Bolin Centre for Climate Research

Annual Report 2020

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: Mount Ngauruhoe, New Zealand. Photo: Martin Jakobsson
Production: Bolin Centre for Climate Research, 2021.
Research highlights produced by Magnus Atterfors and Laila Islamovic.

Contents

Drift wood on a beach, New Zealand. Photo: Inês 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 for 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 publication of the first IPCC report 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 SFO funding of the Bolin Centre exceeds 30 MSEK annually.

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

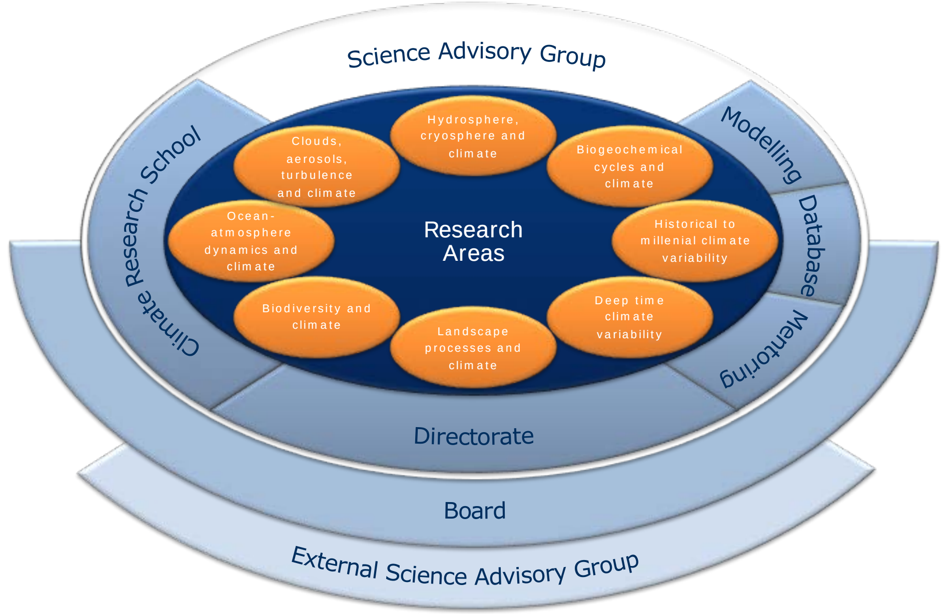
The Bolin Centre aims to bring climate scientists together. The centre comprises eight cross-disciplinary research areas, within which scientists from different disciplines join together to tackle key questions about climate.
The Bolin Centre organises seminars, workshops, conferences, outreach projects, summer schools and mentoring.

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. There is also a mentoring programme which is open to all of its members and a journal club for its post-doctoral community.

The directorate comprises two co-directors and two communicators and co-ordinators, 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 facilitate excellence 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 use 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.

The pandemic put severe challenges on all of us during 2020, and some of us had to endure personal hardships. The way we did research and teaching had to change overnight, and field-based research and education was virtually impossible during 2020. Technologies blossomed that made conference arrangements and participation possible without having to travel and to be present on site – a digital presence was sufficient. The Bolin Centre Climate Festival was one of the first large events at SU that was quickly re-designed and offered in an entirely digital format, with overwhelming success: more than 2,000 persons participated in online lectures, and more than 18,000 watched the recorded lectures (still available at urplay.se) afterwards.

Also, during 2020, global warming passed 1.2°C compared to pre-industrial, and left the small margin of 0.3°C before a warming of 1.5°C would be reached. Just to recall, in the Paris agreement from 2015, the nations of the World agreed to hold the increase in global temperature "well below 2°C", and "to pursue efforts to limit the temperature increase to 1.5°C". A growing number of people, no longer just "young protesters" express their concerns in regard of the ongoing climate crisis. As climate scientist Kimberly Nicholas points out in her book *Under the Sky We Make*: "No one born after 1985 has lived through a normal year on planet Earth; every year of their lives has been warmer than the 20th century average". What are the consequences of such changes, and how do we adapt? It became clear during 2020, that the pandemic – having caused a global crisis – may teach us ways to handle the climate crisis, too.

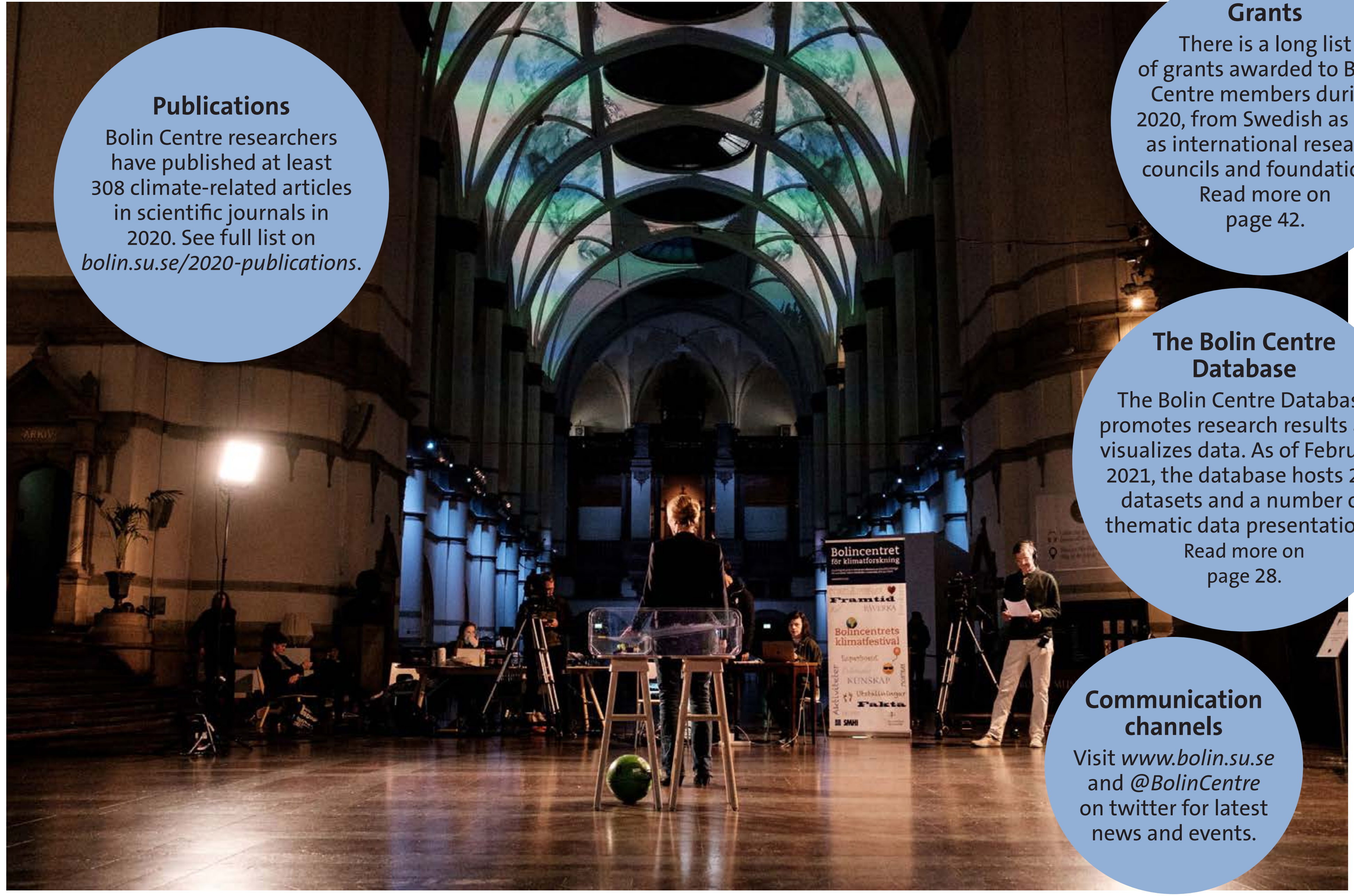
We encourage you to listen to Professor Corinne Le Quéré, who was the distinguished Bert Bolin Climate Lecturer in 2014: Corinne shares her thoughts on the unforeseen consequences of the pandemic (among others, the most rapid emission cuts ever recorded), what they mean for the climate, and how we – humanity – can go forward from where we are now, in the Podcast *Climate Thinkers* (which can be accessed for free on YouTube).

As Directors of the Bolin Centre, we are proud of all our centre members who, during 2020, continued to produce excellent science under very difficult conditions, resulting in more than 308 articles in peer reviewed scientific journals. Out of the 308 articles published during the year, the directorate of the Bolin Centre chose eight of them to highlight in this report as well as on our website and other communication channels. These publications were picked because they represent the many dimensions of climate research that is carried out at the centre, and they exemplify the importance of cross-disciplinary work.

We are also especially proud of our communication and coordination team, who not only accomplished heroic deeds for the Bolin Centre in a turbulent, almost entirely virtual 2020, but also produced the eight popular science articles which you can read in the next chapter.

Co-director | Alasdair Skelton is a professor of geochemistry and petrology. He works at the Department of Geological Sciences, Stockholm University. Most of his published works are on climate of the past, earthquake forecasting and metamorphic petrology. Photo: Eva Dalin

Co-director | Nina Kichner is an associate professor of glaciology at the Department of Physical Geography at Stockholm University. Her research focuses on ice-ocean interaction at marine ice margins in order to improve reconstructions of ice sheet complexes and modelling of their present and future dynamics. Photo: Riko Noormets



Publications

Bolin Centre researchers have published at least 308 climate-related articles in scientific journals in 2020. See full list on *bolin.su.se/2020-publications*.

Grants

There is a long list of grants awarded to Bolin Centre members during 2020, from Swedish as well as international research councils and foundations. Read more on page 42.

The Bolin Centre Database

The Bolin Centre Database promotes research results and visualizes data. As of February 2021, the database hosts 272 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.

Co-director Nina Kirchner during UR Samtidens taping of her presentation "Flytande glaciärer" (floating glaciers in English), at the Bolin Centre Climate Festival 2020. Photo: Vetenskapens Hus

The Bolin Centre Research Areas

The eight research areas within the Bolin Centre receive financial resources each year for research activities. Through calls, the research areas select among the applications from Bolin-members, funding initiatives such as pilot studies, field work or covering laboratory analyses costs. The research areas also give seminars, open to other research areas 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.

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 Matt 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.

The numbers that control how bad global warming is going to be

How sensitive is the climate to carbon dioxide emissions, more precisely? Will a doubling of atmospheric carbon dioxide from preindustrial levels result in a 1.5°C or 4.5°C warmer Earth? The answer has far reaching consequences, since the uncertainty range includes both the merely troubling and the catastrophic. In 2018, 25 scientists were challenged by the World Climate Research Programme (WCRP) to narrow the climate sensitivity and three years later they presented a range between 2.6°C and 3.9°C, updating the climate sensitivity range that has been used for over 40 years.

It's quite a challenge to try to estimate the consequences of rising greenhouse gases emissions on Earth's temperature. What temperature will a doubling of atmospheric carbon dioxide from preindustrial levels result in? Back in 1979, climate scientists gathered in Woods Hole, Massachusetts, to come up with an answer. Informed by climate models available at that time, they produced a seminal paper known as the Charney report, predicting that the Earth would eventually warm between 1.5°C and 4.5°C. The authors did not quantify the probability that the sensitivity was inside or outside this range. Even though projections based on more recent climate models have been presented, the latest IPCC report from 2013 uses the interval 1.5–4.5°C, with an addition of a 66% chance of being within the interval. These earlier estimates were for the most part based on climate models, some of which would have trouble representing things that can be observed and therefore scientifically dissatisfying. Also, no progress had been achieved in over 40 years. To tackle this, the new WCRP study instead weighs together three independent lines of evidence.

New lines of evidence

The new narrowed bound of climate sensitivity between 2.6°C and 3.9°C is based on three lines of evidence. The first one is based on the trend of the average surface temperatures since record keeping began back in the 19th century. The average surface temperature has risen 1.1°C, and if the trend continues we would end up on the lower end of the interval. However, new studies have pointed out that the planet isn't warming uniformly. Two examples are the eastern Pacific Ocean and Southern Ocean, which have been almost untouched by warming due to the fact that cold, deep water well up and absorb heat on these parts of the Earth. Both models and paleoclimate records suggest that these heat sinks won't last forever. Sooner or later, also these waters will warm, giving rise to cloud formations that will trap more heat. As a result, the lower end of the interval has to be adjusted upwards.

The second line of evidence rests on climate feedbacks mechanisms. One of them – clouds – can either cool (through reflecting sunlight) or warm (through trapping heat) the Earth. But it has been unclear whether the total contribution from cloud changes in a warming climate is a positive or negative one. Thanks to new data from satellites, monitoring and field campaigns and also detailed computer simulations of individual clouds, the picture clarifies. "There's a growing consensus that the cloud feedback is positive, but not super-large," says Thorsten Mauritsen, co-leader for RA1 and one of the authors of the article.

Recent research also suggests that climate sensitivity changes over time and that it is dependent on the temperature. The research team therefore took a closer look at two states of the climate in the past, a cold period 20,000 years ago at the peak of the last ice age, and the Pliocene warm period 3 million years ago when atmospheric CO2 levels were similar to today's levels.

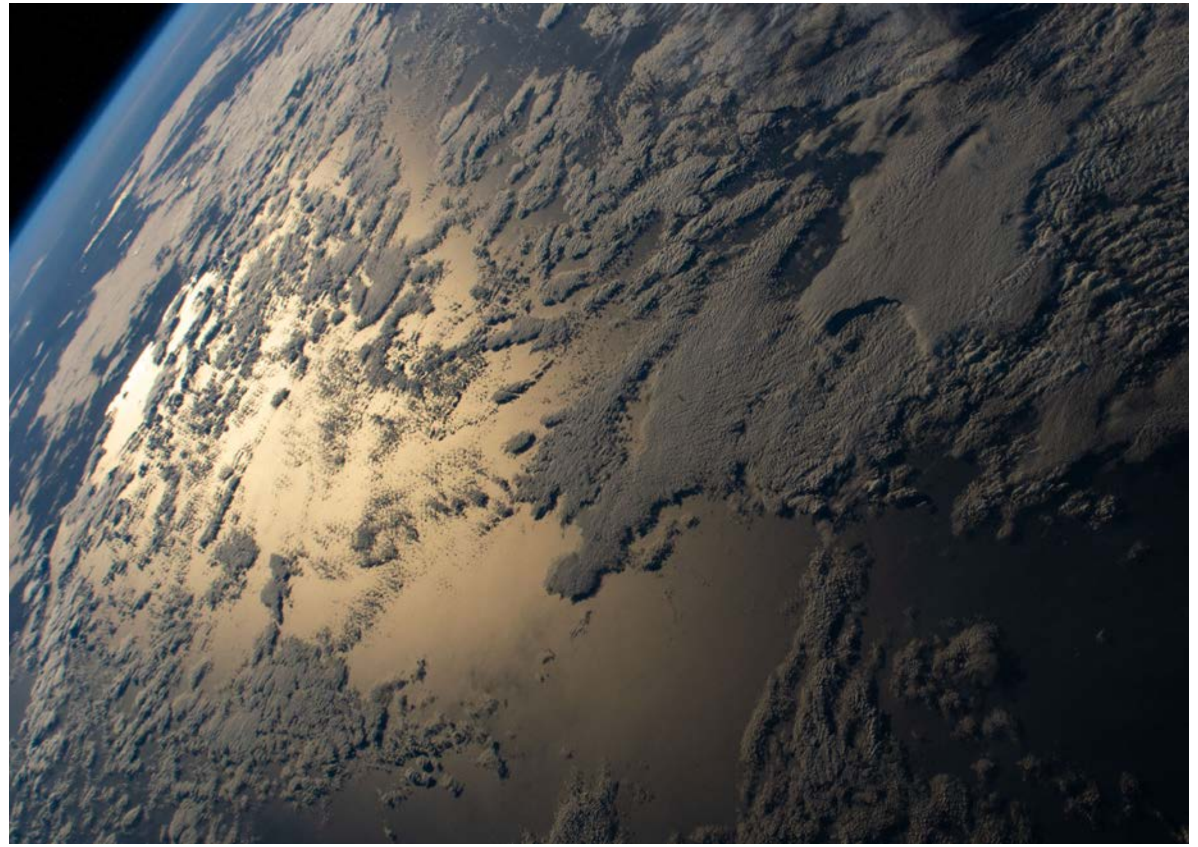


Image Credit: NASA

What does it mean that the study rules out the milder levels of warming?

"Actually, the study points to climate sensitivity being moderate, neither low nor high, and the statistical uncertainty has been more than halved. This is a scientific quantum leap and all of a sudden, we have to think far more critically about evidence that challenges this new tighter range. For example, evidence from distant paleoclimates 10–15 degrees warmer than present suggest climate sensitivity could be higher, but is that a real signal or is it due to errors in the data? Or does it support theories that climate sensitivity increases with warming? The research field has become revitalized, which is fantastic", explains Thorsten Mauritsen.

How will the new climate sensitivity estimate be used?

"The recently published United Nations IPCC sixth report on climate change uses much of the experience gained in the WCRP study, as well as new results of studies that are published in 2020", says Thorsten Mauritsen.

Thorsten Mauritsen is Co-leader at Bolin Centre's Research Area 1 *Ocean-atmosphere dynamics and climate* and works at Department of Meteorology, Stockholm University. Mauritsen is active as a lead author on the recently published IPCC sixth assessment report. Photo: Krister Junghahn

The next step was to weigh together the three lines of evidence. With Bayesian statistics, a general method to weigh independent pieces of evidence, the team could produce a climate sensitivity range between 2.6°C and 3.9°C with a 66% confidence interval, matching IPCC's traditional "likely" range.

The article *An Assessment of Earth's Climate Sensitivity Using Multiple Lines of Evidence* was selected as a runner-up 2020 breakthrough of the year by Science. It was published in Reviews of Geophysics on 22 July 2020, *https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019RG000678*.

Identifying major threats of environmental factors and climate change to biodiversity

In an effort to better predict what future environmental changes will most likely influence biodiversity, Bolin Centre researcher Johan Ehrlén and co-authors conducted a study to investigate which of multiple environmental drivers (abiotic, biotic, and/or anthropogenic) affected wild plants the most. This information can aid in identifying the major threats of environmental and climate change to biodiversity.

Hundreds of models have been developed to measure the impacts of drivers on per capita plant population growth rate, which is a metric of change in abundance of a plant over time, and ultimately determines the geographic distribution of the plant. However, no previous studies have taken advantage of this knowledge base to investigate what environmental drivers affect population growth rate the most. By figuring out which environmental drivers have the strongest impact, one can focus on those when predicting the consequences of environmental and climate change on biodiversity and designing mitigation strategies.

Ehrlén and co-authors collected data from 207 published studies, which provided them with 644 comparisons of per capita population growth rate at different levels of multiple drivers for 208 terrestrial plant species from 72 families. They classified the drivers into three main types, each having three subtypes. The first being abiotic drivers, including climate (such as temperature and precipitation) nonclimate abiotic drivers (such as pH, soil texture, and CO2 concentrations), and disturbance (like fires and hurricanes). The second being biotic drivers, including interactions with neighboring plants, natural enemies, and mutualists (e.g. pollinators). Anthropogenic drivers being the third main type, including grazing by domesticated herbivores and mowing, harvesting, and other types of land use.

No shortcuts when predicting future ecological and evolutionary responses

The analysis of the best available data showed that “there is no one main type of driver (abiotic, biotic or anthropogenic) that has overwhelmingly stronger effect on plants population growth and fitness relative to the others”, according to Ehrlén and co-authors. However, they found that plant population growth rate was less sensitive to changes in biotic drivers relative to abiotic drivers, although it deserves to be examined further once more data becomes available. Additionally, the best estimates suggest that biotic changes will be more than one-half as influential as abiotic changes of the same magnitude. The results have four important ecological and evolutionary implication.

Four important ecological and evolutionary implications

First, when predicting how a plant species population growth and fitness will respond to climate change, only looking at the direct effects of changes in climatic drivers will not yield accurate prediction. This is because the effects of climate change are likely to also be indirect, e.g. acting via changes in fire frequencies and land use.

Second, there were no clear geographical patterns regarding the relative importance of different factors. For example, abiotic factors were not more important towards the poles and biotic more important towards the equator, which has been previously suggested.

Third, the strength of the impacts of anthropogenic drivers rivals abiotic and biotic drivers, which means that we must always consider the possibility that changes in land use by humans will in turn modify or even overwhelm the effects of climate change.

Fourth, the fact that no one driver type (abiotic, biotic, or anthropogenic) is overwhelmingly more influential than the other has important evolutionary implications. Because the results of this study are based on total fitness (population growth rate), they may more accurately indicate the importance of different selective agents than many previous studies that have looked only on one or a few aspects of organism performance. Another implication is that selection on traits that impacts effects of the different drivers on fitness should be substantial for all of the main driver types. Ehrlén explains: “For example, traits that reduce negative effects of climate, traits that reduce herbivory or its impacts, and traits that compensate for harvesting effects should on average experience selection strengths that do not differ greatly”.

The photo is from Sandemar shore meadow, south of Stockholm, an appreciated site for visitors to look at birds and plants. Less than 200 years ago this shore meadow was beneath the sea level. Photo: Sara Cousins

What were your thoughts and expectations before this study? Were your findings surprising?

“I would say that the findings of this study were not very surprising to us, but that our notion before carrying out the study was that the performance of plants, as well as other organisms, is the result of many different aspects of the environment. Perhaps the most surprising finding was that biotic interactions, e.g. in terms of competition, did not come out as more important”, says Ehrlén.

Is there a natural next step in this particular research topic? In other words, what could the next study focus on, as a continuation of this study?

“I think that a natural continuation of this study would be to try to assess how important direct vs. indirect effects of climate are. For example, it would be interesting to explore how climate affects fire frequency or competition between different plant species, and how does this in turn affect plant performance”, explains Ehrlén.

Johan Ehrlén is a professor at the Department of Ecology, Environment and Plant Sciences at Stockholm University, and is also one of the co-leaders for Research Area 8 *Biodiversity and Climate* at the Bolin Centre for Climate Research. His research interests pertain identifying the environmental drivers of variation in natural selection and population dynamics. Photo: Niklas Björling

The article *Biotic and anthropogenic forces rival climatic/abiotic factors in determining global plant population growth and fitness* was published in the Proceedings of the National Academy of Sciences (PNAS) on January 14th, 2020, *https://www.pnas.org/content/117/2/1107*.

Aerosols, uncertainties and Arctic warming

Aerosols – small, invisible particles in the air around us – plays a significant role in the climate system. They affect the radiative balance of the Earth both directly, by scattering and absorbing light, and indirectly, by influencing cloud properties, which in turn influences the temperature. Aerosols can also influence remote atmospheric circulation and rainfall patterns. Currently, these aerosol interactions are one of the largest sources of uncertainty when trying to look into future climates. A team of Bolin Centre researchers at the Department of Meteorology and the Department of Environmental Sciences, Stockholm University, took a closer look at how aerosols affects the Arctic climate.

Aerosols are liquid or solid particles suspended in air, which may have adverse air quality and health impacts. Sulfate aerosols, originating from the burning of fossil fuel, also have a cooling influence on climate. In other words, they can mask some of the greenhouse gas-induced global warming.

Now, the impacts of aerosol emissions are not limited to where they are emitted. Studies using global climate models have shown that changing sulfur dioxide emissions in Europe can have significant impacts on the Arctic climate. This new study investigates more precisely how this is happening.

During the past 40 years, there has been two distinct patterns of global anthropogenic aerosol emission changes; the reduction in emissions from Europe and North America and the increase in emissions from East and South Asia. Several studies have shown that emissions from these regions can have remote and global climate impacts. Generally, removal of European and North American aerosols have increased regional warming and reduced Arctic sea ice. Also, when evaluating the impact of drawdown of European sulfate aerosols since the 1980s, an enhanced Arctic response has been found in modeling studies. That is, with less aerosols originating from Europe, the model result produces a warmer Arctic.

The question is how this works more in detail, what are the mechanistic reasons for this remote response? Which is most important for the aerosol-driven Arctic warming, is it processes in the ocean or processes in the atmosphere?

The researchers used the Earth system model NorESM to compare the climate response in experiments that vary which parameter is allowed to respond to aerosol changes:

1. atmosphere alone
2. ocean alone
3. both atmosphere and ocean.

They conducted experiments with two modes of model configuration, a fully coupled model (which simulates both the ocean and the atmosphere) and a slab ocean model (which allows the user to run a full atmosphere model on top of a much simplified ocean model).

The researchers found that the atmosphere plays the primary role in driving Arctic warming in response to European aerosol reductions. Warming driven by that atmospheric pathway is partially offset by a cooling resulting from changes in ocean heat flux convergence. In both cases, a key mediator of the temperature response is changes in sea ice extent, through modifications of turbulent flux exchanges and surface temperature. The Arctic temperature response is smaller in the fully coupled experiments than the slab ocean experiments, due to the tendency in the fully coupled model to maintain Arctic sea ice and transport excess heat away from the Arctic. This suggests that a good representation of Arctic sea ice is vital for confident projections of future Arctic climate change, even for remote mid-latitude forcing changes.

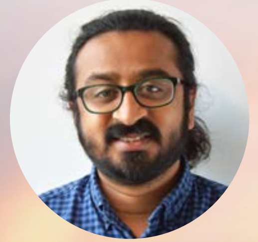
What does it mean in a wider context that the atmosphere plays the primary role?

"Understanding whether the atmosphere or ocean plays a major role is important for describing causal links between mid-latitude aerosol emissions and the Arctic climate. Broadly, heat can be transported from the mid-latitudes to the poles either through the atmosphere or the ocean. Changes in atmospheric heat transport can occur over annual timescales but changes in ocean heat transport can take longer to manifest itself – possibly over decadal to centennial timescales. Therefore, if the atmosphere plays a primary role, then changes in mid-latitude aerosol emissions would affect the Arctic climate within the first few decades, rather than over a longer period of time – which would be the case if oceans played the primary role, says Srinath Krishnan, lead author of the study." He continues:

"Thus, if one was to investigate the impacts of mid-latitude aerosol emissions on Arctic sea-ice, then the timescale of change if the atmosphere plays a major role would be much quicker than if the ocean did. But a couple of important caveats here are that there are several links and feedbacks between the atmosphere and the ocean, so it is not entirely possible to treat them separately and that this result can be sensitive to the model and grid resolution used, both ocean and atmosphere."

How can the results be used?

"If the atmosphere plays a primary role in affecting Arctic climate, as suggested here, then it is important to understand the changes within the atmosphere due to aerosol emission changes within the first 30 years. This involves running a transient simulation, or an ensemble of transient simulations, with the focus on early changes in atmospheric dynamics and teleconnections. The use of equilibrium fully coupled simulations may not fully explain the causal link between mid-latitude aerosol emissions and the Arctic", concludes Srinath Krishnan.



Srinath Krishnan is a Bolin Centre member and affiliated to the Department of Meteorology, Stockholm University. Presently, he works at CICERO, Center for International Climate, in Oslo. Photo: Amund Aasbrenn/CICERO

The article *The Roles of the Atmosphere and Ocean in Driving Arctic Warming Due to European Aerosol Reductions* was published in Geophysical Research Letters on 28 March 2020, *https://doi.org/10.1029/2019GL086681*.

Clouds over Utqiaġvik, Alaska. Photo: Martin Jakobsson

Abrupt thaw of permafrost has large impact on future global warming

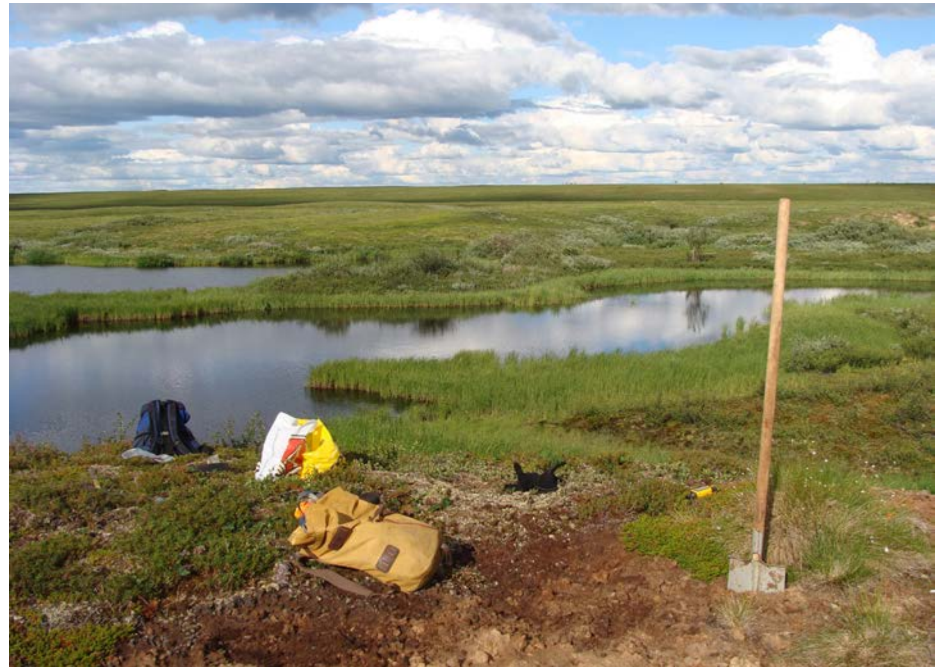
Permafrost is one of Earth's largest terrestrial carbon stocks. It stores around 1,500 billion tonnes of carbon, which is near twice the amount of carbon in the atmosphere. But rising temperatures cause permafrost thaw and ground surface collapse, leaving behind dramatic changes in the landscape. In a study that was selected one of the most important insights in climate science 2020, Bolin Centre researcher Gustaf Hugelius and colleagues shows that the emissions of greenhouse gases from permafrost will be larger than earlier projections because of abrupt thaw processes affecting frozen peatlands, which are not yet included in global climate models.

Peatlands are areas with constant waterlogged conditions that slow plant decomposition, allowing dead plant remains to accumulate as peat. This process has produced one of the largest natural carbon stores on land. Now, nearly half of northern peatlands are affected by permafrost, meaning that they are perennially frozen and that the peat is protected from decomposing organisms such as bacteria and fungi. If abrupt thaw of this permafrost occurs, that could shift the entire northern hemisphere peatland carbon sink into a net source of global warming, dominated by methane and lasting several centuries.

Despite their importance to the global climate, peatlands remain poorly mapped, and the vulnerability of permafrost peatlands to warming is uncertain. Until now.

"Our study compiles over 7,000 field observations to present a data-driven map of northern peatlands and their carbon and nitrogen stocks. We use these maps to model the impact of permafrost thaw on peatlands and find that warming will likely shift the greenhouse gas balance of northern peatlands. At present, peatlands cool the climate, but anthropogenic warming can shift them into a net source of warming," says Gustaf Hugelius.

Permafrost is a key factor in climate change. In the Arctic, it covers the area of three times the size of EU, and if it thaws, vast amounts of CO2 and methane would be released. Those emissions are largely not included in the IPCC climate change projections that the Paris agreement rests on.



Sampling soils next to thermokarst lakes forming as permafrost thaws in a Russian peatland area. Photo: Gustaf Hugelius

Certain emissions are included in more recent studies, but up until now no models have included abrupt thaw processes, so called thermokarst, when the ground quickly collapses and exposes deep layers of permafrost. During 2020, calculations of the effects they are causing was presented for the first time.

"If we include the emissions from the abrupt thaw and thermokarst, the total warming from permafrost in the next hundred years will be almost doubled compared to what have been prognosed earlier," says Gustaf Hugelius.

The new finding has major implications for how fast emissions on Earth must be reduced. The human remaining CO2 budget is a concept that is used to illustrate how large emissions of greenhouse gases can be allowed to meet the goals of the Paris agreement. If the new findings from emission from permafrost are included, the CO2 budget is radically changed.

Thawing coastal permafrost in Arctic Canada with person for scale. Photo: Gustaf Hugelius

"The permafrost alone eats up one third of the budget we have left, in order to stay below 1.5 degrees warming. I hope that the new calculations can be used as an argument to show the importance of acting quick," says Gustaf Hugelius.

"When the ice in the ground melts and drains away, it is forever lost. The permafrost ice has formed during hundreds of thousands of years, and when it thaws we have a new reality to face. From a human perspective, these processes are permanent," says Gustaf Hugelius.

Included in *10 insights in climate science 2020 – a horizon scan*

The article *Large stocks of peatland carbon and nitrogen are vulnerable to permafrost thaw* was published in PNAS on 25 August 2020 and you can access it here: *https://doi.org/10.1073/pnas.1916387117*.

The article was included in *10 insights in climate science 2020 – a horizon scan*, which summarizes some of the most important findings within climate change-related research, published in Global Sustainability, Cambridge University Press, *https://doi.org/10.1017/sus.2021.2.* They summarise: "... when adding new knowledge on abrupt thaw to what's currently modelled for gradual thaw, the expected carbon emissions from permafrost could as much as double by year 2100. The carbon emissions from permafrost regions could be even higher when including effects on root activity which increase soil decomposition. Accounting for these effects will impose tighter restrictions on the remaining anthropogenic carbon emission budgets."

Gustaf Hugelius is Co-leader at Bolin Centre's Research Area 4 *Biogeochemical cycles and climate* and works at the Department of Physical Geography, Stockholm University. Photo: Niklas Björling

RESEACH HIGHLIGHT

The future of tropical forests under climate change

Often called “the lungs of our planet”, tropical forests play a crucial role in global carbon storage and sequestration. They are some of the most varied environments on Earth, and are under threat from both deforestation and global warming. A study by Arie Staal and co-authors finds that with growing greenhouse gas emissions, there is a chance that a larger part of the Amazon rainforest loses its natural resilience and turns into a savannah-like ecosystem. It could take decades for tropical forests to recover from this, which could have devastating consequences for plants and animals.

Tropical forests are home to the majority of species on Earth, and the loss of them could have detrimental effects to the Earth system. Our tropical forests are also important regulators of the global climate; they mediate their regional climate by enhancing atmospheric moisture recycling, which in turn enhances rainfall levels at both seasonal and annual time scales.

Efforts to limit global warming and the effects of climate change have proposed reforestation and afforestation in the tropics as effective mitigation actions. Previous studies that have analyzed the potential of afforestation, have essentially acknowledged hysteresis in forest cover. The hysteresis of tropical forests, defined here as the difference in forest cover area between the two extremes, is shaped by feedbacks at different spatial scales. These feedbacks ultimately control tropical forests’ resilience to deforestation and response to climate change. However, these previous studies have not taken into consideration that potential forest distributions may change due to rainfall effects of afforestation itself or their interactions with global climate change. “By accounting for these factors, our analysis sheds more light on the forest potential across the tropics, though it is important to note that afforesting natural grassland and savannas may neither be a feasible nor desirable climate-change measure, and a number of other considerations, including biodiversity, would need to be accounted for”, explains Arie Staal.

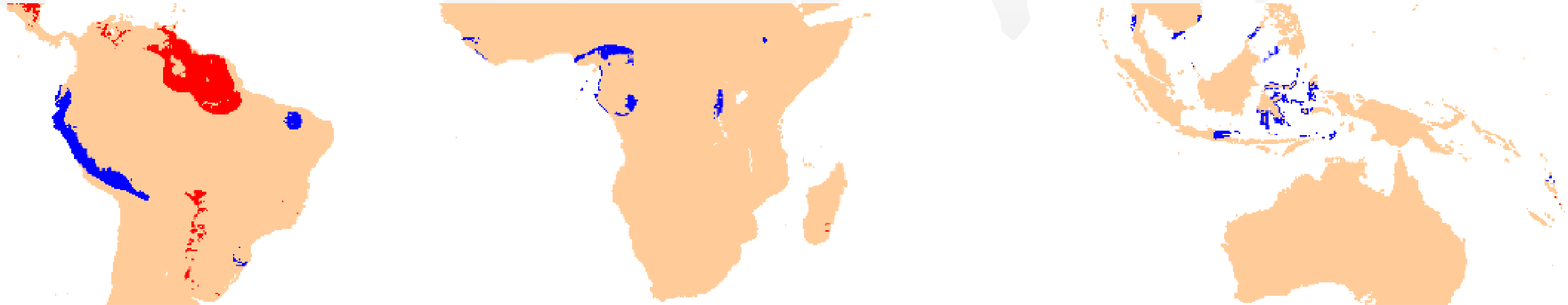
Losing and gaining resilience under future climates

In this study, Arie Staal and his colleagues aim at finding out more about the tropical forest hysteresis that emerges from the combination of local-scale tipping points and regional feedback under current and future climates.

Picture of a forest canopy is taken by lead author Arie Staal from a tower in a forest near Manaus, in Amazonas, Brazil.

These findings can help us better understand the role of tropical forests in the Earth system. Staal and colleagues focused on tropical rainforests in the Americas, Africa, Australasia; specifically, the Amazon rainforest, the Congo rainforest, and Asian rainforests. In assessing how the stability of tropical forests may change under climate change, they used rainfall projections by relying on remote sensing, a global hydrological model, and detailed atmospheric moisture tracking simulations.

What they found was that in areas stricken by drought or aridification due to climate change, some areas that are now forested may cross a tipping point and lose its forests with continuing global warming. This type of transition occurs mainly in the northern part of the Amazon rainforest. In Africa and Australasia, only a small portion of tropical forests might cross this tipping point. In areas where climate change has done the opposite, causing wetter conditions, some non-forested areas may cross a tipping point to a forested area. The areas that may experience this type of transition are more evenly distributed across the three continents, as one can observe in the figure below. Furthermore, Staal explains that “the Amazon forest could partially recover from complete deforestation, but may lose that resilience later this century. The Congo forest currently lacks resilience, but is predicted to gain it under climate change, whereas forests in Australasia are resilient under both current and future climates”.



Supplementary Figure 14 from Staal et. al article Hysteresis of tropical forests in the 21st century. *This figure shows tipping points between forests and savannas in the 21st century based on changes in mean annual rainfall as projected in the SSP5-8.5 scenario from CMIP6 models. Red: from forest to nonforest; blue: from nonforest to forest.*

How can the findings from this study aid in the efforts to try and limit global warming, like for example mitigation efforts?

“They illustrate not only the importance of halting tropical deforestation for climate-change mitigation, but also the importance of mitigation for maintaining resilient forests, especially in the Amazon”, says Staal.

What is a next step in your research to better understand the role of tropical forests in the Earth system?

“One weakness in this study that I plan to solve is that, although we accounted for future rainfall changes under severe climate change, we did not account for atmospheric circulation changes. This would improve our estimates of the future resilience of tropical forests. Next, I aim to use this information to assess where forest restoration efforts could benefit Earth’s tropical forests considering the enhancement of rainfall” explains Staal.

Arie Staal was formerly a Bolin Centre postdoctoral researcher at the Stockholm Resilience Centre. He now works as an Assistant Professor of Ecosystem Resilience at the Copernicus Institute of Sustainable Development, Utrecht University. Photo: Bernardo Flores

The article *Hysteresis of tropical forests in the 21st century* was published in Nature Communications on October 5th, 2020. Access the full article here: *https://www.nature.com/articles/s41467-020-18728-7*.

The Miocene: A climate window into the future

If we go back to a period ~23–5 million years in the past, we will find ourselves in the Miocene epoch. There, we find a world with significantly higher temperatures than today, while CO2 levels were just slightly higher than modern day levels. This can point to that relatively low, near future, CO2 levels can cause a larger warming of Earth's systems than today's climate models can reproduce. In their review paper, titled "The Miocene: The Future of the Past", Bolin Centre researcher Margret Steinthorsdottir and co-authors use climate-reconstructions from the Miocene to test their knowledge about Earth's systems under conditions where both temperatures and CO2 are higher than they are today. In this way, it gives us the rare opportunity to see into the future.

Earth's climate consists of many systems that are both complex and intertwined, which means that a change to any part of the system can cause a series of other changes. This makes it hard to predict what climate change will do to our future Earth, and therefore, climate scientists have long been looking for a paleoclimate period to serve as an analogue for the future. Although much can be learned from studying any time period during Earth's history, the best and most accurate findings will come from studying a period that holds most in common with the future climate state. In that way, one can better understand Earth's vulnerable system components.

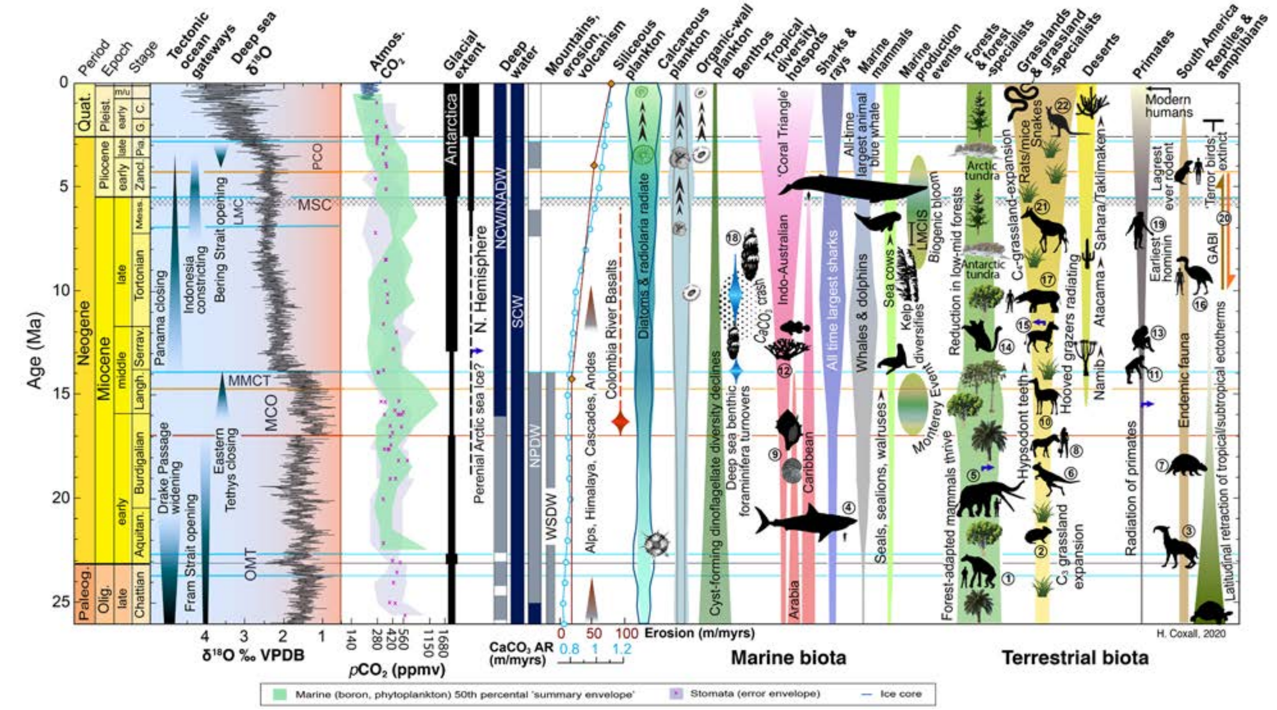
In a community effort to formally evaluate the Miocene as a future warm climate analogue, an international group of paleoceanographers, paleontologists, geologists and modellers came together at two workshops in Stockholm in 2018 and 2019. Among them were a group of Bolin Centre researchers; lead author Margret Steinthorsdottir, and co-authors Helen Coxall, Agatha de Boer, Natasha Barbolini, Steffen Kiel, and Thomas Mörs. The result was this review paper, *The Miocene: The Future of the Past*, and an associated special collection of papers published in Paleoceanography and Paleoclimatology.

While no past time period is the perfect analogue for the future, the authors found it likely that the equilibrium future climate state will bear more in common with the Miocene than with either the Pliocene (~5,3–2,58 million years ago) or the Eocene (~56–33,9 mya), other past warm epochs that have been suggested as future-climate analogues. In particular, the middle Miocene Climatic Optimum (MCO, ~17–14 mya) – a transient warming in the early–middle Miocene was identified as a potential strong near-future climate analogue. She explains that the aim is to "place what we know about the long term, broad-scale evolution of the global Miocene system in context of key scientific questions that are currently (at least partially) answered as well as those that remain unanswered to date".

The knowns and unknowns of the Miocene

The Miocene epoch is a time period characterized by a highly variable climate that was around 5–8°C warmer, but seemingly at atmospheric CO2 levels not much higher than todays. There were no continental-sized ice sheets in the northern hemisphere, only on Antarctica. Much of the geography that we see today was shaped by the tectonic activity during this time period, and many plants and animals had evolved to near modern-day species at this point in time.

By the late Miocene, important subsystems of our modern Earth had evolved and stabilized, such as perennial Arctic sea ice, stronger monsoon systems, the tundra/permafrost biome, modern-type forests and deserts and their ecosystems, and so on. She explains: "that these Earth system components, many of which are now viewed as 'vulnerable' to anthropogenic (caused by humans) climate change, switched on at this time, implies they have their 'tipping points' in the Miocene temperature/CO2 zone".



This figure is taken from the Steinthorsdottir et. al article The Miocene: the Future of the Past, *and provides an overview of Miocene changes in physical, geochemical and biological systems relevant to climate development.*

These findings concluded that the best available analogue for our future Earth affected by human caused climate change is the Miocene. Thus, many lessons can be learned by studying the Miocene. For example, models have forecasted that if global mean temperatures were to go up by 4°C, it would lead to the destabilization of critical climate subsystems. By studying the Miocene world, it could provide valuable insight into what our future climate could look like.

What significance does this review paper and its findings have for other fields in climate science?

"The review paper illustrates the enormous progress that can be made when a group of interdisciplinary scientists interested in a research question (here the many mysteries of the Miocene) work together towards a common goal. We make a strong argument that the Miocene represents a good future climate analogue and that studying this analogue raises some alarming issues, such as that CO2 concentrations not much higher than modern prevailed in the much hotter Miocene world. This may indicate that 'climate sensitivity' (the temperature rise per a given increase in CO2) may increase with rising temperatures. Of note is that the MCO has for the first time been included in the IPCC's latest assessment report (6th, 2021) as a 'Paleo reference period' of a particular interest, citing the review paper", explains Steinthorsdottir.

What's the best approach moving forward?

"In addition to the review paper and associated special issue, collaborations initiated at the workshops have resulted in the development and launch of a Miocene Temperature Portal, hosted at the Bolin Centre for Climate Research. The portal collates a list of key information about published Miocene ocean temperature records, enabling researchers to rapidly locate and evaluate datasets relevant to the study of Miocene climate change, significantly simplifying the arduous process of collating these datasets. The portal presently includes ocean temperature records only, with plans to expand to terrestrial records in the near future. Other outputs in progress include the initiation of a Miocene Model Intercomparison Project (MioMIP), as well as the planning of a third workshop in Utrecht in 2022", says Steinthordottir.

Margret Steinthorsdottir works as a researcher at the Museum of Natural History and is affiliated with the Department of Geological Sciences at Stockholm University. Margret is also one of the co-leaders for Research Area 6 *Deep time climate variability*. Her research focuses on the precise role of CO2 in climate change, and uses past climate change transitions as a "natural laboratory" to do so. Photo: Oskar Omne

The article *The Miocene: the Future of the Past* was published in Paleoceanography and Paleoclimatology on 23 December 2020. Access to the full article: *https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2020PA004037*.

The shape of the seafloor restricts melting of Ryder Glacier in northwest Greenland

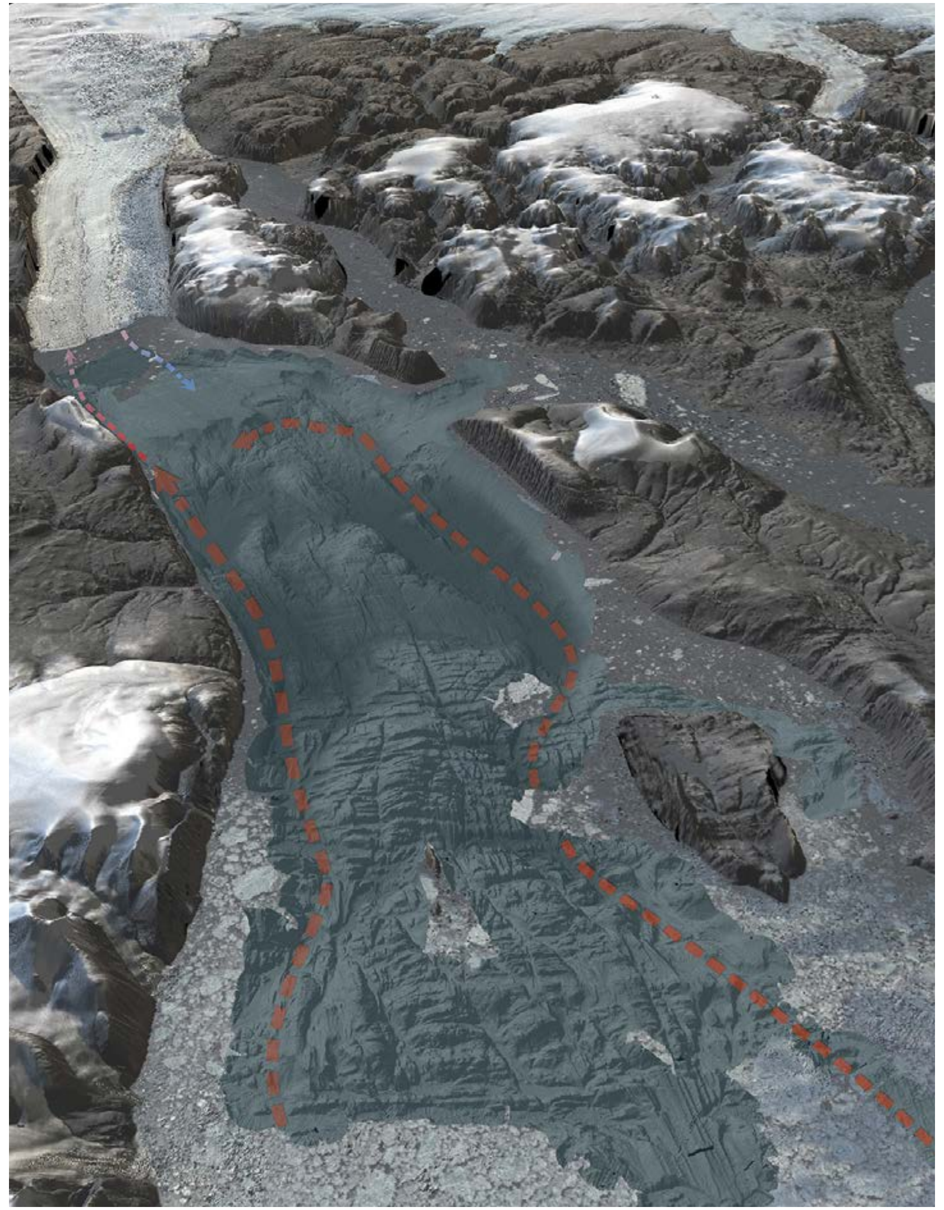
Glaciers and ice sheets around the world have been losing more than 700,000 Olympic swimming pools of water every day. Glaciers form by the transformation of snow into ice, which is later melted by the atmosphere in summer, or slides slowly all the way into the sea. With climate change, glaciers are melting and breaking up into icebergs, which feed into the ocean at an accelerating pace. Exactly how fast depends to a large extent on the shape of the seafloor and on the bed below all the ice. New bathymetric and oceanographic data collected by an international team of marine geoscientists provide important insights into the processes that are controlling the rapid loss of the Greenland Ice Sheet over the last four decades.

In 1997, the impact of inflowing warm water on glaciers with ice tongues stretching out in the sea was observed in western Greenland. The Jakobshavn Glacier thinned rapidly due to a sudden increase in subsurface temperature, associated with water inflows from the Irminger Sea near Iceland. When Jakobshavn Glacier lost nearly all of its ice tongue in the early 2000s, iceberg calving directly from the ice-cliff margin increased drastically. The shape of the seafloor has been suggested to play a vital role in this process. This is supported by a new study investigating the Ryder Glacier in North Greenland.

In late summer 2019, the Swedish icebreaker *Oden* ventured into the previously unmapped Sherard Osborn Fjord, where the Ryder Glacier drains into the Arctic Ocean. Melting and calving glaciers act as key catalysts for the increasing loss of ice sheet. Glaciers with their floating ice tongues buttress inland ice and help maintain the stability of the ice sheet. This controls the movement and velocity of the inland glacier. However, the more precise processes that controls the advance and retreat of outlet glaciers remain relatively unknown, limiting the ability to assess their fate and contribution to global sea-level rise.

After the data obtained in the two week *Oden* field campaign inside Sherard Osborn Fjord was analysed, it was revealed that warmer subsurface water of Atlantic origin enters the fjord, but Ryder Glacier's floating shelf – at its present location – was partly protected from the inflow by a bathymetric sill located in the innermost fjord. In other words, the inflowing warmer water of Atlantic origin is partly prevented from reaching Ryder Glacier by the shape of the seafloor. This reduces under-ice melting of the glacier and provides insight into Ryder Glacier's dynamics and its vulnerability to inflow of Atlantic warmer water. The data may also play a valuable role in undertaking assessments of the North Greenland Ice Sheet's future retreat.

Helicopter view over the Ryder Glacier ice tongue. Photo: Martin Jakobsson



3D-visualization showing the seafloor bathymetry of the previously uncharted Sherard Osborn Fjord in the north of Greenland. The red line illustrates the inflowing warmer water of Atlantic origin that is partly prevented from reaching Ryder Glacier by a bathymetric shoal. Illustration by Martin Jakobsson

The researchers also compared the data with observations from another outlet glacier that discharge ice into the Arctic Ocean. The Petermann Glacier, with a bathymetric sill located more than 40 km from the current ice-tongue terminus and a maximum depth of 443 m, is far more exposed to inflow of warmer Atlantic Water than Ryder Glacier, which is protected by the inner sill in Sherard Osborn Fjord with a maximum depth of 390 m restricted to a narrow, 1 km wide channel.

"The data we have collected aboard *Oden* provides an important insight into why the future mass loss of the Greenland Ice Sheet is complicated to assess. It also highlights the necessity of having a complete map of the ocean floor," comments Bolin Centre researcher Martin Jakobsson, Stockholm University.

The article *Ryder Glacier in northwest Greenland is shielded from warm Atlantic water by a bathymetric sill* was published in Nature's Communications Earth & Environment on November 4, 2020. The article can be accessed here: *https://doi.org/10.1038/s43247-020-00043-0*.

The research team on icebreaker Oden. Photo: Lars Lehnert

RESEACH HIGHLIGHT

New global database aids researchers in mapping threats to wetlands

Wetlands cover only 4–9% of Earth's land surface, but contribute to more than 20% of ecosystem services globally. They are also among the most vulnerable ecosystems on Earth, and are now under threat from both climate change and human activity. The impacts of such threats as well as different natural and manmade drivers influencing wetland conditions are not limited to just the local scale of each individual wetland, but extend over larger landscape areas that integrate multiple wetlands and their total hydrological catchment – the wetlandscape. However, our understanding of these interactions has been limited because data and knowledge of conditions and changes over entire wetlandscapes are still scarce. Bolin Centre researcher Navid Ghajarnia and co-authors have now developed a new global database that maps how these factors have changed at 27 wetlandscapes during a 30-year period. This new database makes it easier for researchers to study changes in wetlandscapes that are due to climate change and human activity.

Ecosystems that are covered by water during various time periods, it could be permanently (years or decades) or seasonally (weeks or months), are called wetlands. These could be either marshes and ponds, areas at low altitudes that are flood-prone, or the delta at the mouth of a river. They serve many important functions in the Earth system, among them being water quality remediation, regulation of soil moisture and groundwater replenishment, biodiversity conservation and so forth. Wetlands also store large amounts of carbon in the form of peat.

However, they are also one of the most vulnerable ecosystems on our planet. Human activity such as the development of land and water use, as well as climate change and variability, are now resulting in rapid and continued decline in wetland areas all over the world. The term *wetlandscapes* are used in this study to refer to wetlands that are interconnected with the larger surrounding landscape, by for example the hydrological cycle. This is an important perspective to apply because human activity and climate change does not impact wetlands as isolated areas. Ghajarnia further explains "the combination of high wetland vulnerability and rapid large-scale changes subject to major knowledge and data gaps highlights the need to synthesize and create datasets available for evaluating change effects and feedbacks at the scales of whole wetlandscapes".

Showing the Gialova lagoon wetland (on the right) and the Lonian Sea (Lonio Pelagos, on the left) in Greece. Photo by Navid Ghajarnia

WetCID – a new survey-based collection of local information and data about wetlands

Wanting to fill these knowledge and data gaps, a group of researchers came together to create a novel database, among them Bolin Centre researchers Gia Destouni, Josefin Thorslund, Zahra Kalantari, Imenne Åhlén, Fernando Jaramillo, Jerker Jarsjö, John Livsey, Britta K. Sannel, Samaneh Seifollahi, and Guillaume Vigouroux, in addition to lead author Navid Ghajarnia.

The database was named the Wetlandscape Change Information Database, WetCID for short, consisting of a survey-based collection of local information and data combined with gridded large-scale hydroclimate and land-use datasets. As seen in the figure, the database includes 27 wetlandscape sites around the world, and their associated geographical, wetland, hydrology, hydroclimate and land-use conditions. For each wetlandscape, there are gridded datasets representing 30-year time series of mean monthly rainfall, temperature, and annual averages for land uses and their changes.

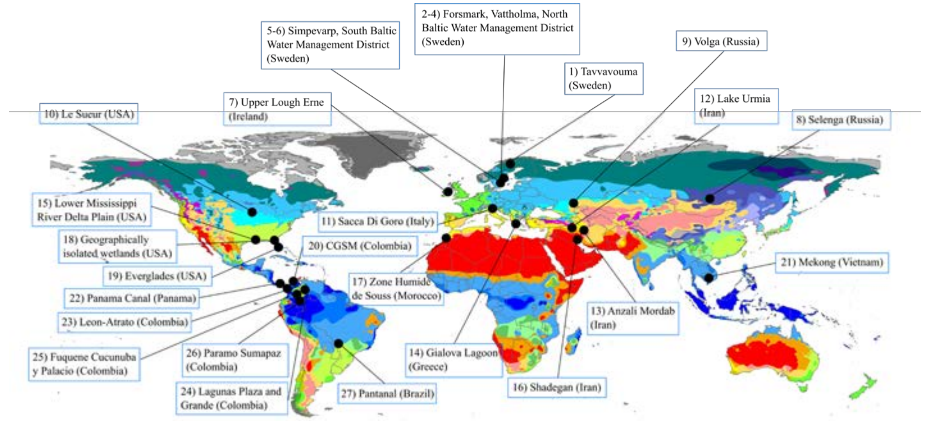
This new database can support site assessments, cross-regional comparisons, and scenario analyses of the roles and impacts of various land-use, hydroclimatic, and wetland conditions as well as the associated changes on the functions and ecosystem services of wetlandscapes. WetCID will also make it easier for climate researchers to identify and map potential threats to wetlands caused by climate change and human activity. Another valuable function of the database is that the information gathered there can guide researchers in identifying additional information or data gaps that needs further attention.

Did this database, or the research leading up to it, reveal something about wetlands and wetlandscapes that you and your colleagues did not know before this study was initiated?

"An interesting aspect of this work is the inclusion of local information on wetland changes that are hardly available for non-local researcher from online and public sources. For example, we have the summary information about the most noticeable changes in water quality and quantity of the wetlands and wetland's upstream hydrological catchments in the survey information forms, provided by local experts which is indeed valuable and unique data. Such information is normally not accessible to the public but WetCID makes it possible for international researchers to access these valuable information", explains Ghajarnia.

Who can access this database, and what do you think its primary use will be for?

"The WetCID database is publicly available through the PANGAEA repository (*https://doi.pangaea.de/10.1594/PANGAEA.907398*). Everyone with any type of research, education, or even commercial interest can have free access to the database, but must provide appropriate credit and citation after usage. The primary usage of WetCID is to study hydro-climatological characteristics of wetlands in connection with their surrounding environment (wetlandscape) and also to investigate impacts of different climatic and anthropogenic drivers on long-term changes of wetland ecosystems", says Ghajarnia.



This figure is taken from the Ghajarnia et al. article Data for wetlandscapes and their changes around the world, *showing the geographical distribution of the 27 wetlandscape sites included in the WetCID database.*

Navid Ghajarnia is a researcher at the Department of Physical Geography, Stockholm University. His research interests lie in global hydrology, water resources analysis, climate change, and data science.
Photo: Samaneh Seifollahi-Aghmiuni

The article *Data for wetlandscapes and their changes around the world* was published in Earth System Science Data on May 13th, 2020. Access the full article here: *https://essd.copernicus.org/articles/12/1083/2020.*

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 October 22nd of 2020. There were 22 short presentations given in Aula Magna by PhD students and post docs from all of our six departments as well as the Stockholm Resilience Center, to audience on site as well as via Zoom. A jury consisting of five members evaluated each presentation underhand and feedback with advice and suggestions on how to improve their presentation and presentation skills was given to each presenter. The Climate Research School awarded prizes to the best presentations, 20,000, 10,000, and 50,000 SEK, to be used in their research. A big congratulations to the winners:

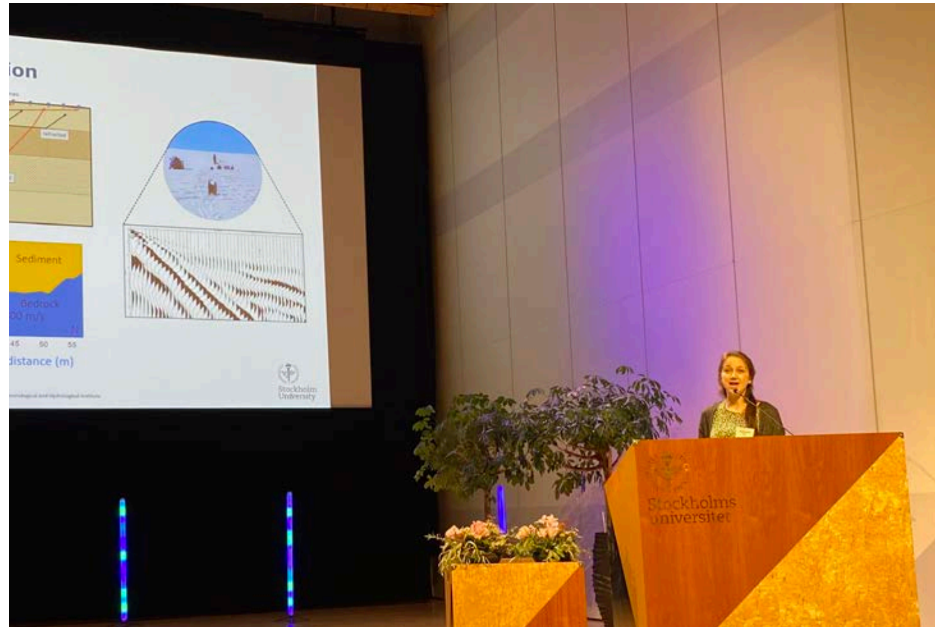
- First place: *Geophysics at Glacier Forelands* by Hannah Watts.
- Second place: *The archive value of peatlands* by Caroline Greiser.
- Third place I: *The mysterious Arctic aerosols – what are they and where do they come from?* by Karolina Siegel.
- Third place II: *Detailed Structure and Evolution of Energic Flow in the Baltic Sea Revealed by Wideband Acoustics* by Julia Muchowski.

In 2020, a cooperation was initiated between the Bolin Centre and ClimBEco Graduate School at the Centre for Environmental and Climate Science (CEC), Lund University. This widens the possibility for Climate Research School students to participate in courses and workshops offered by the ClimBEco programme, and for students 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.

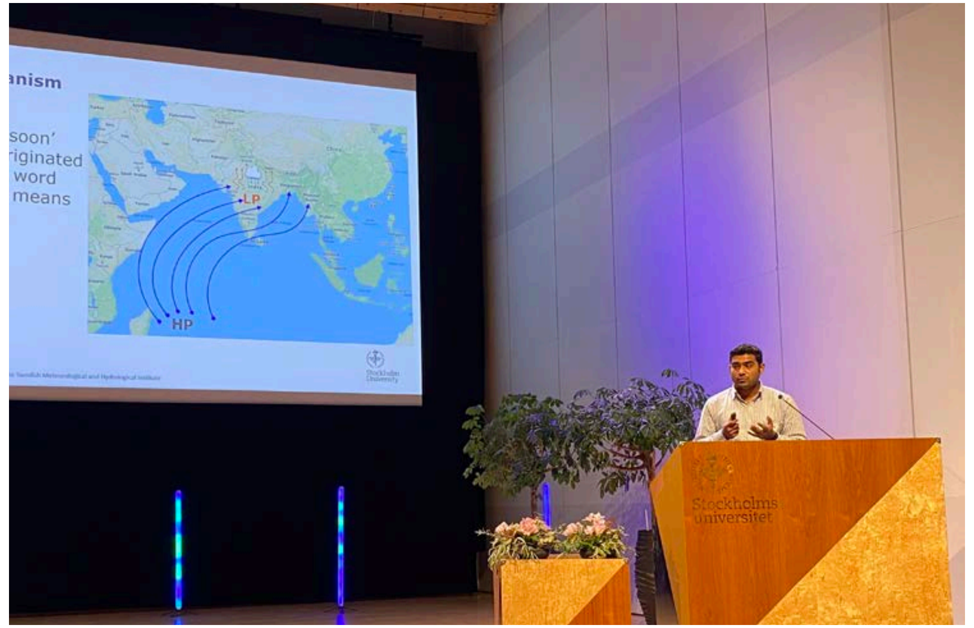
The courses offered are based on student feedback and demand, in other words, there is an active effort by the Climate Research School to provide courses that students deem valuable to their future career as researchers. During 2020, the course *Climate Science and the Anthropocene* was offered, other planned courses unfortunately had to be canceled due to Covid-19 restrictions.

Otto Hermelin is a senior lecturer and study director of life learning studies at the Department of Geological Science, Stockholm University. He has been doing research on large-scale climate variation, mostly based on proxies as microfossils and geochemistry. Photo: Magnus Atterfors

Carmen Prieto is a research engineer at the Department of Physical Geography, Stockholm University. She does research on the quantity and quality of water resources in different parts of the world. Photo: Magnus Atterfors



Hannah Watts from the Department of Physical Geography. Photo: Magnus Atterfors



Dipanjan Dey from the Department of Meteorology. Photo: Magnus Atterfors

Arjun Chakrawal from the Department of Physical Geography. Photo: Magnus Atterfors

Third price winners, Karolina Siege and Julia Muchowski. Photo: Magnus Atterfors

The Bolin Centre Database

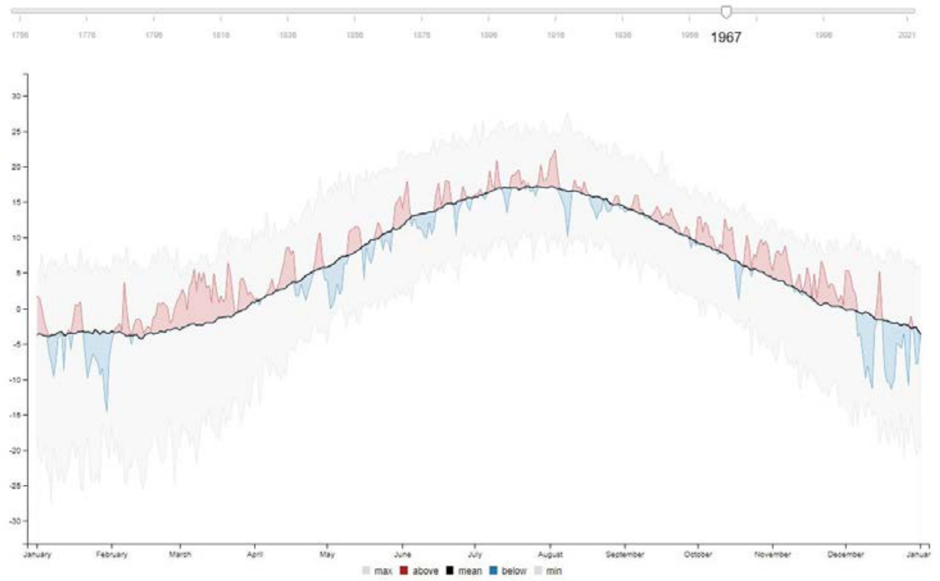
–provides open access to climate and Earth system data

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.

"There are other repositories that researchers can use to share their data. But we have the possibility to also visualize the research results from our centre in a unique way", says Anders Moberg. He works as a coordinator for the Bolin Centre Database (*www.bolin.su.se/data*), which contains 272 datasets as of February 2021. Even though that is only a small part of all data from Bolin researchers, the database gives an overview of what kind of research that is being performed.

Climate data visualized

In 2020, the concept of *data collections* was introduced, with possibility to include interactive graphics. "Stockholm Historical Weather Observations" was the first one, depicting weather observations from 1756 to present day in an interactive format. It is one of the world's longest records of meteorological observations, and provides invaluable information about weather and climate change for more than 260 years. With the cursor, the visitor can select temperature for a specific year and compare it with the long-term average (1756–2005). The daily mean temperature for each date in the selected year is shown, as well as the long-term average and range between the highest and lowest recorded daily mean temperature for each calendar date. New temperature data is uploaded on a daily basis. Check it out!



Daily mean temperatures in Stockholm each year. Black curve: Long-term average (1756–2005) daily mean temperature for each calendar date. Red/blue curve: Daily mean temperature for each date in a selected year. Grey band: Range between highest and lowest recorded daily mean temperature for each date, within the first 250 years of data. On the top slider bar, the the visitor can select a specific year.

Ocean floor data indicating past ice-flows

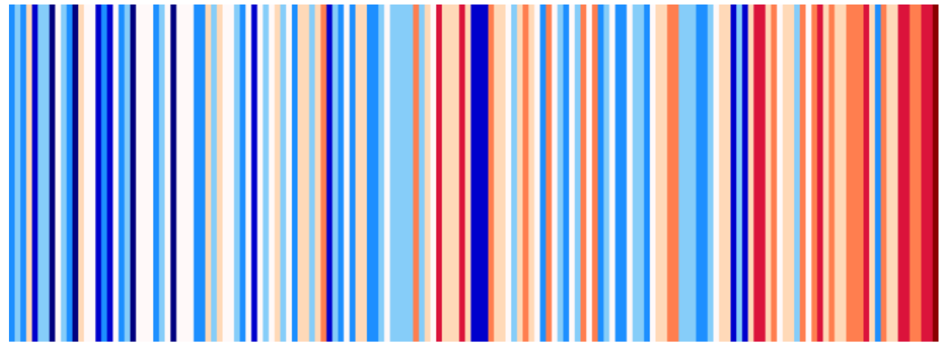
The collection for the Ryder 2019 expedition, to the Arctic Ocean off Northwest Greenland, contains several types of data. The bathymetric data shows high-resolution pictures of the ocean floor. It reveals an abundance of submarine glacial landforms indicating past ice-flows of the North Greenland Ice Sheet through Nares Strait and out of the mapped fjords. The collection also contains oceanographic data, marine chemistry data, meteorological observation data and a glacier calving front imagery – the latter showing in detail how glacier calving happens. In the near future, the plan is to create similar collections for many of the earlier expeditions on icebreaker *Oden*.

Warming stripes shows temperature development

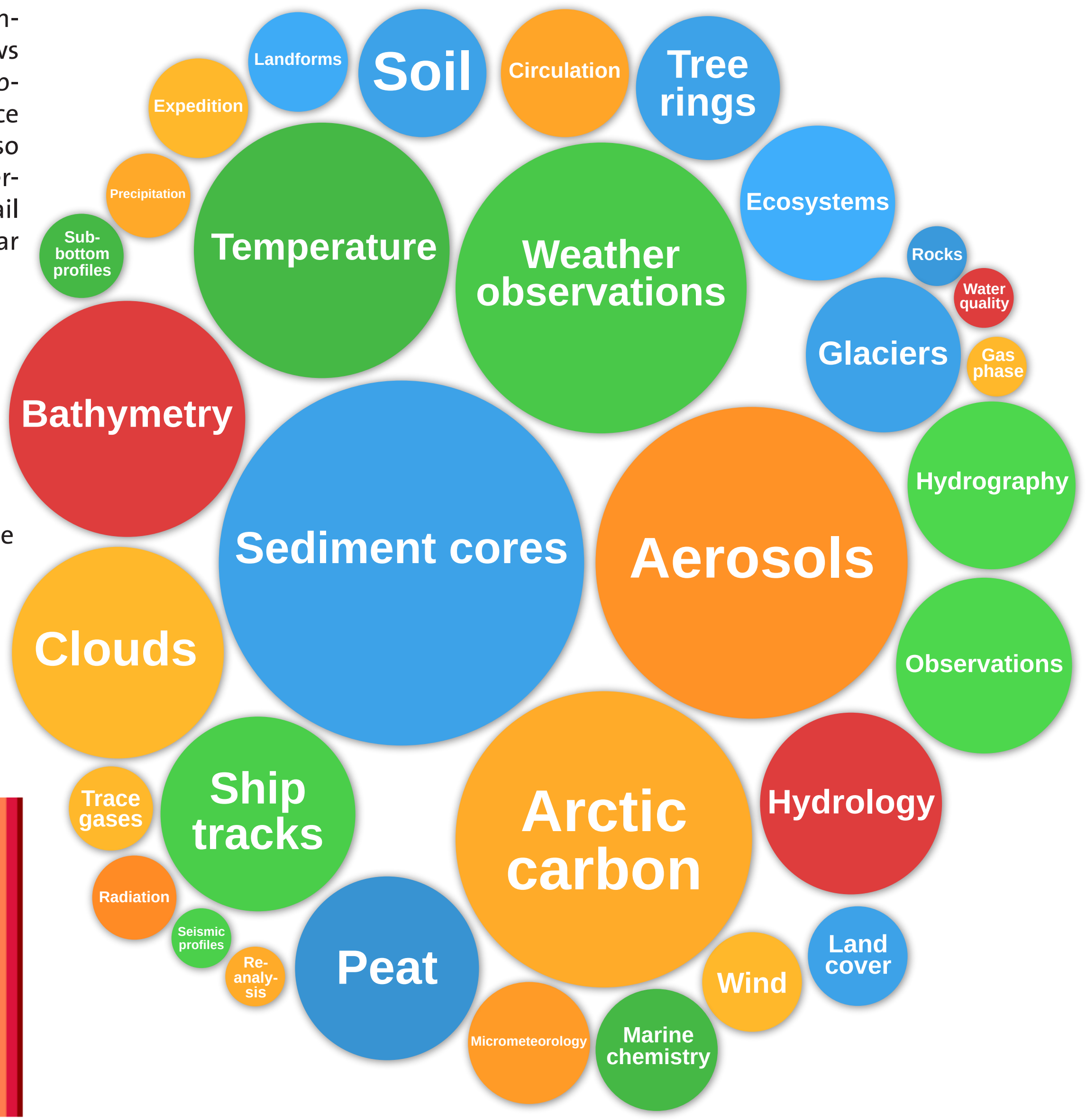
Warming stripes is a way of concisely describing changes in mean annual air temperature at a specific place over a long period of time. For each year where measurements are available, a stripe is drawn; in shades of blue if the year was cold, in shades of red if the year was warm. The result is a barcode-like picture representing the development of the annual mean temperature. The method can also be used to visualize future climate scenario data together with observation data in one and the same picture.

"By adding data visualisations to data collections or individual datasets, the database connects data and research with communication," says Rezwan Mohammad, technical manager for the Bolin Centre Database.

www. bolin.su.se/data



Warmings stripes visualize the ongoing warming. The picture shows annual mean temperature in Sweden between 1860–2020.



The Bolin Centre database contains different types of data, organized in various categories as shown in this figure. The size of the bubbles represent the amount of data that the database holds in each category.

Bolin Centre modelling and 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.

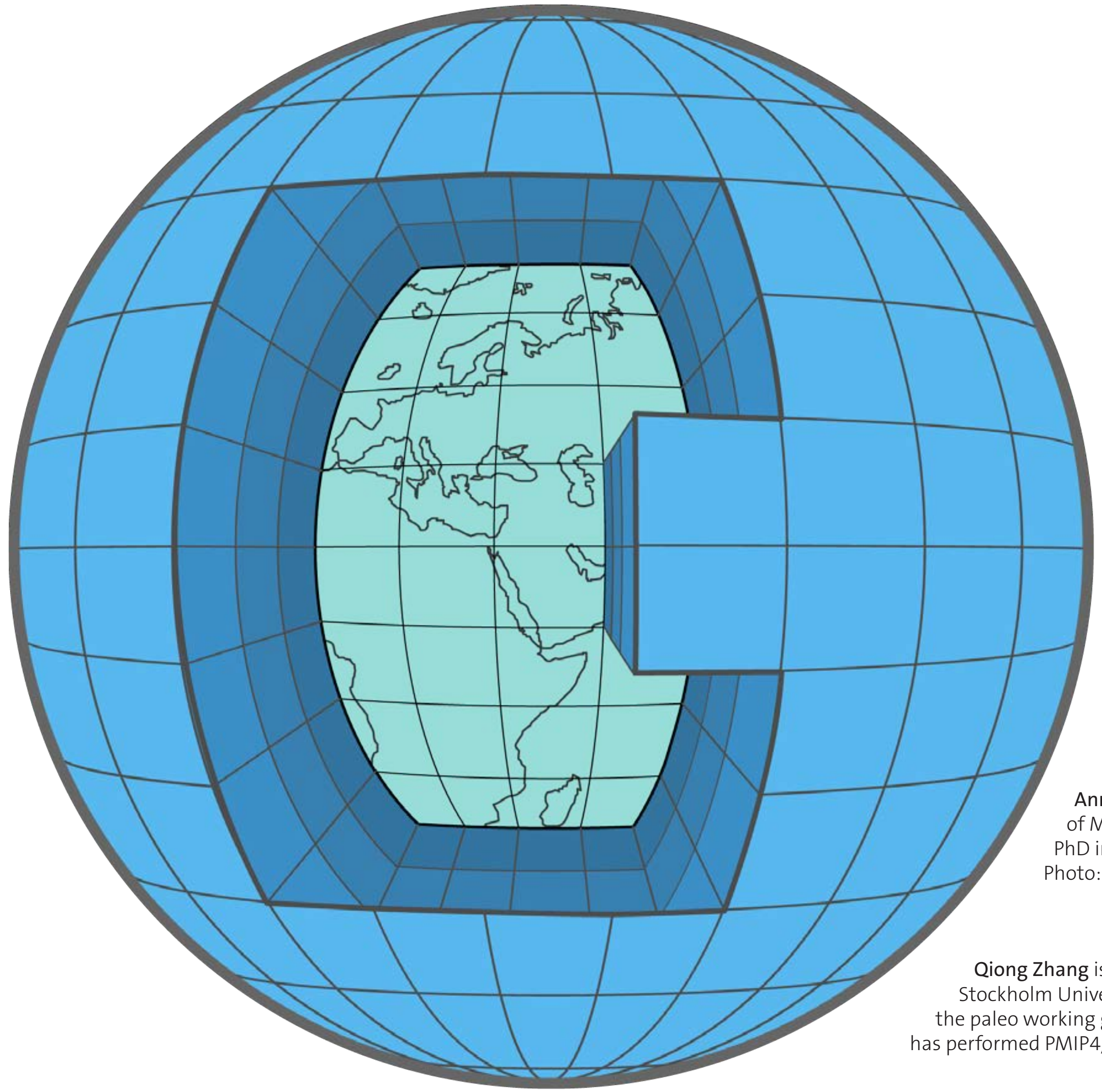
Climate models are important tools for improving our understanding and predictability of climate behavior on seasonal, annual, decadal, centennial and millennial time scales. The Bolin Centre uses the climate models EC-Earth and NorESM to understand how the Earth's climate varies in time and space, and 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 links up interested junior and senior researchers in a mentor-mentee relationship. A mentoring year runs from the Bolin Days in November each year for at least one year at a time. The initiative started in 2012, and normally has 20–30 mentor and mentee pairs.

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 an associate professor in Physical Oceanography and Paleoclimatology at the Department of Geological Sciences, Stockholm University. She uses climate models to investigate the role of the ocean in climate, now and in the geological past. Photo: Eva Dalin

Malin Kylander has a PhD in Environmental Geochemistry from Imperial College London, UK and is now at the Department of Geological Sciences, Stockholm University. Kylander's work looks at past climate change using lake sediments and peats. Photo: Eva Dalin

Photo: Sara Cousins

Communication and coordination

The coordination and communication 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.su.se* website, and also provides our members with a weekly 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 both smaller and larger events.

2020 was an unprecedented year with lots of unforeseen events due to the ongoing covid-19 pandemic. This required us as communicators and coordinators to quickly redirect our efforts to make sure that the planned events did not get cancelled, since we firmly believe that dealing with the climate crisis cannot wait.

The annual Bolin Days, which is our largest internal event, took place on November 25th–26th. It was digitalized using a hybrid event platform as well as Zoom. This allowed our researchers to still meet, mingle and share research results without the need to meet physically. Despite it not being the Bolin Day's that most of us are used to, the conference had 230 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 six digital seminars were carried out during the year, with four of them being translated into virtual seminars. 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.

Bringing climate science to the public

The Climate Festival was carried out between May 19th and 21st, and is our flagship outreach event for middle- and high-school students, teachers, and people from the general public. It was set to be our biggest yet, with a five day-program instead of three, ending the festival big on the main stage in Kungsträdgården. However, by mid-March when the pandemic hit, we had to quickly regroup and digitalize the festival in its entirety. The new program was shortened but included livestreamed popular science lectures, interactive activities, virtual visits in labs and greenhouses at Campus Frescati, and much more. We had in total over 2,000 pupils and persons from the interested public attend our popular science lectures and activities via the Zoom platform, and reached an audience of over 100,000 people from all over Sweden and Europe through our social media posts. Popular science lectures that were posted to our Facebook page had 18,000 viewers, and the likes for our page increased by 1,682%. The popular science lectures as well as the full program on the last day of the festival 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 2020.

One of the interactive digital activities offered during the Climate Festival. This activity, titled Flax – migratory birds & the climate, *is aimed at middle- and high school students and led by staff from Vetenskapens Hus. Photo: Vetenskapens Hus*

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, two policy briefs were produced. The first one, titled *Aviation, climate and the 'high altitude effect*, was published in October of 2020. The second policy brief was published in November of 2020, titled *Making and educated decision about carbon offsetting*. A third policy brief was also started, covering the subject of carbon capture and storage (CCS), set to be published in early 2021. All the policy briefs can be found and read at our home page, *bolin.su.se*.

Bolin Centre co-director Alasdair Skelton giving his virtual popular science lecture at the Swedish Royal Museum of Natural History, taped by UR Samtiden. Photo: Vetenskapens Hus

Wanting to build a stronger network with the media, the Bolin Centre Journalist Breakfast sessions were initiated. The breakfast sessions are thought 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. A total of two sessions were carried out, one in May and the other one in December of 2020. Relationships were formed with journalists from public services as well as private media companies, and a strong foundation was built for further collaboration and synergies.

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 organisations.

Magnus Atterfors joined the Bolin Centre in April 2020. He holds a master in Media and communication and political science and has worked at RISE Research Institutes of Sweden, The Swedish Research Council and, earlier, as a freelance writer and editor. Photo: Laila Islamovic

Annika Granebeck has been working as a communicator and coordinator at the Bolin Centre since 2017. She has a master of science in geography, and has worked at different centres of learning in academia and in non-profit associations with focus on climate and environmental issues. Photo: Inês Jakobsson

Laila Islamovic joined the Bolin Centre as a communicator in January of 2020. She recently earned a bachelor's degree in communication, with a focus on environmental communication, at University of Southern California. 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 12th Bert Bolin Climate Lecture was a virtual webinar given on May 11th, 2020 by Roberto Buizza, Full Professor in Physics at Scuola Superiore Sant 'Anna in Pisa, Italy.

The lecture was titled *Climate change: How can we motivate transformation?* Climate change is here and we have to deal with it. Observations give us evidence of what is happening, and science helps us understand how we got here. Technology is available to address the problem, and the investments needed to transform human activities are manageable. Yet, why have we not taken impactful actions? Why do governments keep talking about future goals, while they fail to put in place policies that can trigger immediate and effective actions? In this talk, Professor Buizza discuss these aspects and how we can motivate a radical transformation.

Professor Buizza is an expert in numerical weather prediction, ensemble methods, and predictability, and has more than 200 publications of which 100 in the peer-reviewed literature. Since joining Sant 'Anna, he has been very active in communicating climate science to the public, and works on initiatives aiming to promote immediate and impactful actions dealing with climate change. Professor Buizza has also been working to establish a new initiative on climate with the support of the three Scuole Universitarie Federate (Sant 'Anna, Scuola Normale Superiore of Pisa, and Scuola IUSS of Pavia).

Professor Roberto Buizza, Centre Pompidou 2019. Photo: Private

Lecturers

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

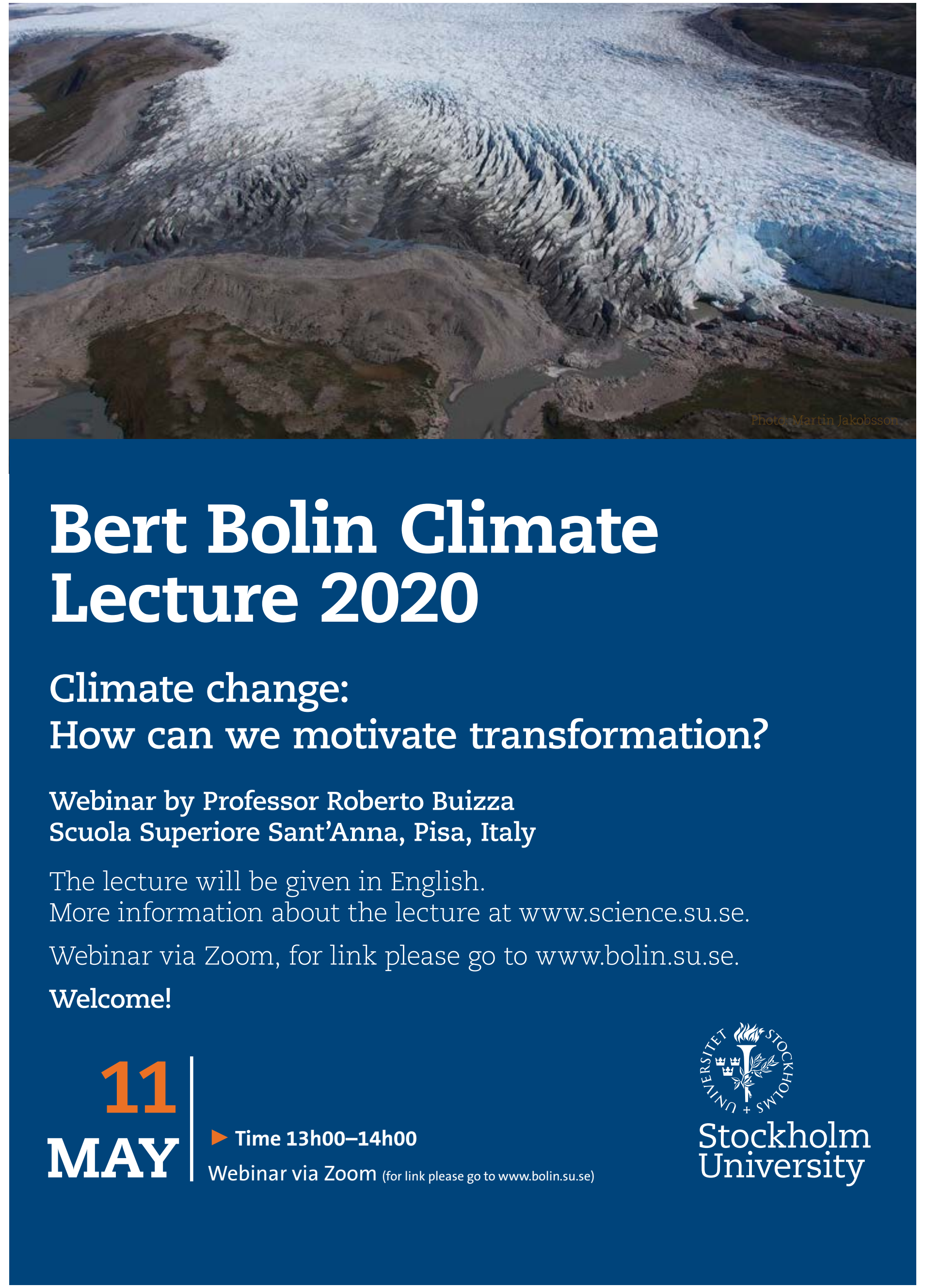
2012 | Professor Sherilyn Fritz
The climate during the past 10,000 years

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 comprises 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 and external member and a student representative.

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

Professor Magnus Breitholtz
Department of Environmental Sicences, 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
KTH, Royal Institute of Technology, Stockholm.

Professor Bengt Karlsson
Department of Zoology, Stockholm University.

Anna-Karin Nyström, MSc
Swedish Environmental Protection Agency.

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

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, Coordinator 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.

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

Lake Tarfala. Photo: Annika Granebeck

The External Science Advisory Group

The Bolin Centre has appointed an External Scientific Advisory Group which comprises 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 Maureen E. Raymo
Bruce C. Heezan Lamont Research Professor and Director at Lamont-Doherty Core Repository of Columbia University.

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

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

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

Professor Raymond T. Pierrehumbert
Halley Professorship of Physics at the Department of Physics at University of Oxford, UK.

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

In a world of fast climate change and worrying reports of a decline in number of species on Earth it is important to know why new species evolve while others get extinct. The course Speciation and extinction in time and space *is about these issues, and interested course participants have been offered to visit and see prime examples on fast speciation in the Galápagos archipelago. The phot shows a Sally Lightfoot carb on the barren lava fields of Santiago, Galápagos. Photo: Otto Hermelin*

External grants awarded during 2020

One way to present an overview of the research initiatives that Bolin Centre members are involved in the upcoming years is to list the grants awarded. Here we present the grants that Bolin Centre members received during 2020. They include, but are not limited to:

European Research Council (ERC) Consolidator Grant, *Soil Microbial responses to land use and climatic changes in the Light of Evolution (SMILE)* (ERC-2020-COG 101001608). 1,69 MEUR, Stefano Manzoni.

European Research Council (ERC), *Compound Climate Extremes in North America and Europe: from dynamics to predictability (CENÆ).* ~1,5 MEUR, Gabriele Messori.

European Research Council (ERC), *Next generation Earth System Models (NextGEMS)*. Project lead: MPI Hamburg, total budget; 11 MEUR. 783,750 EUR to Stockholm University and Bolin Centre researchers Frida Bender and Thorsten Mauritsen.

Horizon 2020 (LC-SFS-22-2020 – Forest soils Research and Innovation Action), *Holistic management practices, modelling and monitoring for European forest soils* (main applicant: R. Mäkipää, 101000289 – HoliSoils). ~10 MEUR in total, 375,119 EUR in Stockholm University budget, co-applicant: Stefano Manzoni.

Horizon 2020 Marie Skłodowska-Curie Actions, Individual Fellowship, *DECRYPT: Drivers of Ecosystem Collapse and Recovery across the Permo-Triassic.* 214,160 EUR, Lead PI: Natasha Barbolini.

International Continental Scientific Drilling Program: Full Proposal Funding, *The Nam Co Drilling Project, Tibet (NamCore): A One Million Year Sedimentary Record from the Third Pole*, US$ 1,500,000, Lead Co-PI Natasha Barbolini.

Knut och Alice Wallenbers Stiftelse (KAW), *PlantEra: Biomolecular and structural comparisons of ancient and modern plants– tools for tracing phylogeny and survival strategies during mass extinctions*. 28,6 MSEK over 5 years, Vivi Vajda (Swedish Museum of Natural history) and co-applicant Allan Rasmusson, (Lund University).

Mistra, *Mistra Food Futures: Achieving a sustainable and resilient Swedish food system in a global world*. 64 MSEK during 2020–2024. (ca 12 MSEK for SRC/SU), Line Gordon, main proposal led by Helena Hansson and Per-Anders Hansson at Swedish Agricultural University. Collaboration between SRC/SU, SLU and RISE.

REA (European Commission), *European Weather Extremes: Drivers, Predictability and Impacts (EDIPI).* ~4,8 MEUR, Gabriele Messori (coordinator/lead PI) plus several co-PIs in Sweden and abroad. Rodrigo Caballero, also member of the Bolin Centre, is one of the co-PIs.

EDIPI European weather in Europe, EU MSCA ITN grant, 3,8 MEUR total funding, co-PI: Rodrigo Caballero.

Swedish National Space Agency (Rymdstyrelsen), *Arctic Atlantic Water and the topographic railroad: mechanisms and future change of Arctic Ocean circulation studied using satellite altimetry and GRACE data*. 4,23 MSEK, Johan Nilsson.

Swedish Research Council (VR), *Constraining the climate-scale impact of aerosols on cloud droplet number concentration.* 3,45 MSEK, Annica Ekman.

Swedish Research Council (VR), *A long term perspective on Arctic Atlantic Water interactions with North Greenland's Cryosphere.* 3,38 MSEK, Johan Nilsson.

Swedish Research Council (VR), *The Arctic cryosphere at the Last Interglacial; an analogue for the future?* 3,38 MSEK, Agatha de Boer (PI), Helen Coxall (Co-I), Torben Koenigk (Co-I).

Swedish Research Council (VR) Research Grant, *Does nutrient limitation promote carbon storage in forest soils?* (VR 2020-03910), 3,85 MSEK, Stefano Manzoni.

Swedish Research Council (VR), *Integrative studies of diversity and evolutionary history of tropical plants in Madagascar through mass extinctions*. 400,000 SEK over 2 years, Vivi Vajda & co-applicant Sylvain Razafimandimbison (Swedish Museum of Natural history, Dept. Paleobiology and Botany respectively).

Swedish Research Council (VR) project grant, *Reconstructing hydroclimatic extremes across south-eastern Africa using paleo-data and climate modelling*. 2,79 MSEK over 3 years, Elin Norström.

Swedish Research Council (VR), *Utsläpp av klimatpåverkande substanser från ofullständig förbränning i södra Asien: Källbestämning med multipla isotoper*. 3,45 MSEK, August Andersson,

Swedish Research Council (VR), *Överbrygga klyftan mellan egenskaperna hos färsk havssprut och aerosol observerad i det marina gränsskiktet*. 3,45 MSEK, Claudia Mohr.

Swedish Research Council (VR), *Luftmassors omvandling och påverkan på klimatkopplingen mellan Arktis och mellanbredderna*. 3,87 SEK, Gunilla Svensson.

Swedish Research Council (VR), *Kalibrering av Norra ishavets klimathistoria en miljon år tillbaka med nanofossil och forntida DNA*. 3,84 MSEK, Matt O'Regan.

Swedish Research Council for Sustainable Development (FORMAS), *Scandinavian Storminess during the Holocene: Separating the Signals*. 2,96 MSEK, Malin Kylander.

Swedish Research Council for Sustainable Development (FORMAS), *Less but Better Meat: What is the scientific basis?* 2,98 MSEK, Line Gordon in collaboration with Elin Röös at SLU.

Belmont Forum (through Formas), *Marine Arctic Resilience, Adaptation and Transformations*. Co-applicant and PI: Juan Rocha Gordo, 4 MSEK from Formas, and ~4 MSEK from NSF and NCERC.

Swedish Research Council for Sustainable Development (FORMAS), *Inequality and the biosphere: achieving sustainable development goals in an unequal world*. ~20 MSEK, Co-applicant: Juan Rocha Gordo, PI: Carl Folke.

Swedish Research Council for Sustainable Development (FORMAS), *Finanschocker i nätverk – hur finanssektorn kan drabbas av dominoeffekter i klimatet och ekosystem*. ~4 MSEK, Co-applicant Juan Rocha Gordo, PI: Victor Galaz.

Swedish Research Council for Sustainable Development (FORMAS), Early Career Research grant, *Seeding transformative futures for people and nature in Africa*. 4 MSEK, Laura Pereira.

Swedish Research Council for Sustainable Development (FORMAS), *Rethinking water in the landscape - co-creating knowledge and pathways for collective climate action*. 3 MSEK, Erik Andersson and Maria Tengö.

Swedish Research Council for Sustainable Development (FORMAS) Early-career researchers (FORMAS 2020-01000), *A paleoclimate perspective on recent European summer heatwaves and droughts*. 3 MSEK, Frederik Schenk.

Swedish Research Council for Sustainable Development (FORMAS), *Analys av hundraårig vindhastighetsvariabilitet från ett räddningsprojekt för historiska väderdata i Sverige*. 2,96 MSEK, Erik Engström, Cesar Azorin-Molina, Deliang Chen, Erik Kjellström.

Swedish Research Council for Sustainable Development (FORMAS), *Trender i aerosoler och uppvärmning i norra Europa*. 879,800 SEK, Paul Glantz.

Swedish Research Council for Sustainable Development (FORMAS), *Förvaltning av ekosystemtjänster för hållbar produktion av ris i Mekong Deltat i Vietnam*. 2,99 MSEK, Håkan Berg.

Swedish Research Council for Sustainable Development (FORMAS), *Plastföroreningar: ett globalt social-ekologiskt systemperspektiv på utmaningarna*. 2,99 MSEK, Sarah Cornell,

Swedish Research Council for Sustainable Development (FORMAS), *Klimatdrivande BC+sulfat aerosoler samt CH4 och CO från Indien: Observationsbaserade bestämningar av källorna genom isotopavtryck*. 2,99 MSEK, Örjan Gustafsson.

Swedish Research Council for Sustainable Development (FORMAS), *Oförutsedda allianser och rivalitet bland vänner: Hur aktörers olika intressen i relation till komplicerade miljöproblem leder till både samverkande och motverkande intressekoalitioner*. 2,99 MSEK, Örjan Bodin.

Swedish Research Council for Sustainable Development (FORMAS), *Begränsning av osäkerheterna kring viktiga klimatpåverkande komponenter från storskaliga bränder i Afrika*, 2,95 SEK, August Andersson.

Swedish Research Council for Sustainable Development (FORMAS), *Vi svälter innan vi blir sjuka: Korta- och långsiktiga effekter av corona-pandemin för informella arbetare i det urbana Afrika*. 2,99 MSEK, Ilda Lindell.

Mannerfelt Fund of SEB Foundations, *Water availability prediction under multiyear droughts*. 121,500 SEK and Ahlmann Fund: 15,000 SEK, Sina Khatami.

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.

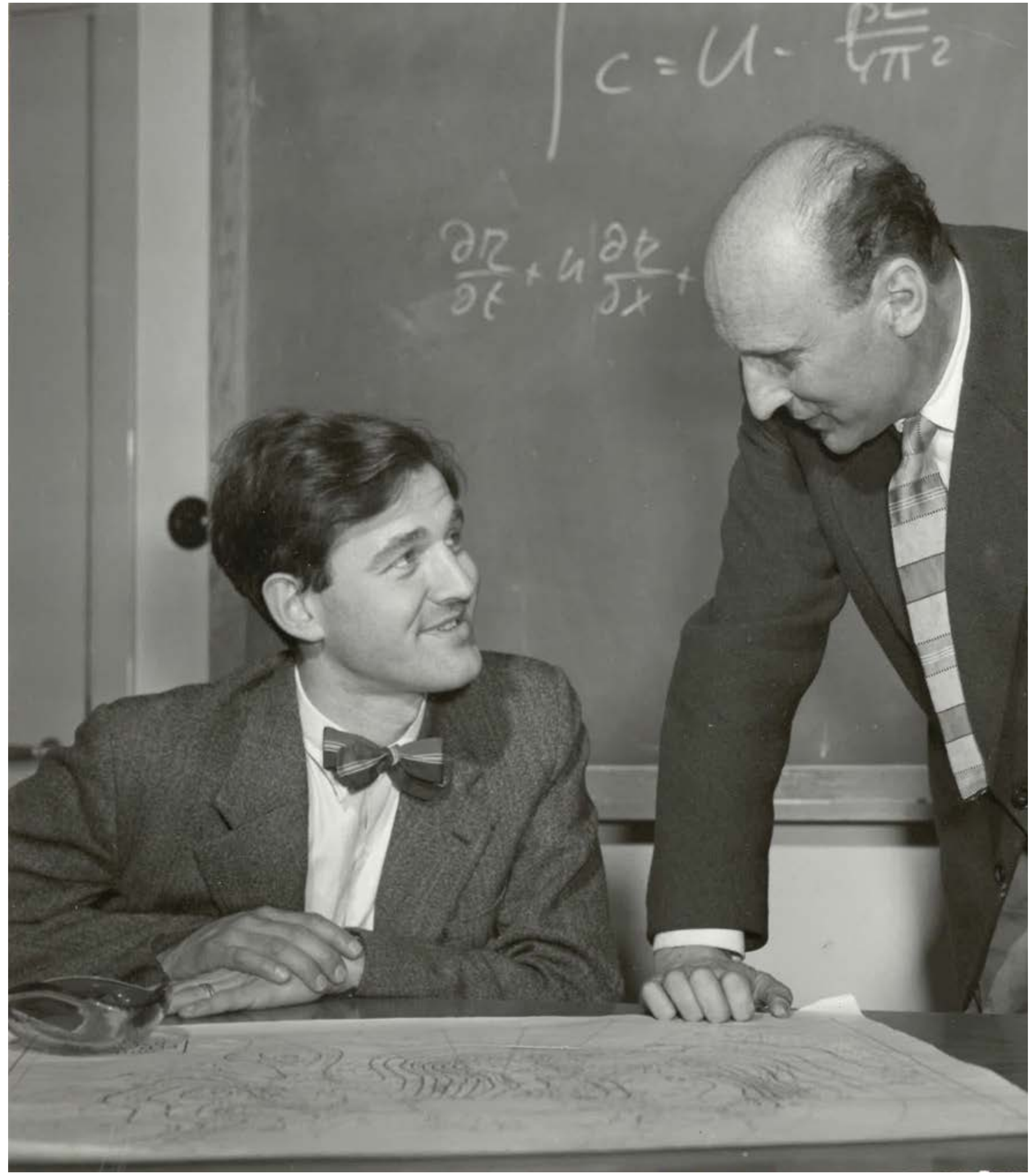
Bert Bolin was not only a prominent scientist. His role as an inspirer and organiser of international climate research has been of outstanding importance. Due to his broad and deep scientific knowledge, his unusual ability to see the big picture, his eminent ability to express himself orally and in writing, 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.

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

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



Bert Bolin defended his PhD thesis in 1956.
Photo credit: MISU, Department of Meteorology, Stockholm University

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.

Bolin Centre for Climate Research | Stockholm University | KTH | SMHI

ISBN print: 978-91-89107-22-9
ISBN pdf: 978-91-89107-23-6