures will cause a substantial decrease in permafrost extent within this century. This rapid warming and permafrost degradation could intensify the microbial decomposition of organic matter thereby releasing more greenhouse gases into the atmosphere, representing a strong positive feedback on global warming.

AIMS OF THE PROJECT

The aim of this project is to reduce a critical gap in the Northern Circumpolar Soil Carbon Database (NCSCD) which will improve the recent estimates for these important and vast areas considerably. This gap is represented at two Russian research stations which are in ecosystems of the highest uncertainties regarding the current knowledge on soil organic carbon (SOC) storage and distribution.

WHAT DID WE DO?

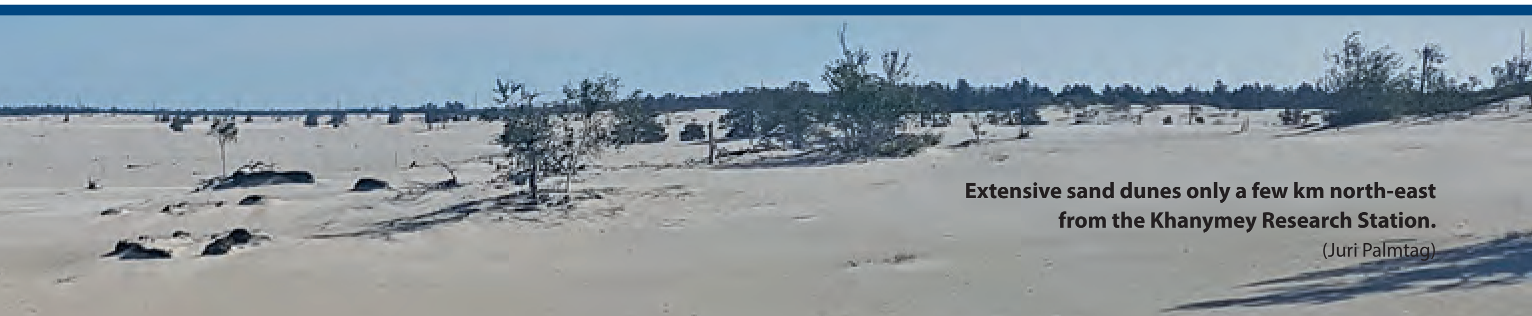
We conducted a detailed landscape-level soil organic carbon (SOC) inventory. The fieldwork was conducted during late summer when the maximum seasonal soil thaw (active layer) thickness is reached. Soil samples were taken across the landscape covering all the important land cover and vegetation types. The method consisted of sampling the top-soil organic horizons (layers), the mineral active layer below, and the permafrost horizon down to at least 100 cm of depth. In the laboratory, all the soil samples were analysed for dry bulk density, loss on ignition at 550 and 950 °C (a measure of organic and inorganic matter content), and elemental carbon and nitrogen analysis. From this data, we were able to calculate the SOC, inorganic carbon (IC) and total nitrogen (TN) content for each sample. These results were used to upscale to the landscape level using satellite imagery.

WHERE DID WE WORK?

The fieldwork took place at two Russian research stations. The Khanymei Research Station is situated south-east of the Yamal-Nenets Autonomous District, in the northern taiga of

As the permafrost ground thaws, trees are toppling into the expanded lake. (Juri Palmtag)

Soil sampling preparation in a dense forest with a very shallow active layer thickness. (Juri Palmtag)



Extensive sand dunes only a few km north-east from the Khanymey Research Station. (Juri Palmtag)

West Siberia. The area is surrounded by extended peatlands located within the discontinuous permafrost zone (50% to 90% of the surface has permafrost under it). The second station, the Elgeii Scientific Forest Station is located in the south-eastern region of the Republic of Sakha (Yakutia), in the taiga within the continuous permafrost zone (> 90% of the surface is underlain by permafrost).

WHAT DID WE FIND?

In Khanymei, many of the extensive wetlands exhibit a relatively shallow (less than 1 m) peat layer underlain by sand deposits. In some cases, the sand emerged at the surface forming extensive dunes. As suggested by our preliminary results, it is likely that the presence of these features reduce substantially the amount of SOC stored below 1 m than values reported in the NCSCD, at least for this specific area. In Elgeii, thick organic layers underlain by fine-grained sediments and partly by high ground-ice content suggests that, under future warming, thermokarst formation (sinking due to permafrost thaw) could occur rapidly and cause dramatic land surface changes. However, on the western side of the Aldan River, the landscape differed with rather coarse-grained sandy soils with low SOC amounts.

WHY ARE THE RESULTS IMPORTANT?

The overall aim of this proposal is to improve SOC storage estimates from under-represented areas in the northern permafrost region. The two selected research stations with their ecosystems of a continental climate are typical for vast areas in Siberia. The improvement of such large-scale SOC maps as the NCSCD is of great importance since these carbon stocks are used in Earth System Model projections of the permafrost-carbon feedback on climate change and therefore refine our estimates of future global warming.

THE ADVENTURE

Travelling from Sweden to these remote places in the Siberian taiga is already an experience. After 3 days and multiple planes, boats and cars, we arrived at the Elgeii Scientific Forest Station. Despite this place having one of the coldest winters on earth, the summer weather during our stay was gorgeous, which were appreciated during the long days in the field. Any effort done during the day was compensated by the fantastic hospitality at the Elgeii station. On our flight to Khanymei, we were amazed by the fantastic view of countless thermokarst lakes and forest islands occurring over vast peatlands. With the help of the great station staff, every field day ended up with a basket full of mushrooms that provided an extra bonus to the already delicious food served at the station.

A sandy soil profile with a thin layer of lichens on the surface horizon. (Juri Palmtag)

Unfrozen 50 cm peat deposit above a permafrost layer. (Juri Palmtag)

A podzol, a typical soil of coniferous forests. (Juri Palmtag)

Boreal wetland ecosystems, covering a large fraction of the Northern Hemisphere, are an important terrestrial carbon pool. However, they are prone to rapid ecological changes related to climate, which modify the interactions between hydrology, carbon cycle, vegetation cover, and microtopography. In West Siberia, the range of carbon dioxide (CO_2) exchange and methane (CH_4) emission rates are largely uncertain because discontinuous and short-term observations have been often used to derive regional and long term carbon budgets.

Greenhouse gas exchange in boreal wetland ecosystems

Ivan Mammarella, Pavel Alekseychik & Janne F.J. Korhonen

AIMS OF THE PROJECT

Our project aimed to provide insights into the carbon cycle and greenhouse gas exchange dynamics in boreal wetland ecosystems in West Siberia. Specific aims were to determine the magnitude, diurnal and seasonal variations as well as drivers of CO_2 and CH_4 (methane) fluxes.

WHAT DID WE DO?

Ecosystem scale fluxes of CO_2 and CH_4 were measured with the Eddy Covariance (EC) technique, where high frequency turbulent fluctuations of wind vertical velocity, measured by an ultrasonic anemometer, are correlated with gas concentration fluctuations, measured by fast-response gas analysers. We have added a CH_4 gas analyser (LI-7700) to the current setup at the Mukhrino flux tower, which had been established by our team back in 2014 to measure exchanges of CO_2 and H_2O between the Earth's surface and the atmosphere. We ensured the equipment was working correctly and that data was being collected and of sufficient quality to determine the diurnal and seasonal variations as well as drivers of CO_2 and CH_4 fluxes. Finally, we provided training and support to the local staff concerning the EC system operations and maintenance, raw data collection and storage in the database, data processing and quality control.

The eddy covariance flux tower at the Mukhrino bog site. (Janne F.J. Korhonen)

The meteorological and flux tower at the Mukhrino bog site. (Janne F.J. Korhonen)

Sunset at the Mukhrino bog site. (Janne F.J. Korhonen)

WHERE DID WE WORK?

We worked at the Mukhrino Field Station in West Siberia, and in particular at a wetland bog site close to the station, where an EC flux tower has been run since 2014 by our team in collaboration with the Yugra State University.

WHAT DID WE FIND?

After solving a few initial technical problems, data have been processed and quality checked, and it seems that we were successful in measuring eddy covariance CO_2, CH_4 and energy fluxes during the whole 2019 growing season. However, the analysis is not yet completed and the results interpretation is still going on. Preliminary results show a peak in methane emissions during the spring thawing period and high fluxes during the summer. We expect that the methane emissions are mainly controlled by the peat temperature and the water table depth.

A small river covered by snow passing nearby the Mukhrino Field Station.
(Janne F.J. Korhonen)

WHY ARE THE RESULTS IMPORTANT?

Mukhrino eddy-covariance measurements are of high value since they represent a vast peatland region of Western Siberia — there is no other active site within a 1,000 km radius. For this reason, this dataset is unique. Moreover, this type of ecosystem is particularly vulnerable to climate change, and long term observations of carbon and water surface exchanges are needed if we want to understand present and future changes of the boreal climate, precipitation patterns, water availability and the whole carbon cycle. Data from within our project at Mukhrino have contributed to international studies.

THE ADVENTURE

The wilderness of Siberia is amazing. No roads lead to the station, and we were taken there before snowmelt by snowmobiles. Later in the spring the visit would have been impossible. The hospitality of the organisers was amazing, and rolling in the snow as a part of the sauna ritual and the almost ceremonial whipping with whisks was a great way to bond with the station staff, as we have similar habits way back home in Finland. A journey to Mukhrino always feels like a rendezvous with the pristine Siberian nature, a unique opportunity to get fully immersed into the subject of our research. This journey is full of dangers — the bears being one of them — but it only adds to the spirit of adventure.

Changes throughout the day and night in carbon concentrations and emissions from thaw ponds of frozen peatlands

Liudmila S. Shirokova, Dahédrey Payandi-Rolland, Artem G. Lim, Rinat M. Manasypov, Paty Nakhle, Pascale Bénézeth & Oleg S. Pokrovsky

Despite the importance of surface waters of permafrost landscapes in the cycling of carbon and metal elements, the majority of available observations in high latitude aquatic systems deal with one-time only or seasonal sampling without accounting for diurnal (throughout the day and night) variations in temperature, primary productivity, and respiration cycles.

The Argo all-terrain vehicle used to go between each lake for sampling. (Dahédrey Payandi-Rolland)

AIMS OF THE PROJECT

We assumed that the variability in external factors, like temperature and light, will exert the main control on dissolved organic carbon (DOC) and related micronutrients (Fe, Mn, Zn) and toxicants (As, Cd, Pb) present as organo-mineral complexes. This will produce a diurnal cycle in concentrations of carbon and trace elements in thermokarst (thawing permafrost) lakes as well as greenhouse gases (GHG) emissions from them. We further anticipated that the higher the DOC in a peatland lake, the smaller will be the response of the chemistry down the water column to diurnal light and temperature variations. This response is likely to vary depending on lake size.

WHAT DID WE DO?

In order to test these hypotheses, we studied one thermokarst lake and one thaw pond of different sizes and dissolved organic matter (DOM) contents. We quantified (1) the variation of dissolved carbon (C) and metal element concentrations between day and night, (2) the degree of diurnal variation in carbon dioxide (CO_2) flux and (3) the control of these processes by the variability in external factors like temperature and light. For this, we monitored CO_2, methane (CH_4), organic carbon, major and trace element concentrations and CO_2 fluxes in thermokarst lakes during 2 days of anticyclonic weather in July 2018.

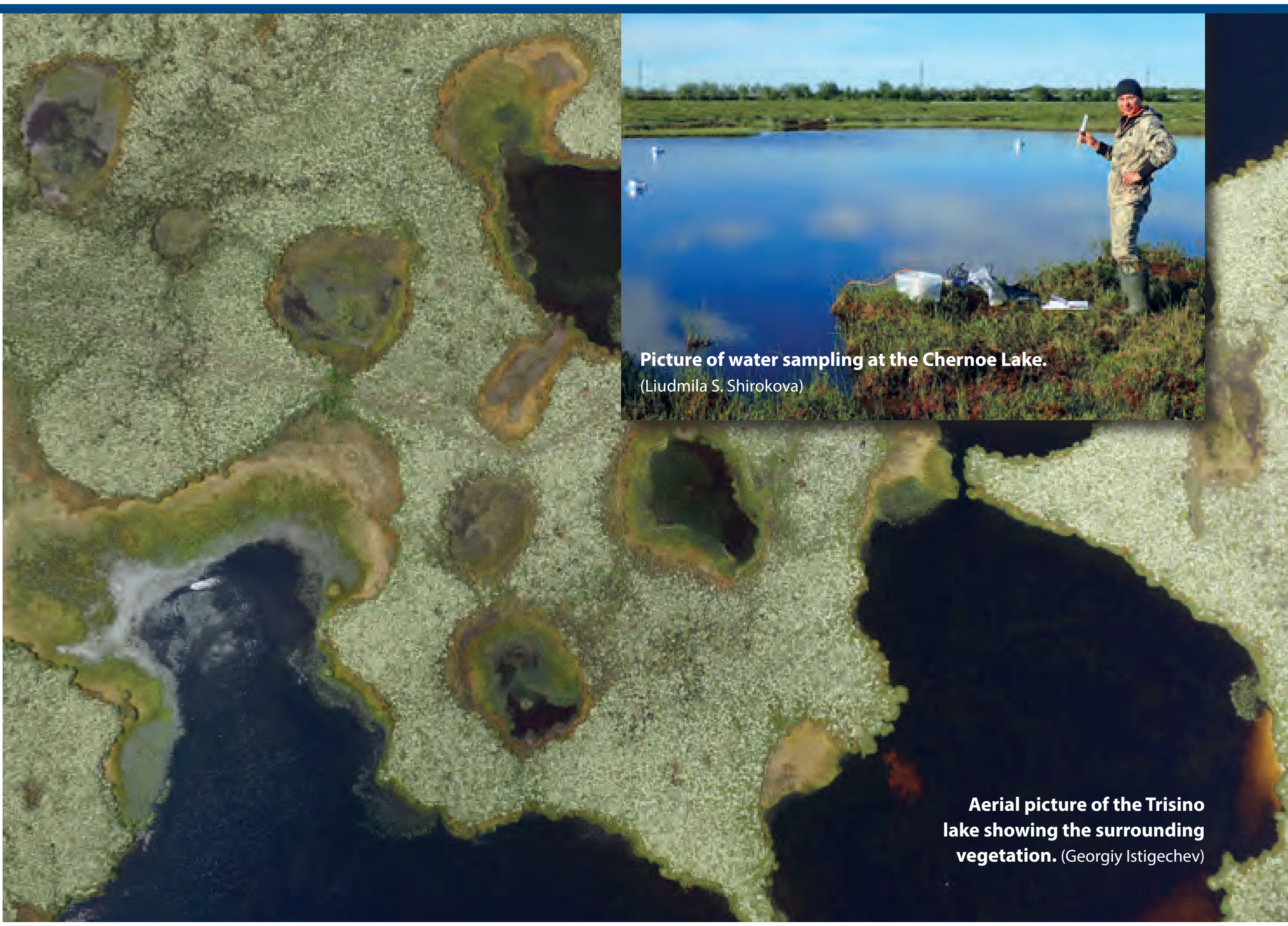
WHERE DID WE WORK?

The lakes we sampled were in the Western Siberian Lowland of Russia and we were based at the Khanymey Research Station.

WHAT DID WE FIND?

We observed stable concentrations of pH, DOC, UV-absorbency, nutrients, carboxylic acids, and most major and trace elements in waters of the acidic and humic (peat-rich) thermokarst lake and thaw pond during a continuous 2-days observation period. The CO_2 concentration and emission negatively correlated with water temperature and exhibited a clear diurnal pattern with a maximum after sunrise (when surface water temperature was minimal) and a minimum during late afternoon day time (when surface water temperature was at a maximum). Among the major drivers of this observed CO_2 variation, we excluded the photosynthetic activity in the water column and photolysis of DOM (break-down of organic matter by light). We rather concluded that the balance between the respiration of microbes at the bottom of the lakes, which can produce CO_2, and the primary productivity (uptake of the dissolved carbon by organisms to construct their biomass) of micro-organisms attached to submerged surfaces (large water plants and mosses) was responsible for increased CO_2 emissons during the night and CO_2 decrease or even uptake during the day.

Picture of water sampling at the Chernoe Lake. (Liudmila S. Shirokova)



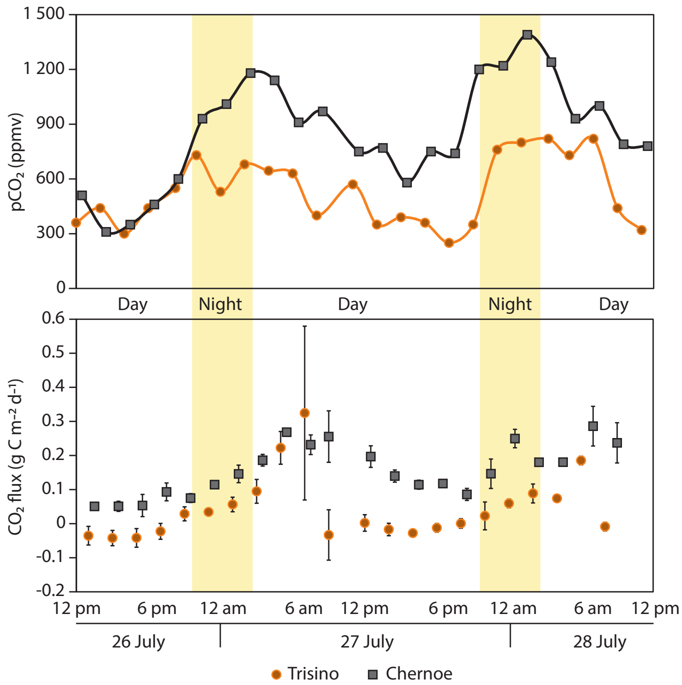
Aerial picture of the Trisino lake showing the surrounding vegetation. (Georgiy Istigechev)

WHY ARE THE RESULTS IMPORTANT?

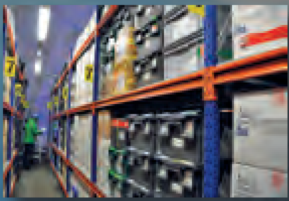
Neglecting night-time CO_2 flux, especially in large thermokarst lakes, greatly underestimates the C emission for the whole region. This calls for a need to study diurnal variations in C emissions from large (10-500 ha) thermokarst lakes because they cover most of the overall inland water surface of the region. These measurements should be focused on late summer and autumn periods when the diurnal cycles are more pronounced because the heterotrophic respiration (respiration by microbes and small animals that cannot photosynthesise) may dominate over primary productivity. The results could be globally important because of the vast carbon stores in the Western Siberian Lowlands.

THE ADVENTURE

We worked over 3 days, staying in a tent next to the lakes. The regular sampling required going between two lakes using an Argo all-terrain vehicle each 2 hours, deploying the boat, placing the chambers, performing on the spot measurements and filtering the sampled water. We returned to the tent to relax for half an hour and then the new sampling started! The most challenging part of this field trip in summer was not the temperature or the fieldwork itself but all the mosquitos that fly by thousands around you while you are sampling water, especially during night-time.



Graphics of the dissolved CO_2 (pCO_2) and flux of CO_2 during 2 days of two lakes: Trisino and Chernoe.



Seed boxes from many gene banks and many countries stored side by side on the shelves in the Seed Vault. (Svalbard Global Seed Vault). https://www.flickr.com/photos/landbruks-_og_matdepartementet/sets/72157623004641656/

Arctic permafrost protects global biodiversity

Arne Instanes

Overview of the Longyearbyen area. The yellow circle shows the location of the seed vault. Svalbard airport at the extreme right. (Arne Instanes)

The Svalbard Global Seed Vault is a store for duplicates of the world's crop collection in a safe environment, thus ensuring that the seed duplicates are safe from seed extinctions during large-scale regional or global crises. The vault contains seeds that are essential food crops, such as beans, wheat and rice. It is located in permafrost rock in the close vicinity of Longyearbyen, Svalbard. This location is considered ideal because of the area's low tectonic activity, the presence of permafrost (permanently frozen ground) and it is 130 metres above the present-day sea level, thereby allowing for future sea level rise.

Soon after the opening of the vault in 2008, meltwater from thawing permafrost and seasonal snow melt found its way into the access tunnel that links the iconic portal building to the rock tunnel system. The problems with meltwater in the access tunnel escalated after the extreme warm summer and autumn that occurred in Svalbard in 2016. This problem was quickly linked to climate warming, even though the root of the problem was mainly related to engineering and construction challenges that commonly occur in permafrost regions.

The Norwegian government decided in 2017 to upgrade the Svalbard Global Seed Vault and Instanes Consulting Engineers was responsible for the geotechnical design and supervision of the earth works during the 2017-2019 upgrade.

AIMS OF THE PROJECT

The main objective of the upgrade of the Svalbard Global Seed Vault was to construct a storage facility for seeds, that will remain cold, dry, and dark for the next centuries, even under the most extreme climate warming scenarios. This design was achieved by a combination of construction procedures including watertight concrete, low permeability backfill material and artificial cooling of the permafrost soils and rock.

WHAT DID WE DO?

The upgrade included opening a 20 metres deep excavation in the permafrost, and replacing the access tunnel from 2008 with a new water-tight concrete tunnel, The access tunnel through the soil is approximately 40 metres long with a slight inclination towards the vault. The excavation was then backfilled with well-graded sandy soils with low hydraulic conductivity and three layers of bentonite (clay) liners. Artificial cooling of the backfill material was applied to ensure a frozen material after closure of the excavation. A new refrigeration system and technical service building were included in the project. The vault is designed to maintain subzero temperatures without artificial cooling for at least 100 years under extreme warming scenarios.

After completion, the tunnel system had multiple barriers to prevent water from entering the vaults, including a water-tight access tunnel, low permeable soils as backfill, clay liners, and temperature in the backfill permafrost and rock lowered to approximately –10 °C.

WHERE DID WE WORK?

The Svalbard Global Seed Vault is located near Longyearbyen, Svalbard (78°13'N, 15°33'E) at 130 metres above sea level. The mean annual air temperature in Longyearbyen has increased from approximately –6.7 °C in 1989 to –3.9 °C in 2019. In 2016 the mean annual air temperature was only –0.1 °C and there were several unusual precipitation events in the autumn of 2016 that caused extensive landslide activity and flooding. However, the permafrost in Svalbard remains relatively stable as long as the organic layer on top is not disturbed. The temperature at depth is still –3.7 °C even after 40 years of extreme warming.

Deep excavation in permafrost. The portal building in the forefront. (Arne Instanes)

WHAT DID WE FIND?

There are a few basic "not to do's" that apply to construction and engineering work in permafrost regions:

- The construction work and operation of the buildings and structures should not change the thermal regime of the ground.
- Water should not be ponded near a structure or construction site.
- Snowbanks should not be allowed to form around the structures.
- Excavations should be avoided.

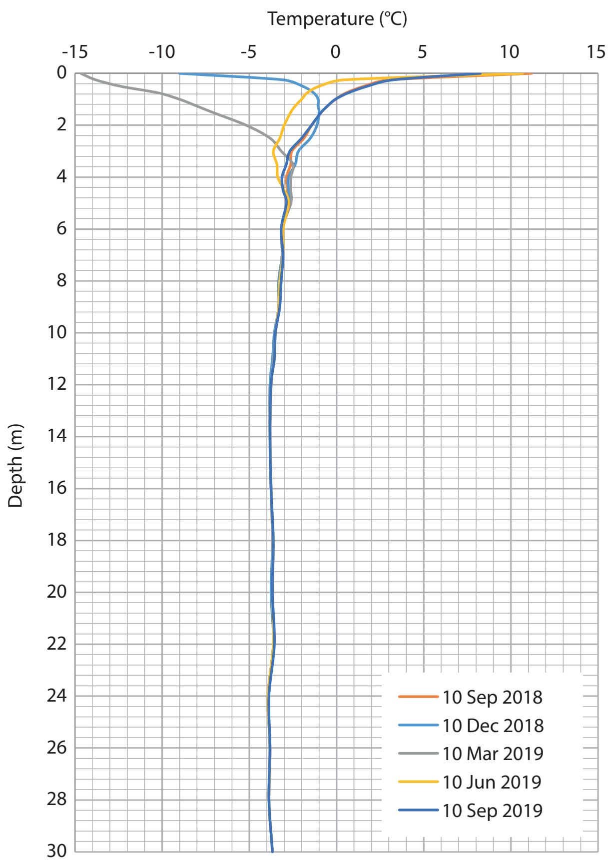
In permafrost regions, damage to infrastructure is in general caused by insufficient focus on the "not to do's". During the initial construction work in 2007-2008, the main problem was that the challenges related to a deep excavation in permafrost were not addressed properly. The result was a facility that did not function according to plan and an upgrade was necessary.

WHY ARE THE RESULTS IMPORTANT?

The results are important because it shows that construction work in permafrost regions are challenging, especially in a climate warming scenario. Without thorough planning the result may be a facility that has to be replaced shortly after completion. While the construction principles we highlighted are extremely important for all types of construction on permafrost and could prevent major oil spills etc., in our particular example, the Arctic permafrost is playing a role that might be globally important in the future.

THE ADVENTURE

It is exciting to be part of a project and structure that will remain intact for centuries and provides an "insurance policy" for Planet Earth's most important crop species.



Ground temperature profile adjacent to the University building, Longyearbyen. Data from the NGTS project https://www.ngi.no/eng/Projects/NGTS-Norwegian-Geo-Test-Sites

7 Working together — let's INTERACT

SECTION OVERVIEW

The stories gathered together in this book increase our understanding of the rapidly changing Arctic and the consequences of these changes for the people of the North and the global community. Already, the mere act of scientists working together across national boundaries and disciplines and working with Indigenous Peoples and decision makers is helping to create bonds and decrease tensions in a globally sensitive area. In this final section, we learn about the higher-level political activities to preserve peace in the Arctic and to facilitate research. The final story shows how INTERACT is continuing its many activities aimed at facilitating the research of excellent scientists while providing valuable information to important decision makers. It is also providing educational resources to enthuse and empower the next generation of scientists, local communities and leaders.

Recording, understanding and responding to a changing Arctic requires cooperation.
Puffins congregating on Anden in the Vesterålen Islands, Norway.
(Lorenzo Ragazzi)

7

Peace, politics and science in the Arctic

As you travel to the Arctic or work there as a scientist you will encounter a lot of exciting natural phenomena and also a rapidly shifting geopolitical arena.

Martin Breum

NEW DEAL TO EASE CROSS-BORDER SCIENCE

In 2017 the eight Arctic states agreed to make it as easy as possible for scientists to work across borders in the Arctic.

They agreed to ensure easy access to

- research areas (entry and exit of persons, equipment, and material),
- research infrastructure, facilities and data.

They also agreed to promote education, career development and training and to encourage activities associated with traditional and local knowledge.

The agreement is known as the "Agreement on Enhancing International Arctic Scientific Cooperation". The map shows all areas covered by the agreement. https://www.state.gov/key-topics-office-of-ocean-and-polar-affairs/arctic/

The coast guards of the eight Arctic states meet twice every year in the Arctic Coast Guard Forum to facilitate safe and secure maritime activity in the Arctic from a practical, operational perspective. They also do live exercises at sea to strengthen their joint search and rescue capacity.

The eight Arctic states also cooperate through the Arctic Council's working group on Emergency Prevention, Preparedness and Response (EPPR). This group focuses on the prevention, preparedness and response to environmental emergencies, on search and rescue, on natural and man-made disasters and on accidents in the Arctic from a more strategic policy perspective.

The armed forces of the eight Arctic states have no formal joint organisation like the Arctic Coast Guard Forum or EPPR. In 2012, the chiefs of staff of the armed forces of the Arctic states met in Canada to discuss matters of common interest. They met again in 2013 and 2014, but since 2014, these meetings have been on hold.

The emblem of the Arctic Coast Guard Forum.

Coast guard vessels from Canada, Denmark, Iceland, Norway and the United States took part in exercise Arctic Guardian off the coast of Reykjavik in September 2017.
(Arctic Coast Guard Forum/YouTube)

Many governments, peoples and businesses are working to ensure that the Arctic remains peaceful and sustainable, even as economic activity is fast on the rise. Even countries far away from the Arctic like Singapore and Italy are getting involved, as they see that changes in the Arctic affect also their futures. Changes to the Arctic climate have global impacts, new shipping routes are opening and access to the vast natural resources in the Arctic is increased.

The Arctic Indigenous Peoples and the eight Arctic nations (Russia, the US, Canada, Norway, Sweden, Finland, Iceland, and Denmark with Greenland and the Faroe Islands) work together in the Arctic Council and its six scientific working groups, which all assess important knowledge on climate change, biodiversity and human development in the Arctic. China, other Asian states and a string of European nations are observers in the Arctic Council and contribute to these scientific efforts. Some of these efforts benefit from collaboration with INTERACT.

As sea ice diminishes and human activity in the Arctic grows, all Arctic states are boosting their capacity for search and rescue and their military presence in the region. This calls for careful management to avoid misunderstandings and tension. Some see increased risks that tension and conflicts elsewhere in the world might spill over into the Arctic, and that improved access to resources and new navigation possibilities in the Arctic could cause international discord. However, most analysts celebrate the current peace and stability in the Arctic and expect it to last.

TOGETHER

International cooperation in the Arctic continues to grow. In 2018, for instance, all Arctic states plus China, Japan, South Korea and the EU signed a legally binding accord that prevents commercial fishing in the high seas of the Arctic Ocean for at least 16 years while scientists learn more about its marine life and resources. This may be the world's most ambitious preventative, marine environmental arrangement so far.

More efforts are urgently needed. Climate change has already increased the mean temperature of some areas in the Arctic with more than five degrees Celsius, the permafrost is thawing, the seas are warming and we have yet to understand the full scale of the consequences for the Arctic and the rest of the world.

As you engage with the Arctic as scientists you will produce knowledge urgently needed to throw light on all these crucial changes and you will also add to INTERACT's contribution to much needed international understanding and friendships across the Arctic borders and cultures.

Happy travels!

Developing future Stories of Arctic Science: INTERACT into the future

Terry V. Callaghan, Margareta Johansson & Hannele Savela

INTERACT has been visionary in many ways. It was conceived out of the necessity to identify, measure and understand perhaps the world's most rapidly changing region. The challenges — and some opportunities — are so great for the Arctic and the global community that only a pan-Arctic collaboration of infrastructures on the ground and access for researchers from around the world could make a difference. As you have seen in this second book of "Stories of Arctic Science", INTERACT has made a highly significant contribution to priority, science-based understanding to aid management of the Arctic and its impacts on planet Earth.

It is essential to recruit and empower the next generation of researchers. Here an INTERACTer seeks to inspire students to study the Arctic at Tomsk State University, demonstrating Science Diplomacy in action. (Elena Sannikova)

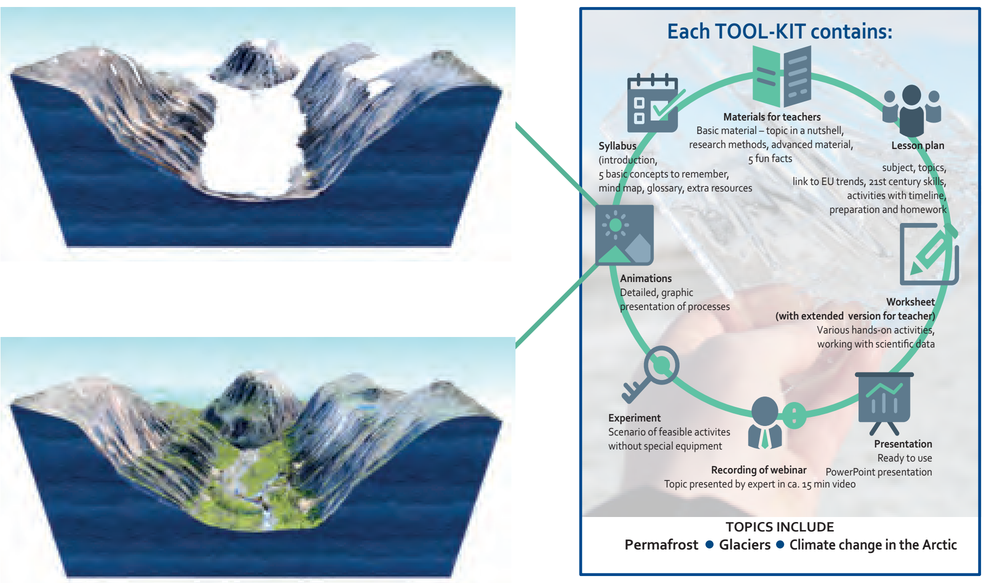
INTERACT realised that by uniting 88 research stations operated by 18 countries, we could provide the overarching infrastructure for the support of the important work of more than 150 single discipline networks from local to globally important networks, organisations and processes. With years of pan-Arctic collaboration, our vision became focused on the suggestion that the INTERACT stations working together could provide a rapid response system to identify potential wide-spread hazards and make observations and collect samples to record and increase timely awareness of dangerous impacts such as the spread of diseases and major contamination events. Ironically, within three years of establishing this capability, at the time of writing we are experiencing the Covid-19 pandemic. INTERACT has responded by facilitating remote access to the Arctic. This means that station staff can assist researchers by collecting the samples for them to reduce travel to remote areas, often with isolated local and Indigenous populations. At the same time, INTERACT is working with The University of the Arctic to develop and make available educational materials delivered on-line throughout the world.

INTERACT has made a difference and will continue to make a difference. So far, it has been operating thanks to generous EU grants and contributions from the US and Canada with in-kind support from Russia. These resources have provided many opportunities and allowed considerable international interactions. However, the grants are time-limited and some have geographical restrictions. For the future therefore, INTERACT will operate also as a non-profit organisation serving the community, facilitating science and enhancing science diplomacy. At the same time as expanding the development of groundbreaking research across national and disciplinary borders, we will encourage and facilitate the development of the next generation of researchers and give educators and their students improved resources and virtual access to the Arctic.

INTERACT facilitates globally-important research that can contribute to better health and wellness of local and Indigenous People, and the global community. Family Selander, Nenets reindeer herders from the Yamal-Nenets Autonomous Region. (Andrei Lobanov)

All of these activities help the global community to visualise, virtually experience, understand and react to dramatic changes in the Arctic. However, we must remember that the Arctic is home to thousands of local and Indigenous Peoples and provides their life support. They have a deep understanding of their environment that some say is "broken now". They have major contributions to make to the research in their territories and deserve considerable respect from "outsiders". INTERACT is proud to span the scale from global to local communities and will continue to facilitate globally-important research and studies that can contribute to better health and wellness of local and Indigenous People, and the global community.

We all share one Earth but we should not underestimate the importance of specific parts of it, such as the Arctic which has many more stories to tell.



INTERACT collaborates widely to produce educational and outreach materials. "Toolkits" produced with the Polish Academy of Sciences reach schools in over 50 countries while animations made by Tomsk State University reach over 200 universities with 15,000 viewers so far.

Appendices

Further reading and related information

1 Different ways of knowing

SS 1.1 A Siberian indigenous knowledge system for understanding climate change

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SS 1.2 Using climate records preserved in ancient ice to understand modern climate change and its impact

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Media:

Eastgrip.org

Iceandclimate.dk

SS 1.3 How inland waters have changed over many thousands of years in north-eastern Russia

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SS 1.4 Remotely sensing Arctic plant productivity

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Publications:

Rogers, A., Serbin, S.P., Ely, K.S., Sloan, V.L., and Wullschleger, S.D. 2017. Terrestrial biosphere models underestimate photosynthetic capacity and CO_2 assimilation in the Arctic. *New Phytologist* 216: 1090-1103. https://doi. org/10.1111/nph.14740

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SS 1.5 Exploring waves under the ice of Arctic lakes

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SS 1.6 High tech exploration of water flow inside glaciers

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2 Human impacts on Arctic environments

SS 2.1 Airborne delivery versus surface accumulation of microbes, mineral dust and black carbon onto the Greenland Ice Sheet

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SS 2.2 Black carbon in snow and water in Iceland, the Faroes and Scotland

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SS 2.3 Biodiversity changes and microplastics on Arctic beaches

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SS 2.4 Vegetation changes in the Fennoscandian tundra over 60 years

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SS 2.5 Plants moving along mountain roads and trails

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Publications:

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SS 2.6 Arctic night skies show effects of light pollution on nocturnal orientation

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3 Ecosystem services

SS 3.1 Microbes inside glaciers

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SS 3.2 Vegetation is changing on mountain-tops in northern Sweden

Liyenne Wu Chen Hagenberg[1], Thomas Vanneste[2], Øystein Hjorthol Opedal[3], Hanne Torsdatter Petlund[3], Håkon Holien[3], Juul Limpens[1], Bente Jessen Graae[3], and Pieter de Frenne[2]

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SS 3.3 Fragile permafrost ecosystems in Siberian lowland tundra

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SS 3.4 Wood formation and carbon balance in forest trees growing in cold environments

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SS 3.5 Is the Subarctic treeline moving under global warming?

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SS 3.6 Low resistance to high temperatures of cold-adapted bumblebee species unveils a global threat for Arctic pollinators

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SS 3.7 How an insect-eating shorebird may reduce the harmful effects of a warming Arctic

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4 Minimising surprises for society

SS 4.1 Unusual winter weather events cause rapid changes in the tundra ecology

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SS 4.2 Thawing permafrost and human health

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SS 4.3 Modern extreme weather in the low Arctic is recorded in growth-rings of shrubs

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SS 4.4 Forest recovery after fire

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SS 4.5 Fate of dissolved black carbon after fire in boreal forests in Finland

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SS 4.6 The exploding tundra: from mounds to craters in permafrost

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5 Impacts on local societies

SS 5.1 Forest fires are increasing in Siberia

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SS 5.2 Treating Arctic Peoples with respect: ethical principles for Sámi health research in Finland

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SS 5.3 Adapting reindeer husbandry to changes in vegetation and snow cover

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SS 5.4 Bridging knowledge systems in Greenland

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SS 5.5 Ensuring tourism and Arctic Peoples cooperate for mutual benefit

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SS 5.6 New challenges for hunting, fishing, agriculture and conservation in the taiga

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SS 5.7 Faroe Islands' communities: social isolation or connectivity?

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Landscapes of the Faroe Islands, images by Pól Sundskarð: https://hikewithpol.fo/products?x=1&_ProductFilterIds=7:85

SS 5.8 **Coastal erosion threatens infrastructure and cultural sites in the western Canadian Arctic**

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6 Impacts on global societies

SS 6.1 When the ice goes black!

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SS 6.2 Melting of Arctic glaciers and ice caps and its impact on sea level

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SS 6.3 Soil organic carbon stocks in the Russian taiga

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SS 6.4 Greenhouse gas exchange in boreal wetland ecosystems

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SS 6.5 Changes throughout the day and night in carbon concentrations and emissions from thaw ponds of frozen peatlands

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SS 6.6 Arctic permafrost protects global biodiversity

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Government of Norway: https://www.regjeringen.no

www.hvl.no

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7 Working together — let's INTERACT

SS 7.1 Peace, politics and science in the Arctic

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SS 7.2 Developing future Stories of Arctic Science: INTERACT into the future

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Publications:

INTERACT Stories of Arctic Science, 2015 (eds. Callaghan, T.V. and Savela, H.) https://eu-interact.org/publication/1349/

Callaghan, T.V., Kulikova, O., Rakhmanova, L., Topp-Jørgensen, E., Labba, N., Kuhmanen, L-A., Kirpotin, S., et al. 2019. Improving dialogue among researchers, local and indigenous peoples and decision-makers to address issues of climate change in the North. *Ambio* 49: 1161–1178. https://doi.org/10.1007/s13280-019-01277-9

Media:

INTERACT: a project with the objective to build environmental observing capacity and offer access to research stations around the Arctic.

https://eu-interact.org/

SECNET: an open community with focus on the Siberian environment and society, aiming to understand and predict societally important changes in order to minimise negative anthropogenic consequences.

http://www.secnet.online/home-eng.html

UARCTIC: a network of universities, research institutes, and organisations with education and research focusing on the Arctic.

https://www.uarctic.org/

APECS: an organisation with the objective to create a network for polar researchers, acting as a platform for collaborations, and promotion of education and outreach.

https://apecs.is/

Projects supported by INTERACT Transnational Access 2017-2019

See stations no. list on the inside of cover

Project	Project leader	Affiliation	Stations visited
Cold ice in a warm bath? Capturing proglacial lake temperature and Arctic glacier retreat in a changing climate	Adrian Dye	University of York, UK	13
Tundra shrub growth in a changing Arctic – influence of climate and topography	Agata Buchwal	Adam Mickiewicz University, Poznan, Poland	42, 52
Phenotypic plasticity in clonal tundra shrubs	Alba Anadon-Rosell	University of Greifswald, Germany	10
Comparison of geomorphology and dynamics of alluvial and colluvial fans and cones in the Arctic based on examples from Greenland, Svalbard and Iceland.	Aleksandra Tomczyk	Adam Mickiewicz University, Poznań, Poland	74, 80
Evaluation of soil activity, functioning and green-house gas emissions in different Subarctic ecosystems	Alessandra Lagomarsino	CREA-AA, Florence, Italy	22
The role of deadwood for biodiversity conservation and carbon storage in boreal forests	Alessandro Paletto	Council for Agricultural Research and Economics (CREA), Trento, Italy	30
Wood formation and carbon balance in forest species growing in cold environments **(SS 3.4)**	Alessio Giovannelli	Consiglio Nazionale Ricerche (CNR), Roma, Italy	18
The microbiome of englacial habitats **(SS 3.1)**	Alexandre Anesio	University of Bristol, UK	13
Sensing wild spaces: integrated participatory mapping for understanding community relationships to dynamic mountain landscapes	Alice Eldridge	University of Sussex, Brighton, UK	14
Dendro-ecological exploration of shrubs in the northern Carpathians and in West Greenland	Allan Buras	Technical University of Munich, Germany	28, 74
Climatic sensitivity of taiga-tundra mire vegetation; a multi-proxy palaeo approach to evaluating changing biome dynamics and C accumulation	Angelica Feurdean	Senckenberg Biodiversity and Climate Research Centre, Frankfurt am Main, Germany	38
Microhabitats as a buffer for tundra vegetation change under climate warming	Anne Bjorkman	Senckenberg Biodiversity and Climate Research Centre, Frankfurt, Germany	74
Life in the shade: diversity and distribution of chlorophyll-f containing cyanobacteria and infrared photosynthesis in the Arctic	Anne D. Jungblut	The Natural History Museum, London, UK	8
Genetic analyses of the Arctic *Cochlearia groenlandica* and its close relatives	Anne Krag Brysting	University of Oslo, Norway	74, 76
Genomic basis of climate-change associated brownification/ darkwater adaptation in Eurasian perch: the Trans-Eurasian perspective	Anti Vasemägi	Swedish University of Agricultural Sciences, Drottingholm, Sweden	32, 38
Permafrost soil microbiome	Beat Frey	Swiss Federal Research Institute WSL, Switzerland	8, 13
Dynamics of photosynthetic pigment in Subarctic plants under fluctuating light conditions	Beatriz Fermarin	University of the Basque Country, Bilbao, Spain	18
Biological soil crusts in polar cold desert biomes	Bjorn Tytgat	Ghent University, Belgium	8
Glacier recession as a source of environmental pollutants	Caroline Clason	Plymouth University, UK	13
Investigating Faroe Island dissolved organic matter	Catherine Moody	University of Leeds, UK	87
Biodiversity and ecology of the Arctic intertidal: changes over time **(SS 2.3)**	Catherine Waller	University of Hull, UK	74, 76, 82, 85
Will spatiotemporal heterogeneity in arthropods buffer effects of phenological mismatches on growth and survival in insectivorous Arctic birds?	Christiaan Both	University of Groningen, the Netherlands	80

Project	Project leader	Affiliation	Stations visited
Global snow and vegetation survey at climate stations in cold biomes: a novel approach to understand drivers of snowmelt, biodiversity and ecosystem functioning	Christian Rixen	Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Davos, Switzerland	15, 20, 42, 74, 76
Fungal contributions to the carbon cycle of Subarctic thermokarst ponds	Christian Wurzbacher	University of Gothenburg, Sweden	52, 66
Bog-Breathing in Ryam: ecosystem controls on annual changes in the peat surface monitored by InSAR	Christopher Marshall	University of Nottingham, UK	32
Improving model estimations of boreal forest structural influences on radiation regime during snowmelt	Clare Webster	University of Edinburgh, UK	16
Amphibians in the Arctic – aging and growth on the edge	Dan Cogalniceanu	University Ovidius Constanta, Romania	11, 15
Developing a qualitative methodology for assessment of cultural ecosystem services	Daniel Orenstein	Technion -Israel Institute of Technology, Haifa, Israel	18, 88
Spatial distributions of black carbon and mineral dust in air and snow surface layers upon Hornsund glaciers	David Cappelletti	University of Perugia, Italy	9
Atmosphere-snow exchange of organic matter	Dusan Materic	Utrecht University, the Netherlands	25
Pollination across the Arctic	Eero Vesterinen	University of Turku, Finland	3, 10, 80, 85
Plant traits of northern peatlands as impacted by global change	Eeva-Stiina Tuittila	University of Eastern Finland, Joensuu, Finland	14, 32
Stream water chemistry in crystalline headwater areas in Finland and Poland	Eliza Płaczkowska	Polish Academy of Sciences, Cracow, Poland	15, 20, 22
The role of deep-rooting plant species for carbon and nitrogen cycling in thawing permafrost ecosystems	Ellen Dorrepaal	Umeå University, Sweden	52
Chemical weathering and the inorganic carbon flux of a High Arctic river	Emily Stevenson	University of Cambridge, UK	80
Snow accumulation patterns on Hardangerjøkulen ice cap, using geophysical methods	Emma Pearce	University of Leeds, UK	10
Vibroseis imaging of Konsgvegan's internal structure and thermal regime	Emma Smith	The Alfred Wegener Institute, Bremerhaven, Germany	3
Growing season changes over the past Millennium in northern high latitudes	Friederike Wagner-Cremer	Utrecht University, the Netherlands	74
Kola Peninsula plant success	Gareth Marshall	British Antarctic Survey, Cambridge, UK	30
Environmental controls on Arctic plant success	Gareth Rees	University of Cambridge, UK	30, 43
Ice cover extinction by wave motions in polar lakes **(SS 1.5)**	Georgiy Kirillin	Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany	15
Combining near-surface geophysics and sedimentology to assess proglacial sediments at Midtdalsbreen, southern Norway	Hannah Watts	Stockholm University, Sweden	10
Transect studies between warm Svalbard and cold North Greenland – comparing permafrost and landscape dynamics aross the largest climatic gradient in the High Arctic	Hanne Hvidtfeldt Christiansen	The University Centre in Svalbard, Longyearbyen, Norway	81
Fire-permafrost interactions and forest regeneration in Siberian larch forests **(SS 4.4)**	Heather D. Alexander	Auburn University, USA	43
Remote sensing of plant physiological traits in Arctic vegetation **(SS 1.4)**	Holly Croft	University of Sheffield, UK	14
A global litter decomposition study	Ika Djukic	Environment Agency Austria, Vienna, Austria	30, 74
Composition of soil organic matter fractions from the Arctic and the Subarctic	Isabel Prater	Technische Universität München, Germany	8, 11
Greenhouse gas exchange in boreal wetland and freshwater ecosystems: a multi-scale approach **(SS 6.4)**	Ivan Mammarella	University of Helsinki, Finland	32

Project	Project leader	Affiliation	Stations visited
Ice thickness measurements of Lyngmarksbræen, Qeqertarsuaq, West Greenland	Jacob Clement Yde	Western Norway University of Applied Sciences, Sogndal, Norway	74
Inversion layers in Greenland – a multi-site approach	Jakob Abermann	University of Graz, Austria	77
Water and sediment flux from Arctic glacier catchments	Jan Kavan	Masaryk University, Brno, Czech Republic	9
Disturbances and their consequences for vegetation of arctic tundra ecosystem, comparison to the experience from alpine tundra	Jana Müllerová	Institute of Botany of the Czech Academy of Sciences, Pruhonice, Czech Republic	74
Fluorescence across space and time – focus on leaf optical properties	Jean-Baptiste Feret	IRSTEA, UMR TETIS, Montpellier, France	18
Pan-Arctic precipitation isotope ($\delta^{18}O$ & $\delta^{2}H$) network: interactions between sea ice-atmospheric dynamics and precipitation isotope geochemistry	Jeff Welker	Unversity of Oulu, Finland	8, 52, 74, 76
Geomorphological characterisation and activity analysis in the Zackenberg region	Jeffrey Evans	Loughborough University, UK	80
New insights into ablation processes from ultra-high resolution DEMs of glacier surface changes	Jeremie Mouginot	Institut des Géosciences de l'Environnement, Grenoble, France	77
Baseline conditions and Arctic mining impacts under hydro-climatic change	Jerker Jarsjö	Stockholm University, Sweden	30
Atmospheric mercury isotope monitoring in the Arctic	Jeroen Sonke	CNRS, Toulouse, France	81
End members of CH_4 oxidation in cold mountain soils	Jesper Riis Christiansen	University of Copenhagen, Denmark	53
Shrubs – tundra response in the Arctic climate/environmental shift	Jiří Lehejček	Tomas Bata University, Zlín/ Uherské Hradiště, Czech Republic	66
Microbial genomics and functional diversity in wetlands	Joel White	Lund University, Sweden	80
The effect of warming on the Arctic soil microbiome assessed by soil transfer along an altitudinal gradient and between aspects	Johanna Donhauser	Swiss Federal Research Institute WSL, Birmensdorf, Switzerland	14
Alien species dynamics along mountain roads **(SS 2.5)**	Jonas Lembrechts	University of Antwerp, Belgium	14
Greenland atmospheric isotopic and nutrient fluxes	Jonathan Martin	University of Florida, USA	76
Climate induced change in the forested-to-open bog ecotone over time	Joshua Ratcliffe	University of Waikato, Hamilton, New Zealand	32
Microplastic pollution and effects on carbon-degrading microbial communities in Arctic peatlands	Juanita Mora-Gómez	Institut des Sciences de la Terre d'Orléans (ISTO), Orléans, France	32
Long-term changes in the biogeochemistry of permafrost forests as a result of fire	Jukka Pumpanen	University of Eastern Finland, Joensuu, Finland	54
Soil organic carbon pools in the Russian taiga **(SS 6.3)**	Juri Palmtag	Stockholm University, Sweden	34, 44
Resampling forest and tundra vegetation after decades of climate and land-use change **(SS 2.4)**	Jutta Kapfer	Norwegian Institute of Bioeconomy Research, Tromsø, Norway	15, 16
Short and long term effects of forest fires on the stability of carbon pools in the arctic permafrost and Subarctic forests	Kajar Koster	University of Helsinki, Finland	54
Clouds lower the albedo of ice microbiota	Karen Cameron	Aberystwyth University, UK	13
Glacial-fed sediments as a greenhouse gas sink	Karen Cameron	Aberystwyth University, UK	76
High Arctic aphids reproductive system	Karina Wieczorek	University of Silesia, Katowice, Poland	3, 76
Link between soil chemistry, vegetation cover and springwater chemistry in the crystalline headwater areas in Finnish Lapland	Katarzyna Wasak	Polish Academy of Sciences, Krakow, Poland	15, 22
Glacial meltwater sediment transformation in Arctic river systems	Kathryn Adamson	Manchester Metropolitan University, UK	74, 81
Ecology and diversity of Tardigrada in the northern glacial biome – are they unique?	Krzysztof Zawierucha	Adam Mickiewicz University, Poznań, Poland	10

Project	Project leader	Affiliation	Stations visited
Effects of climate change on microbial community of soil in Greenland	Laura Zucconi	University of Tuscia, Viterbo, Italy	76
Climate change effects on glacial river ecosystem functioning	Lee Brown	University of Leeds, UK	10
AirMiMiC – Airborne delivery vs. surface accumulation of microbes, mineral dust and black carbon onto the Greenland Ice Sheet **(SS 2.1)**	Liane G. Benning	The GFZ German Research Centre for Geosciences, Potsdam, Germany	77
Arctic island communities: shifting lifestyles and traditional economies facing climate change & globalization **(SS 5.7)**	Lidia Rakhmanova	State Hermitage Museum, St. Petersburg, Russia	87
Organo-mineral Interactions from permafrost disturbance to sediment sink	Lisa-Marie Bröder	Vrije Universiteit Amsterdam, the Netherlands	80
New biotic and abiotic factors controlling carbon cycle in thaw lakes of western Siberia (in comparison with lakes of NE Europe) **(SS 6.5)**	Liudmila Shirokova	University of Paul Sabatier, Toulouse, France	34
Glaciation of the Kola Peninsula, Arctic Russia	Lorna Linch	University of Brighton, UK	30
Biological crusts of different Arctic extreme environments and their impact on the soil ecosystem (biodiversity, gas exchange and nutrient cycling)	Luigi P. D'Acqui	ISE-CNR, Firenze, Italy	81
Multisensory submersible drifters to study glacial water flow **(SS 1.6)**	Maarja Kruusmaa	Tallinn University of Technology, Estonia	3
High-resolution multi-proxy temperature reconstruction using lake sediments in West Siberia	Maarten Van Hardenbroek	Newcastle University, Newcastle upon Tyne, UK	32, 38
Growth-ring record of modern extreme weather phenomena in the Low Arctic **(SS 4.3)**	Magdalena Opala-Owczarek	University of Silesia, Sosnowiec, Poland	66, 85
Pan-Arctic N_2O flux screening network	Maija Marushchak	University of Eastern Finland, Kuopio, Finland	2, 8, 10, 13, 52
Holocene glacial oscillations in Zackenberg area (Greenland)	Marc Oliva	University of Barcelona, Spain	80
Annual rings to better understand long-term abiotic drivers of shrub growth at the northernmost limits of their distribution	Marco Carrer	University of Padova, Italy	76, 82, 87
Next-generation microwave radars for Arctic snowpack monitoring	Marco Pasian	University of Pavia, Italy	16
Fungal contributions to the carbon cycle of Subarctic and Arctic ponds	Mariana Kluge	SLU, Uppsala, Sweden	34, 74
Arctic night skies as an orientation cue – Quantifying the effects of light pollution on lunar and stellar orientation **(SS 2.6)**	Marie Dacke	Lund University, Sweden	16
Ecology and phylogeography of glacier tardigrades	Marie Sabacka	University of South Bohemia, Ceske Budejovice, Czech Republic	39, 81
Tree-ring records of extreme events in northern Europe	Marina Gurskaya	Institute of Plant and Animal Ecology, Ekaterinburg, Russia	14, 22
Genetic diversity in northern grass-endophyte populations	Marjo Helander	University of Turku, Finland	52, 53, 87
Reactive oxygen species as a stressor in the Arctic	Mark Hopwood	GEOMAR, Kiel, Germany	76
Glacier aerodynamic roughness estimation	Mark Smith	University of Leeds, UK	13, 24
Genetic adaptation to freezing and thawing in Enchytraeids	Martin Holmstrup	Aarhus University, Denmark	4, 11, 66, 76, 85
The Late Holocene climate change inferred from the wetland ecosystems in the lower Indigirka River basin	Mateusz Płóciennik	University of Lodz, Poland	45
Anaerobic oxidation of methane: Potentials, estimation and transition	Maxim Dorodnikov	University of Göttingen, Germany	12
Chemical weathering and the inorganic carbon flux of a High Arctic river	Melissa Murphy	University College London, UK	80
Asynchronous evolution of glaciers in Greenland Based on Be-10 surface exposure dating technique	Melody Biette	Laboratoire de Géographie Physique, Meudon, France	77, 80

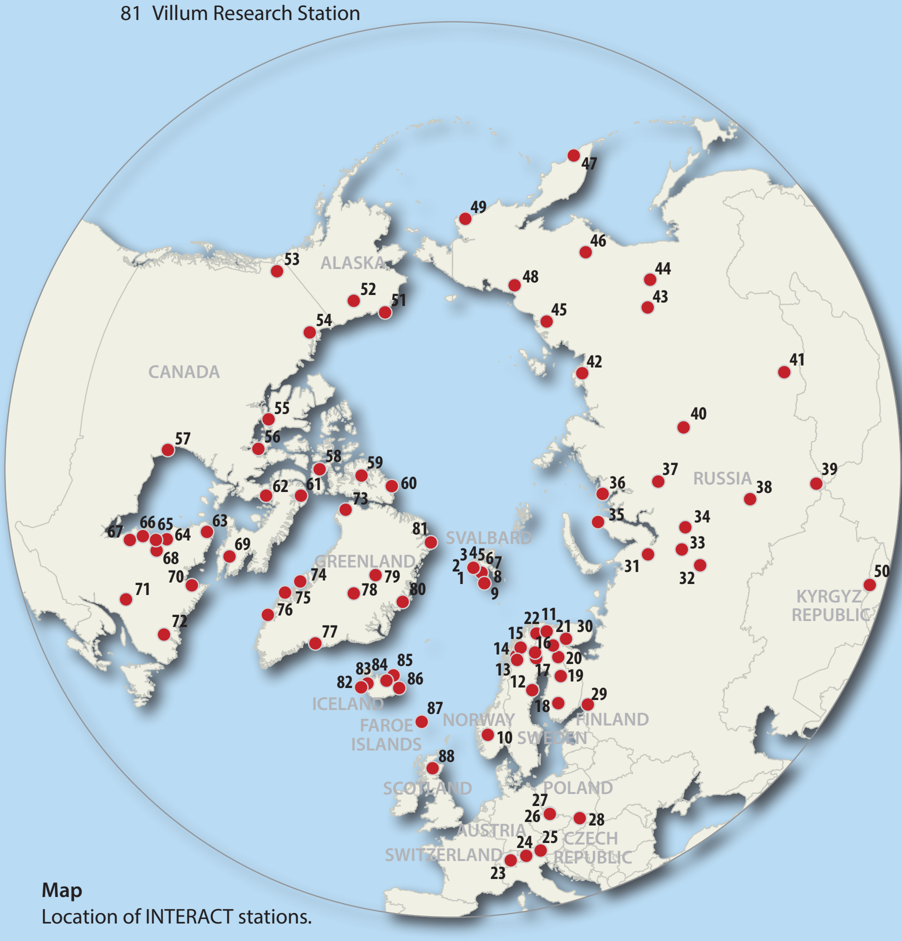
Project	Project leader	Affiliation	Stations visited
Siberian peatlands as an archives of climate warming and long-term carbon dynamics	Michał Słowiński	Institute of Geography and Spatial Organization Polish Academy of Sciences, Warsaw, Poland	32, 34
Background insect herbivory in Arctic ecosystems	Mikhail Kozlov	University of Turku, Finland	76
Soil organic carbon research in alpine tundra ecosystems	Mikhail Maslov	Lomonosov Moscow State University, Russia	10, 14
Molecular steps of new particle formation in the Arctic atmosphere	Mikko Sipilä	University of Helsinki, Finland	2
Woody expansion in Subarctic permafrost peatlands: interactive effects of permafrost degradation, plant facilitation and herbivores	Milena Holmgren	Wageningen University, the Netherlands	22
Fate of dissolved black carbon after fire disturbances in boreal forest ecosystems in Finland **(SS 4.5)**	Mizue Ohashi	University of Hyogo, Himeji, Japan	18, 21
Vegetation – permafrost interactions in a lowland tundra ecosystem: shrub decline due to abrupt thaw triggered by wet summers? **(SS 3.3)**	Monique Heijmans	Wageningen University & Research, the Netherlands	45
Dynamic stream flow impacts on hyporheic and riparian contributions to reach-scale microbial activity	Nicolai Brekenfeld	University of Birmingham, UK	12
Linking above- and below-ground communities: microbial effects on carbon cycling under changing tundra vegetation	Nina L. Friggens	University of Stirling, UK	14
Understanding phosphorus cycling in peatlands under climate change	Olga Marfalev	Centre for Ecological Research and Forestry Applications, Bellaterra, Cerdanyola del Vallés, Spain	14, 52
Global spore sampling project	Otso Ovaskainen	University of Helsinki, Finland	2, 13, 14, 52, 74, 76, 82
Black carbon in snow and water **(SS 2.2)**	Outi Meinander	Finnish Meteorological Institute, Helsinki, Finland	82, 87, 88
The importance of cryptogams in the primary succession process on glacier forelands in Svalbard	Paulina Wietrzyk	Jagiellonian University, Cracow, Poland	3, 13
Soil organic carbon stocks in the central Asian mountain permafrost region	Peter Kuhry	Stockholm University, Sweden	39
Arctobombus resistance to extreme climatic variations of arcto-alpine bumblebees: Biogeography, phylogeny, physiology of hyperthermic stress **(SS 3.6)**	Pierre Rasmont	University of Mons, Belgium	34, 45, 66
Validating microwave radiative transfer models of tree canopies in wintertime	Qinghuan Li	University of Waterloo, Canada	16
Kola Peninsula plant success 2	Rachael Turton	University of Cambridge, UK	30
Phosphorus transformation across Pan-Arctic tundra ecosystems	Reiner Giesler	Umeå University, Sweden	52
Ethical principles for Sámi health research in Finland **(SS 5.2)**	Rhonda M. Johnson	University of Alaska Anchorage, USA	22
Understanding the dynamics of plant-pollinator responses to climate change	Richard Gill	Imperial College London, UK	14
Global peatlands under pressure	Richard Payne	University of York, UK	32, 38
Impact of catch-and-release practices on pikeperch (*Sander lucioperca* (L.)) during spawning period	Robert Arlinghaus	Humboldt-University of Berlin, Germany	19
Tracing eskers beneath glaciers	Robert Storrar	Sheffield Hallam University, UK	8
Permafrost coastal erosion: observation and modelling	Samuel Hayes	Northumbria University, Newcastle Upon Tyne, UK	54
Quantifying the impact of retreating Arctic glaciers on the global carbon cycle	Saule Akhmetkaliyeva	Manchester Metropolitan University, UK	13, 80

Project	Project leader	Affiliation	Stations visited
Albedo observations on mountain glacier ice in Greenland **(SS 6.1)**	Sebastian Mernild*	University of Southern Denmark, Denmark	77
Fluvial sediment transport characteristics in periglacial and glacial environments of northern Sweden	Sergey Chalov	Lomonosov Moscow State University, Russia	13
Ecohydrology of peat interface zones	Simon Dixon	University of Birmingham, UK	12
Response of terrestrial microbial communities to environmental changes in Arctic, Subarctic, and Alpine regions	Stefano Ventura	CNR-Institute of Ecosystem Study, Sesto Fiorentino, Italy	39
Microscale impacts of groundwater/hyporheic upwelling on stream temperature under varying discharges	Stephen Dugdale	University of Birmingham, UK	12
Riverine invertebrates as biological indicators of climate driven changes along environmental gradient within the glaciarized Kuray watershed in Altai, Russia	Tadeusz Namiotko	University of Gdansk, Gdansk, Poland	39
Fire history reconstruction of Siberian boreal forests through dendrochronology: interacting effects of climate and ecohydrological conditions	Tatiana Shestakova	Woods Hole Research Center, Falmouth, USA	38
From snow to wedge ice – tracing recent ice-wedge genesis	Thomas Opel	University of Sussex, Brighton, UK	42
Shrubs and soil organic carbon	Thomas Parker	University of Stirling, UK	74, 76
Global observation research initiative in alpine environments – Latnjajaure **(SS 3.2)**	Thomas Vanneste	Ghent University, Belgium	14
Biotic interactions tracked by computer vision	Toke Høye	Aarhus University, Denmark	4, 52, 74, 85
Coping with phenological mismatch: how an insectivorous migrant shorebird may mitigate the negative effects of a warming Arctic by prey and patch selection **(SS 3.7)**	Tom Versluijs	Royal Netherlands Institute for Sea Research, the Netherlands	80
Linking chlorophyll fluorescence from the leaf to the satellite for improved monitoring of boreal forest carbon dynamics	Troy Magney	NASA Jet Propulsion Laboratory, Pasadena, USA	18
Comparative analysis of treeline trees across latitudinal gradient	Vaclav Treml	Charles University, Prague, Czech Republic	22, 88
Pyrogenic carbon in boreal forest ecosystems: fate and environmental impact	Viktor Bruckman	University of Natural Resources and Life Sciences, Vienna, Austria	18, 21
Glacier-climate fingerprints of cooling events in the Subarctic Atlantic	Willem van der Bilt	University of Bergen, Norway	85

* Sebastian Mernild was affiliated with the Nansen Environmental and Remote Sensing Centre, Norway, at the time of the fieldwork.

● **INTERACT Stations**

1 AWIPEV Arctic Research Base
2 CNR Arctic Station "Dirigibile Italia"
3 Ny-Ålesund Research Station – NPI Sverdrup
4 UK Arctic Research Station
5 Netherlands' Arctic Station
6 Nicolaus Copernicus University Polar Station
7 Adam Mickiewicz University Polar Station "Petuniabukta"
8 Czech Arctic Research Station of Josef Svoboda
9 Polish Polar Station Hornsund
10 Finse Alpine Research Centre
11 Nibio Svanhovd Research Station
12 Svartberget Research Station
13 Tarfala Research Station
14 Abisko Scientific Research Station
15 Kilpisjärvi Biological Station
16 Pallas-Sodankylä Stations
17 Kolari Research Unit
18 Hyytiälä Forest Research Station
19 Kainuu Fisheries Research Station
20 Oulanka Research Station
21 Värriö Subarctic Research Station
22 Kevo Subarctic Research Station
23 Alpine Research and Education Station Furka
24 Station Hintereis
25 Sonnblick Observatory
26 Krkonoše Mountains National Park
27 Karkonosze Mountains National Park
28 M&M Kłapa Research Station
29 Lammin-Suo Peatland Station
30 Khibiny Educational and Scientific Station
31 The Arctic Research Station
32 Mukhrino Field Station
33 Numto Park Station
34 Khanymey Research Station
35 Beliy Island Research Station
36 Willem Barentsz Biological Station
37 Igarka Geocryology Laboratory
38 Kajbasovo Research Station
39 Aktru Research Station
40 Evenkian Field Station
41 International Ecological Educational Center "Istomino"
42 Research Station Samoylov Island
43 Spasskaya Pad Scientific Forest Station
44 Elgeeii Scientific Forest Station
45 Chokurdakh Scientific Tundra Station
46 Orotuk Field Station
47 Avachinsky Volcano Field Station
48 North-East Science Station
49 Meinypil'gyno Community Based Biological Station
50 Adygine Research Station
51 Barrow Arctic Research Center/ Barrow Environmental Observatory
52 Toolik Field Station
53 Kluane Lake Research Station
54 Western Arctic Research Centre
55 Canadian High Arctic Research Station
56 M'Clintock Channel Polar Research Cabins
57 Churchill Northern Studies Centre
58 Flashline Mars Arctic Research Station
59 Polar Environment Atmospheric Research Laboratory
60 CEN Ward Hunt Island Research Station
61 CEN Bylot Island Field Station
62 Igloolik Research Center
63 CEN Salluit Research Station
64 CEN Boniface River Field Station
65 CEN Umiujaq Research Station
66 CEN Whapmagoostui-Kuujjuarapik Research Station
67 CEN Radisson Ecological Research Station
68 CEN Clearwater Lake Research Station
69 Nunavut Research Institute
70 CEN Kangiqsualujjuaq Sukuijarvik Research Station
71 Uapishka Research Station
72 Labrador Institute Research Station
73 DMI Geophysical Observatory – Qaanaaq
74 Arctic Station
75 Arctic DTU, ARTEK Research Station
76 Greenland Institute of Natural Resources
77 Sermilik Research Station
78 Summit Station
79 EGRIP Field Station
80 Zackenberg Research Station
81 Villum Research Station
82 Sudurnes Science and Learning Center
83 Litla-Skard
84 China-Iceland Arctic Observatory
85 RIF Field Station
86 Skálanes Nature and Heritage Center
87 Faroe Islands Nature Investigation
88 ECN Cairngorms



Map
Location of INTERACT stations.

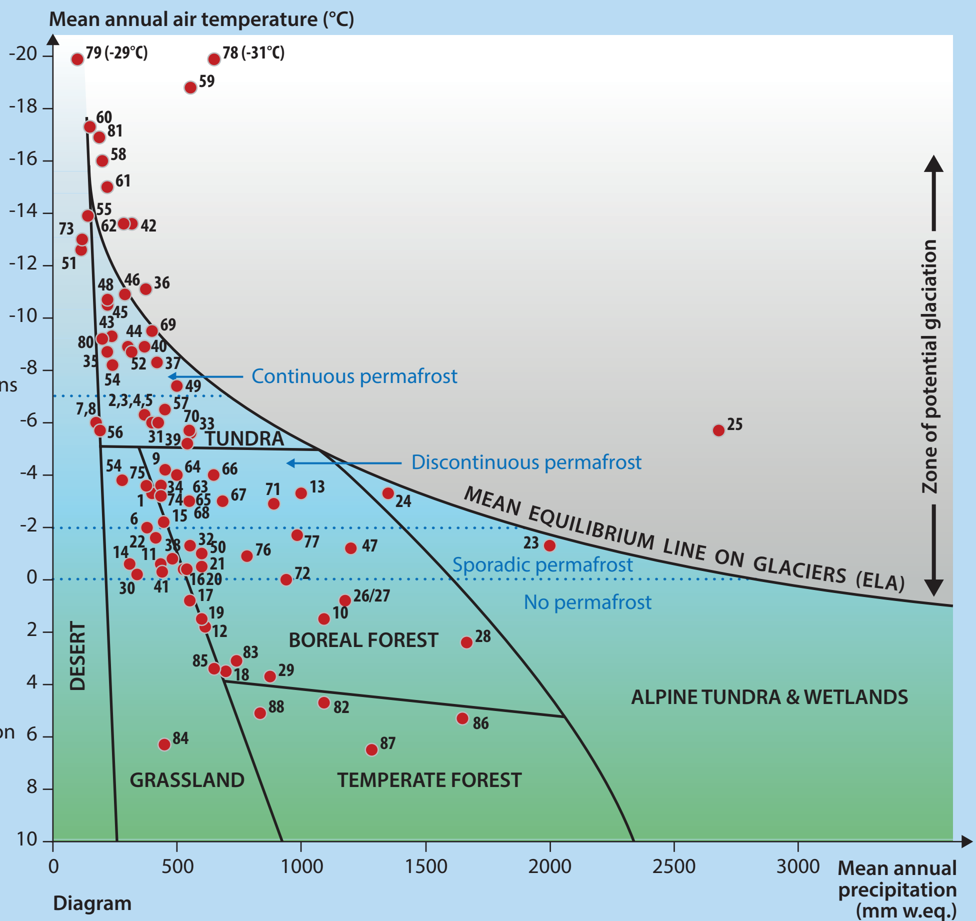


Diagram
Location of INTERACT stations in 'environmental space'.

INTERACT

International Network for Terrestrial Research and Monitoring in the Arctic

INTERACT is a circumarctic network of more than 88 terrestrial field bases in Arctic, alpine and neighbouring forest areas.

The main objective of INTERACT is to provide a circumarctic platform for identifying, understanding, predicting and responding to current environmental changes that take place in the Arctic and neighbouring areas. The INTERACT stations host over 18,000 research visits annually, facilitating top-level research and monitoring programmes within a wide range of scientific disciplines from natural sciences to the human dimension. INTERACT cooperates with local and Indigenous Peoples.

This second Science Stories book takes the reader on a continuing journey through the Arctic and neighbouring alpine and forest areas, and presents the excitement and adventure that a new group of researchers both enjoy and endure. The book consists of seven highly illustrated sections focusing on different ways of knowing, human impacts on Arctic environments, ecosystem services, minimising surprises for society, impacts on local and global societies and ways of working together. These topics are all interconnected and together contribute to the “Arctic System” – a system of great importance to the global community but one that is changing dramatically. The book has been developed into an e-book to provide wider content for the public, students and school children with videos, animations and activities (access this e-book via the QR code on the inside of the back cover).

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https://eu-interact.org/

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