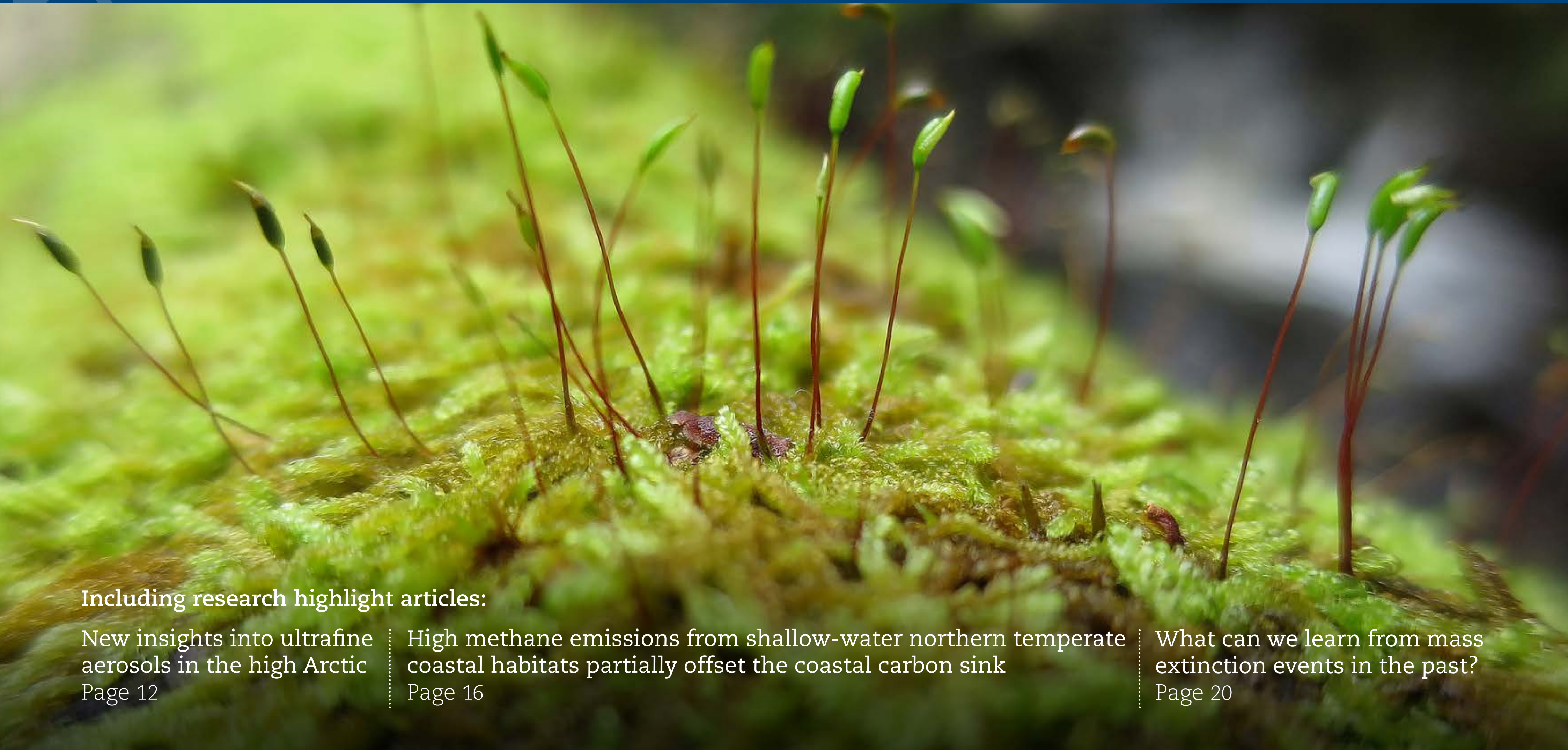
Bolin Centre for Climate Research

Annual Report 2021



Including research highlight articles:

Bolin Centre Vision

Our vision is to place the Bolin Centre as the nationally leading and an internationally recognised centre for interdisciplinary climate research and a primary Swedish contact point for scientists, media and the public on issues relating to the past, present and future climate.

Bolin Centre Mission

The mission of the Bolin Centre is to create and communicate fundamental knowledge about climate and the Earth system as part of an evolving global effort to understand and adapt to the Earth's changing climate.

Front page: The moss Hypnum cupressiforme with sporophytes. Photo: Caroline Greiser
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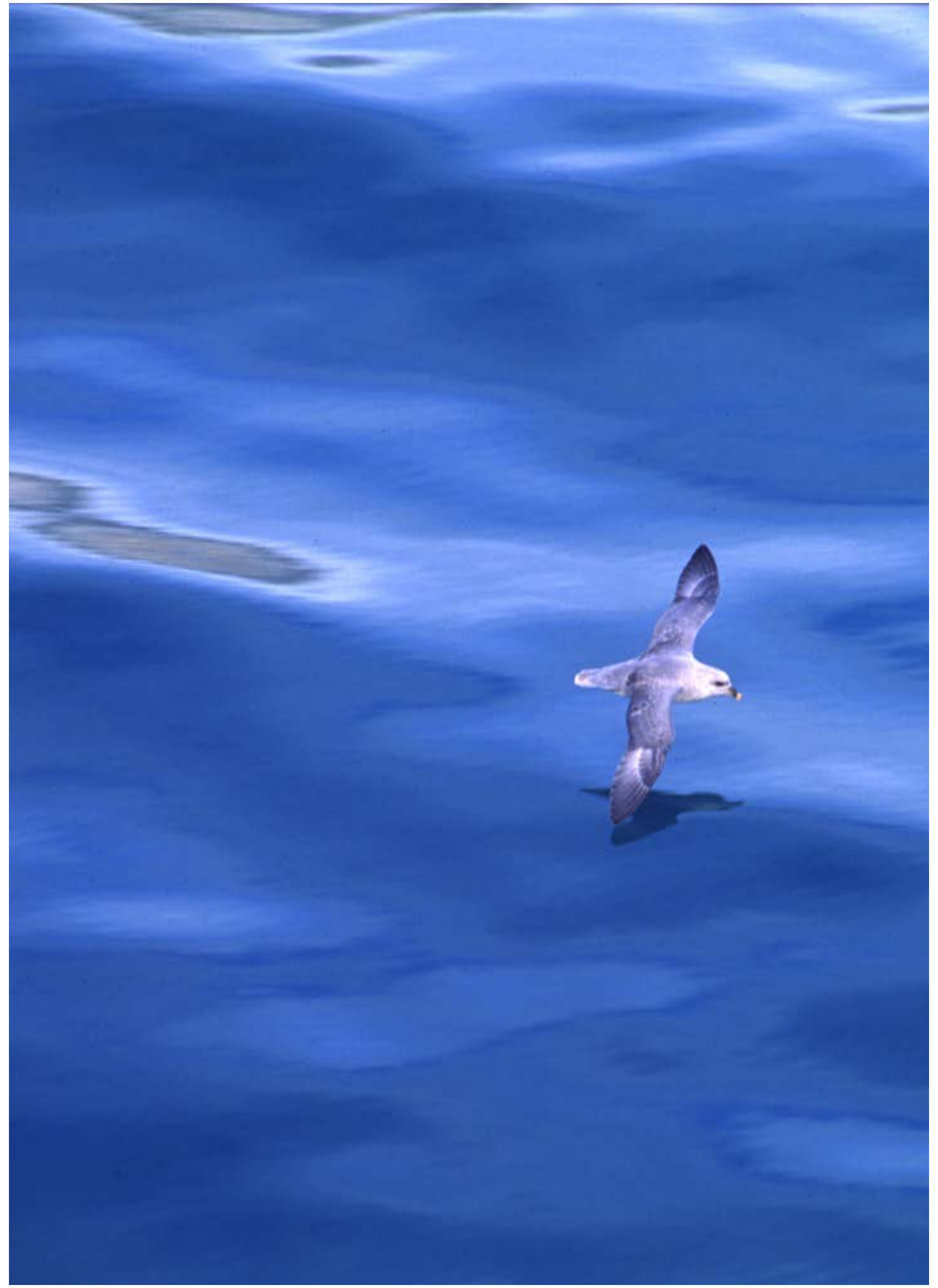


Photo: Martin Jakobsson

The Bolin Centre for Climate Research

The Bolin Centre is a multi-disciplinary consortium of more than 400 scientists in Sweden who conduct research, graduate education and outreach related to the Earth's climate. It was formed in 2006 by Stockholm University, and in 2010 the KTH Royal Institute of Technology and the Swedish Meteorological and Hydrological Institute joined the centre. The Bolin Centre is named in honour of Professor Bert Bolin of Stockholm University, a world leader in climate and carbon cycle research.

The Bolin Centre focuses on extending and disseminating knowledge about the Earth's natural climate system, climate impacting processes, climate modelling, human impact on the climate and climate impacts on ecosystems, biodiversity and humanity as well as how society can minimise the negative impacts of climate change. It contributes to the knowledge base climate mitigation and adaption policies nationally and internationally.

The Bolin Centre is named after Professor Bert Bolin of Stockholm University, one of the founders of the Intergovernmental Panel on Climate Change (IPCC). The work of the IPCC and others led to the recognition of the need for cross-disciplinary collaboration on climate science at Stockholm University. This resulted in a Climate Research School being established in 2005 and shortly thereafter the research program SUCLIM (Stockholm University Climate Research Centre) being awarded a 10 year Linneaus grant from the Swedish government in 2006.

In 2008, SUCLIM was renamed the Bert Bolin Centre for Climate Research, a name which was shortened to the Bolin Centre for Climate Research in 2013. From 2010, the Swedish Hydrological and Meteorological Institute and the KTH Royal Institute of Technology joined the Bolin Centre in a collaboration aimed at strengthening climate modelling within the centre. This initiative was funded as a strategic research area by the Swedish government.

In June 2016, the Bolin Centre merged with another strategic research area at Stockholm University: EkoKlim – A multiscale, cross-disciplinary approach to the study of climate change on natural resources, ecosystem services and biodiversity. This merger widened the scope of the Bolin Centre to include the impacts of climate change on landscape processes and biodiversity.

Following this merger, the combined strategic funding of the Bolin Centre exceeds 30 MSEK annually.

The Bolin Centre has initialized a process of restructuring and redefining its' strategic plan. The new structure is planned to be implemented in 2023.

Bolin Centre for Climate Research
A collaboration between Stockholm University, KTH and the Swedish Meteorological and Hydrological Institute

Stockholm University

KTH VETENSKAP OCH KONST

SMHI

Bolin Centre organisation

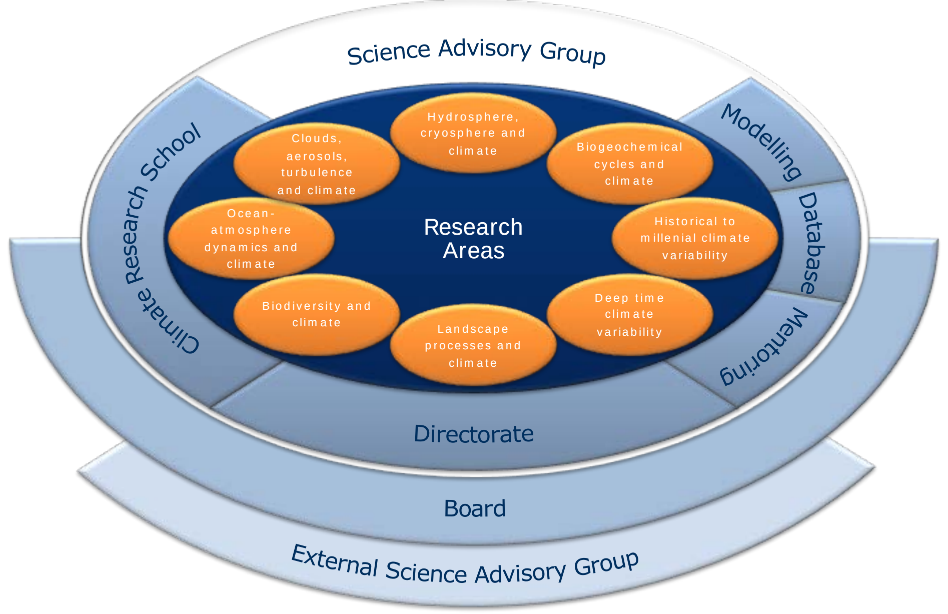
The Bolin Centre aims to bring climate scientists together. The centre has eight cross-disciplinary research areas, where scientists from different disciplines join together to tackle key questions about climate. The Bolin Centre organises seminars, workshops, conferences, outreach projects, research education and a mentoring program.

The Bolin Centre is built around its eight multi-disciplinary research areas, each of which is led by two (or three) scientists. The centre hosts a research school and an open access database as well as provides communication support and support for climate modelling activities.

The directorate is formed by two co-directors and two communicators and coordinators, who share the day-to-day tasks of centre operations. All research area co-leaders, coordinators and the directorate meet regularly in the Science Advisory Group, working to support in climate-related science conducted by the Bolin Centre members.

The Bolin Centre is led by its board, which includes heads of participating departments at Stockholm University, representatives from KTH Royal Institute of Technology and the Swedish Hydrological and Meteorological Institute, and external members. The Bolin Centre receives guidance from its External Science Advisory Group. These internationally recognised leaders in climate science aim to visit the Bolin Centre annually at its internal conference: the Bolin Days.

The operational philosophy of the Bolin Centre is one of mutual respect and trust – a philosophy which is reflected in the form of paired leadership which is applied throughout the organisation.



Directors' corner

The Bolin Centre has evolved from an idea among a few inspired individuals to a thriving node embracing more than 400 scientists focusing on science, education and outreach activities related to the Earth's climate. The Bolin Centre is a common effort, and its success is the success of its members.

In 2021, the COVID-19 pandemic continued to be ever present, and kept its hard grip on virtually all parts of life. Work life continued digitally, from home offices, and with occasional in-person meetings.

In the digital realm, the Research Areas kept on giving webinars in the Bolin Centre Seminar Series (most of them were recorded and can be viewed on our Youtube channel); the Bert Bolin Centre Climate Lecture was given by Professor William F. Ruddiman from the University of Virginia; and the Climate festival took place over Zoom.

In Glasgow, the COP26 meeting was held during the first two weeks of November. The public wanting to follow COP26 remotely, could meet members of the Bolin Centre and the International Cryosphere and Climate Initiative at an open space in Kulturhuset Stadsteatern in Stockholm, in order to watch and discuss livestreamed events from Glasgow.

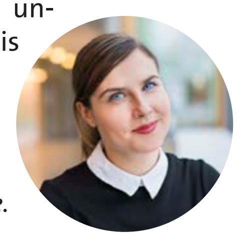
Our meetings with the Bolin Centre Board and the Scientific Advisory Group focused to a large extent on the process of restructuring the Centre, a process that is still ongoing. At the end of 2021, the Bolin Centre leadership was handed over to a new director, Prof. Ilona Riipinen from the Department of Environmental Science (ACES), a new vice-director, Assoc. Prof. Gustaf Hugelius from the Department of Physical Geography (NG), and two new co-Chairs of the Board, Prof. Johan Nilsson from the Department of Meteorology (MISU) and Prof. Martin Jakobsson from the Department of Geological Science (IGV). We feel proud to be able to pass on leadership of a flourishing centre, whose members continue to create the fundamental knowledge on which a sustainable transformation must be based, and wish Ilona and Gustaf all the best.

Nina Kirchner and Alasdair Skelton, co-directors of the Bolin Centre.

"We are excited to take over the leadership of the Bolin Centre from 2022 onwards. In our first few months into the job, we feel excited, honored and admittedly even a bit overwhelmed. We are impressed not only by the breadth and quality of Bolin Centre research, but also the engagement and support from our members.

The research and education activities within the Bolin Centre span across all components of the Earth system, providing fundamental knowledge needed to understand how humans modify and interact with our environment. This breadth makes us unique. But it also presents challenges, such as keeping informed on new developments across research fields, renewing ourselves in a coherent yet inclusive manner, and nurturing the sense of community within the Bolin Centre. We feel up for this challenge but also humbled by it – first and foremost we aim to learn from the world-class expertise within the centre.

Building from the restructuring process started and carefully overseen by our predecessors Nina and Alasdair, we have initiated a renewal of the Bolin Centre strategic plan for the coming five-year period. We are aiming for a sharp yet inclusive strategic plan that positions the Bolin Centre locally, regionally, nationally and globally. Our expertise is more relevant than ever. In these times of unprecedented societal momentum for climate-related questions, robust and well-grounded scientific understanding of the climate system is needed to ensure a safe and prosperous future for the humankind."



Ilona Riipinen and Gustaf Hugelius, incoming co-directors of the Bolin Centre.

Publications

The total number of publications where researchers have listed an affiliation to the Bolin Centre in the article is 232. The total number of publications by researchers (listed as Bolin-members on our website) is 814.

The Bolin Centre Database

The Bolin Centre Database promotes research results and visualizes data.

As of April 2022, the database hosts 321 datasets and a number of thematic data presentations. Read more on page 28.

Communication channels

Visit *www.bolin.su.se* and *@BolinCentre* on twitter for latest news and events.

Photo: Krister Junghahn

The Bolin Centre Research Areas

The [1]eight research areas within the Bolin Centre receive financial resources each year to support research activities. Based on applications from the Bolin members, the research area leaders select and fund initiatives such as pilot studies, field work or laboratory analyses. The research areas also organise seminars, open for knowledge transfer and networking. You can read about the focus of each research area here. In the following pages, we present eight longer texts, illustrating the research efforts in our different research areas.

RA1 | Ocean-atmosphere dynamics and climate

We conduct fundamental research on the dynamics of the atmosphere and oceans and their influence on climate. We develop, evaluate and apply different models, ranging from simple box models to regional and global component models up to fully coupled global Earth system models. Models and observational based data sets are used to gain insight into the underlying mechanisms that govern the variability of oceanic and atmospheric circulation, exchanges of heat and water between atmosphere and ocean, predictability of the climate systems and extremes as well as potential future climate changes under different future emission scenarios.

Co-leaders: Thorsten Mauritsen, Department of Meteorology at Stockholm University and Torben Königk, Rossby Centre/SMHI, Stockholm.

[1]From 2022 and onwards, our research is structured in four Research Themes. Read more about them on our website.

RA 2 | Clouds, aerosols, turbulence and climate

Clouds, aerosols and their interactions with each other and with the climate remain the main uncertainty in future climate projection. We work across scales to improve understanding, observation and model representation of these highly important processes. Our modelling activities range from Large Eddy Simulations to Earth System Modelling, and our experimental efforts range from lab experiments to ice breaker expeditions to the high Arctic. By understanding aerosols and clouds, their interactions, and the roles they play in the climate system, our work contributes to refined estimates of anthropogenic forcing and of the sensitivity of the climate system to this forcing.

Co-leaders: Frida Bender, Department of Meteorology and Matthew Salter, Department of Environmental Science, both at Stockholm University.

RA 3 | Hydrosphere, cryosphere and climate

Water circulation at, or near, Earth's surface occurs by rainfall, evapotranspiration, surface water and groundwater flows. Frozen water forms snow cover, glaciers, ice sheets and permafrost. We study couplings between water in all physical states and climate systems and their changes in time, along with their repercussions for socioecological systems. These changes may be effects of natural or man-made changes in land cover, vegetation, water flow paths, stocks, or effects of climate change on water-borne flows of substances including contaminants.

Co-leader: Fernando Jaramillo. Department of Physical Geography at Stockholm University.

RA 4 | Biogeochemical cycles and climate

We study the interactions between climate and carbon-nutrient cycles through modelling, experimental, and observational studies. Biogeochemical cycles are influenced by feedback on climate, ecosystems and societies. Understanding the processes and dynamics of biogeochemical cycles is a fundamental part of understanding the Earth system and how it responds to climate change.

Co-leaders: Volker Brüchert, Department of Geological Sciences and Gustaf Hugelius, Department of Physical Geography, both at Stockholm University.

RA 5 | Historical to millennial climate variability

We reconstruct past climate evolution by investigating natural records such as marine, lake and terrestrial sediment cores, ice cores, cave deposits, tree rings, landforms and historical documents. By developing appropriate statistical methods and comparing with climate model simulations, we aim to better understand and interpret past climate variability on historical and millennial timescales. This work helps us better predict the climate of the future.

Co-leaders: Malin Kylander and Frederik Schenk, Department of Geological Sciences at Stockholm University.

RA 6 | Deep time climate variability

To appreciate the full range of Earth's climate variability it is necessary to look far back into geologic time where we find intervals when the world has been much warmer and colder than today. Our mission is to reconstruct and interpret past climate variations on long timescales by comparing computer simulations and data from natural archives such as rocks, sediments and fossils. This helps us place limits on natural climate variability and better understand the Earth system. It also provides context for current global change. We would not understand that Earth's climate is rushing towards extreme change, unprecedented in historical experiences, without the deep time perspective.

Co-leaders: Helen Coxall, Department of Geological Sciences at Stockholm University and Margret Steinthorsdottir, Swedish Museum of Natural History, Stockholm.

RA 7 | Landscape processes and climate

The combined effects of changes in climate, land-use and water-use may heavily influence natural resources in terrestrial and marine environments in the coming decades. We gather natural and social scientists to study the effects of climate change on ecosystems including its abiotic and biotic components and integrated effects on human wellbeing. The focus is both on fundamental questions of how natural and anthropogenic processes at multiple scales play out in the landscape and on how the society can respond to this, for example by adaptive governance. We are interested in climate and climate change projections on various relevant scales for different processes and for land-use, water-use and natural resource management and governance.

Co-leaders: Kristoffer Hylander, Department of Ecology, Environment and Plant Sciences, Zahra Kalantari and Regina Lindborg, Department of Physical Geography, all at Stockholm University.

RA 8 | Biodiversity and climate

We investigate how climate influences ecological and evolutionary processes in natural populations. Field observations and experiments are used to examine effects on abundance and distribution of single species or biodiversity, as well as how climate affects interactions between species, community structure and ecosystem functioning. We also use this information to develop methods to mitigate negative effects of climate change on biodiversity.

Co-leaders: Sara Cousins, Department of Physical Geography, Johan Ehrlén, Department of Ecology, Environment and Plant Sciences and Carl Gotthard, Department of Zoology, all at Stockholm University.

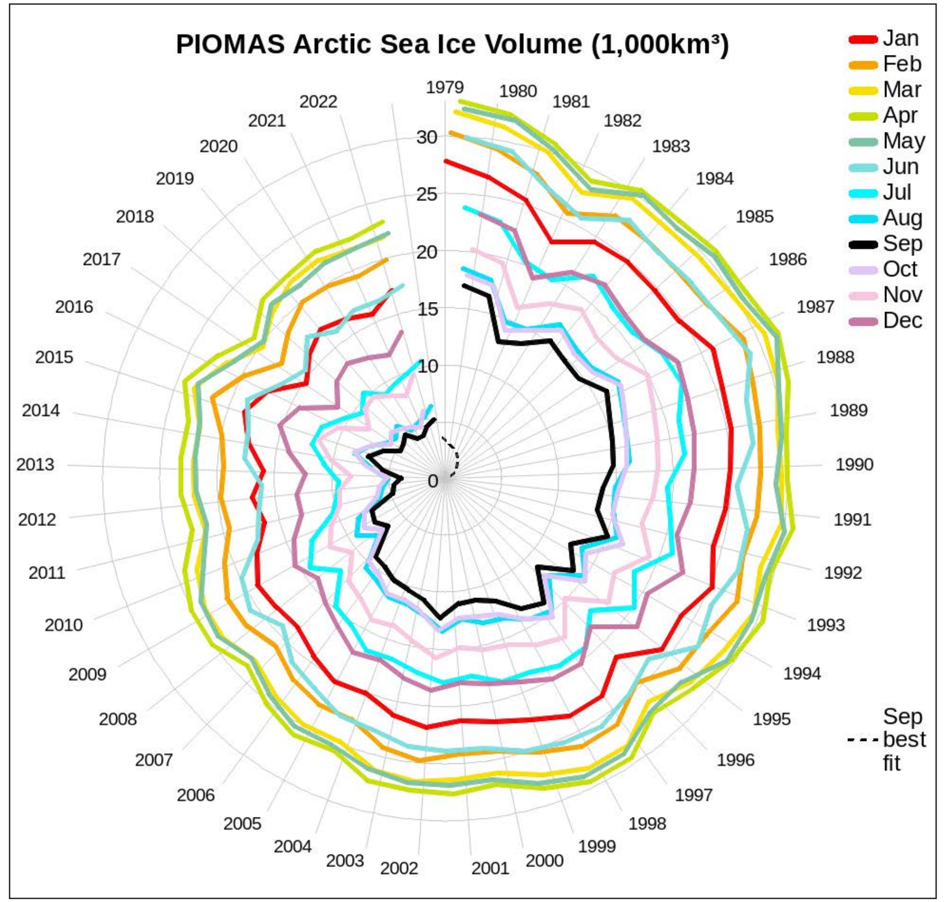
Observation-based Climate models selected with support in observational data projects Arctic ice-free summers from 2035 onwards

The retreat of Arctic sea ice is one of the most striking consequences of global warming and has strong implications for local and remote climate, biosphere and society.

The total area of the Arctic Ocean covered by sea ice has decreased by about 2 million km^2 in the past 40 years of satellite observations, with more pronounced loss in the summer. As sea ice has also thinned by 1.5–2 m in the central Arctic, the total Arctic sea-ice volume has decreased as well, from around 15,000 km^3 to 5,000 km^3 in summer (in winter from around 30,000 km^3 to slightly above 20,000 km^3). The current Arctic sea-ice losses are strongly connected to rising global temperatures and thus to the increased greenhouse gas emissions into the atmosphere.

Our best tool to investigate how the Arctic sea ice will develop in the future are climate models coupling the atmosphere, ocean and land. The latest generation of climate models, which has been contributed to the 6th phase of the Coupled Model Intercomparison Project (CMIP6) and fed into the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 6, performed climate mod-el projections following different future greenhouse gas emission and land-use scenarios until year 2100. While these latest models are generally better representing the observed changes of Arctic sea ice compared to earlier model generations, a number of individual models still substantially over- or underestimate the observed sea ice conditions and trends. Thus, just calculating the average over all the models might not provide the best estimate for future sea ice development. On the other hand, it is not given that a model that simulates todays ice conditions best is also best to simulate future conditions, which means that selecting only one or very few models might lead to an overconfidence in the results.

Ice in Bråviken. Photo: Torben Koenigk



The Arctic Death Spiral shows the evolution of the Arctic sea ice volume for each month (colored lines) from 1979 to 2021 (time following the clock). The ice volume is getting smaller towards the middle of the circle. The Arctic Death Spiral data can be found here: http://psc.apl.washington.edu/research/projects/arctic-sea-ice-volume-anomaly *and has been created by Andy Lee Robinson 2013 with yearly updates.*

Our study selects thus the half of all climate models that best represents the observed present Arctic sea-ice area and thickness, their trends, and northward ocean heat transport into the Arctic, as the latter is a major driver of recent sea-ice loss. Thereby, we exclude those models, which deviate strongly from the observed conditions and which are thus likely not well suited to reliable project the future sea ice, but we still include a variety of models allowing for different outcomes based on the different models.

We find that the sea-ice loss over this century is larger using our different model selection criteria compared to the average over all models without model selection. In particular, we find that sum-mer ice-free Arctic conditions could occur as early as year 2035 in the selection case, compared to around 2060 in the no-selection case following a high-emission scenario. Even in a low-emission scenario, the selection of models based on their performance in the past leads to a much stronger sea ice reduction compared to averaging over all models, and an almost 50% probability for a total summer ice loss in the 21st century.

Our results highlight a potential underestimation of the future Arctic sea-ice loss when including all models that contributing to CMIP6.

The article *Observation-based selection of climate models projects Arctic ice-free summers around 2035* was published in Communications Earth & Environment and can be found here: *https://doi.org/10.1038/s43247-021-00214-7*

Torben Koenigk was co-leader of Research Area 1
Ocean-atmosphere dynamics and climate.
Photo: Jacob Fräjdin

New insights into ultrafine aerosols in the high Arctic

One major uncertainty in future climate projections concerns how aerosol particles impact cloud properties and distribution. Pristine summer Arctic low-level clouds contain low numbers of activated aerosol particles. Therefore, these clouds are often optically thin and have fewer but larger droplets compared to other regions. Combined with the semi-permanent ice cover, small changes in either the number of natural aerosol particles or the ice cover are very important to the heat transfer to the ice and the subsequent ice-melt. A team of researchers from different departments took a closer look at the aerosol formation process in this climate-critical and changing region, and found a surprising result.

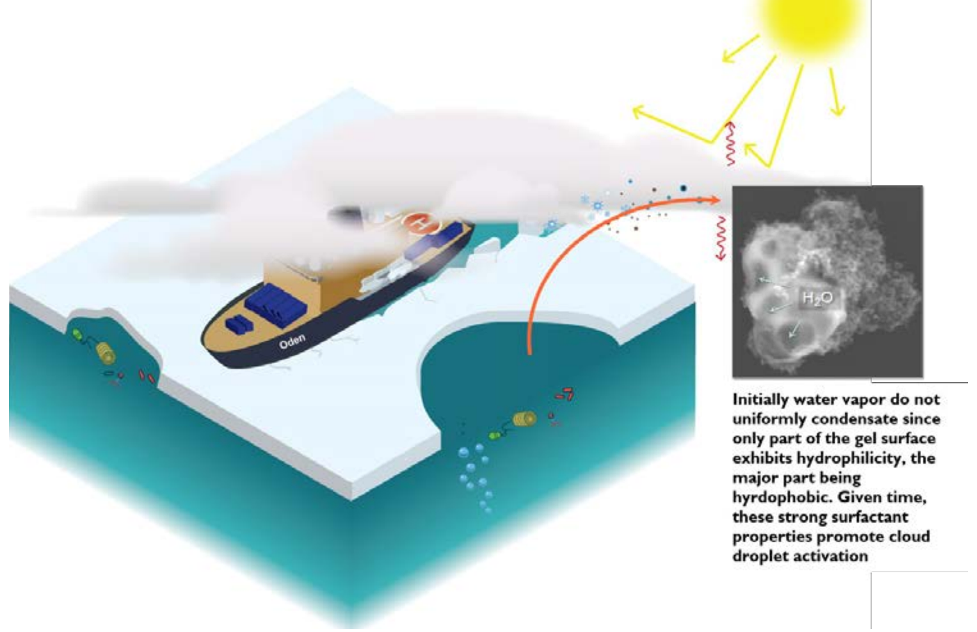
Clouds are an important part of the Earth's climate system. They play a role in controlling how much energy passes from the sun to Earth's surface, and from the surface back out into the space. Aerosols – small, invisible particles in the air – acts as seeds onto which water can condense to form cloud droplets. The high Arctic region, near the North Pole, is a unique environment, with median daily very low aerosol concentrations ranging typically between 15 and 30 per cm^3, and occasionally below 1 per cm^3. These conditions impact the formation of clouds and their energy trapping and releasing properties. For large parts of the year, the surface reflectivity is as high as, or higher than, the cloud albedo, and longwave radiation processes dominate, thus constituting a net warming effect. During the most intense summer ice melt, surface reflectivity is reduced when melting sea ice opens up dark ocean surfaces and melt ponds form on the ice. Low-level clouds may therefore cool the surface for a short time period in summer.

One key question is which sources may contribute to the aerosol over the central Arctic Ocean. It has been shown that the concentration of transported continental aerosols, influenced by man-made activities, and aerosol precursors are extremely low over the pack ice. The absence of strong winds over the relatively small area of open water, 10–30 percent, in the pack ice has been observed also to result in a weak local source of primary sea spray aerosol. In fact, aerosol concentrations in the summer time high Arctic are sometimes low enough to prevent cloud formation. This means that even if the local natural aerosol source is weak, it can have a significant impact on cloudiness, surface temperature, and ice melt.

Previous Stockholm University coordinated Arctic studies in the years of 1991, 1996, 2001 and 2008, on the Swedish icebreaker *Oden*, have been successful in demonstrating that local emissions of marine biota can form clouds. Near-surface aerosols, as well as low-level cloud and fog droplets, contained the same type of organic material, as found in the leads (open water between ice floes) in support of a local or regional aerosol source within the pack ice.

The established weak lead source of particles could however not explain the simultaneously observed near-surface airborne aerosol concentrations.

Nonetheless, the appearance of high concentration of ultrafine particles (smaller than 100 nm in diameter, also called the Aitken mode), under certain conditions (sunny with intermittent fog and light winds, melting of the fringes or during early refreezing of the leads), strongly suggests substantial particle sources in the innermost Arctic. To explain this, it has been speculated that the marine biota, which behaved similar to marine polymer gels (3D cross-linked networks of poly saccharides stabilized by Ca^{2+} bonds and/or hydrophobic forces), once airborne, would disintegrate and generate progressively smaller particles.



Schematic modified from original by Paul Zieger.

On the most recent expedition in 2018, an Aitken mode event presented itself. For the first time, researchers managed to measure the chemical composition of the ultrafine particles over time. They found that these very tiny particles indeed contained polysaccharides. To their surprise, it also seemed as if large numbers of particles were formed from the breakup of larger composite particles, which corroborates earlier speculations. At this stage the mechanism for subsequent breakup of gel aggregates in the atmosphere is difficult to assess and remains an open research question.

What are the implications of the results? How can they be used?

"One overall implication of these new results is that they may explain why only a few percent of the observed airborne total particle number variability was explained by the direct measurements of particle number fluxes and as such strongly suggest substantial particle sources, behaving similar to marine gels, in the innermost Arctic", says Caroline Leck, one of the researchers in the study. The presence of marine gel-particles in the atmosphere were first discovered in the year of 1996.

Furthermore, the suggested a hydrophobic character for the central Arctic Aitken-mode aerosols would in turn impede water uptake and suppress cloud activation. As such, it seems that very high-water supersaturations, about four times higher than for larger sized and more water-soluble particles, would be required in order for the Aitken mode particles to be activated. Based on a large-eddy simulation (LES) study it seems possible that such high-water supersaturations occur where small total droplet number concentrations are present such that excess water vapor is not depleted by larger particles and helps sustain the cloud even when the Aitken particles have low hygroscopicity.

What could be the next natural step in this area of research?

"The Arctic is a region to which one must return again and again in order to succeed. In the end, most often the success is a matter of happenstance."

The study was conducted by several Bolin Centre members across different departments; Linn Karlsson, Matthew Salter, and Paul Ziegler at the Department of Environmental Science, and Caroline Leck at the Department of Meteorology. First author was Mike Lawler, Department of Earth System Science at the University of California.

Caroline Leck is Professor of Chemical meteorology at the Department of Meteorology, Stockholm University. Photo: Anna-Karin Landin

The article *New Insights Into the Composition and Origins of Ultrafine Aerosol in the Summertime High Arctic* was first published on 25 October 2021 in Geophysical Research Letters, *https://doi.org/10.1029/2021GL094395*.

This work was supported by the United States' National Science Foundation Arctic Natural Sciences program, Swedish Research Council, the Bolin Centre for Climate Research (RA2), Swiss National Science Foundation, the Swiss Polar Institute, the BNP Paribas Swiss Foundation, the Knut and Alice Wallenberg Foundation within the ACAS project (Arctic Climate Across Scales), and Swedish Polar Research.

Online seminar series – *Perspectives of Hydrology and Water Resources*

Research Area 3 has focused on an online seminar series called *Perspectives of Hydrology and water resources*. Renowned researchers from around the world were invited to present. In 2021, four webinars were announced.

The first presenter in the seminar series was Prof. Jay Famiglietti from the University of Saskatchewan, Canada, who gave a presentation titled:

Emerging Threats to Global Water Security as Viewed from Space

The evolving water cycle of the 21st century is proving to be stronger and more variable, resulting in broad swaths of mid-latitude drying, accelerated by the depletion of the world's major groundwater aquifers. A well-defined geography of freshwater 'haves' and 'have-nots' is clearly emerging. What does water sustainability mean under such dynamic climate and hydrologic conditions, in particular when coupled with future projections of population growth? How will water managers cope with these new normals, and how will food and energy production be impacted?

Jay reviewed what nearly two decades of satellite research tells us about emerging threats to water security. He shared his personal experiences with science communication and water diplomacy, and encouraged the next generation of water scientists to seek out transdisciplinary experiences as part of their graduate and postgraduate training.

Jay is also a member of the Bolin Centre's External Science Advisory Group.

Climate scientist Lukas Gudmundsson at the Institute of Atmospheric and Climate Science, ETH Zurich, Switzerland, presented under the heading:

Detecting and attributing global change in terrestrial water systems

One of the key concerns with anthropogenic climate change are its effects on the terrestrial water cycle. Model projections indicate that anthropogenic climate change can affect regional water availability and may trigger more floods and droughts. While there is mounting evidence showing human impacts in the atmospheric part of the water cycle, the limited availability of relevant observations has so far prevented an unambiguous detection and attribution of anthropogenic climate change in terrestrial water resources and hydrological extremes.

Recent advances in mobilizing large quantities of river flow time series around the globe and breakthroughs in data-driven reconstructions of essential freshwater variables using machine learning now allow for an unprecedented assessment of global hydrological change. Causal drivers of observed change are investigated using climate change detection and attribution methods, that ingest both observational information and model-based evidence. The analysis allows to conclude that it is very likely that anthropogenic climate change is already impacting water resources and hydrological extremes at the global scale.

Dr. Fabrice Papa at the Institut de Recherche pour le Développement in France, presented:

The variability of water storage and fluxes over large tropical river basins from multi-satellite observations and their impacts on the land-ocean continuum

Terrestrial waters, despite being less than one percent of the total amount of water on Earth's ice-free land are essential for life and human environment. They play a primary role in the global water and carbon cycles, with significant impacts on climate variability. A better characterization of their distribution and dynamic over the whole globe is therefore of highest priority, including for the management of water resources. However, despite their importance, basic questions are still open, such as: what are the spatio-temporal variations of the fluxes and storages of continental freshwater across scales and how do they interact with climate and the anthropogenic pressure? Those questions are specifically important for the Tropics which are now facing growing demands for freshwater availability.

During the seminar, Fabrice discussed different observation techniques to quantify the freshwater variations in different parts of the Earth.

Marc F.P. Bierkensat the Department of Physical Geography, Utrecht University in the Netherlands, presented:

Advances in Modelling Global Hydrology and Water Resources under Change

This seminar reviews the current state of global hydrological and water resources modelling under change, discusses past and recent developments, and extrapolates these to future challenges and directions. It starts with describing the history of global hydrological model development in three established domains: atmospheric modelling, global water resources assessment and dynamic vegetation modelling. Next, a genealogy of global hydrological models is given. Thereafter, recent efforts to connect model components from different domains are reviewed with special reference to multi-sectoral inter-comparison projects. Also, new domains of application are identified where global hydrology is now starting to become an integral part of the analyses.

Marc ended the seminar with a short overview of recent and future work on global hydrology and water resources in his own group on three related subjects: very-high resolution global modelling of surface and groundwater hydrology; including surface water quality and groundwater salinity; the global limits of groundwater use.

With Researchers from around the World

Useful tool to help water scientists keep together

What was the aim of this online series and how did it turn out? We asked RA3 leader Fernando Jaramillo.

"It has been difficult for us to interact during the pandemic. It has also been challenging to invite renowned scientists to the Bolin Centre to describe their latest scientific research concerning water. The online series on *Perspectives of Hydrology and Water Resources* aimed to bring these important scientists to our researchers' homes. We had a high attendance rate, in some cases above 50 participants, with active discussion and interesting questions from the public. It was definitely a useful tool to help water scientists keep together within the Bolin Centre" says RA3 leader Fernando Jaramillo.

Fernando Jaramillo was co-leader of Research Area 3 *Hydrosphere, Cryosphere and Climate.* Photo: Krister Junghahn

High methane emissions from shallow-water northern temperate coastal habitats partially offset the coastal carbon sink

The human atmospheric warming from methane is second after only that of carbon dioxide. Since the beginning of the industrialisation the global methane atmospheric inventory has increased by 150 percent due to agricultural, industrial, and natural emissions. Because of its short half-life of 12 years in the atmosphere, methane is established as the most important short-term climate forcer with the greatest potential for climate mitigation over the next decades. Understanding and controlling methane emissions is therefore of key importance for near-term climate mitigation efforts. In order to achieve this goal, it is important to pinpoint the key emitters and to understand the regulating biogeochemical dynamics under which they operate.

Assessing the quantitative feedbacks of anthropogenic change on naturally occurring processes poses significant challenges. Depending on how the emissions are apportioned to their putative different sources, significant discrepancies arise in the emission budgets. If bottom-up approaches are used – summing up the emissions from putative sources, significantly larger emissions are calculated than when top-down approaches are used, i.e., when back-calculating from atmospheric measurements to their putative sources using air mass trajectories. The correct apportionment therefore involves several challenges:

- what specific area and environment is the emitter and at what magnitude is methane emitted?
- how will the area and environment change in the future?
- where and what effective nature-based solutions may be used to mitigate carbon emissions?

The formation and emission of methane occurs largely through microbial activity in soils and sediment and is directly related to the occurrence of organic-rich habitats with low levels of oxygen. Here, large amounts of organic matter are fixed photosynthetically or have accumulated historically. Aquatic ecosystems comprise about 50 percent of the natural global methane emissions. Northern temperate shallow-water coastal wetlands and seagrass beds can be such highly productive systems, but have strong temporal and spatial variability in methane emissions. While freshwater environments have long been in the focus as methane sources, northern coastal wetlands, seagrass beds and macroalgal beds have now come into the focus as, so far, underestimated methane sources. Coincidently, these ecosystems, some of which are the most productive ecosystems on Earth, have also been the targets of blue carbon efforts to mitigate carbon accumulation through natural carbon storage. Significant methane emissions from them would significantly offset their carbon mitigation potential.

Measuring methane emission in shallow water.

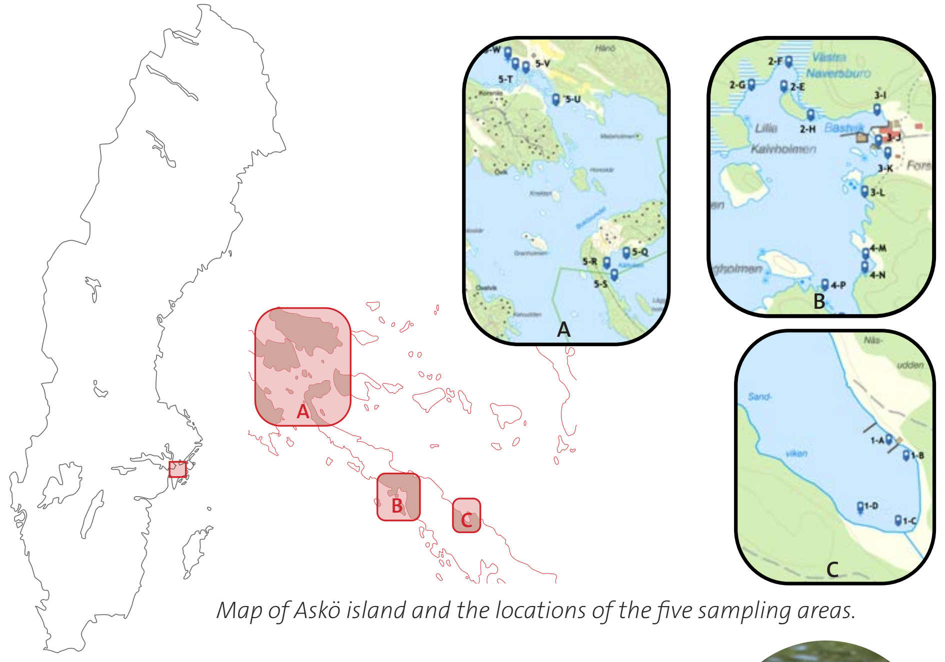
A team of Bolin Centre researchers joined forces with scientists from the Baltic Sea Research Centre at Stockholm University and initiated a long-term investigation to establish the temporal variability of methane emissions from high latitude organic-rich marine coastal environments. Specifically, they wanted to address the scaling problem for inshore coastal ecosystems and to quantify the methane emissions in these habitats.

Directly capturing the spatial and temporal variability of emissions simultaneously by bottom-up scaling is not practically possible. Instead, one has to rely on continuous measurements in a few selected key habitats, and combine these with discrete measurements at many different localities and times. These measurements can then be used to calibrate widely available environmental monitoring data, and to extrapolate the measured emissions.

In an effort to scale the observed emissions over a large area of the Baltic coast, the researchers used a small eddy correlation tower and conducted high-frequency methane and carbon dioxide analyses with a laser spectrometer at the tower. These data were combined with a large array of flux measurements, diverse instrumental arrays and different techniques of field and laboratory analyses in order to quantify methane fluxes throughout the year and in different key habitats.

"Our results indicated that these very shallow waters proved to be very significant methane emitters, largely through the emission of methane in the form of rising bubbles that are emitted almost unimpededly from the sediment substrate to the atmosphere. When we scaled up their emissions along the complex coastline of the archipelago waters of the Baltic Sea, we revealed an important, overseen methane source of these inshore coastal waters", says Volker Brüchert.

These efforts are still in their infancy and longer time series and multiple measurement techniques to establish and calibrate fluxes are being established. The ultimate goal is to expand the database of methane emissions by deliberate inclusion of directly measured flux data.



Map of Askö island and the locations of the five sampling areas.

Volker Brüchert was co-leader of the research area 4, *Biogeochemical cycles and climate* and works at the Department of Geological Sciences, Stockholm University. Photo: Helle Ploug

The article *Sea-Air Exchange of Methane in Shallow Inshore Areas of the Baltic Sea* was published on 12 Aug. 2021 in Frontiers in Marine Sciences, *https://doi.org/10.3389/fmars.2021.657459*.

The research was made with support from the Research School for Teachers on Climate and the Environment, Swedish Research Council, project support from the Bolin Centre for Climate Research (RA4), and a donation stipendium from Sandström.

A 725-year long compilation of annually resolved sediment cores demonstrates how fast the ice retreated in south-western Sweden at the end of the last ice age

By using newly collected cores of sediments from the sea-bottom in the region between Öland and the Swedish mainland, new onshore samples in Blekinge and Skåne, and digitizing unpublished varve data from 1900–1985, researchers have mapped out how fast the large ice-sheet retreated during the termination of the last ice age around 15,000 years ago. Although the climate was still very cold, the ice retreat was rapid. It was 3–5 times faster offshore compared to onshore.

One of the most critical uncertainties in the behavior of continental ice sheets is the response time in relation to climate forcing and the rates of ice margin retreat (i.e. ice sheet mass loss). While the observational record of contemporary ice-sheet change is a few decades long at best, the geological record of former ice-sheet demise offers an opportunity to assess rates of ice-margin retreat over several thousand years of climate change after a glacial maximum.

Records with annual to seasonal precision

Sediments from within and in front of the ice sheet, transported by glacial meltwater and deposited in proglacial lake basins, can provide such records with annual to seasonal precision in the form of laminated sediments, also called varves. Varved proglacial sediments give an unparalleled means to not only reconstruct the annual pattern of ice sheet decay, but also to draw conclusions about the climate in former times.

Gap in the map

The Swedish Varve Chronology is an unparalleled tool for linking the deglacial history of Sweden with associated palaeo-environmental change at an annual time scale, and it forms part of Sweden's historical scientific heritage.

Rachael Avery in the room where the collected sediment cores are stored. Photo: Private

A full deglacial chronology connected to the present day does not yet exist though. A notable gap is in the most southeastern part of Sweden, where few varved records are successfully connected to reconstruct ice-margin retreat.

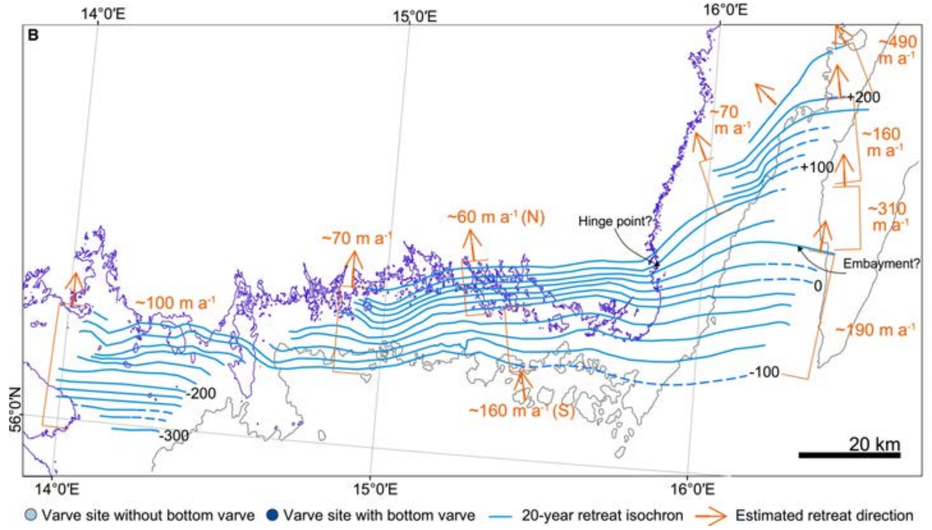
Eyeing that gap, geologist and Bolin Centre scientist Rachael Avery and colleagues set out to fill it.

"By using new offshore samples, we have been able to provide a credible answer to an over 100 years old problem. We have extended the existing south coast chronology to the troublesome east coast," she explains.

With Stockholm University's research vessel Electra, they managed to obtain 10 cm diameter varved cores from eleven of the 13 selected coring sites in Kalmarsund, the strait between mainland Sweden and Öland. "Researchers working during the last century didn't have access to offshore cores, but they have been key to integrating the varve chronologies in this difficult area. These offshore cores are an invaluable resource," says Rachael Avery.

Faster off shore retreat rates

In the study, legacy varve records collected since the early 1900s also have been revisited, and combined with new terrestrial and offshore cores. The new chronology covers the subaqueous–terrestrial transition of the retreating ice sheet and spans 725 varve years of deglaciation. It reveals that the retreat rates in the offshore sector were three- to fivefold faster than where the margin was close to or above the palaeo-shoreline. This means a retreat rate of 160–490 meters per year offshore, compared to 60–100 meters per year onshore. The results are shown in the figure.



The figure shows varve sites and the ice retreat.

What are the practical implications of the results? Are they used to improve climate models?

"Most glaciers and ice sheets currently retreat at a breathtaking pace. But hardly any of our current Climate or Earth System Models are ready to interactively simulate the shrinking of ice sheets. In addition to several numerical challenges, we lack detailed observational knowledge to tune and test ice sheet models. The 725 years of annually resolved data is really unique as it allows us to verify changes in retreat rates dependent on zonal versus lateral retreat across an offshore versus onshore interface. The Department of Geological Sciences is currently adding an ice sheet modeller to our team, and we're about to complete a high-resolution climate simulation for 15,000 years ago to provide the atmospheric forcing", says Frederik Schenk, co-author of the study and leader of Research area 5.

Faster offshore retreat rates

The 'father of the field' of clay varve chronology was Gerard De Geer, a professor of Geology, and later also president at Stockholm University. Some of his original data was used in this new study. The pioneering work of De Geer can be seen on the Department of Physical Geography's website (in Swedish). The continuation of De Geer's work was carried on by new generations of scientists, including Lars Brunnberg and Barbara Wohlfarth and forms an important part of the legacy and work done at Stockholm University.

Frederik Schenk was co-leader of the research area 5, *Historical to millenial climate variability*, and a researcher at the Department of Geological sciences, Stockholm University. Photo: Private

View data in the Bolin centre database: *https://bolin.su.se/data/hang-2021* and *https://bolin.su.se/data/avery-2020*

The article *A 725-year integrated offshore terrestrial varve chronology for south-eastern Sweden suggests rapid ice retreat ~15 ka BP* was published in Boreas on 17 November 2020. *https://onlinelibrary.wiley.com/doi/10.1111/bor.12490*

The study was financed by Knut and Alice Wallenberg foundation, Stockholm University and Bolin Centre for Climate Research, (RA5).

What can we learn from mass extinction events in the past?

When looking back into the deep history of the Earth, there are signs of at least 13 mass extinction events of varying severity. The worst of them was the so-called end-Permian event 252.2 million years ago, when life nearly died out. A team of Bolin Centre researchers and colleagues investigated fossil, sedimentary and geochemical data from Australia to piece together the change in environmental conditions at that time, and how these relate to the climate changes we see today.

The world at the time of the Permian geological period was constituted by one connected landmass, the supercontinent Pangaea. After millions of years of a relatively stable global greenhouse, the environmental conditions changed drastically, caused by a volcano-driven hothouse climate. In a recent study, the researchers used organic microfossil and geochemical data from five stratigraphic sections in the Sydney Basin and they found a series of successive ecological phases in connection to the end-Permian event (EPE).

Pre-EPE: Late Permian wetland communities and ecosystem collapse

This phase, immediately before the end-Permian Event (252.2 million years ago), is represented in the fossil record by abundant wood, leaves and pollen typical of a flourishing wetland ecosystem. Algal diversity was relatively high, but their concentrations were low. Highly productive forest-mire ecosystems dominated the humid coastal plains of the Sydney Basin.

Early Post-EPE: The microbial rising from the "dead zone"

This 700,000-year-long interval initiated with sedimentary rocks typical of shallow standing water and fossils of fungi, charcoal and other opaque wood fragments. This picture corresponds to the earlier reported "dead zone", characterized by widespread wildfires and deforestation which led to ponding and submerging of the land. The research team's high-resolution analysis revealed successive green algal associations as the first colonizers of continental waterways following the "dead zone". After this, recurrent toxic algal blooms occurred across the entire basin throughout the first 100,000 years following the EPE. One of the sites revealed fresh to brackish water conditions in which algae and bacteria reached extremely high concentrations. These values correspond to blooms of chlorophyte algae in lake sediments today, following local deforestation and the resultant influx of nutrients. At such high concentrations, these algae and bacteria lead to poorly-oxygenated waters upon their death, and many produce metabolic by-products that are toxic to animals. The researchers write: "Enhanced weathering intensity and destabilization of soils following deforestation, promoted nutrient influx into the floodbasins. Combined with elevated CO_2, temperature and precipitation seasonality, these factors promoted numerous intermittent pulses of algal and bacterial proliferation."

Late post-EPE: a recurrent microbial haven in the Early Triassic lowlands

Bacterial and algae continued to thrive throughout most of this 2.2-million-year-long interval, promoted by high global CO_2 and temperatures because of continued volcanic outgassing. Large parts of the Pangaea supercontinent experienced strongly seasonal precipitation, and the regular drying prevented the establishment of permanent wetland floras, delaying the return of peat-mire carbon sinks. The researchers write: "Compared to pre-EPE wetland floras, the open post-EPE vegetation would have had relatively low biomass and evaporation rates, facilitating seasonally high water tables and maximizing light availability to aquatic bacteria and algae." The combined data show that the conditions tended to promote enduring fresh/brackish-water ecosystems with sustained abundances of algae and bacteria within fluctuating coastal plain waterbodies.

The end of the microbial regime

It wasn't until approximately 3 million years after the EPE that pre-extinction conditions began to return. This phase started 249.2 million years ago, and is reflected by increased abundances of land plant fossils, and a reduction of microbe-derived organic remains. This is in line with global vegetation trends, which are characterized by the widespread emergence of a new flora dominated by gymnosperms (flowerless plants that produce cones and seeds), promoted by climatic cooling.

How do the findings in the four phases relate to the climate change we see today? What implications does it have on our environmental condition?

"Today, humans are providing the ingredients for toxic microbial blooms in generous amounts, and with predictable results. When such bloom events occur in lakes and coastal environments, these cause animals to die en masse with devastating impacts on fisheries, severe health effects on humans and livestock, and an annual global economic cost of >$8B USD," says Chris Mays, lead author of the article. He continues:

"This is a good example of what we can learn about climate change from the deep past. When life on Earth nearly died out, lethal concentrations of bacteria and algae choked the freshwater ecosystems, fed by extreme CO_2, warming and soil nutrient run-off. All three of these ingredients are on the rise today, and the resultant blooms are leading to ecological stress that rivals the most extreme mass extinctions of the deep past."

The study was conducted by Bolin Centre members Chris Mays, Stephen McLoughlin, Sam M. Slater, and Vivi Vajda, all affiliated with the Swedish Museum of Natural History, and colleagues Profs Tracy Frank and Christopher Fielding at the University of Connecticut, USA.

The article *Lethal microbial blooms delayed freshwater ecosystem recovery following the end-Permian extinction* was first published on 17 September, 2021, in Nature Communications. The article can be accessed here: *https://doi.org/10.1038/s41467-021-25711-3*

As the global hothouse climate takes over at the end of the Permian, extensive forests die, and lowlands fill with seeping groundwater and runoff no longer taken up by living tree roots. The water brims with soil nutrients that fuel blooms of bacteria and algae, choking the waters with toxic slime and consuming dissolved oxygen, causing mass-kills of fish and other aquatic life. Artist credit: Victor O. Leshyk.

Searching for signs of life in a dead zone. The authors, Vivi (left), Steve (middle) and Chris (right), squeeze in a few hours before sunset at the coastal outcrops south of Sydney. Photo: Private

Chris Mays at the outcrop near Coalcliff, eastern Australia, Chris points out the dead zone above the las coal of the Permian Period. Chris Mays isa postdoctoral researcher at the Swedish Museum of Natural History. Photo: Private

This work was funded by the Swedish Research Council (SE), the National Science Foundation (USA), and the Bolin Centre for Climate Research, (RA6).

RA7 – RESEARCH HIGHLIGHT

Forest management can both warm and cool understory plant communities

With climate change, it is generally expected that plants and animals move northwards, following their temperature preferences. But, on a hot summer day, a dense forest canopy and sheltering topography can create microclimates that are several degrees colder inside the forest than outside it. The capacity to reduce temperature extremes, means that forests can act as microrefugia for plants and animals in landscapes that otherwise would have unfavourable regional climate conditions. A team of Bolin Centre researchers has studied how forest management and climate impact plant communities at the local scale using data from the National Forest Inventory of Sweden. As forest density had a large effect on the temperature preferences of the plant communities, creating and keeping denser forests might be a way to counterbalance the climate effect on larger scales for understory plant communities.

The understorey is the space between the forest canopy and the forest floor at the ground level. Here, we find plant communities that have adjusted to, and prefer, specific temperature conditions. If it gets warmer, some of the species might go locally extinct, whereas other species might colonize new spaces.

The local climate in forest understories can differ substantially compared to outside the forest. A dense forest canopy and sheltering topography can create microclimates that are several degrees colder in the forest than outside it, which affects the composition of the plant communities in the understories. Another factor that influence the plant communities, is that forest structures often are characterized by cyclic changes driven by management activities, such as clear-cutting, subsequent planting and thinning. Changes in forest structure affect the capacity of the forest to buffer temperatures, and thereby change the temperatures experienced by the understory plant communities. In order to understand how and why understorey plant communities change in a climate context, there is therefore a need to consider both regional climate change and how forest density and structure varies over time.

In a study conducted in 2021, a research team used inventories from 11,436 productive forest sites in Sweden from the National Forest Inventory, repeated every 10th year between 1993–2017, to examine how the variation in forest structure over time influenced the temperature preferences of the plant communities. As a summarizing indicator of the plant community composition and to relate changes in community composition directly to temperature, the researchers used the Community Temperature Index (CTI), which is the average temperature preference of the species in a community. In other words, CTI is a metric that reflects the composition of warm- and cold-favoured species in a community. It is therefore expected to change with a changing climate.

With CTI data from the inventories, 2–3 times for each site, the research team evaluated to what extent the difference in CTI value between two inventories was related to two main factors: changes in forest density and changes in the macroclimate.

They found that the CTI values of the understorey plant communities increased after clear-cutting, and decreased during periods when the forest grew denser. In other words, cold-favoured species went locally extinct and got replaced with relatively warm-favoured species after clear-cut, whereas cold-favoured species colonized the forest again when it grew denser.

Forest floor covered in reindeer lichen (Cladonia stellaris) and sphagnum moss (Sphagnum capillifolium). Photo: Caroline Greiser

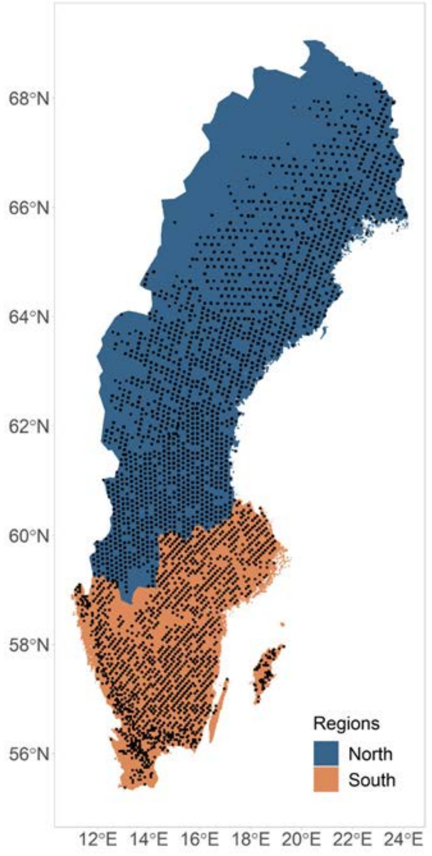
Importantly, the change in understory CTI over 10-year periods was explained more by changes in forest density, than by changes in macroclimate.

Ditte Marie Christiansen is the main author of the study. What does these result mean?

"Our results show that changes in forest structures, in Sweden mainly by management activities, have a large role in explaining temperature preferences of species in understory communities, and that the impact from forest management is at least on short to intermediate time scales, larger than those from regional climate changes. This has two important implications. First, as forest structure is a main driver of plant community compositions regarding temperature preferences, we need to account for changes in forest structures when analyzing community responses to climate changes. Second, as temperature preferences of understory communities decrease with increasing forest density, we might be able to mitigate some effects of ongoing climate changes in forests by creating dense forest stands. However, under current management regimes in Sweden with thinning and especially clear-cutting, the mitigating effect is temporary."

How will you continue with your findings?

"This article is part of my PhD thesis with the overarching aim to examine the impact of forest microclimate and its dynamics on understory plant species distributions as well as individual species performance. This study found large effects of forest management activities on whole communities, and my other projects focus more on individual species and their performance under different microclimate conditions. My main conclusion in my thesis so far is that microclimate matters and that we therefore need to take microclimate differences across the landscape into account when analyzing how forest plant species respond to climate change."



Map of Sweden showing the location of the permanent community plots of the National Forest Inventory included in the analyses on top of the regions used for data partitioning.

The article *Changes in forest structure drive temperature preferences of boreal understorey plant communities* was published in Journal of Ecology on 9 December, 2021. The article can be accessed here: *https://doi.org/10.1111/1365-2745.13825*

Ditte Marie Christiansen is a PhD student at the Department of Ecology, Environment and Plant Sciences, Stockholm University. Photo: Private

Predictive models of insects and the effect from climate change

With a changing climate, predictive ecological modelling becomes important. In the sphere of insects, climate warming is linked to macroecological shifts, such as range margin expansion, which can cause insects-related ecosystem disturbances. Bolin Centre researcher Loke von Schmalensee and colleagues set up an experiment to investigate what is required to predict insect development times in nature.

Many ecological processes are dependent on the temperature and how it varies. But predicting the temperature responses of organisms in nature is hard, and requires an understanding of how an organism's traits respond to a range of temperatures they experience throughout their life cycle.

Ectotherms are organism in which the inner physiological heat sources are generally too weak to control the body temperature. For most of them, constant body temperatures are unnatural – their internal temperatures fluctuate with the surrounding climate. Yet, when estimating temperature dependent trait performance, for example growth and development rate, constant temperatures are commonly used. Now, an unanswered question is whether predictive models developed under constant temperatures leads to correct predictions in nature. It is known that certain mechanisms can kick in and cause differences under constant and fluctuating temperatures, such as acclimation or accumulation of thermal damage (potentially followed by repair during favourable temperatures). These mechanisms can lead to temperature-induced changes in thermal reactions, which makes it hard to bridge the gap between thermal performance under constant and under fluctuating conditions.

Bolin-researcher Loke von Schmalensee and colleagues set out to study this problem. They designed an experiment to measure the development rate of the butterfly *Pieris napi* under different conditions. Specifically, they wanted to know how the outcome of different prediction models with varying complexity and resolution of input climate data corresponded to the development rates on nine different sites across a heterogenous field area in Södermanland, Sweden. The time-span across two life stages, eggs and larvae, was measured in order to validate the models. In the field experiment, five containers were placed in a cage in each site, with coarse-meshed netting protecting against potential predators, while allowing for wind and rain to pass through. Temperatures were logged every 15 minutes at each site.

The prediction models were parameterized using thermal performance of *Pieris napi* in a laboratory environment. The individuals were treated at eight constant temperatures, extended over 10–35°C. Using the resulting thermal reaction norm, they could calculate expected development rates under fluctuating temperatures. They also measured the predictive impact from a low (means over 24 hours) to a high (every 15 minutes) temperature sampling frequency. By also incorporating data from a weather station in the nearby area of the field experiment, they could see how using macroclimate and microclimate temperature measurements influenced the results of the predictive model.

When comparing the results, they found that the development rate in the field can be predicted accurately across naturally variable microclimates under certain conditions, namely when using input temperatures measured frequently at organism-relevant scales together with well-estimated thermal reaction norms. Through an extensive collection of published data, they also showed that these findings are likely generalizable across insect taxa.

What practical implications does these results have?

"I think the findings are both relieving and burdening to people working with insect phenology (relating to seasonal timing) models. The fact that there seems to be negligible temperature-historic effects on insect development rates means that making accurate predictions in naturally fluctuating environments is actually feasible. Great news! On the other hand, our findings highlight that, in order to do so, one must pour a lot of effort into the methodology. Thankfully, microclimate modelling and monitoring are advancing and becoming increasingly available tools to biologists," says Loke von Schmalensee.

What would be the next natural research in this research area?

"The natural step is to start looking at other environmental variables. For example, how does host plant quality influence development rates under variable conditions? Can we find any general patterns? In order to build more complete models of insect population dynamics, there are many life history traits to consider. Sure, being able to ignore temperature-historic effects on development rates removes a dimension and greatly reduces complexity in such a model, but there is still much we don't know about how insect populations behave in nature."

Loke von Schmalensee is a PhD studentat the Department of Zoology, Stockholm University. Photo: Private

The article *Thermal performance under constant temperatures can accurately predict insect development times across naturally variable microclimates* was first published on 25 May 2021 in Ecology Letters. The article can be accessed here: *https://doi.org/10.1111/ele.13779*

This study was made possible through funding from the Bolin Centre for Climate Research, and is a part of the Bolin Centre Research Area 8, research in biodiversity and climate.

Demonstration of different complexity levels in the components of the prediction models. Information content increases from left to right, going from simplified to more complex thermal performance models, low to high temperature sampling frequency, and macroclimate to microclimate temperature measurements.

The Bolin Centre Climate Research School

The Bolin Centre Climate Research School organizes climate-related courses and summer schools for PhD students within the Bolin Centre. The Climate Research School also offers funding to PhD students to support their active participation in conferences, field courses and workshops.

The Climate Research School is led by the Bolin Centre Directorate and the Study Coordinators, Otto Hermelin and Carmen Prieto. It spans over several departments and research areas within Stockholm University, and the aim is to establish a common platform for climate research.

To facilitate and promote networking between PhD students within the Bolin Centre, the Climate Research School annually organizes a PhD Day. This year, the PhD Day was carried out as a hybrid event on 4 November, 2021. There were 15 short presentations given by PhD students and post docs from five departments as well as the Stockholm Resilience Center, to audience on site as well as via Zoom. A jury consisting of three members evaluated each presentation. The Climate Research School awarded prizes to the best presentations, 20,000, 10,000, and 5,000 SEK, to be used in their research. A big congratulations to the winners!

- First place: Ditte Marie Christiansen *High-resolution data necessary to detect effects of climate on plant population dynamics.*
- Second place: Abhay Prakash *Numerical modelling of ice-ocean interaction at the Petermann glacier, Northwest Greenland.*
- Third place: Marnka Brussee *Triple-isotopic source apportionment of methane in the East Siberian Arctic Shelf region – Analysis of existing isotope data from past expeditions.*

In 2021, the cooperation between the Bolin Centre and ClimBEco Graduate School at the Centre for Environmental and Climate Science (CEC) continued. This makes it possible for Climate Research School students to participate in courses and workshops offered by the ClimBEco programme, and for students

The 2021 PhD Day. research presentation winners. From left: Abhay Prakash, Marnka Brussee and Ditte Marie Christiansen. Photo: Otto Hermelin

enrolled in the ClimBEco programme to participate in courses and activities offered by the Bolin Centre Climate Research School.

This is an excellent opportunity for PhD students to network with other early career scientists from beyond the Bolin Centre.

The courses offered are based on student feedback and demand. In other words, there is an active effort by the Climate Research School to provide courses that students deem valuable to their future career as researchers.

Photo: Magnus Atterfors

Courses offered by Bolin Centre Climate Research School during 2021:

- Managing the Anthropocene
- Climate Science
- Geocomputation and Machine Learning for Environmental Applications
- Scientific writing in English
- Storytelling for science in the climate and ecological emergencies
- eScience course – eScience Tools in Climate Science: Linking Observations with Modelling in Tjärnö Marine Biological Laboratory.

The courses offered by the CRS are having some applicants from the ClimBEco graduate research school in Lund. And viceversa, the courses in Lund are having some students from the CRS.

The Bert Bolin Climate Lecturer in 2021, Bill Ruddiman, held a seminar on his Early Anthropocene Hypothesis mainly for PhD students. The Bolin Centre Climate School also organized a workshop on mental health and well-being.

Otto Hermelin is co-study coordinator at the Bolin Centre Climate Research School. He is a senior lecturer and study director of life learning studies at the Department of Geological Science, Stockholm University. Photo: Magnus Atterfors

Carmen Prieto is co-study coordinator at the Bolin Centre Climate Research School. She is a research engineer at the Department of Physical Geography, Stockholm University. Photo: Magnus Atterfors

The Bolin Centre Database

–provides open access to climate and Earth system data

The database promotes and visualizes research results and data. We want to highlight the stories that the data tell, by visualizing research results and data. Our data repository is a natural part of the ongoing world-wide development towards open science, where literature, data and code are accessible and reusable to everybody, including scientists, students, journalists and the general audience. Therefore, it is an important component of the Bolin Centre.

Data in the Bolin Centre Database come from many different research activities around the globe. This includes both longer-term large research projects and monitoring programmes that require a solid host and individual scientists who share a wide range of datasets from finished or ongoing projects.

Highlights of data published in 2021

Miocene temperature portal

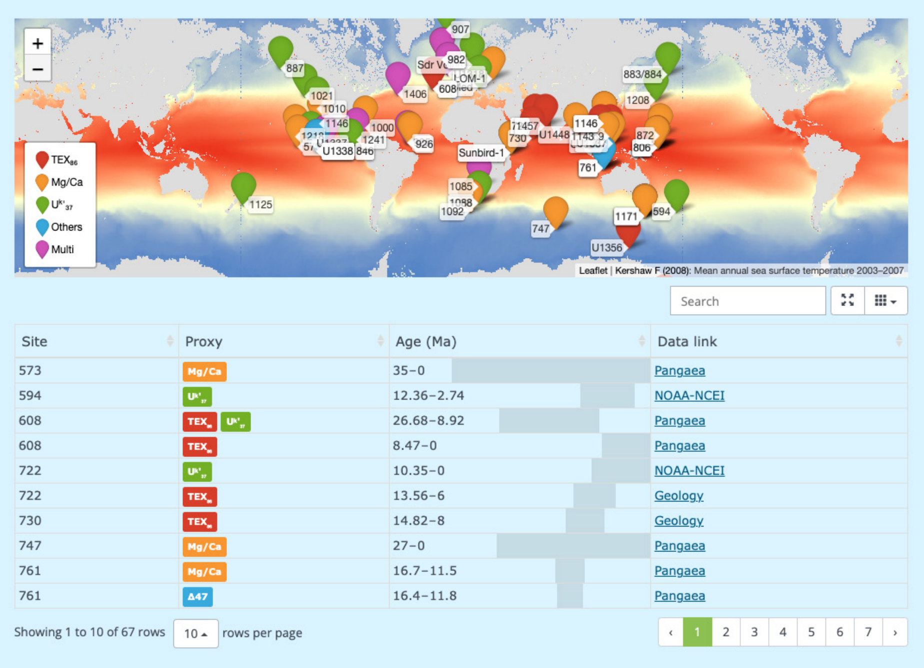
This dataset serves as a resource for investigators interested in the study of Miocene climate, about 23 to 5 million years ago. It collates a list of key information about published Miocene Ocean temperature records to enable researchers to rapidly locate and evaluate datasets relevant to the study of Miocene climate change.

The resource provides the metadata for study sites, a map of the location of these sites, references to papers describing the datasets, and links to where each dataset is archived.

A tailor-suited feature of this resource is a user interface that allows other researchers to add information about their new published datasets to the inventory such that it will continue to provide an up-to-date listing of existing Miocene temperature proxy records.

Icebreaker Oden data repository

The Swedish icebreaker Oden has served as a research vessel for expeditions to polar regions, in both Arctic and Antarctic waters, since 1991.



Site	Proxy	Age (Ma)	Data link
573	Mg/Ca	35–0	Pangaea
594	$U^{K'}_{37}$	12.36–2.74	NOAA-NCEI
608	TEX_{86} $U^{K'}_{37}$	26.68–8.92	Pangaea
608	TEX_{86}	8.47–0	Pangaea
722	$U^{K'}_{37}$	10.35–0	NOAA-NCEI
722	TEX_{86}	13.56–6	Geology
730	TEX_{86}	14.82–8	Geology
747	Mg/Ca	27–0	Pangaea
761	Mg/Ca	16.7–11.5	Pangaea
761	Δ47	16.4–11.8	Pangaea

Screen dump from the Miocene temperature portal.

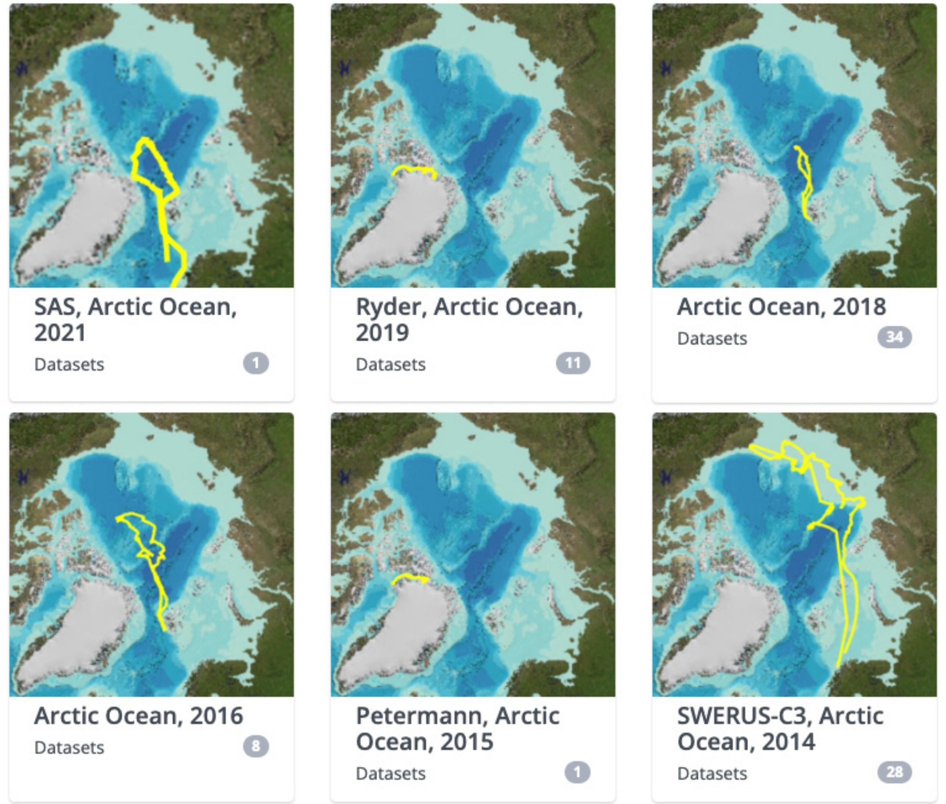
Icebreaker Oden. Photo: Thorsten Mauritsen

Facilities onboard enables scientists to carry out research in different disciplines and include scientific laboratories, space to install research containers and deep ocean winches.

A collection of data from 19 expeditions held between 2007 and 2021 was published in 2021. This includes more than 100 datasets acquired for research in meteorology, marine geology, oceanography, biogeochemistry and glaciology by scientists at Stockholm University and their national and international partners. The main data collection illustrates Oden's ship track and provides sub-collections with the individual datasets for each expedition

High-resolution bathymetry

One type of data that has been collected during all expeditions with Oden is the high-resolution bathymetry data acquired with a multibeam echo-sounder. High-resolution bathymetry data are commonly used to study general seafloor geology, glacial morphology, bottom habitats, and bottom current activities. To help understanding and seeing the information, for every expedition, each high-resolution bathymetry dataset is presented with an interactive visualization where the interested user can zoom into the data and see the details directly in the web browser.



Screen dump from the Oden data repository.

As an example, the data collected during the Petermann 2015 expedition to waters near northwest Greenland reveal submarine glacial landforms in fjords, suggesting the dynamic behaviour of fast-flowing marine-terminating glaciers.

Research data support

During 2021, we published 93 datasets with metadata and made continuous efforts to improve the service to contributors and users. In particular, we started to prepare for the launch (in spring 2022) of information on our website about research data support at the Bolin Centre.

Visit the Bolin Centre Database on *www.bolin.su.se/data*

Bolin Centre modelling coordination

Numerical models of the global climate system are essential tools in research carried out at the Bolin Centre. Earth system models are used across the research areas to study topics covering deep ocean circulation, land surface processes, atmospheric composition and dynamics and upper atmospheric physics. Bolin Centre researchers also participate in the development of the next generation of Earth system models. The modelling coordination team at the centre ascertains that the necessary computational resources are available for the Bolin Centre researchers to be able to carry out this work.

Climate models – large and complex computer codes – require hardware with high capacity both in terms of computational speed and storage. High performance computing facilities of this kind are part of the Swedish research infrastructure on the national level, and even larger facilities are available within Europe. The Bolin Centre modelling coordination team's primary task is to ascertain that adequate resources are available for the researchers within the Bolin Centre.

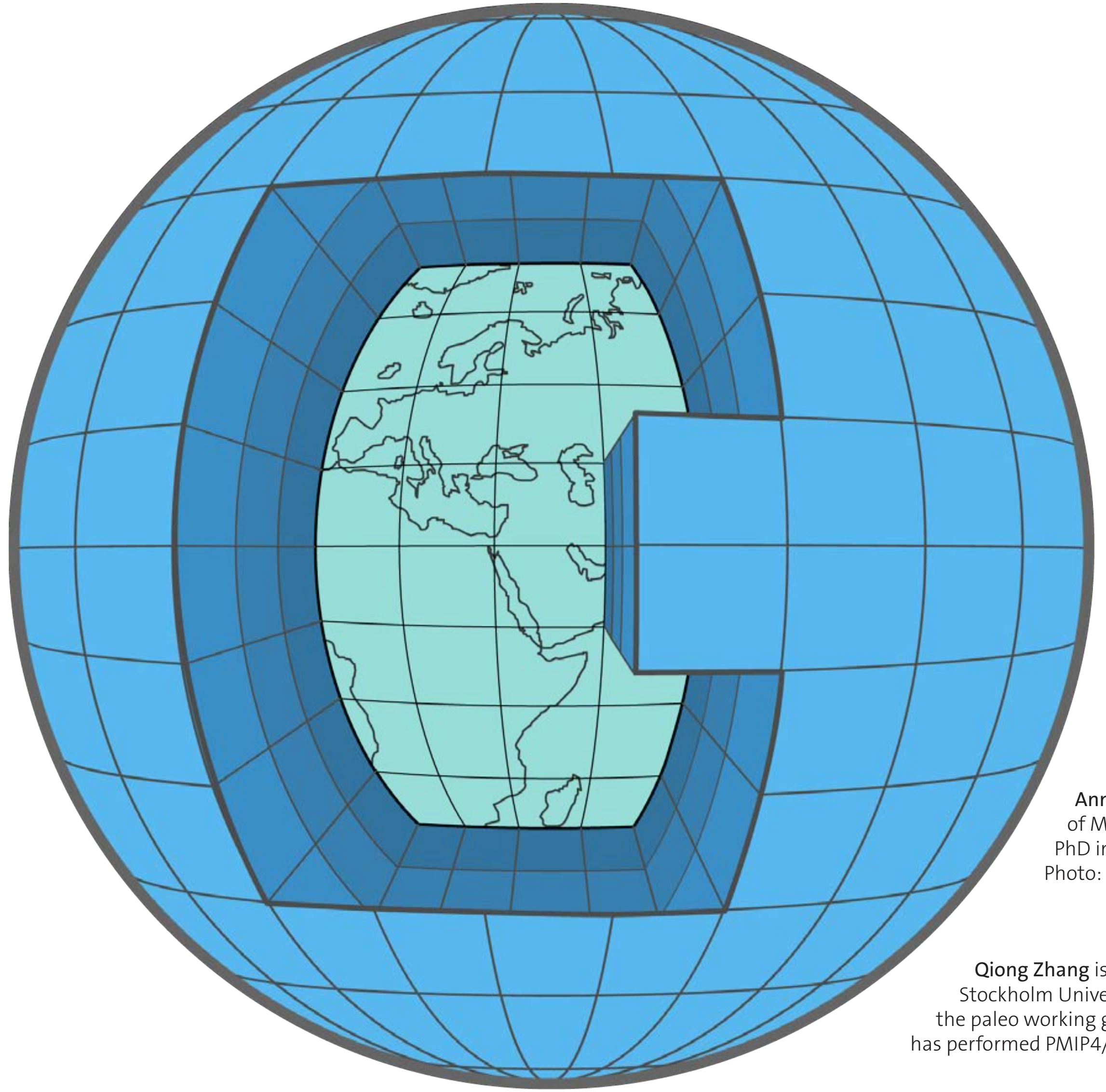
Climate models are important tools for improving our understanding and predictability of climate behavior on seasonal, annual, decadal, centennial and millennial time scales. The Bolin Centre uses the climate models EC-Earth and NorESM to understand how the Earth's climate varies in time and space, and how the physical and biogeochemical cycles, including human activities, interact with the climate system.

So what kind of climate modelling is performed and what has been observed? Bolin researcher Qiong Zhang and colleagues have used EC-Earth to simulate the climate response to a greening of Sahara that happened during mid-Holocene (6,000 years ago) and observed globe-wide climate changes such as a warmer Arctic, weakening of the climate phenomenon El Niño – Southern Oscillation (ENSO), and more tropical Atlantic cyclones. Similar modelling strategies are applied to evaluate the climate consequences to today's clean energy proposal on deployment of massive Sahara solar farms.

Industrial activities generate not only greenhouse gases, but also nano- to micrometer-sized particles in the air. These particles affect climate at the same time as they are harmful for air quality and health. A Bolin Centre team led by Annica Ekman and Hans-Christen Hansson, have used NorESM to examine how future emission paths affect particle concentrations in the air as well as climate – in particular in the Arctic. The simulations show that future decreases in particle emissions may enhance mid-century Arctic warming by about 0.4 °C, unless strong compensating reductions are made in greenhouse gas emissions.

Looking ahead, the Achilles heel of climate models are clouds since these are mostly too small to be simulated with the approximately 100 by 100 kilometer grid cells used in regular climate models. Cloud processes determine both the strength of global warming through cloud feedbacks, and the character of climate change such as precipitation extremes and droughts. With the increasing computational power available an international team led by Thorsten Mauritsen are working to bring the next-generation ICON climate model to a new supercomputer named LUMI that is being built in Finland. They hope to be able to run with a global grid of 1 by 1 kilometers, permitting most clouds to be simulated.

Bolin Centre researchers also use more detailed models than climate models to better understand different processes and interactions within the climate system, for example models covering only a column of the atmosphere and ocean, ice sheets models, hydrological models, and large-eddy simulation.



A climate model is a three-dimensional representation of the atmosphere that is coupled with the Earth's surface and the seas. In short, the atmosphere and the seas are divided into a series of boxes, or grid cells. In each cell of the grid, values of the temperature, humidity, air pressure, wind speed, sea ice and vegetation are calculated. After the climate's condition in each cell has been calculated, a step forward in time is taken, and all values are calculated again. Illustration: SMHI

Anna Lewinschal is a scientific programmer at the Department of Meteorology, Stockholm University, where she also got her PhD in Atmospheric Sciences and Oceanography. Photo: Inês Jakobsson

Qiong Zhang is an associate professor in the Dept. of Physical Geography, Stockholm University, and a subject editor in Tellus B. Zhang is also Leading the paleo working group in EC-Earth community. The group led by Qiong Zhang has performed PMIP4/CMIP6 simulations with EC-Earth. Photo: Eva Dalin

The Bolin Centre mentoring system

The Bolin Centre mentoring system is a voluntary initiative that brings together interested junior and senior researchers in a mentor-mentee relationship. The initiative started in 2014 and was active until November 2021. The number of involved people per year was usually 20–30 pairs. The program is currently paused for evaluation purposes and to align it with the Centre's new structure and future strategy.

The Bolin Centre Mentoring System links interested senior and junior scientists in a mentor-mentee relationship. The mentorship pairings are made annually at the Bolin Days in November. As a mentee you state your mentor preferences such as discipline, gender, language requirement, seniority, etc. and we do our best to meet these requests from our pool of mentors. The format of the mentorship is agreed on by both the mentor and mentee and can range from informal to formal which means the program meets the individual needs of the mentees.

The program has been increasing in its popularity since its establishment in 2014 where we have grown from 9 to 39 pairs in 2019/2020. The program has been greatly appreciated by mentees and mentors both. This program would however not be possible without our mentors who voluntarily give of their free time to help a junior scientist.

Characteristics of the System

Cross-departmental

The mentees are signed up with mentors in other departments to provide more objectivity and avoid conflict of interest.

Voluntary

All mentees and mentors volunteer.

Confidential

We never mention who signs up for the program unless specific permission is given such as for marketing. Mentee-mentor interactions are also strictly confidential.

Mentee-driven

The mentees make the first contact and decide the frequency and format of the meetings. This is because the needs of every mentee are individual and no single format is optimal for all.

Feedback from our mentees

"The program has been incredibly helpful. At the time I reached out I was the middle of my PhD, I had not much supervisor time and had serious concerns about getting delayed. The mentorship has helped to keep focused and get back on track."

"I got good advice on the general timing and prioritizing of different tasks during my PhD."

"I have found it useful to openly discuss my research problems, interactions with other researchers, the nature of criticism and feedback in science, and other issues. It's also great to get a perspective of someone who is not connected to my project, but is very experienced and knowledgeable about this kind of work. I wish I had sought out something like this program when I was a PhD student. I think that would have helped me back then."

"This mentorship program has been a game changer for me. [My mentor] helped me to take charge of my PhD project, keep my goals straight and navigate the occasional conflict. [The] advice ... has been spot-on and with key timing. Ultimately, I started applying to post-doc positions very early on her advice, and now I have a job already lined up for next year starting after I defend."

Feedback from our mentors

"Great initiative. I enjoyed the meetings [with my mentee] and learned a lot myself. Good to hear how SU and PhD education is working from a different perspective as one's own."

"My mentee was very well organized and already had good mentoring from advisor. In general, it was fun to meet and see that there are good working groups out there across campus."

Agatha de Boer is Co-mentor at The Bolin Centre mentoring system. She is an associate professor in Physical Oceanography and Paleoclimatology at the Department of Geological Sciences, Stockholm University. Photo: Eva Dalin

Malin Kylander is Co-mentor at The Bolin Centre mentoring system. She has a PhD in Environmental Geochemistry from Imperial College London, UK and is now at the Department of Geological Sciences, Stockholm University. Photo: Eva Dalin

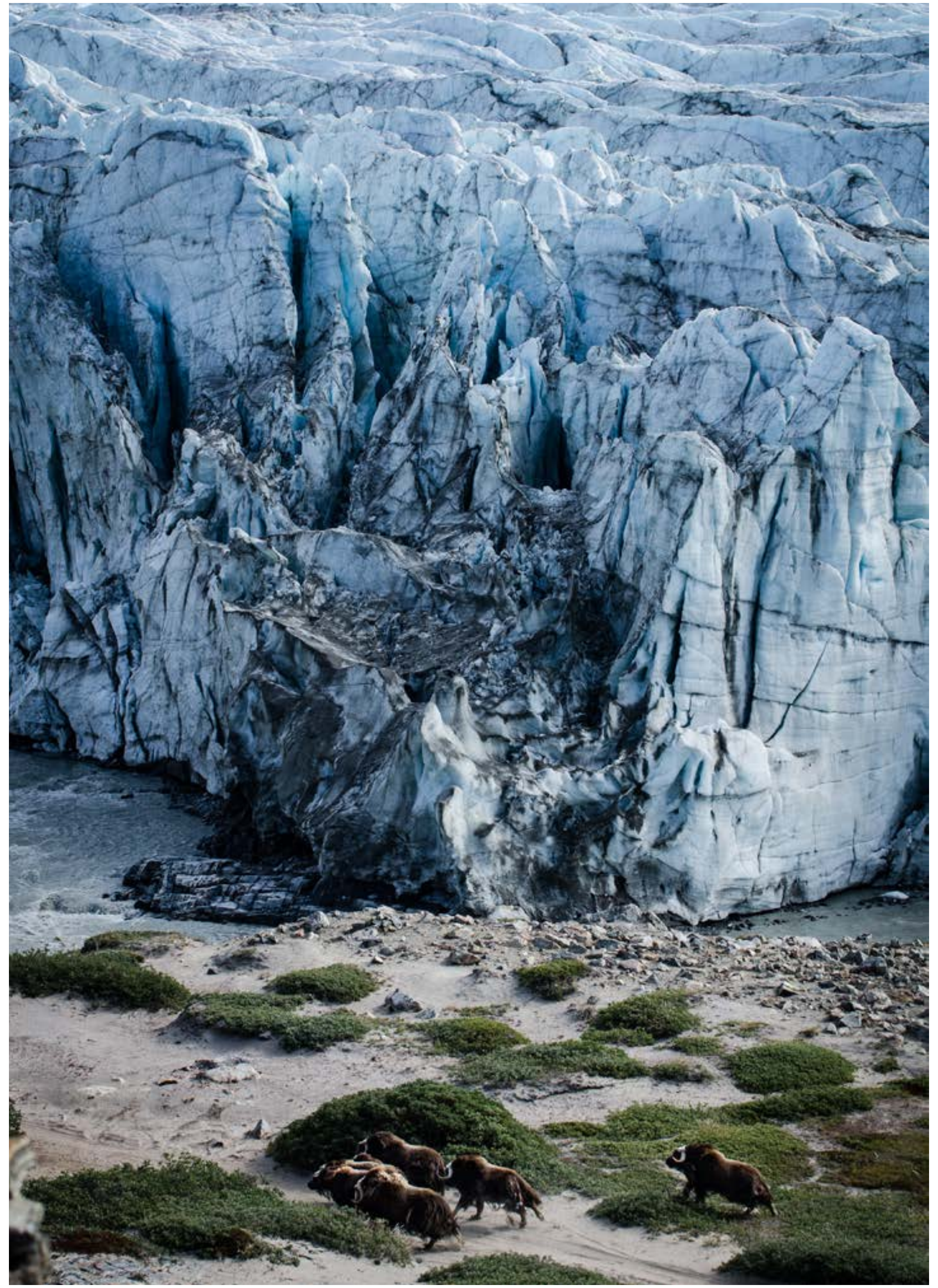


Photo: Petter Halleberg

Communication and coordination

The communication and coordination team at the Bolin Centre produces communication for different channels, organizes outreach events and coordinates internal meetings and events, such as the Bolin Centre Seminar Series and the Bolin Days. The team is also responsible for managing and producing content for the Bolin Centre website, and also provides our members with a newsletter.

Bringing climate researchers together

At the Bolin Centre, the coordinators and communicators work to bring climate researchers together and to further cross-disciplinary collaboration through various internal communication efforts, such as organizing meetings and various smaller and larger events. 2021 was characterized by a high degree of digital activities, due to the ongoing covid-19 pandemic.

The 13th Bolin Days took place on site in Aula Magna on November 18th–19th. Participants could also join in via Zoom. The Bolin Days is our annual internal conference for and by our Bolin Centre members. During these days, new climate science results are presented and we meet each other to exchange ideas, share our experiences and find new inspiration. The days featured research presentations by members from our research areas, a poster exhibition, and as usual, a poster competition for PhD students, lots of mingle, dinner and an unforgettable Ceilidh (Gaelic music and dancing), led by Alasdair Skelton. The conference had 190+ registered participants.

The team also provided coordination and communication support to the Bolin Centre Climate Research School's annual PhD Day, as well as the Bolin Centre Seminar Series. The seminar series, which is organized by research area co-leaders, was fully digitalized as well, and a total of seven digital seminars were carried out during the year. By providing communication and coordination support to smaller internal events organized by our researchers for the research community, the focus is on furthering scientific collaboration and cross-disciplinary work.

In September, we presented the Bolin Centre in the CIVIS Cups&Cakes webinar series. CIVIS is an alliance of 10 Universities, and the series aim to create a discussion forum for researchers to connect and get an overview of what is happening in other partner universities on a specific topic.

Bringing climate science to the public

During COP-26 in Glasgow 31 October–12 November, researchers from the Bolin Centre were on site in Glasgow, communicating climate science to conference participants. In a local COP-26 hub in Stockholm, Bolin scientists and the non-profit organization Researcher's Desk were present, ready to interact with a wider audience at Kulturhuset in Stockholm City. From the dedicated space "Lilla Kilen", citizens could view the live-broadcasted program from the International Cryosphere Climate Initiative's (ICCI) pavilion in Glasgow, interact with researchers, and watch a photo exhibition. The event was produced together with Kulturhuset Stadsteatern.

The Bolin Centre Climate Festival was carried out during two days in the spring and one day in the autumn. Both of them were digital events due to the ongoing Covid-19 pandemic. The programme contained interactive events, climate research popular science presentations, short behind the scenes films and covered issues such as climate change in the Arctic, aerosols, the climate crisis and what can we learn from the pandemic, and much more. School classes could also book climate-related online activities. The popular science lectures on the 18th of October in Aula Magna were taped by UR Samtiden and broadcasted on the TV channel Kunskapskanalen, and it can still be watched on UR play by searching for UR Samtiden – Klimatfestival 2021.

In an effort to bring the centre's climate science to policy-makers, decision-makers, and individuals who are interested in formulating or influencing policy related to the climate, the production of policy briefs continued, this

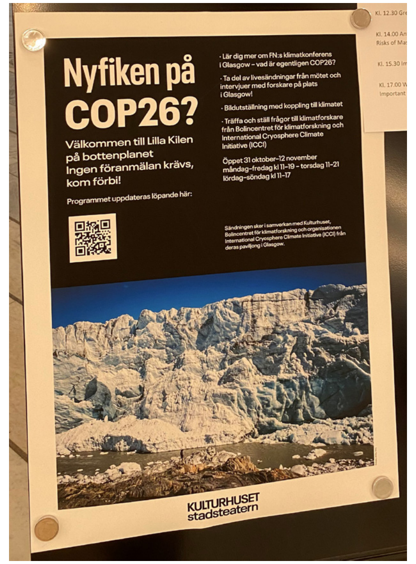
Nina Kirchner och Gustaf Hugelius during Bolin Centre Climate Festival 2021. Photo: Magnus Atterfors

Digitalt Hållbarhetsforum 2021 in Aula Magna. Photo: Jens Olof Lasthein

year covering the subject of carbon capture and storage (CCS). All the policy briefs can be found and read at our home page, *bolin.su.se*.

Wanting to build a stronger network with the media, the Bolin Centre Online Journalist Breakfast sessions continued during the Spring. In February, Bolin Centre member Léon Chafik presented a new scientific article on recent oceanic changes in the Subpolar North Atlantic, a key region for what is popularly known as the Gulf Stream.

In March, Bolin Centre member Margret Steinthorsdottir presented a new Scientific review article: *The Miocene: The Future of the Past*. The breakfast sessions aim to function as a platform for journalists and researchers to meet, share the latest findings in climate research and discuss obstacles and opportunities in climate reporting.



COP26 poster at Kulturhuset, Stockholm.

The communication and coordination team also manage and utilizes social media platforms to bring climate science to the public, such as Facebook and Twitter. Twitter is particularly effective in allowing us to communicate and spread recent publications and research findings to the interested public as well as fellow researchers, journalists, and organizations.

Magnus Atterfors joined the Bolin Centre in April 2020. Photo: Laila Islamovic

Annika Granebeck has been working as a communicator and coordinator at the Bolin Centre since 2017. Photo: Inês Jakobsson

Laila Islamovic joined the Bolin Centre as a communicator in January of 2020. Photo: Magnus Atterfors

The Bert Bolin Climate Lecture

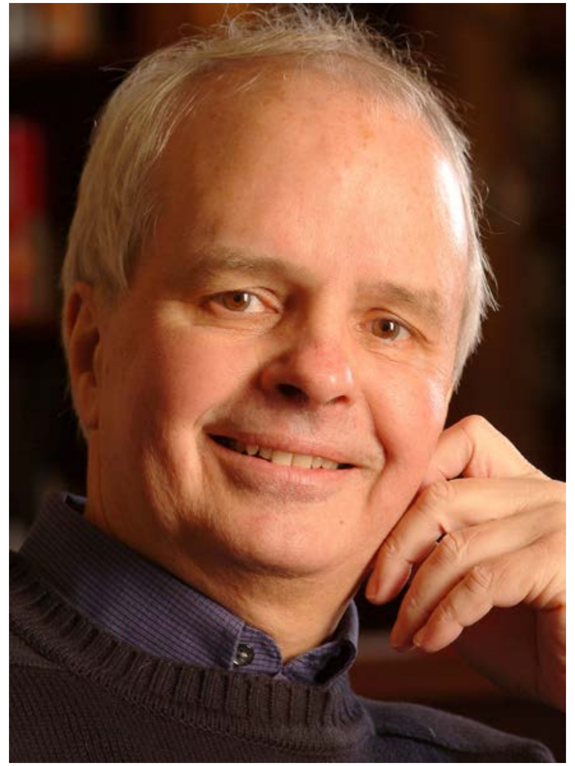
Professor Bert Bolin of Stockholm University was a leader in climate and carbon cycle research and one of the founders of IPCC which received the Nobel Peace Prize in 2007. To honour Professor Bolin, the Faculty of Science at Stockholm University established the annual Bert Bolin Climate Lecture. The distinguished Bert Bolin Climate Lecturer is invited to Stockholm in May to hold a popular science lecture and a science seminar at the Bolin Centre for Climate Research.

The Bolin Climate Lecturer is appointed by the Dean of the Faculty of Science of Stockholm University. Nominations can be made by all Bolin Centre members in response to a call issued during the autumn term by the Bolin Centre directorate. The 13^{th} Bert Bolin Climate Lecture was a virtual webinar given on May 20^{th}, 2021 by William F. Ruddiman, Professor Emeritus at the University of Virginia, USA.

The lecture was titled *For how long have humans effected the climate?*

During the last 10,000 years, Earth's climate has been relatively warm. Until recently, this warmth has been considered a natural phase of a glacial-interglacial (cold-warm) cycle. But now evidence has emerged, that this recent warmth was partly caused by human activity already 7,000 years ago. At this time humans started to clear forests to provided sunlight for growing crops. The result of these changes was a rise in the amount of the greenhouse gas carbon dioxide (CO_2) in the atmosphere. Starting 5,000 years ago, irrigation of lowlands to grow rice also emitted methane (CH_4), another greenhouse gas. These early historical agricultural greenhouse-gas emissions, combined with the well-known emission of these gases since the beginning of the industrial era, did not only keep the Earth warm but stopped what would have by now, if no human influence had taken place, become the start of another glacial cycle. This is called the Early Anthropogenic hypothesis, a hypothesis which has provoked a major scientific debate. For this year's Bert Bolin Climate Lecture, we welcome Professor Ruddiman who has conducted many years of research on this hypothesis. His lecture will provide new insight on this important topic.

William F. Ruddiman is a palaeoclimatologist and Professor Emeritus at the University of Virginia. Ruddiman's research interests center on climate change over several time scales. He has worked at the US Naval Oceanographic Office, at Columbia's Lamont–Doherty Earth Observatory and has served as a Professor in Environmental Sciences. He is a Fellow of both the Geological Society of America and the American Geophysical Union. Ruddiman has also participated in 15 oceanographic cruises, and was co-chief of two deep-sea drilling cruises.


Professor Emeritus William F. Ruddiman. Photo: Private

He has written several books and has published over 125 scientific papers. He has also been awarded the Lyell Medal of the Geological Society of London for 2010.

Lecturers

2021 | Professor Emeritus William F Ruddiman
For how long have humans affected the climate?

2020 | Professor Roberto Buizza
Climate Change: How can we motivate transformation?

2019 | Professor Maureen E. Raymo
Climate, CO2 and Sea Level: Past, Present and Future

2018 | Professor Veerabhadran Ramanathan
Bending the Curve: Climate Change Solutions

2017 | Dr. Thomas Cronin
Biological response to climate change: What would Bolin say?

2016 | Sir Brian Hoskins
The Challenge of Climate Change: How large is it and can we meet it?

2015 | Professor Ulrike Lohmann
Uncertainties in climate projections related to clouds and aerosols

2014 | Professor Corinne Le Quéré
The role of the carbon cycle in regulating climate

2013 | Professor Warren M. Washington
Future Development of Climate and Earth System Models for Scientific and Policy Use

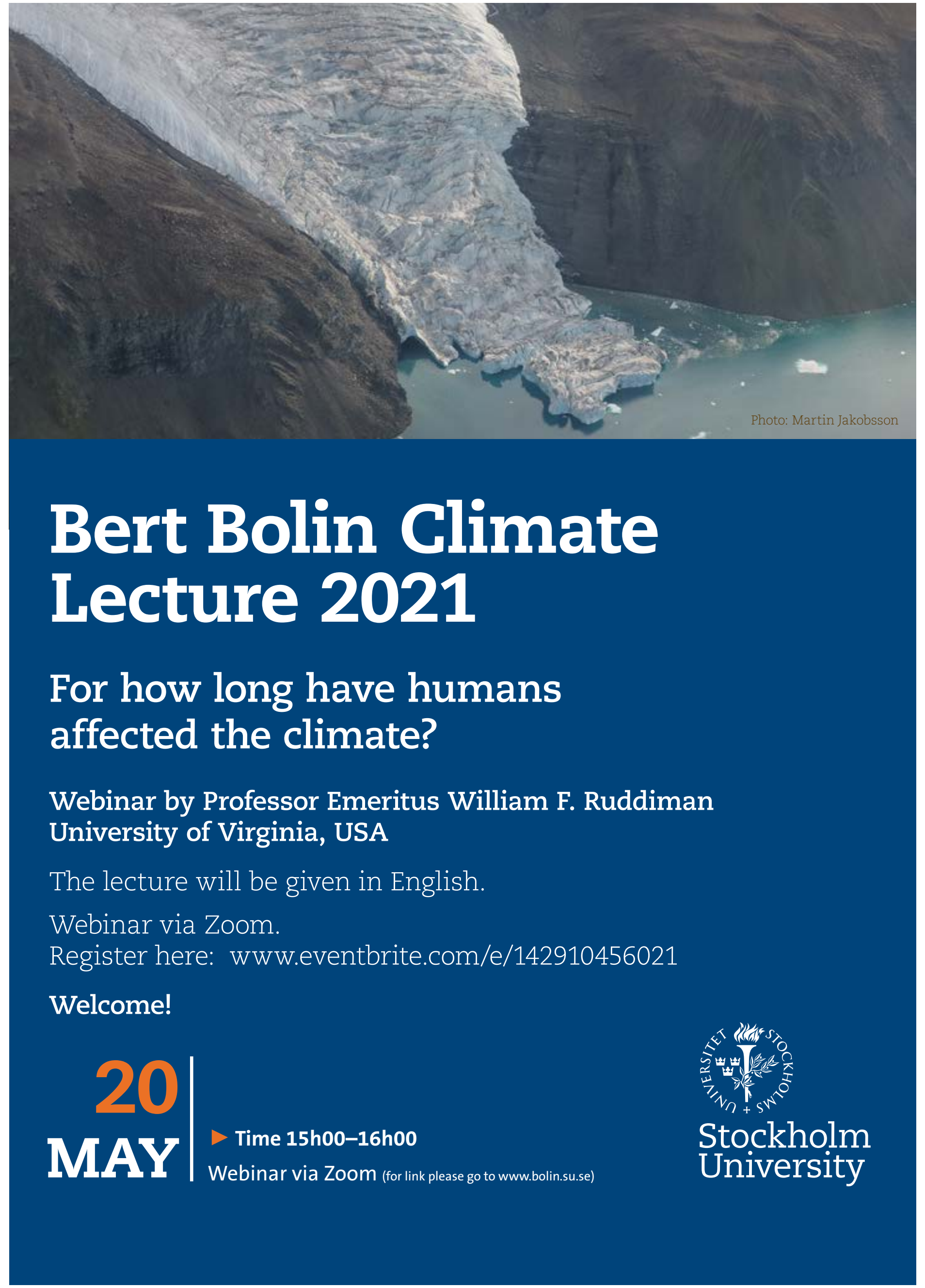
2012 | Professor Sherilyn Fritz
The climate during the past 10,000 years

2011 | Professor. Ralph Keeling
Rising Carbon Dioxide: A Never Ending Story

2010 | Professor Robert J. Charlson
Do We Know Enough to Go Ahead with Control of Greenhouse Gas Emissions?

2009 | Professor Venkatachalam "Ram" Ramaswamy
Dissecting the Roles of Aerosols and Greenhouse Gases in Climate Change

2008 | Professor Susan Solomon
Linkages between Ozone Depletion and Climate Change



The Bolin Centre Board

The Bolin Centre is led by the Bolin Centre Board, which compromises representatives from all its collaborative partners: Six departments at Stockholm University, the Swedish Meteorological and Hydrological Institute and KTH Royal Institute of Technology. In addition, the board includes an external member and a student representative.

Professor Cynthia de Wit
Chair of the Bolin Centre board, Department of Environmental Sciences, Stockholm University.

Professor Magnus Breitholtz
Department of Environmental Science, Stockholm University.

Professor Rodrigo Caballero
Department of Meteorology, Stockholm University.

Professor Gia Destouni
Department of Physical Geography, Stockholm University.

Professor Ove Eriksson
Department of Ecology, Environment and Plant Sciences, Stockholm University.

Professor Fredrik Lundell
Teknisk mekanik, KTH – Royal Institute of Technology.

Professor Bengt Karlsson
Department of Zoology, Stockholm University.

Professor Carl-Magnus Mörth
Department of Geological Sciences, Stockholm University.

Ralf Döscher, PhD
Rossby Centre, SMHI – the Swedish Meteorological and Hydrological Institute.

Anna-Karin Nyström, MSc
Swedish Environmental Protection Agency.

Emelie Graham, PhD Student
Department of Environmental Science, Stockholm University.

Associate Professor Nina Kirchner
Ex Officio, Co-Director of the Bolin Centre, Stockholm University.

Professor Alasdair Skelton
Ex Officio, Co-Director at the Bolin Centre, Stockholm University.

Magnus Atterfors, MA
Ex Officio, Communicator at the Bolin Centre, Stockholm University.

Annika Granebeck, MSc
Ex Officio, Coordinator at the Bolin Centre, Stockholm University.

Laila Islamovic, BA
Ex Officio, Coordinator at the Bolin Centre, Stockholm University.

Photo: Petter Halleberg

The External Science Advisory Group

The Bolin Centre has appointed an External Scientific Advisory Group comprised of leading national and international scientists within climate research. The group's main tasks are to inform the Bolin Centre of its strengths, weaknesses and possibilities for development as well as increase the Bolin Centre's contacts to international networks and research groups within the climate research area.

Professor Jay Famiglietti

Professor and the Executive Director of the Global Institute for Water Security at the University of Saskatchewan, Canada.

Professor Karen Kohfeld

Climate, Oceans, and Paleo-Environments (COPE) Lab at Simon Fraser University.

Professor Ulrike Lohmann

Professor at the Institute for Atmospheric and Climate Science, ETH Zürich, Switzerland.

Professor Camille Parmesan

NMA Chair in Public Understanding of Marine Science & Human Health at the School of Biological & Marine Sciences, Plymouth University, UK.

Professor Raymond T. Pierrehumbert

Halley Professorship of Physics at the Department of Physics at University of Oxford, UK.

Professor Veerabhadran Ramanathan

Distinguished Professor of Atmospheric and Climate Sciences at the Scripps Institution of Oceanography, University of California, San Diego.

Professor Maureen E. Raymo

Bruce C. Heezan Lamont Research Professor and Director at Lamont-Doherty Core Repository of Columbia University.

Photo: Martin Jakobsson

Major infrastructure grants

In 2021, Bolin members at Stockholm University were involved in several successful infrastructure applications to the Swedish Research Council (VR) related to climate research. Here we present three of them and a project grant to continue the successful work with the Bolin Centre Climate Arena.

New research centre to bring marine and atmospheric scientists together

Bolin and Baltic Sea Centre members Matthew Salter, Ilona Riipinen and Christoph Humborg are behind a successful infrastructure funding application to the Swedish Research Council (VR) on the development of a new atmospheric science laboratory at Askö, a marine research station located within the Stockholm archipelago. This funding is the latest milestone in the establishment of a multidisciplinary centre for coastal ecosystem and climate research called CoastClim, which is based on Baltic Bridge, a strategic cooperation research project between the University of Helsinki and Stockholm University launched in 2017. "This centre brings together expertise in the fields of marine ecology, biogeochemistry and atmospheric research in order to develop more integrated knowledge about how different marine processes and the Baltic Sea coastal environments interact with atmospheric processes and what this means for the climate", says Matthew Salter, Researcher at the Department of Environmental Science and Principal Investigator of the project.

Askö Laboratory in the Stockholm Archipelago. Photo: Anna-Karin Landin

The new laboratory will deal with questions surrounding emissions of sea spray aerosols and gases from the Baltic Sea and their impacts on climate. Dr. Salter continues: "Further, the Baltic Sea is highly impacted by the large population centres surrounding it meaning that the concentrations of marine contaminants exceed those of many other marine areas. As such, the laboratory will be a unique facility to probe whether the Baltic Sea is acting as an important source of contaminants to the atmosphere via sea spray aerosol and whether this pathway may be relevant at the global scale."

The icebreaker *Oden*

The hard-to-reach polar regions are key areas for understanding the climate and its changes. *Oden* is one of very few ships in the world that, thanks to its icebreaking capacity, allows for multidisciplinary on-site measurements in and around the Arctic and Antarctic.

The icebreaker is an important platform for scientists in within many research areas, such as climate, environment, ecology, meteorology, geology, marine sciences, geochemistry, geophysics and glaciology. *Oden* can also be used as a mobile laboratory for field measurements in land areas that are hard to access.

Oden is one of the world's most powerful icebreakers and currently one of the leading research platforms in the Arctic Ocean. Photo: Martin Jakobsson

The Council for Research Infrastructure at the Swedish Research Council (VR) awarded a grant dedicated to update and complement several instruments installed on *Oden*. More specifically, an Acoustic Doppler Current Profiler to measure currents will be installed in *Oden*'s hull along with two new echo-sounding transducers for the mid-water split beam sonar which, for example, can be used to map gas seepages or detecting biology in the water such as fish or plankton. In addition, new sensors to measure water properties are included for the CTD (Conductivity, Temperature, Depth) profiler as well as laser- and particle spectrometers to measure atmospheric properties and a meteorological sounding system. Finally, the upgrade includes a container equipped for onboard petrographic and magnetic analyses of rock or sediment samples. Overall, the upgrade will substantially strengthen and broaden *Oden*'s research capacity.

The vessel is owned by the Swedish Maritime Administration, and the Swedish Polar Research Secretariat plans and coordinates the research expeditions.

ACTRIS – Aerosols, Clouds and Trace gases Research Infrastructure

ACTRIS Sweden is the Swedish node of the pan-European research infrastructure ACTRIS (Aerosol, Clouds, Trace gases Research Infrastructure). Short-lived climate forcers (SLCF) – including aerosols, clouds and trace gases – are consistently identified by IPCC as the largest source of uncertainty regarding our ability to account for and predict the human impact on Earth´s radiative balance and thus also climate change. This is largely due to the complexity of the multiple processes emitting, transforming and ultimately removing the SLCF from the atmosphere, causing their concentrations to vary rapidly in time and space. In addition, aerosols and trace gases have adverse health effects estimated to be responsible for more than 400,000 premature deaths annually in the EU-28 countries. Information on concentrations and distributions of aerosols and trace gases is therefore required to reduce air pollution and their related effects on health and ecosystems. ACTRIS' mission is to establish, operate, and develop a pan-European distributed research infrastructure for SLCF. ACTRIS shall provide access for a wide user community to its resources and services, to facilitate high-quality Earth system research and model development. ACTRIS Sweden will contribute to these ambitions. ACTRIS Sweden is a collaboration between six Swedish partners (Lund University, Stockholm University, University of Gothenburg, SMHI, Swedish University for Agricultural Sciences and Uppsala University) – therefore facilitating also a collaboration between the strategic centers Bolin Centre, MERGE and BECC. ACTRIS Sweden will implement five co-located ACTRIS-ICOS stations along a north-south gradient, and two exploratory platforms.

Instrumentation to study aerosols and clouds at Zeppelin station. Photo: Radovan Krejci

New project grant: Partnership for Anthropocene Solutions

Bolin Centre researcher Kevin Noone (PI), with colleagues Alasdair Skelton and Annika Granebeck, along with colleagues at Stockholm Environment Institute, Linköping University and Klimatriksdagen received a Formas grant for the period 2021.12.01–2023.11.30 of 3,990,260 SEK, for the project Partnership for Anthropocene Solutions. The project aims to develop simpler, more transparent and comparable methods by which to assess, report and compare climate impacts of organizations' activities.

The research and goals will be achieved through convening and observing multi-stakeholder groups at events, building on the Climate Arena initiative of the Bolin Centre for Climate Research. These observations will lead to a better understanding of how such multi-stakeholder processes work, and eventually how they can be improved to be able to better address so called "wicked" problems. The research will be enriched by analyzing and learning from participants and results from more than 100 case studies of multi-stakeholder interactions carried out by the organization Thriving Earth Exchange.

Bert Bolin – a world leading scientist and science organiser

Bert Bolin joined the newly created Department of Meteorology at [1]Stockholm University in 1948 as an assistant to Professor Carl-Gustaf Rossby. With short intervening periods, Bert Bolin remained an active member of the department staff until his death in 2007.

During a productive period as Rossby's student he wrote several fundamental papers on atmospheric circulation and on the basic principles for numerical weather prediction. After he received his PhD in 1956, he broadened his interests to include studies of biogeochemical cycles of key life elements. This became the introduction to his world leading research on the carbon cycle in the atmosphere, oceans and biosphere.

Bert Bolin was not only a prominent scientist. His role as an inspirer and organiser of international climate research has been of outstanding importance. Due to his broad and deep scientific knowledge, his unusual ability to see the big picture, his eminent ability to express himself orally and in writing, and his diplomatic talent, he became the natural leader. He initiated several research programmes focusing the global environment including the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP).

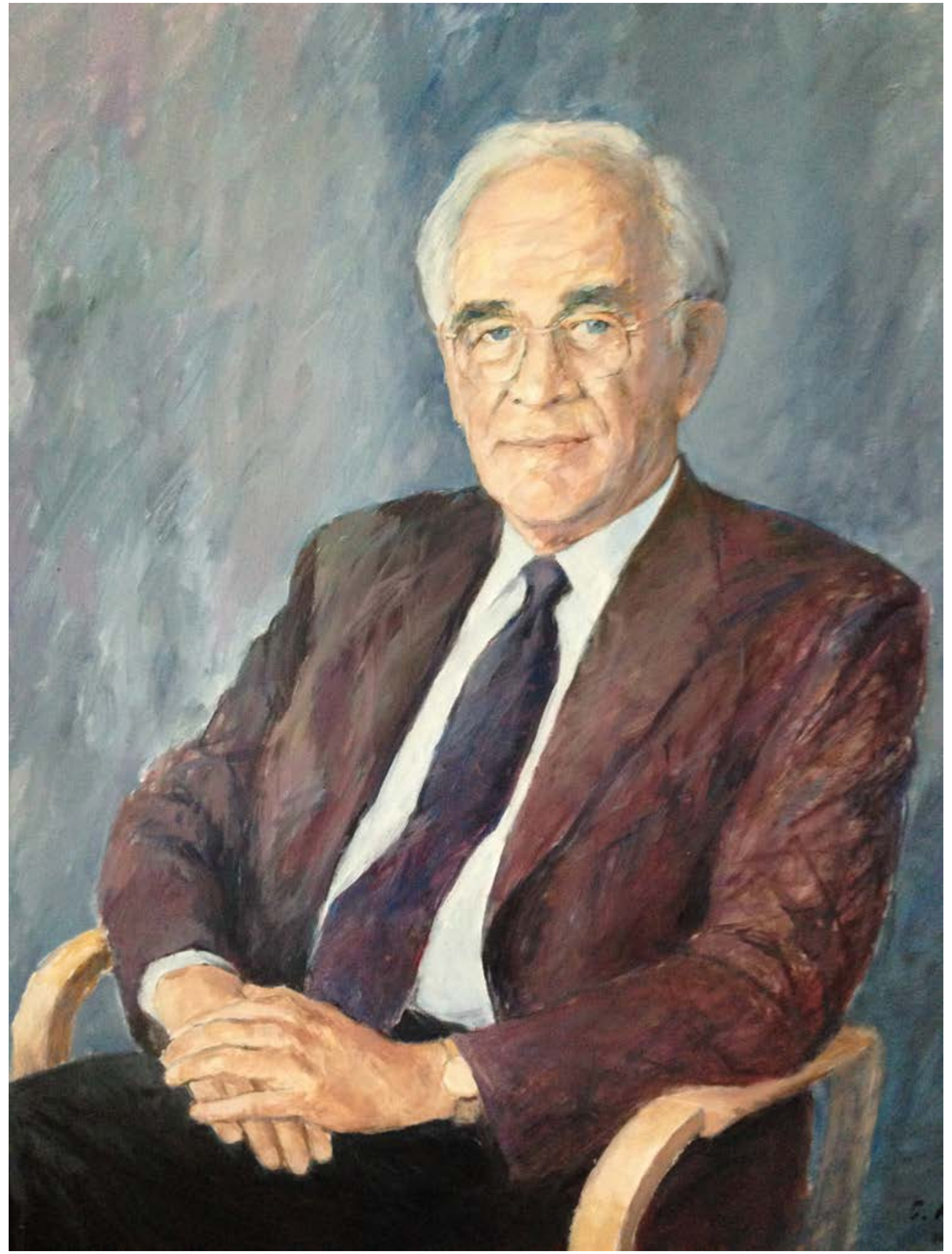
Bert Bolin's most important achievement was his contribution to the formation and development of the Intergovernmental Panel on Climate Change (IPCC) under the UN. He chaired this panel during its first ten years (1988–1997). His extremely important role as the founder and initial leader of IPCC has been testified by many. IPCC received the Nobel Peace Prize in 2007.

[1]Stockholm University was formed 1960 from Stockholms Högskola, which was founded 1878.

The legacy of Bert Bolin remains alive among climate scientists at Stockholm University and at many other places through the inspiration that he brought about with lectures, supervision, his scientific approach and his engagement to make research results available to policy makers and the public.

Henning Rodhe
Bert Bolin's student, colleague and friend

You can watch a slide show about Bert Bolin and the Bolin Centre for Climate Research at https://www.su.se/english/about-the-university/cultural-heritage-and-history/the-history-of-stockholm-university/bert-bolin-founder-of-the-climate-panel-and-world-leading-scientist-1.531330.



Bert Bolin. Painting by Carin Adler

Bolin Centre for Climate Research

The Bolin Centre is a multi-disciplinary consortium of more than 400 scientists in Sweden who conduct research and graduate education related to the Earth´s climate. It was formed in 2006 by Stockholm University, and in 2010 the KTH Royal Institute of Technology and the Swedish Meteorological and Hydrological Institute joined the centre.

The Bolin Centre focuses on extending and disseminating knowledge about the Earth's natural climate system, climate variations, climate impacting processes, climate modelling, human impact on the climate and climate impacts on ecosystems, biodiversity and human conditions as well as how society can minimise negative impacts through responsible management.

The Bolin Centre for Climate Research is named in honour of Professor Bert Bolin of Stockholm University, a leader in climate and carbon cycle research and one of the founders of the Intergovernmental Panel on Climate Change (IPCC) which received the Nobel Peace Prize in 2007.

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