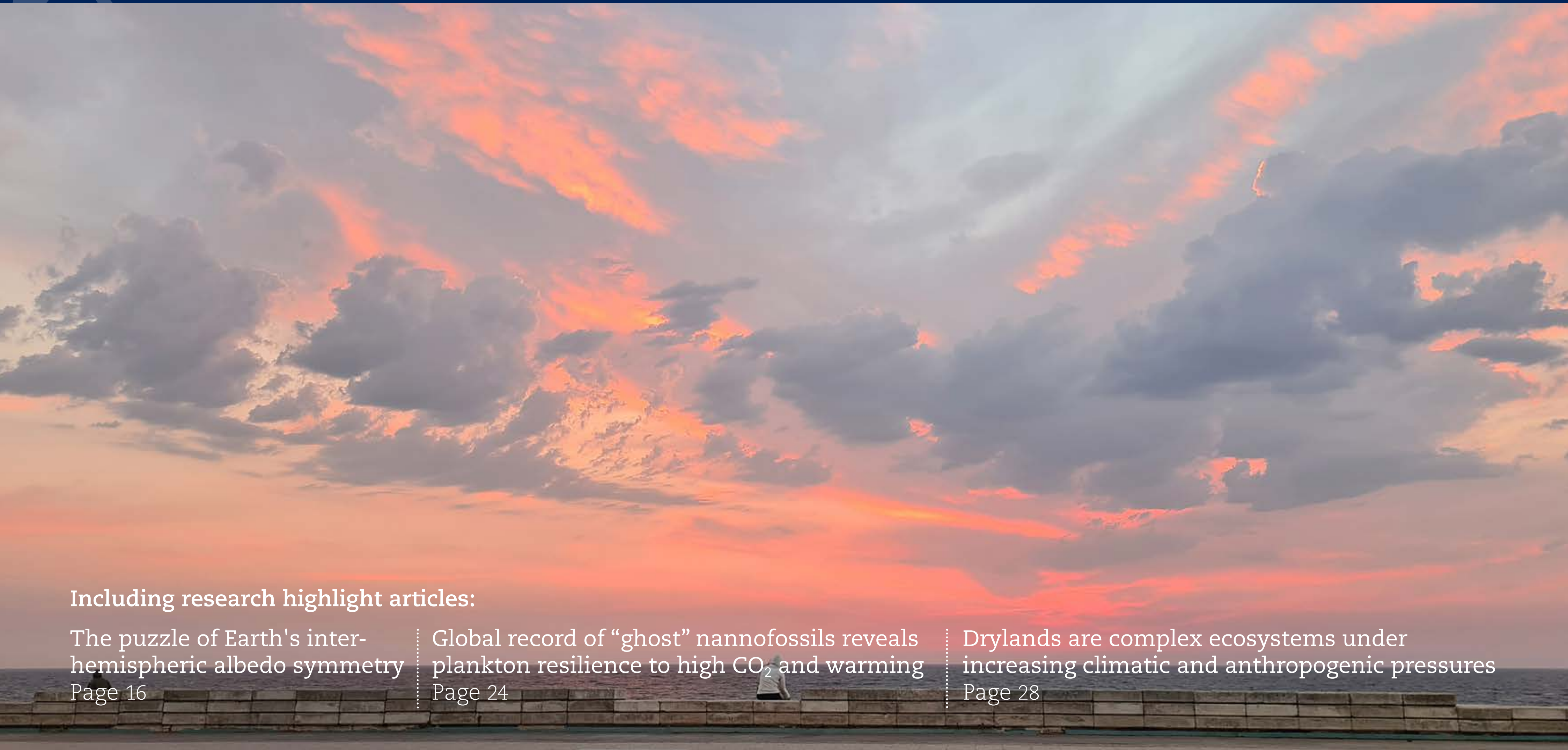
Bolin Centre for Climate Research

Annual Report 2022



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Bolin Centre Mission

The mission of the Bolin Centre is to create and communicate fundamental knowledge about the coupled climate system and its interactions with life on Earth in the past, present and future, and to connect this knowledge to effective societal actions.

Bolin Centre Vision

Our vision is for the Bolin Centre to be a thriving research environment at the international forefront, uniting experts across disciplines, training future generations of climate scientists, and delivering climate knowledge that supports societal action to mitigate and adapt to climate change.

Cover photo: Inês Jakobsson
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Graphic layout by Inês Jakobsson. Printed by Ljungbergs Tryckeri AB, 2023.

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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 fundamental knowledge about the coupled climate system and its interactions with life on Earth, 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 on climate mitigation and adaptation policies nationally and internationally.

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

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. In 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. As a result of the merger, the Bolin Centre's strategic funding now surpasses 20 MSEK per year.

In 2022, the Bolin Centre began a process of redefining its strategic plan and restructuring its organisation, with the aim of enhancing its impact on various climate-related research disciplines and within Earth system science.

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 follows four Research Themes (RTs), where scientists from different disciplines come together to tackle key questions about climate. The Bolin Centre organises seminars, workshops, conferences, outreach projects and research education.
The Bolin Centre aims to foster collaboration and interdisciplinary research among climate scientists. To this end, the centre has established four Research Themes that bring together experts from diverse fields to address key questions related to climate. In addition, the Bolin Centre organises a range of activities, such as seminars, workshops, conferences, and outreach projects, and also provides research education opportunities.

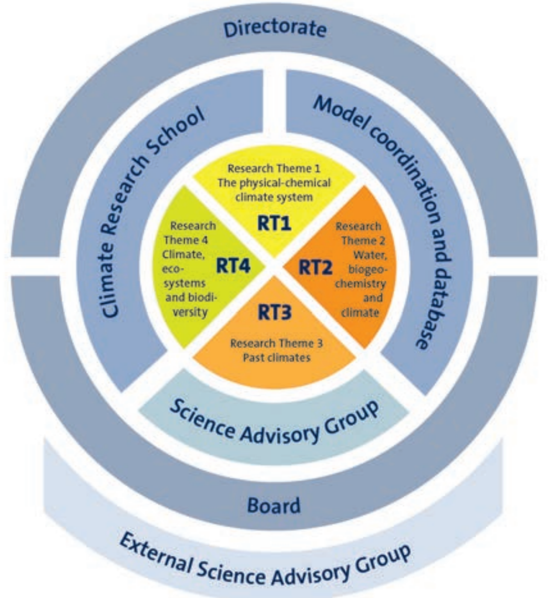
The Bolin Centre is built around its four multi-disciplinary Research Themes, each of which is led by two (or three) scientists:

- Research Theme 1 | The physical-chemical climate system
- Research Theme 2 | Water, biogeochemistry and climate
- Research Theme 3 | Past climates
- Research Theme 4 | Climate, ecosystems and biodiversity.

The centre hosts a research school and an open-access database and also provides communication support and support for climate modelling activities.

The directorate consist of a director, a co-director and a coordinator, who share the centre's daily tasks. All Research Themes' co-leaders and the directorate meet regularly in the Science Advisory Group, working to support climate-related science conducted by the Bolin Centre members.

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



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

Directors' corner

The Bolin Centre has evolved from an idea among a few inspired individuals to a thriving research hub with 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.

This has been a year of transitions and new beginnings for the Bolin Centre. In 2022 the leadership and directorate staff were entirely renewed. We welcomed our new coordinator, Maria Basova, in September 2022. She has done an impressive job, taking ownership of the numerous internal processes and events within our broad centre. Together with our members, our board, the Scientific Advisory Group (SAG), and with valuable input from the External Science Advisory Group (ESAG, see p. 42), we have put together a new strategic plan, mission and vision for the centre for 2023–2027. The strategic plan focuses on the role of the Bolin Centre as the hub for world-class climate research, education and communication, providing a solid foundation for decision-making and addressing societal challenges related to climate change.

Although we have focused on our organisation, much that is visible also to the outside world has happened within the centre. The scientists within our Research Themes (RTs) have yet again produced exciting and high-quality research (see RT highlights, p. 14–29) ranging from understanding the fundamentals of the global energy balance and climate system responses to the ways that species and ecosystems respond to climate change. Many of the highlights underline the important, yet uncertain, role of the biosphere under past and future climate change. During 2022 we also, for the first time, organised the climate festival in conjunction with ForskarFredag and in close collaboration with Vetenskapens hus (see p. 37). The event was a success, where Bolin Centre scientists met with several hundred high school students to discuss e.g., the role of clouds and wetlands in the climate system, but also to demonstrate how the dietary choices that we make every day influence greenhouse gas emissions. Within the Bolin Climate Research School, we have started a process of expanding our activities also to post-doctoral researchers. We are also analysing how well the courses and activities that we offer meet the needs of the early career researchers within the centre. During 2022, the Bolin Centre Database became a part of the central Research Data Management team at Stockholm University. Recently, the Bolin Centre Database also became a flagship project within the Swedish National Data Service. Both of these developments demonstrate the weight and importance of the Bolin Centre Database as a pioneer of research data storage, publication and sharing both within Stockholm University as well as nationally. The Bolin Centre also offers research support in the form of model coordination. This organisation has been following and providing input on the developments of the reorganisation of Swedish high-performance computing, while also continuing to support Bolin Centre scientists in their computational needs on a day-to-day level.

These ongoing changes pave the way for our continued support of the climate science community and society. Our contributions are meaningful, true to the academic core values, yet comprehensive and we are fearless in sharing the knowledge that we generate and nurture. During the coming year, we look forward to further strengthening the role of post-doctoral researchers as key members of the Bolin Centre community, continuing our collaborations within the Stockholm Trio, including on connecting climate to the health of both ecosystems and humans (see p. 9). We also look forward to welcoming new members to the ESAG, launching and developing a new website, and finally, working tirelessly to find openings for new exciting initiatives for the centre.

Thank you for your engagement and support during our first year as the Bolin Centre directors!

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

Photographer: Sören Andersson

Publications

The total number of publications where researchers have listed an affiliation to the Bolin Centre is 332. The total number of publications by researchers (listed as Bolin-members on our website) is 821.

The Bolin Centre Database

The Bolin Centre Database promotes research results and visualizes data.

As of April 2022, the Database hosts 321 datasets and several thematic data presentations. Read more on page 32.

Communication channels

Visit *www.bolin.su.se* and *@BolinCentre* on X (Twitter) for the latest news and events.

Photo: Carina Härlin

Projecting the future: Bolin Centre's Strategic Plan 2023–2027

In 2022 the members of the Bolin Centre for Climate Research dedicated extensive effort to developing our strategic plan for the years 2023–2027. This collaborative process has been a valuable experience, bringing together researchers from various disciplines to contribute towards our common goal.

Anthropogenic climate change remains one of the most urgent challenges facing our society. Finding effective solutions to mitigate and adapt to climate change requires enhanced knowledge of the intricate interactions between the climate system, ecosystems, and society.

The mission of the Bolin Centre is to generate and communicate fundamental knowledge about the coupled climate system and its connections with life on Earth across different time scales. We aim to bridge the gap between scientific knowledge and practical actions to address climate change.

Looking ahead to the second decade in the Bolin Centre's history, we have outlined strategic goals for the period of 2023-2027. These goals include securing the necessary resources for research, fostering local and national partnerships, strengthening internal integration, enhancing research infrastructure, creating career opportunities for climate researchers, and implementing effective external communication strategies.

By expanding our influence in climate-related research and Earth System science, we aim to contribute significantly to addressing climate change challenges. Our vision is to establish the Bolin Centre as a thriving research environment at the forefront of international climate research, fostering collaboration, training future generations of climate scientists, and delivering climate knowledge that supports informed decision-making and action.

Together, we will work for a desirable future by deepening our knowledge of the climate system and collaborating to find effective climate solutions.

Illustration: Inês Jakobsson

Bolin Centre becomes an active participant of University Alliance Stockholm Trio in 2022

In 2019, Karolinska Institutet, KTH, and Stockholm University formed the University Alliance Stockholm Trio, a collaborative effort to develop and highlight the internationally prominent research and education environment that the three universities represent in the Stockholm region.

These institutions, known for their excellence in medicine, technology, science, humanities, law, and social sciences, conduct a significant portion of academic research and postgraduate education in Sweden, accounting for over 30 percent of the country's total.

With a shared vision and the aim of fostering in-depth collaboration, the alliance agreement has provided new opportunities for joint research and education initiatives. The universities have a combined total of 5,200 doctoral students and generate SEK 12.4 billion in research and research education revenue, operating with a budget of SEK 17.3 billion. As a unified academic environment, the Stockholm Trio stands among the world's strongest educational collaborations.

The three universities have a long-standing history of collaboration across various scientific fields and offer joint educational programmes. By forming the University Alliance Stockholm Trio, Karolinska Institutet, KTH, and Stockholm University have improved their competitiveness on a global scale. This alliance enables the universities to foster new international collaborations, attract leading researchers, and draw in students from around the world. Additionally, the alliance strengthens the universities' regional and national impact by engaging with decision-makers, authorities, businesses, and industries.

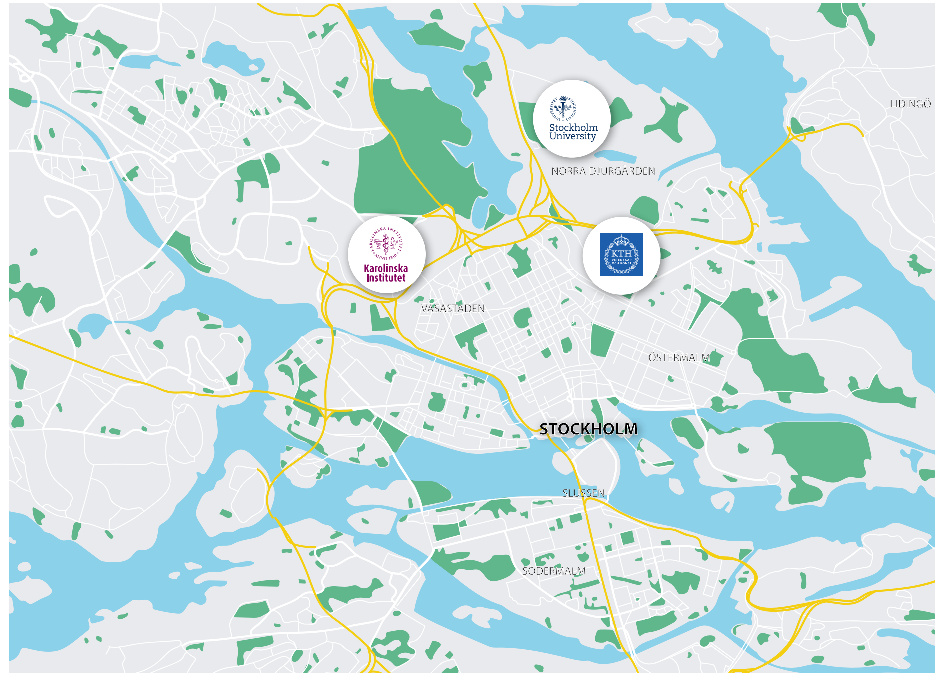


Illustration: Inês Jakobsson

One of the key initiatives launched by the Stockholm Trio is the Stockholm Trio for Sustainable Actions. On June 1, 2022, during the conference *Sustainable planet, sustainable health – how science-based solutions can drive transformative change*, the universities officially announced this collaborative effort. The Stockholm Trio for Sustainable Actions aims to enhance the universities' capacity to contribute to the achievement of the 17 Sustainable Development Goals.

The initiative focuses particularly on climate and global health challenges. By leveraging the knowledge and expertise of all three universities, complex societal issues can be tackled from a multi-disciplinary perspective. Together, these higher education institutions have the potential to drive the sustainability agenda at local, national, and international levels, fostering the necessary transformative changes in society.

The Stockholm Trio for Sustainable Actions has several objectives. Firstly, it aims to strengthen both the Stockholm Trio as a whole and the individual universities in the field of sustainability. Secondly, it seeks to enhance the universities' capacity to provide science-based knowledge for sustainable societal transformation. Thirdly, the initiative aims to facilitate interdisciplinary research and education, fostering collaboration with the city, region, non-profit organisations, and industry. Lastly, the Stockholm Trio for Sustainable Actions strives to strengthen society in terms of climate, health, innovation systems, and entrepreneurship.

To support the Stockholm Trio's sustainability efforts, each university will invest SEK 1 million annually for four years. External funding will be sought for various assignments and collaborations, and additional internal resources may be allocated for specific initiatives and activities. The Stockholm Trio's sustainable development group, consisting of representatives from Karolinska Institutet, KTH, and Stockholm University, is responsible for establishing and driving this initiative forward.

The inclusion of the Bolin Centre in the University Alliance Stockholm Trio collaboration further strengthens the consortium's expertise in sustainability and climate-related research. With its renowned scientists and multi-disciplinary approach, the Bolin Centre will play an important role in advancing the Stockholm Trio's sustainability goals.

Source and more information can be found here: *https://www.su.se/english/about-the-university/collaboration-and-societal-development/partnerships-and-collaborations/university-alliance-stockholm-trio-1.514796*

The Bolin Centre Research Themes

Until the end of 2021, the research was structured into eight multi-disciplinary research areas (you can read more about them on our website). Since the beginning of 2022 the Bolin Centre is reorganised into four Research Themes with the following titles:

Research Theme 1 | The physical-chemical climate system

Research Theme 1 addresses some of the major knowledge gaps in the physical-chemical climate system. Covering a range of scales, we study aerosols and clouds; the dynamics of the atmosphere, ocean and cryosphere; risk for reaching climate system tipping points and regional effects of global warming and; climate sensitivity and the carbon budget. We develop and use tools ranging from Large Eddy Simulation to Earth system models, and from in-situ observations to satellite and reanalysis products.

Co-leaders:

Torben Königh, Swedish Meteorological and Hydrological Institute (SMHI)

Thorsten Mauritsen, Dept. of Meteorology, Stockholm University

Frida Bender, Dept. of Meteorology, Stockholm University

Research Theme 2 | Water, biogeochemistry and climate

Research Theme 2 studies the coupled water and biogeochemical cycles and their interactions with climate and society over multiple spatial and temporal scales. Our ultimate goal is to define the adaptation necessary to address climate risks related to these cycles and to guide policy towards the mitigation of these risks. For this task, we rely on field- and space-based observations, modelling, monitoring, and experiments on land, in the ocean, and in the atmosphere.

Co-leaders:

Fernando Jaramillo, Dept. of Physical Geography, Stockholm University

Volker Brüchert, Dept. of Geological Sciences, Stockholm University

Research Theme 3 | Past climates

Research on past climates encompasses climate variability on tectonic, orbital, millennial, centennial and historical timescales. We use a wide range of geoscientific data to reconstruct the evolution of the climate system, including its landscapes and ecosystems, from local to global scales. Climate models are used to simulate extreme climate states in the past, and to study impacts, mechanisms and feedback operating in the climate system under different climate forcings. Past climates provide a thorough test of models to project future changes in a confident way.

Co-leader:

Margret Steinthorsdottir, Swedish Museum of Natural History, affiliated with Dept. of Geological Sciences, Stockholm University

Frederik Schenk, Dept. of Geological Sciences, Stockholm University.

Research Theme 4 | Climate, ecosystems and biodiversity

Research on climate, ecosystems and biodiversity at the Bolin Centre aims to understand how the climate affects ecological, evolutionary and biophysical processes, as well as to understand the possible feedback of these processes on climate and human use of land and water. The research relies on using field observations, experiments, and modelling to examine the effects of the climate on different aspects of ecosystems and biodiversity.

Co-leaders:

Regina Lindborg, Dept. of Physical Geography at Stockholm University

Carl Gotthard, Department of Zoology, all at Stockholm University

Photo: NASA

Photo: Karin Jonsell

Photo: Malin Kylander

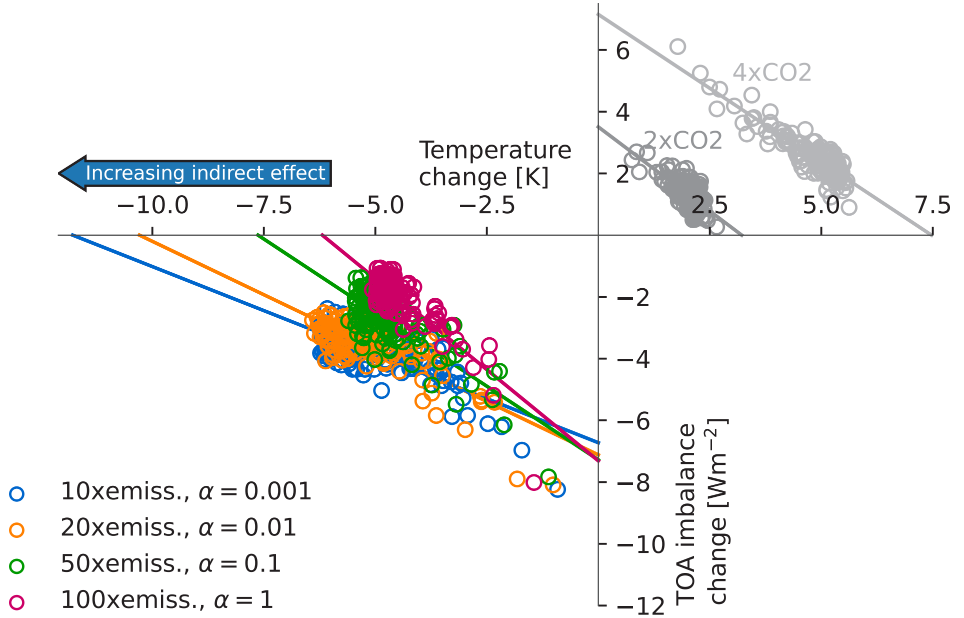
Photo: Sara Cousins

RT1 | Investigating the impact of aerosol interactions on global climate: Why cloud effects matter

Aerosols, small particles suspended in the atmosphere, emitted by humans, tend to cool the climate. They do this directly by reflecting incoming sunlight, and indirectly by affecting cloud properties such that clouds reflect more sunlight. The scientists investigated how the global surface air temperature responds to changes in the two types of aerosol interaction with solar radiation. They found that the cloud effect causes a larger global mean temperature change than the direct effect of the aerosol particles. Interactions between aerosols and clouds are difficult to represent in climate models and are sometimes excluded entirely. These results highlight the importance of including the cloud effect to get an accurate representation of the Earth's climate.

The term *aerosols* refers to small particles that are suspended in the air. They occur naturally in the atmosphere but are also emitted through human activities. In the atmosphere, the aerosols interact with radiation, either directly by reflecting or absorbing sunlight, or indirectly by interacting with clouds which in turn reflect or absorb radiation. By modifying the radiation that reaches the surface, the aerosols emitted by humans affect the climate. This effect that aerosols have on the surface temperature is known as aerosol radiative forcing.

A recent study by Huusko *et al*. investigated the impact of the two types of aerosol interaction with solar radiation on the global surface air temperature. The researchers found that the temperature response per unit forcing is larger for aerosol-cloud interactions than for direct aerosol forcing. While direct aerosol forcing has a localised effect primarily over tropical land, aerosol-cloud interactions induce cooling over remote oceans in the extratropics. The results suggest that the spatial patterns of temperature change from direct and indirect effects of aerosols cause different forms of climate feedback.



Relationship between the global mean radiative forcing and the resulting temperature change in four simulations with different combinations of direct and indirect effects. In all four cases, the radiative forcing (y-axis intercept) is approximately the same, yet the temperature change (x-axis intercept) is larger in the simulations with a stronger indirect effect, indicating a larger forcing efficacy. For reference, two cases forced with increased carbon dioxide concentrations are also included.

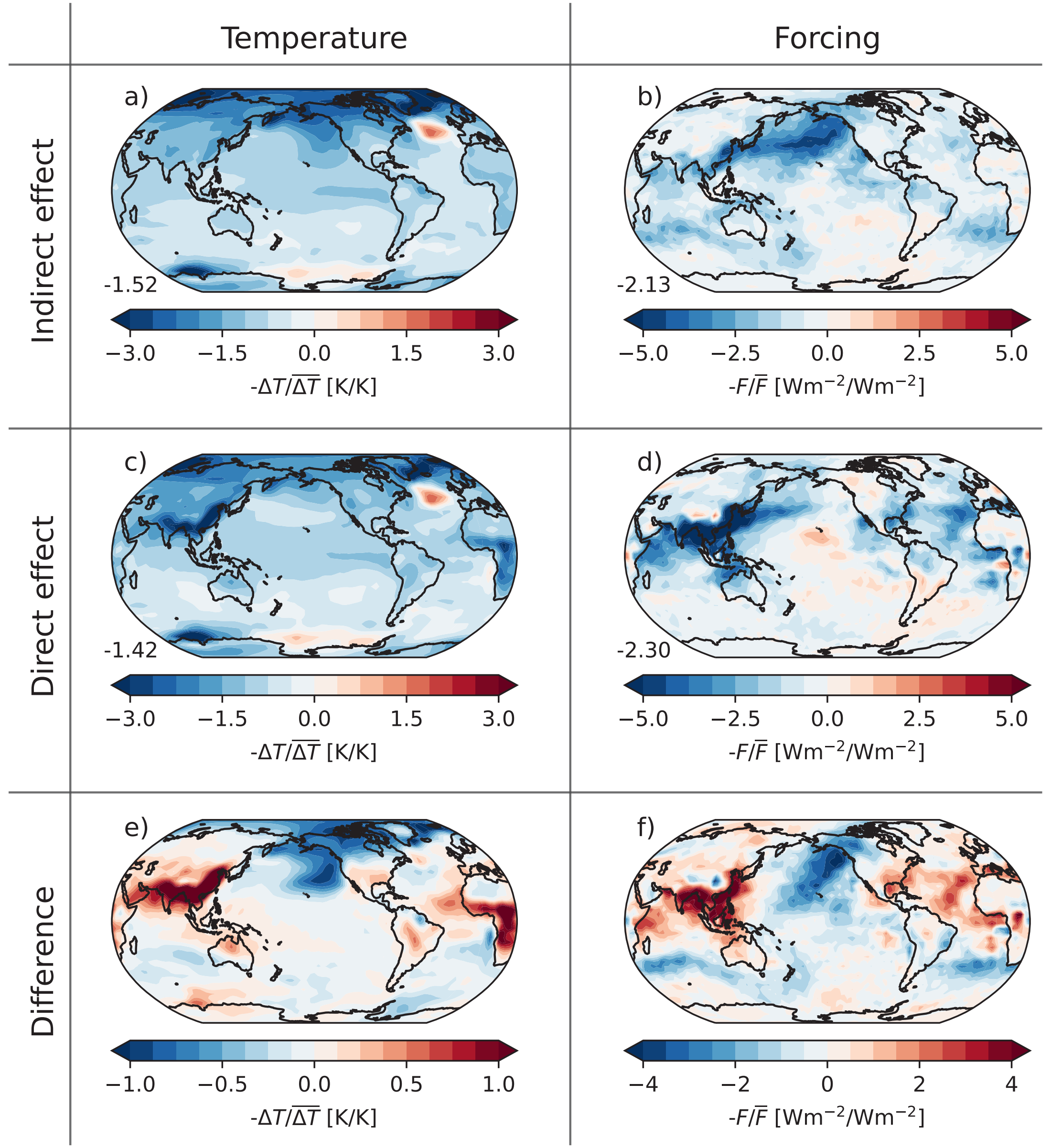
The radiative effect from anthropogenic aerosols, particularly from aerosol-cloud interactions, is the largest contributor of uncertainty to the total radiative imbalance at the top of the atmosphere, which changes the state of the climate system. Forcing efficacy, which accounts for the differences in temperature response to different types of forcing, can be incorporated into the mathematical energy balance framework that is often used to study global climate change. However, the aerosol forcing efficacy remains difficult to constrain.

The study by Huusko *et al.* used the Max Planck Institute for Meteorology Earth System Model version 1.2 to simulate the Twomey effect, which represents the impact of aerosol particles on cloud formation. The model's simple aerosol scheme makes it computationally lightweight and allows for systematic investigation of the climate response to aerosol forcing of different strengths. In the study, the Twomey effect was enhanced in the Earth System Model as a proxy for representing other uncertain indirect effects.

The study concludes that enhancing the indirect effect causes a larger forcing efficacy. The response to the enhanced indirect effect is dominated by remote oceans and an Arctic-amplified cooling, while the direct effect causes a radiative forcing and a resulting temperature response localised to major emission source regions. The study provides a mechanistic explanation for the enhanced remote response to the aerosol indirect effect.

The findings of this study have important implications for our understanding of the impact of aerosol interactions on global climate. By highlighting the importance of including the cloud effect in climate models and investigating the different feedback mechanisms that are affected by direct and indirect effects of aerosols, scientists can gain a more accurate understanding of how the Earth's climate responds to different pollutants.

Huusko, L., Modak, A., & Mauritsen, T. (2022). *Stronger response to the aerosol indirect effect due to cooling in remote regions*. Geophysical Research Letters, 49, e2022GL101184. *https://doi.org/10.1029/2022GL101184*



Maps showing the spatial distribution of the temperature change and radiative forcing in two simulations with enhanced indirect and direct effects, respectively. The values are normalised by the global average value, which is indicated in the bottom left corner of the maps. The bottom row shows the difference between the first two rows.

RT1 | The puzzle of Earth's inter-hemispheric albedo symmetry

Approximately 30% of the incoming radiation from the sun is reflected back into space. The reflection, or albedo, is determined by the properties of the atmosphere and surface. The greater fraction of land surface, and larger amount of airborne particles or aerosols, in the Northern Hemisphere (NH) compared to the Southern Hemisphere (SH) would suggest that the reflection in the NH is greater. Satellite observations, however, have shown that the reflection from the two hemispheres is nearly identical. This indicates that differences in cloud cover and cloud properties between the hemispheres compensate for the clear-sky difference in reflection.

Clouds are an integral part of the climate system, regulating the Earth's temperature by reflecting incoming solar radiation but also by trapping outgoing thermal radiation. Clouds respond to changes in climate, and in turn affect the climate, and this cloud feedback is a key uncertainty in climate modelling and projection of future climate change. The framework of inter-hemispheric albedo symmetry offers an opportunity to study clouds and cloud feedback in new ways. It is not known whether the symmetry is an inherent property, so that the climate system self-regulates towards symmetry, or if it occurs by chance as a function of the current climate conditions. If there are forms of feedback that bring the system back to symmetry in response to natural climate variability, they may also give clues to feedback in response to anthropogenic forcing. Hence, by studying the albedo symmetry and how clouds at different latitudes contribute to it, in models and observations, we can learn about clouds and their interplay with climate.

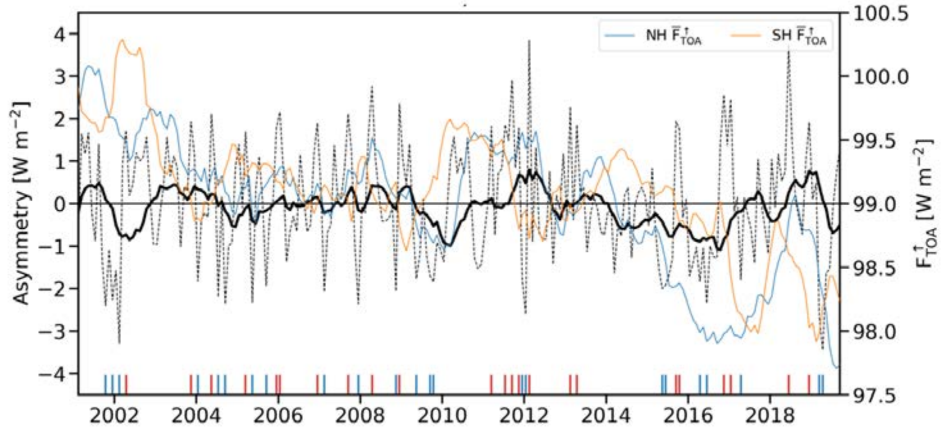
Jönsson and Bender (2022) study the inter-hemispheric albedo symmetry in observations from the satellite-borne CERES (Clouds and Earth's Radiant Energy System) instrument, which has collected data on Earth's radiation budget at the top of the atmosphere for nearly two decades. Throughout this observational record, the inter-hemispheric symmetry has persisted, within 0.1 W/m² for the decadal mean.

The variability in symmetry is most strongly determined by variations in cloud cover at low latitudes, in the tropics and subtropics. The variations are closely related to non-neutral phases on the El Niño – Southern Oscillation (ENSO) so that cloud distribution for months when the SH is significantly brighter resembles an El Niño pattern, and cases when the NH is brighter resemble La Niña.

The NOAA-20 satellite. https://ceres.larc.nasa.gov/instruments/satellite-missions

The observational data are also compared with climate models from the Coupled Model Intercomparison Project, Phase 6 (CMIP6). The models represent the inter-hemispheric albedo symmetry to varying degrees, and most of them underestimate the symmetry by having a brighter SH. The biases are mostly related to biases in reflected radiation in SH mid-latitudes. Models that overestimate the variability in reflection in mid-latitude clouds also overestimate the variability in albedo symmetry.

When models are forced to follow the observed historical sea surface temperature evolution, they represent the albedo symmetry better, showing that the albedo symmetry is dependent on the representation of cloud responses to coupled ocean-atmosphere processes, and that the cloud distribution follows the surface temperature pattern.

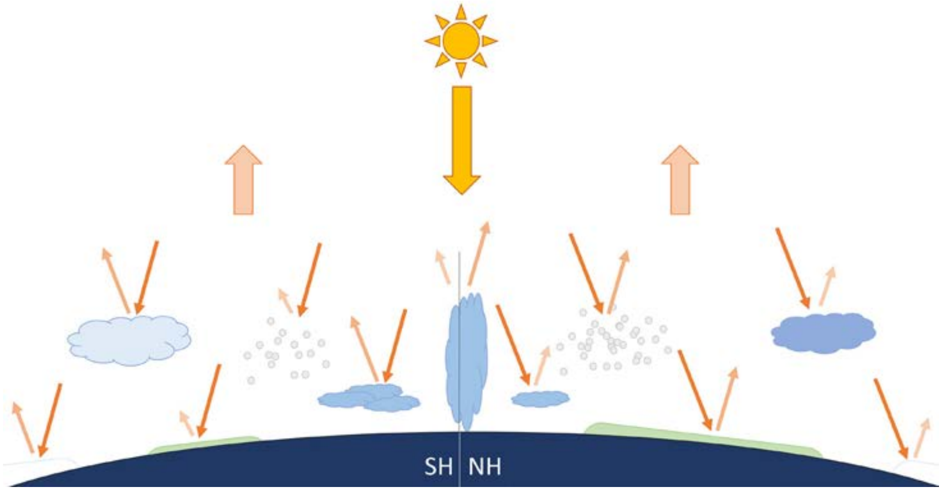


This figure shows the hemispheric symmetry in reflected solar radiation, as measured by CERES, from 2000 to 2019. The black dotted line is the monthly difference between NH and SH mean reflection, and the solid black line is the 12-month running average (left axis). The blue and red lines are the NH and SH monthly means respectively (right axis). The red and blue tick marks indicate months when the asymmetry is more extreme than the 10th percentile, in either direction.

The presented paper is part of Aiden Jönsson's PhD project. He has also looked at how CMIP6 models represent albedo symmetry changes in response to strong CO_2 forcing, how the symmetry in a specific model is determined by cloud parameterisations, and how high-resolution climate models represent the albedo symmetry.

Reference: Jönsson, A. R. and Bender, F. A.-M. (2022) *Persistence and Variability of Earth's Inter-hemispheric Albedo Symmetry in 19 Years of CERES EBAF Observations*, J. Clim., 35, 1, *https://doi.org/10.1175/JCLI-D-20-0970.1*.

This work has been shown in invited presentations at AGU 2021 and EGU 2022.



This figure illustrates how differences in land, surface snow/ice, aerosols and clouds between the hemispheres result in the same reflection from the NH and SH, i.e. an inter-hemispheric albedo symmetry.

RT2 | Understanding water storage differences in headwater and downstream wetlands for effective management and ecosystem services

With an incredible effort of monitoring wetlands in Sweden, Åhlen *et al.* show that two distinct storage behaviours depend on the position of the wetland in the landscape. First, they found that wetlands located in headwater regions temporarily stored surplus water from regular summer rains. In contrast, water levels of downstream wetlands dropped to seasonal low values without responding to individual summer precipitation events. These differences between headwater-downstream wetlands imply that the functionality of an entire wetlandscape cannot be assessed by simply extrapolating data from monitoring stations that are typically located downstream of headwater regions. Understanding these differences can support wetland management practices targeting nature-based solutions and ecosystem services.

Wetlands are crucial for maintaining ecosystem balance by supporting diverse flora and fauna, buffering floods, and retaining nutrients. Specifically, many ecosystem services from wetlands are driven by wetland water storage dynamics. However, current climate and land use changes affect wetland water storage dynamics and ecological services, and thereby will also affect the capacity of wetlands to contribute to the realisation of different sustainable development goals.

Hence, the impact of large-scale processes on wetland systems involving entire landscapes needs to be better understood.

A recent study in Vattholma, Sweden, investigated water storage differences within wetlands in the same catchment. The study found that headwater wetlands had pronounced water level variations throughout summer, while downstream wetlands maintained low water level conditions. Changes in inundated wetland areas in response to water level variations were therefore considerable for headwater wetlands. Headwater wetlands were also shown to store excess water from regular summer rains, while downstream wetlands maintained their capacity to buffer extreme floods. The study implies that wetlandscape functionality cannot be assessed by monitoring stations downstream of headwater regions. It is therefore essential to understand location-specific wetland differences for effective wetland management.

The study showed that water storage dynamics in wetlands are highly dependent on their location within the landscape. Headwater wetlands rapidly filled during regular precipitation events and had reduced capacity for buffering larger volumes of water during extreme events. Downstream wetlands maintained a large buffering capacity for future extreme flood events. This has implications for wetland use in nature-based solutions and ecosystem service delivery. Therefore, high-resolution monitoring of multiple wetlands in a catchment is crucial for understanding both large-scale (wetlandscape scale) and local-scale hydrological dynamics of wetlands.

The article *Wetland position in the landscape: Impact on water storage and flood buffering* was published in Ecohydrology, 2022. Åhlén, I., Thorslund, J., Hambäck, P., Destouni, G., Jarsjö, J. doi: *https://doi.org/10.1002/eco.2458*

Groundwater pipe. Photo: Imenne Åhlén

Photo: Imenne Åhlén

A wetland in Vattholma. Photo: Imenne Åhlén

RT2 | The variability in methane concentrations over time and space poses a challenge to estimating emissions from vegetated coastal ecosystems

Aquatic ecosystems may account for up to half of global methane emissions from natural environments and have been proposed to drive the increase in global methane emissions over the past decade. Large uncertainties remain with respect to the global upscaling of individual measurements and matching them with model-derived emission assessments. Roth *et al.* addressed this problem for rarely investigated shallow-water near-shore marine ecosystems in northern temperate latitudes and demonstrated that high methane emissions from these environments can offset the carbon dioxide uptake efficiency, but that flux assessments of statistical significance require at least 50 discrete measurements per day to resolve the scale and drivers of the natural variability. The study demonstrated an urgent need for further improvements of the underlying database for bottom-up scaling from rarely investigated coastal environments promoted as "blue carbon repositories".

Coastal methane emissions are a significant factor in the global ocean methane budget and can offset the "blue carbon" storage capacity of coastal ecosystems. Despite their importance, current estimates of coastal methane emissions lack systematic, high-resolution, and long-term data, making them sensitive to statistical assumptions and uncertainties. However, the recent study conducted by Roth *et al.* has shed light on the variability and spatial patchiness of coastal methane emissions.

The study highlights the importance of high-resolution measurements in improving the reliability of methane estimates and identifying habitat-specific contributions to regional and global methane budgets. The researchers identified northern temperate coastal habitats with mixed vegetation and macroalgae as understudied but significant sources of atmospheric methane. The study concludes that more extensive and intensive measurements are needed to understand and confine the habitat-specific contribution to regional and global methane budgets.

Seascape of a typical vegetated coastal ecosystem in the Baltic Sea. Photo: Xiaole Sun

Coastal marine environments are responsible for significant amounts of methane emissions, which can have negative impacts on global climate change. However, a lack of systematic, long-term measurements has made it difficult to evaluate the potential for coastal ecosystems to mitigate climate change by storing carbon. Coastal sediments are particularly prone to high methane emissions due to vegetation and organic matter accumulation. Despite this, the heterogeneous nature of coastal environments, including varying habitats and species communities, makes it difficult to measure carbon dynamics effectively.

Global estimates of coastal methane emissions primarily focus on three types of ecosystems, namely seagrasses, salt marshes and mangroves, leaving other coastal areas out of the equation. This creates a major knowledge gap in understanding the variability of methane emissions over short spatial scales, reflecting the ecosystem mosaic typical for the coastal environment. To narrow the uncertainty in the global coastal methane budget, there is a need for methodologies that can quantify natural variations arising from biotic and abiotic drivers across multiple timescales.

The study looked at three different areas along the coast of Askö Island in the Baltic Sea. The research team used a novel tool called the Water Equilibration Gas Analyzer System – short, WEGAS – to measure CH_4 and CO_2 in the water and air. They also used a model to estimate how much CH_4 was being consumed in the water before reaching the atmosphere. The study found that CH_4 levels varied between the different areas and times of the year, and that the amount of CH_4 consumed by microbes in the water was different, too.

Roth *et al.* found that a high sampling intensity was necessary to capture the coastal CH_4 variability, especially on timescales from hours to days. The researchers conducted a bootstrapping analysis on their continuous data to determine the minimum number of individual concentration samples required to obtain an accurate, representative mean dissolved CH_4 concentration. They found that collecting one discrete water sample per day, which is a typical approach, results in great uncertainty and the potential to over- or underestimate the mean CH_4 concentration by almost 70%. Increasing the sampling intensity to 50 samples per day narrows this uncertainty to 10%, closer to the observed true mean CH_4 concentration.

In conclusion, the study reveals the surprising variability and spatial patchiness of coastal methane emissions, emphasising the importance of high-resolution measurements in improving the reliability of methane estimates and identifying habitat-specific contributions to regional and global methane budgets.

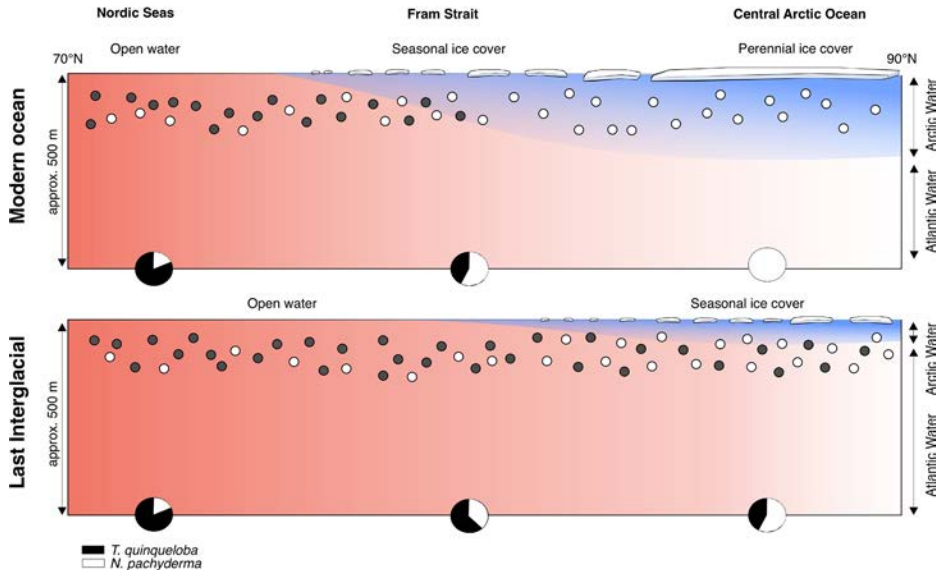
Houseboat, on which the researchers placed the Water Equilibration Gas Analyzer System (WEGAS) for continuous measurements of CO_2 and CH_4 in the coastal zone. Photo: Florian Roth

RT3 | Invasion of the Arctic Ocean by Atlantic plankton species reveals a seasonally ice-free ocean during the Last Interglacial

Arctic sea ice, an important component of the Earth system, is disappearing fast under climate warming. Summer sea ice is anticipated to vanish entirely within this century. To gain a deeper understanding of the climate dynamics in a world without Arctic sea ice, researchers have turned to analogues from the geological past. The Last Interglacial (~129,000–115,000 years ago) is an interesting period to study because it is the last time in Earth's history when global average temperatures were similar or perhaps higher than currently and sea levels were considerably higher (+6 to +9 m).

However, the extent of sea ice during this period has been intensely debated and there is no consensus, limiting understanding of this period and the ability of researchers to simulate it in climate models. To address this, a team of marine geology researchers from the Department of Marine Geological Sciences at Stockholm University analysed the microfossil content of an array of sediment cores from sites that today lie directly beneath the thickest parts of the modern Arctic ice pack. In these cores, they investigated the variability in the occurrence and composition of planktonic foraminifera, a type of free-floating, shell-building unicellular zooplankton that is sensitive to changes in oceanographic and environmental conditions.

The researchers found high abundances of the typically subpolar, Atlantic-water species *Turborotalita quinqueloba*, documenting a large-scale expansion of the species far into the central Arctic Ocean. The ecological preference of *T. quinqueloba* for predominantly ice-free, seasonally productive waters typically present in the Atlantic Ocean suggests that the species was following such conditions that had spread to the central Arctic Ocean. The absence of summer sea ice and the increased influence of Atlantic currents in the Arctic domain during the Last Interglacial are analogous to ocean transformations being observed today in parts of the Arctic, and which are collectively referred to as "Atlantification" of the Arctic Ocean.



Illustrative model depicting ocean stratification and sea ice conditions (upper 500 m) in the modern Nordic Seas-Arctic Ocean region and their hypothesised transformation during the Last Interglacial.

The marginal ice zone of the Arctic Ocean, summer 2021. Photo: Flor Vermassen

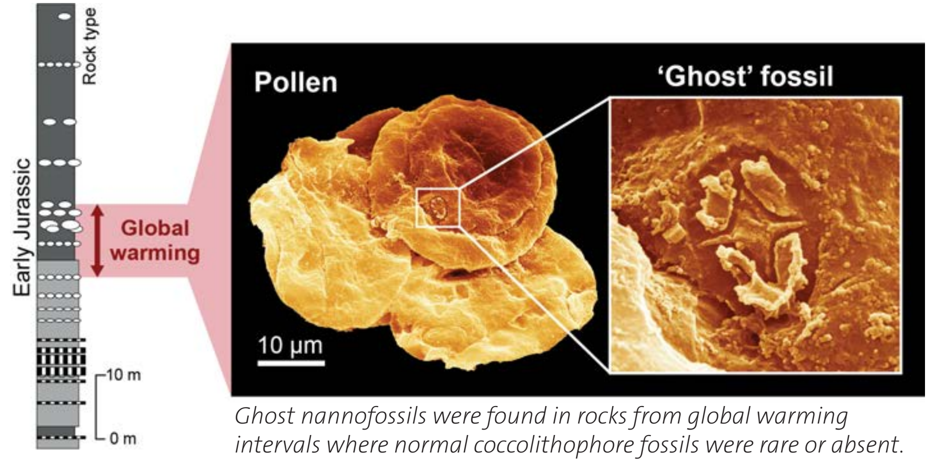
The finding that the Arctic Ocean was seasonally ice-free during the Last Interglacial is worrying because temperatures in this period would have been only around 1.5°C above pre-industrial levels, comparable to the targets of the Paris Agreement. Yet the global sea level is estimated to have been several metres higher than at present. Hence, the researchers propose the Last Interglacial as the most recent and potentially most relevant geological epoch for investigating a seasonally ice-free Arctic Ocean, particularly if the objectives of the Paris Agreement are not exceeded. To fully comprehend the physical conditions and environment of this unfamiliar Arctic during the Last Interglacial, additional quantitative proxy reconstructions of sea surface temperature and other water mass parameters are needed, along with targeted climate and oceanographic model studies of the same period.

This article is based on the the publication Vermassen, F., O'Regan, M., de Boer, A., Schenk, F., Razmjooei, M., West, G., Cronin, T. M., Jakobsson, M. and Coxall, H. K. *A seasonally ice-free Arctic Ocean during the Last Interglacial*. Nature Geoscience 16, 723–729 (2023), doi: 10.1038/s41561-023-01227-x

Scanning electron microscope images of the planktonic foraminifer Turborotalita quinqueloba. Scale bars = 100 microns.

RT3 | Global record of “ghost” nannofossils reveals plankton resilience to high CO_2 and warming

New discoveries from the fossil record suggest that planktonic organisms, called coccolithophores, were more resilient to several past global warming events than previously thought.



Ghost nannofossils were found in rocks from global warming intervals where normal coccolithophore fossils were rare or absent.

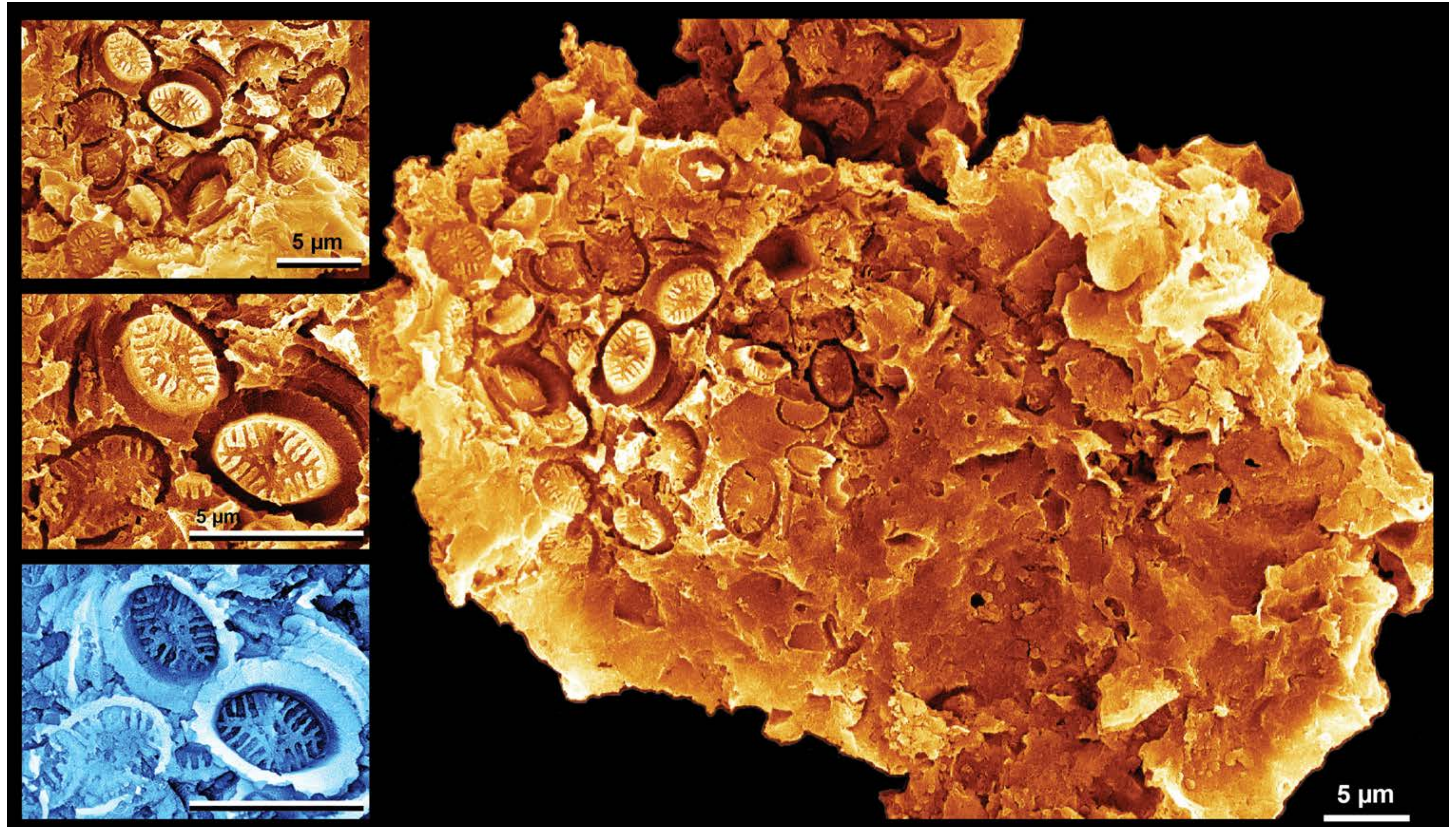
An international team of scientists, including two Bolin Centre RT3 members, Dr. Sam Slater and Prof. Vivi Vajda, from the Swedish Museum of Natural History, reported on a remarkable style of fossilisation that has remained almost entirely overlooked until now. Their findings, published in the journal Science in 2022, presented a microscopic imprint or “ghost” fossils of coccolithophores preserved in exquisite detail. Coccolithophores are a type of single-celled marine plankton that surround their cells with hard calcareous plates, called coccoliths, which are the fossil elements normally found in rocks. The ghost fossils of these coccoliths formed after they were buried within sediments on the seafloor. As more mud was gradually deposited on top, the resulting pressure squashed the coccolith plates and other organic remains together, and the hard coccoliths were pressed into the surfaces of pollen and other soft organic matter. Later, acidic waters within spaces in the rock dissolved away the coccoliths, leaving behind just their impressions – the ghosts.

The study examined three global warming events in the deep past, in which abundance declines of coccolithophore fossils were thought to have been due to a plankton crisis caused by ocean acidification. The research focused on the Toarcian Oceanic Anoxic Event (T-OAE), an interval of rapid global warming in the Early Jurassic (183 million years ago), that was caused by an increase in atmospheric CO_2 levels from massive volcanism in the Southern Hemisphere. Ghost fossils associated with the T-OAE were found from the UK, Germany, Japan and New Zealand, but also from two similar events in the Cretaceous: Oceanic Anoxic Event 1a (120 million years ago) from Sweden, and the Oceanic Anoxic Event 2 (94 million years ago) from Italy.

The discovery of abundant and diverse ghost fossils through these events thus suggests that coccolithophores were probably thriving, rather than experiencing a crisis. Despite their apparent resilience, the researchers state that coccolithophore blooms, which occur in modern oceans, may have been widespread during these past events, contributing to the expansion of seafloor “dead zones”, regions where oxygen levels were too low for most species to survive.

The findings of this study offer new avenues of research into the mechanisms that allow certain organisms to survive under changing environmental conditions, and the discovery of this unusual and cryptic style of fossilisation is changing our understanding of how plankton in the oceans is affected by climate change.

S.M. Slater, P. Bown, R.J. Twitchett, S. Danise, V. Vajda. *Global record of “ghost” nannofossils reveals plankton resilience to high CO_2 and warming*. Science 376, 853–856 (2022). doi:10.1126/science.abm7330



Microscopic plankton cell-wall coverings preserved as “ghost” fossil impressions, pressed into the surface of ancient organic matter (183 million years old). The images show the impressions of a collapsed cell-wall covering (a coccosphere) on the surface of a fragment of ancient organic matter (left) with the individual plates (coccoliths) enlarged to show the exquisite preservation of sub-micron-scale structures (right). The blue image is inverted to give a virtual fossil cast, i.e. to show the original three-dimensional form. The original plates have been removed from the sediment by dissolution, leaving behind only the ghost imprints.

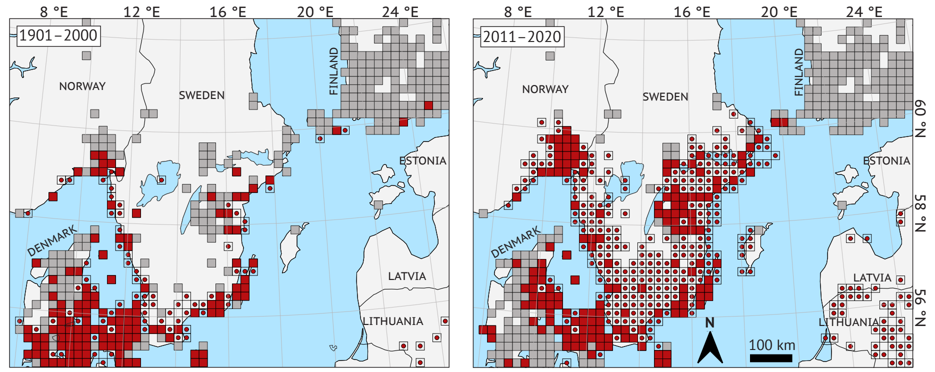
RT4 | The wall brown butterfly adapts to life in the north: A story of rapid evolution

Climate change pushes species distributions towards the poles. In Scandinavia, the wall brown butterfly (*Lasiommata megera*) used to live mainly in Denmark and along the southernmost coasts of Sweden but has now become established as far north as Uppland in the east, and north of Oslo in the west. But even in a warming climate, such expansion over latitudes may not be as straightforward as it seems because important environmental factors stay the same although climate change. A new study published in the journal *Ecology Letters* shows how the wall brown has evolved to cope with the longer late-summer days of the north, a crucial adaptation because butterflies use annual cycles in day length as a calendar to time their hibernation.

In laboratory experiments, the Bolin Centre's researchers found that larvae from northern populations are, compared to those from more southern populations, well adapted to northern day lengths. This evolutionary change probably occurred during the last 20 years, when the species expanded northwards. The ability to adapt to longer day lengths is important because wall browns, like many insect species, use day length to determine what time of year it is. Failure to adapt could limit the spread of these species, especially as they shift over latitudes, which differ in seasonal day length cycles.

The rapid evolution in the wall brown suggests that day length does not strongly limit insects' climate-driven poleward shifts. If such rapid evolvability is general, it would benefit both much-loved butterflies and pest insects. This is an important finding as the climate continues to change and temperatures increase, facilitating shifts in the distribution of numerous insect species.

While the wall brown benefits from warmer climates in Sweden and Norway, it has declined sharply in Western Europe. It has been suggested that the faster growth of caterpillars in warmer climates leads to western-European wall browns attempting a third annual generation of adult butterflies, for which the growth season is too short. Wall browns overwinter as caterpillars, and the last offspring of the summer must be large enough to survive the winter.



The distribution of the wall brown in Scandinavia, Finland, and the Baltic states in the time periods 1901–2000 (left) and 2011–2020 (right), based on citizen science records. The overall number of reported observations has grown rapidly, which was corrected for by identifying areas that were well-recorded in both time periods. Filled squares are well-recorded (more than 100 records of any butterflies within a 20x20 km square in both time periods), and red ones have recorded wall brown observations. Red circles show other (that is, not well-recorded) 20x20 km squares within which wall brown observations have been recorded. Note how the distribution has expanded northwards even when considering only the filled squares. This figure is an edited version of one in the research article (https://doi.org/10.1111/ele.14085), originally published in published in Ecology Letters under a CCBY 4.0 (https://creativecommons.org/licenses/by/4.0) license

This highlights the complex and often unpredictable impacts that climate change can have on different species and ecosystems. However, the new study, showing the quick evolution of changing responses to day length in Scandinavian wall browns, gives hope for the species' western-European populations.

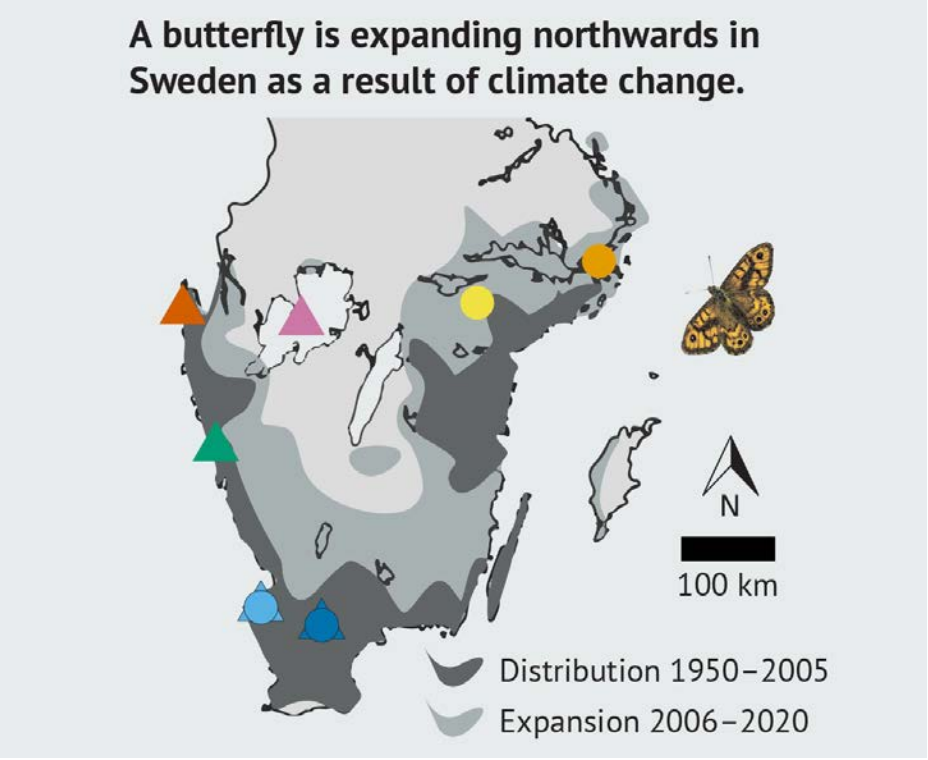

Caterpillar of the wall brown butterfly. Photo: Mats Ittonen


The wall brown butterfly. Photo: Mats Ittonen

The study benefitted from open databases, such as the Swedish Species Observation System (Artportalen), where anyone can publish their species observations. The researchers used these citizen science databases both to analyse changes in the distribution of the species and to meet their very practical need to find butterflies to catch for the experiments. Anyone's observations can help advance our comprehension of the natural world and its rapid transformations.

In conclusion, the adaptation of the wall brown butterfly to longer day lengths in the north is a fascinating example of how species can evolve rapidly in response to climate change.

The study *Local adaptation to seasonal cues at the fronts of two parallel, climate-induced butterfly range expansions* was published in the journal Ecology Letters 2022. *https://doi.org/10.1111/ele.14085*



RT4 | Drylands are complex ecosystems under increasing climatic and anthropogenic pressures

Drylands cover 40% of the Earth's land surface and host more than two billion people. These complex ecosystems are adapted to water scarcity, but increasing aridity and human activities are undermining drylands' ecological functioning and their ability to provide essential ecosystem services. Climate change could make matters worse, but we do not know where and to what extent. Furthermore, the degree to which ongoing and future changes in dryland vegetation will influence climate changes is not fully understood.

Predictions of dryland dynamics are difficult because, on the one hand, drylands are subjected to highly variable climatic conditions, which drive responses of vegetation and soils at multiple scales, ranging from hours to decades. On the other hand, human activities are placing pressure on dryland ecosystems via land conversion to agriculture, intensifying grazing, fire management, and redistribution of the limited water resources. Ongoing climate change is contributing to the uncertainty because various aspects of climate change are having opposite effects. In fact, warming and drying are reducing vegetation productivity, while increased atmospheric carbon dioxide is improving water-use efficiency, thus helping plants to grow better using less water. As a result, drylands are expected to expand to nearby regions due to decreasing rainfall, but some drylands where precipitation does not change much might benefit from higher atmospheric carbon dioxide— a phenomenon known as "dryland greening", which is still debated.

While we know that plants suffer during dry periods and their productivity gradually decreases, in drylands, there can also be dramatic changes when precipitation decreases below specific thresholds. In other words, a vegetated dryland ecosystem can transition to a degraded, desert-like ecosystem that cannot sustain vegetation and associated ecosystem services. This transition can occur even after a small decrease in mean precipitation or an increase in its variability. The very cause of such dramatic change is the plants' own capacity to use limited water resources. In drylands, vegetation promotes infiltration, captures water from fog or dew, and nutrients from the atmosphere, and reduces erosion. These processes maintain vegetation in a delicate equilibrium so that even relatively small climatic changes break down the positive feedback that retains water and nutrients, resulting in a sudden transition to a less functional ecosystem. Predicting these transitions remains difficult because these processes are strongly nonlinear, meaning that even small perturbations have large and long-lasting consequences.

Irrigation in dryland agriculture, California, US. Photo: Giulia Vico, Swedish University of Agricultural Sciences (SLU), Uppsala

Not only vegetation but also soil processes in drylands rely on water and are sensitive to variations in precipitation. After dry periods, soil microorganisms are reactivated and release large amounts of carbon dioxide via respiration. These respiration "pulses" represent a significant source of carbon from drylands. At the same time, microorganisms start growing again after the dry period, which can lead to the stabilisation of carbon in soils. We still do not know how lengthening droughts is affecting these respiration and growth responses, but if respiration increases or microbial growth decreases, we expect drylands to become stronger carbon dioxide sources.

Dryland vegetation in Utah, US. Photo: Stefano Manzoni, Stockholm University

Human pressures on drylands are also increasing, partly in response to the increased population in dryland regions, and partly due to global food markets. Unfortunately, these pressures exacerbate the problems in drylands. For example, agricultural activities often require higher water withdrawals from streams and groundwater through irrigation, which can worsen the drought conditions in these regions. Additionally, increased grazing pressure drives ecosystems towards degraded states from which recovery is slow or nearly impossible under drying conditions.

To address these challenges, it is important to design holistic approaches to dryland management, accounting for the increasing climate and anthropogenic pressures, as well as the associated uncertainties in the observations and predictions of dryland productivity.

In summary, drylands are complex ecosystems facing increasing pressures from both climate change and human activities. The unpredictability of climatic conditions and nonlinear responses of vegetation and soil processes make it difficult to predict the dynamics of these ecosystems. The transition from a vegetated to a degraded ecosystem can occur suddenly, with long-lasting consequences. Drylands are also significant sources of carbon, and it is still unknown how lengthening droughts will affect microbial respiration and growth responses. Human pressures on drylands, such as agricultural activities and grazing, worsen the problems in these regions. To address these challenges, holistic approaches to dryland management that account for interactions between complex natural processes and human activities are necessary. The future of drylands and their ability to provide essential ecosystem services to billions of people depend on the effective management of these ecosystems in the face of ongoing climatic and anthropogenic pressures.

This article is based on the study: Wang L., Jiao W., MacBean N., Rulli M. C., Manzoni S., Vico G., and P. D'Odorico (2022). *Dryland productivity under a changing climate.* Nature Climate Change: *https://doi.org/10.1038/s41558-022-01499-y.*

The Bolin Centre Climate Research School

The Bolin Centre Climate Research School (CRS) aims to provide a common platform for early career researchers working on climate across disciplinary boundaries and to support their training to provide society with greatly needed expertise on climate.

The Climate Research School is led by the Bolin Centre Directorate and the Study Coordinators, Otto Hermelin and Carmen Prieto. On November 14, the Bolin Climate Research School organised an early career researcher side event in connection to the Bolin days (15–16 November). The event focused on how to develop successful interdisciplinary proposals and was followed by a dinner in the Geoscience building. It was well attended by about 40 early career researchers, mainly from six departments and the Stockholm Resilience Centre.

Group photo with members of the Bolin Centre CRS and ClimBEco Graduate Research School at Sörsjöns Adventure park. The excursion was part of a join side event organised during the Swedish Climate Symposium in Norrköping, 18 May 2022. Photo: Otto Hermelin

During 2022, the cooperation between the Bolin Centre and ClimBEco Graduate School at the Centre for Environmental and Climate Science in Lund University continued and students from both schools had the opportunity to meet and interact on May 18 during the first organised joint event that took place in connection with the Swedish Climate Symposium in Norrköping (16–18 May). About 25 PhD students from both schools attended the event which had a scientific as well as a social programme only for PhD students. The scientific programme included several short oral presentations, each of them followed by a discussion session. The social part of the event was a common lunch followed by a climbing in the trees activity at the beautiful Sörsjön Adventure park. The joint side event at the symposium was highly appreciated by all participants and we hope to have the possibility to organise other joint events in the future.

Later on, in August, the Bolin Climate Research School organised a summer school in Gotland with a focus on "Extreme events – in time and space". The school gathered 14 early career researchers and six invited speakers who provided inspiring lectures and engaged in discussions with the students.

Apart from the summer school, other courses supported by the Bolin Climate Research School during 2022 were:

- Scientific writing in English, 7.5 hp
- eScience Tools in Climate Science: Linking Observations with Modelling, 7.5 hp

In addition to the courses and events, the Climate Research School continued during 2022 offering funding to early career researchers to support their active participation in international conferences, field courses and workshops.

Participants of the summer school organised by the Bolin Climate Research School in Gotland, 22–26 August 2022. Photo: Otto Hermelin

The Bolin Centre Database

– provides open access to climate and Earth system data

The database serves to promote and visualise research results and data, allowing us to highlight the stories that emerge from the data. By providing accessible and reusable literature, data, and program code to scientists, students, journalists, and the general audience, our data repository actively contributes to the global movement towards Open Science. As such, it plays a crucial role as an integral component of the Bolin Centre.

Data management is vital in scientific research, enabling transparency, reproducibility, and reusability. At the Bolin Centre, we understand the significance of effective research data management and provide comprehensive support to our scientists. In 2022, a joint effort was made to develop documentation supporting Research Data Management at the Bolin Centre, in collaboration with Anna Lewinschal, one of the Bolin Centre Modelling Coordinators. This initiative proved to be a key milestone.

Data life cycle and Open Science

Adopting an Open Science approach, the Bolin Centre recognises the importance of making scientific processes transparent. A key aspect of Open Science is ensuring that produced data is well-documented, understood, and reusable. To achieve this, we embrace the concept of the data life cycle, which encompasses various stages from planning to archiving.

Supporting the Data life cycle

Plan

Research funders often require a Data Management Plan (DMP) for funded projects. To assist researchers, Stockholm University offers centralised support and an online tool with a template for the Bolin Centre. By integrating DMP into the early stages of research planning, we ensure that data management considerations are addressed comprehensively.

Create and Analyse

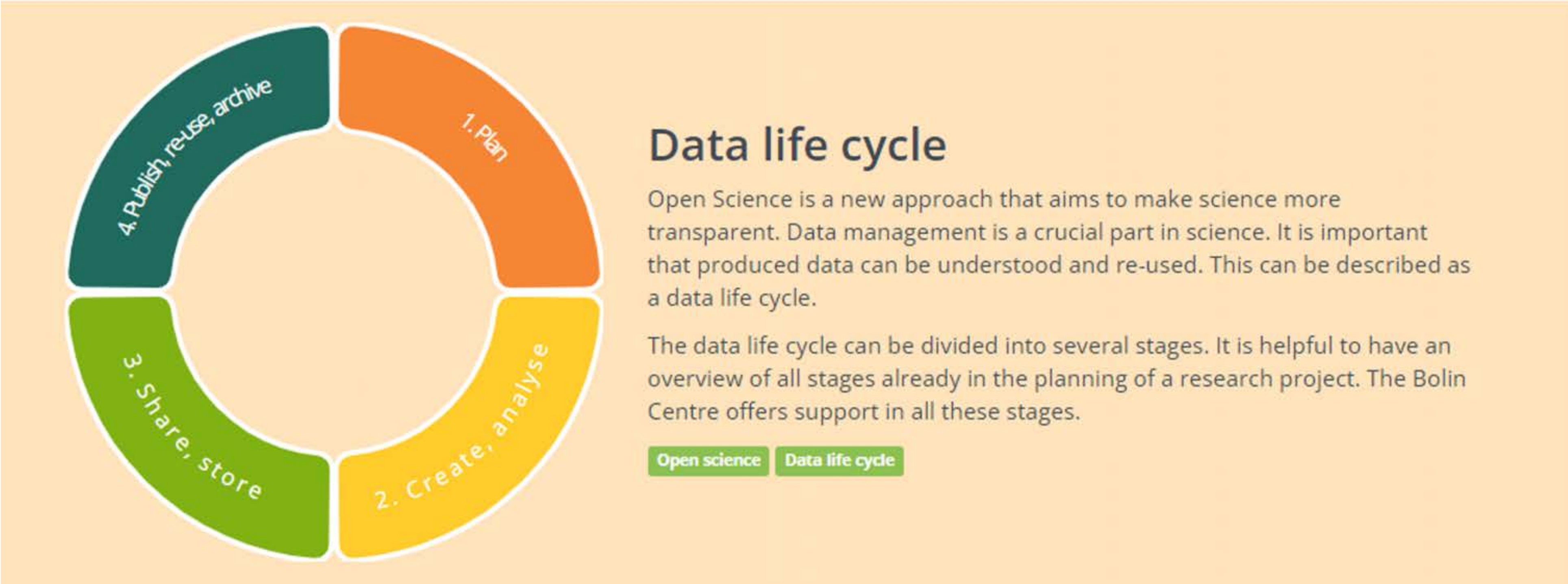
Depending on the research type, data can be generated through diverse methods. The Bolin Centre provides support for high-performance computing and storage through SNIC (Swedish National Infrastructure for Computing). This empowers our scientists by providing them with access to large-scale data resources, thereby facilitating efficient data creation and analysis.

Share and Store

To promote collaboration and secure data storage, the Bolin Centre offers two general data storage alternatives. Scientists can utilise Sunet Drive and Swestore for intermediate data storage and sharing.

Publish, Reuse, and Archive

Journals and research funders increasingly emphasise the publication of data following the FAIR principles (Findable, Accessible, Interoperable, and Reusable) in open repositories. The Bolin Centre strongly recommends utilising the Bolin Centre Database for data publication, ensuring compliance of data with FAIR principles. Additionally, the database provides digital object identifiers (DOIs) for enhanced discoverability, integrates with Git for version control, and connects with Stockholm University's e-archive, ensuring long-term data archiving.



Effective Research Data Management is dominant in modern scientific practices. The Bolin Centre's collaboration with Bolin Centre Modelling Coordination, has resulted in comprehensive documentation and support for Research Data Management. By following the data life cycle and embracing Open Science principles, we empower our scientists to generate high-quality, transparent, and reusable data. With access to HPC resources, storage alternatives, and the Bolin Centre Database, researchers can confidently navigate the complexities of data management, enabling collaboration and innovation, and helping the researchers to make impactful scientific contributions.

Read more here: *https://bolin.su.se/data/support*

Bolin Centre Modelling Coordination

Numerical models of the global climate system are essential tools in research carried out at the Bolin Centre. Earth system models are used across the research areas to study topics covering deep ocean circulation, land surface processes, atmospheric composition and dynamics and upper atmospheric physics. Bolin Centre researchers are also participating 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 – extensive 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.

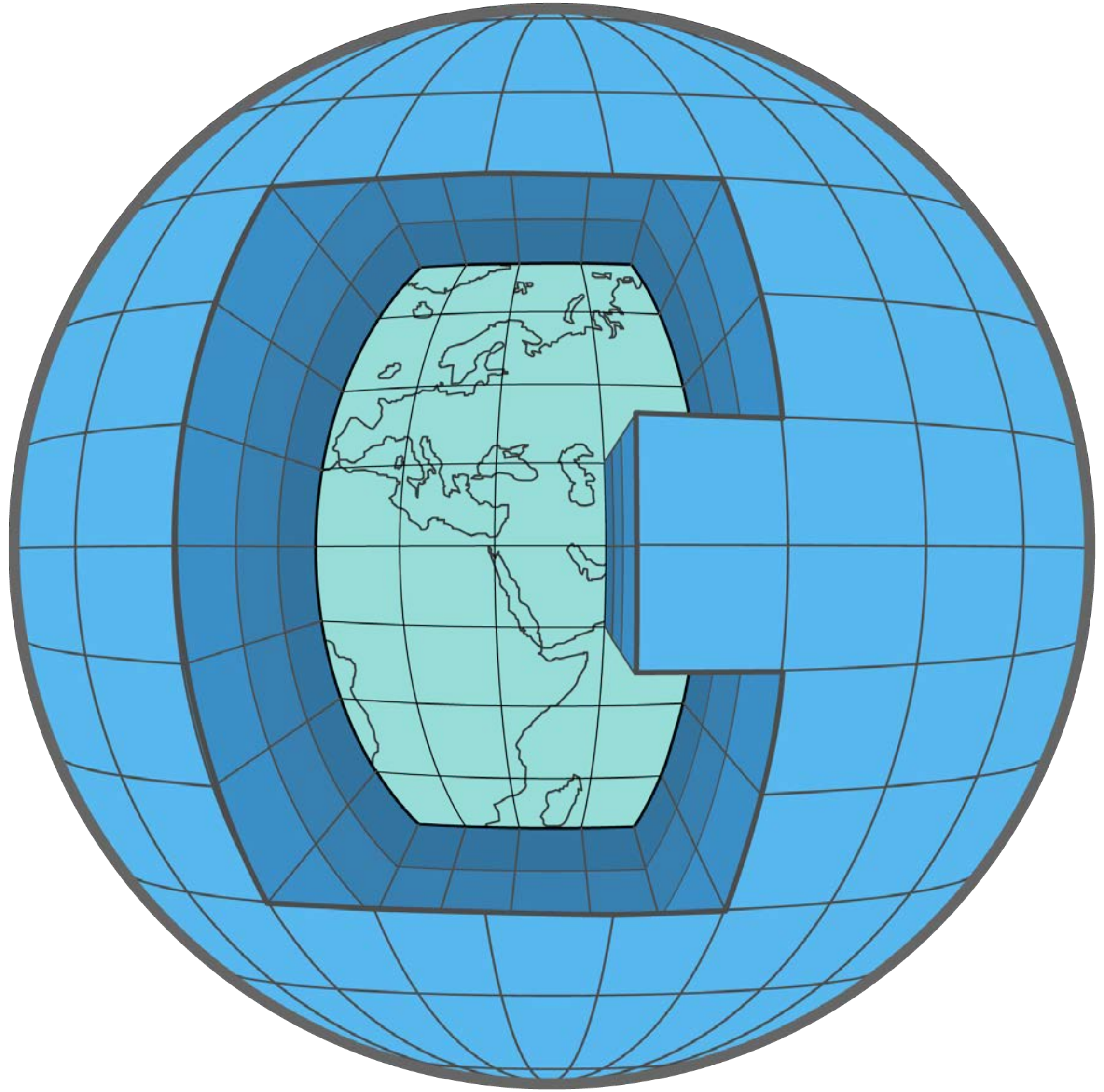
Climate models are important tools for improving our understanding of climate behaviour and the predictability of its effects on seasonal, annual, decadal, centennial and millennial time scales. The Bolin Centre uses the climate models EC-Earth and NorESM to understand how the Earth's climate varies 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 the Sahara that happened during the 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 of today's clean energy proposal on the deployment of massive Sahara solar farms.

Industrial activities generate not only greenhouse gases but also nano- to micrometre-sized particles in the air. These particles affect climate at the same time as they are harmful to 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 will 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 is clouds since these are mostly too small to be simulated with the approximately 100 by 100-kilometre grid cells used in regular climate models. Cloud processes determine both the strength of global warming through cloud feedback, 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 is working to bring the next-generation ICON (Icosahedral Nonhydrostatic) 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 one by one kilometres, 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 sheet 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

Communication and coordination

The Bolin Centre's Communication and Coordination Team works to ensure effective communication and coordination across the centre. They produce content for various channels, organise outreach events, and coordinate internal and external meetings and events such as the Annual Bert Bolin Climate Lecture and the Bolin Days. They are also responsible for managing and producing engaging content for the Bolin Centre website and for providing a regular newsletter to Bolin Centre's members.

Bolin Centre's Researchers reach out with research results during COP27

The annual COP27 climate summit in Sharm el-Sheikh, Egypt concluded with a historic breakthrough to help vulnerable countries deal with losses and damage from the impacts of climate change. The Bolin Centre for Climate Research co-organised the Cryosphere Pavilion at the summit, where Gustaf Hugelius, an expert on permafrost and vice-director of the Bolin Centre, presented his research on the effects of human emissions on the cryosphere. The presented research emphasised the impact of climate change on the Arctic, permafrost, and wetlands, with a particular emphasis on the effects of thawing permafrost that releases greenhouse gases. Gustaf Hugelius also participated in open negotiations and lent his expertise to the discussions.

As the COP27 climate summit drew to a close, Gustaf Hugelius expressed his hopes for the outcome of the conference. He hoped that more countries would commit to ambitious emission reductions, specifically through the announcement and argumentation of nationally determined contributions. Gustaf Hugelius also emphasised the importance of negotiations on “loss and damage,” involving discussions on how developed countries should take financial and moral responsibility for the damage caused by climate change. Reducing the use of coal as an energy source was also a pressing issue, and he hoped that the summit would lead to rapid emissions reductions and the potential for a common global market for emission rights.

For the Bolin Centre, Gustaf Hugelius hopes that its important research results will reach decision-makers, officials, and organisations, in order to promote evidence-based solutions to global climate change challenges. Although it remains to be seen what concrete actions will be taken by participating countries, Gustaf's hopes for the summit serve as a reminder of the importance of global cooperation and ambitious action to address the urgent challenge of climate change.

The communication and coordination team at the Bolin Centre manages and utilises social media platforms to communicate climate science to the public. Platforms such as Facebook and Twitter are used to achieve this goal effectively. Twitter, in particular, is an excellent tool for sharing recent publications and research findings with interested members of the public, fellow researchers, journalists, and organisations.

The Bolin Days 2022

The Bolin Centre successfully hosted the 14th Bolin Days on November 15 and 16, 2022, both on-site at Aula Magna and via Zoom. This annual conference brought Bolin Centre members together to share new climate science results, exchange ideas, and engage in cross-disciplinary sessions organised by Research Theme leaders. The event featured poster exhibitions, research presentations, and a poster competition for PhD students, as well as opportunities for networking, dinner, and a lively ceilidh led by Alasdair Skelton. We are pleased to report that the event was a great success, with approximately 200 Bolin Centre members participating. We are looking forward to the 15th Bolin Days in the coming year.

Bolin Climate Lecture 2022 at Aula Magna. Photo: Maria Basova

Bolin Centre's researchers at ForskarFredag 2022. Photo: Maria Basova

The Bolin Centre engages with high school students on climate change mitigation

The Bolin Centre participated in ForskarFredag in late September. ForskarFredag is a national event coordinated by the Vetenskap & Allmänhet association, which aims to encourage young people to pursue higher education and research careers. The event provides a platform for researchers to engage with the public and challenge stereotypes about researchers.

The theme for ForskarFredag 2022 was *A better and healthier world*, aligned with the EU's five mission areas. As part of the event, the Bolin Centre researchers and PhD students contributed interactive demonstrations and experiments and asked high school students about how they could minimise their own impact on the climate. The purpose of this activity was to raise awareness about individual actions and their impact on the climate and environment.

The Workshop on Effective Scientific Presentations, held in October, aimed to equip PhD students and researchers with the skills necessary to improve their scientific presentation style. The workshop covered various topics, including structuring presentations, delivering memorable presentations, and maximising the impact of one's voice. The instructor, Alan Crivellaro, provided a supportive and non-judgemental environment in which participants could practice speaking and could learn from each other. The workshop provided participants with a set of tools to immediately improve their presentations and a framework for continuous improvement.

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

Maria Basova joined the Bolin Centre in September 2022 as coordinator. Photo: Uly Konstantinow

Sara Gershagen joined the Bolin Centre in January 2022 as a part-time coordinator. Photo: Luliana Domina

The Bert Bolin Climate Lecture

Professor Bert Bolin was not only a leader in climate research, but also one of the founders of the IPCC, which received the Nobel Peace Prize in 2007. To commemorate his contributions, the Faculty of Science at Stockholm University established the annual Bert Bolin Climate Lecture.

Every year, the Faculty of Science selects a prominent scientist in the field of climate research to give the lecture, which is held at Stockholm University. The Bolin Climate Lecturer is appointed by the Dean of the Faculty of Science, and nominations can be made by all Bolin Centre members in response to a call. The lecture provides an opportunity for the distinguished scientist to give both a popular science lecture and a science seminar, sharing their knowledge and insights with the wider community.

In 2022, the honourable speaker was Professor Hans Joosten, who delivered the 14th Bert Bolin Climate Lecture on November 23, 2022

The lecture was entitled: ***The Great Rewetting: why we must stop draining peatlands – worldwide and as fast as possible***

Prof. Hans Joostens is an internationally renowned peatland scientist, conservationist and educator. Throughout his career, he has made extraordinary efforts to raise awareness of the role of peatlands in the Earth system. He has acted as general Secretary (since 2000) of the International Mire Conservation Group and has been co-founder and Coordinating Committee member (since 2015) of the Greifswald Mire Centre. In 2021, he was awarded the prestigious German Environmental Award established by the German Federal Foundation for the Environment (DBU).

Although peatlands contain more carbon worldwide than all forest biomass combined, their importance has long been overlooked. Drained primarily for agriculture and forestry, peatlands emit over two gigatonnes of CO_2 equivalent per year. This means that 0.3% of the Earth's land area is responsible for a disproportionate 5% of anthropogenic greenhouse gas emissions. Possibly even more important globally is peatland subsidence: while sea levels are rising due to global warming, peatlands are literally bogged down through drainage-based land use, losing between a few millimetres to several centimetres of height per year, depending on climate and land use. Globally, we may lose 10–20 million hectares of productive land to uncontrolled flooding in the coming decades as a result. To meet the Paris climate targets, all still-natural peatlands must remain wet, those that have been drained must be rewetted, and agricultural use should only take place under wet conditions.

Professor Hans Joosten.
Photo: Tobias Dahms

The highest priority and the greatest challenges in rewetting lie with the agriculturally used peatlands. Until now, these have mostly been taken out of production after rewetting. However, we will no longer be able to afford this comprehensively. The development and implementation of wet production methods ("paludiculture") is urgently needed. Such action can avoid the environmental damage of conventional peatland use and at the same time allow peatlands to be used productively.

The advantages of wet use of peatlands are so great in economic terms that one may ask why such "paludiculture" should not be implemented quickly and across the board. However, paludiculture is contrary to the historical heritage of 10,000 years of "dry" agriculture. It usually involves a redesign of the entire production chain: from training, crop selection, technology, infrastructure and logistics, products, promotion, research, to integrative value chain concepts. Payments for ecosystem services – especially carbon credits – can serve as a transitional strategy for the full implementation of paludiculture.

Peatlands must be wet: For the peatland, for the land, for the climate, forever!

Lecturers

2022 | Professor Hans Joosten
The Great Rewetting: Why we must stop draining peatlands – Worldwide and as fast as possible

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

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

2019 | Professor Maureen E. Raymo
Climate, CO_2 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

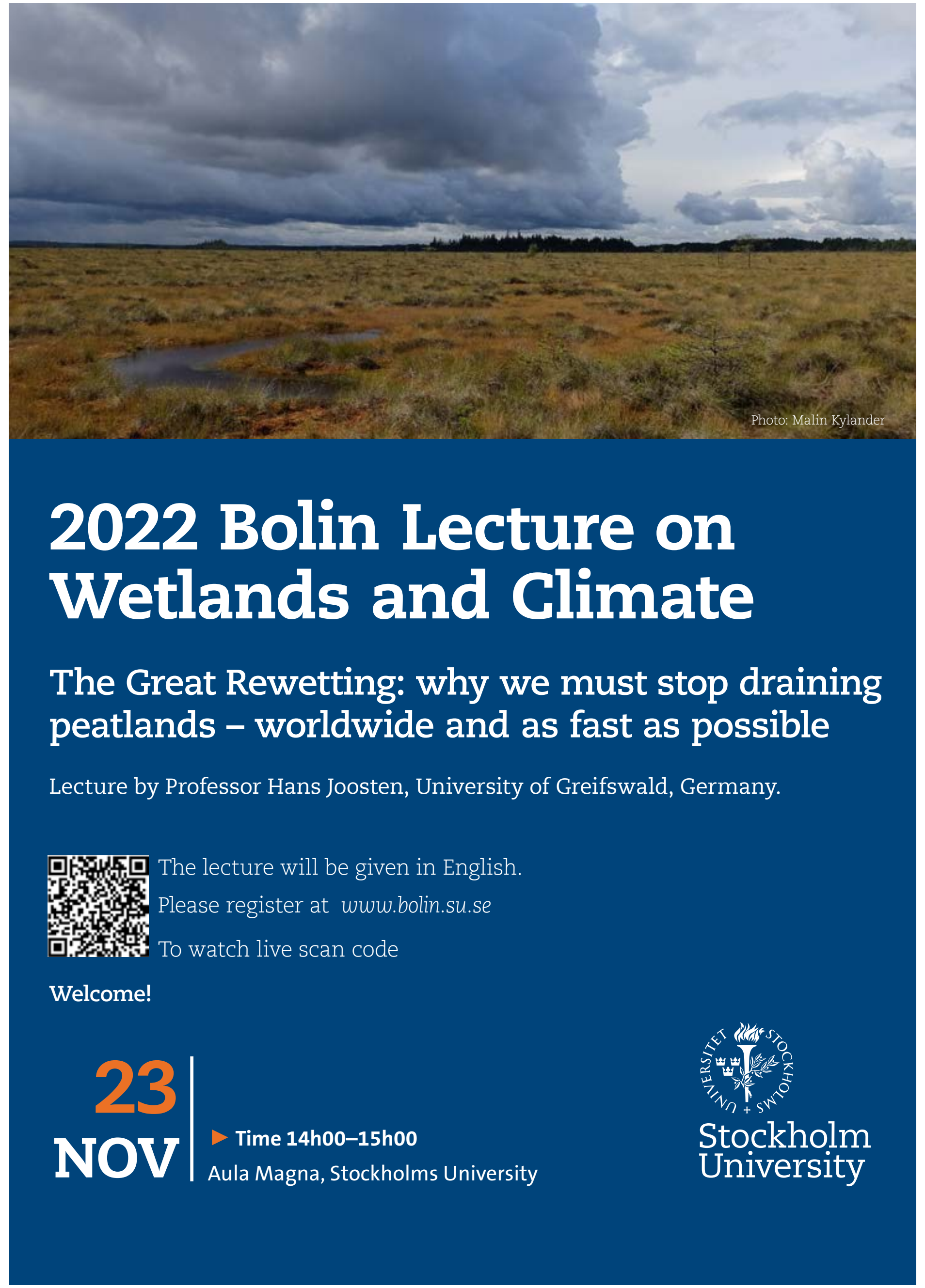
2012 | Professor Sherilyn Fritz
The climate during the past 10,000 years

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 of its collaborative partners: six departments at Stockholm University, the Swedish Meteorological and Hydrological Institute, and KTH Royal Institute of Technology. In addition, the board includes an external member and a student representative.

Professor Johan Nilsson
Chair of the Bolin Centre Board, Department of Meteorology, Stockholm University.

Professor Martin Jakobsson
Vice-chair of the Bolin Centre board, Department of Geological Sciences, Stockholm University.

Professor Magnus Breitholtz
Department of Environmental Science, Stockholm University.

Professor Rodrigo Caballero
Department of Meteorology, Stockholm University.

Professor Sara Cousins
Department of Physical Geography, Stockholm University.

Professor Kristoffer Hylander
Department of Ecology, Environment and Plant Sciences, Stockholm University.

Professor Bengt Karlsson
Department of Zoology, Stockholm University.

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

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

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

Anna-Karin Nyström, MSc
Head of the Climate Objectives Unit, Swedish Environmental Protection Agency.

Jonathan Wiskandt, PhD student
Department of Meteorology, Stockholm University.

Professor Ilona Riipinen
Ex Officio, Director of the Bolin Centre, Stockholm University.

Associate Professor Gustaf Hugelius
Ex Officio, Vice-Director at the Bolin Centre, Stockholm University.

Sara Gershagen
Ex Officio, Coordinator at the Bolin Centre, Stockholm University.

Maria Basova
Ex Officio, Coordinator at the Bolin Centre, Stockholm University.

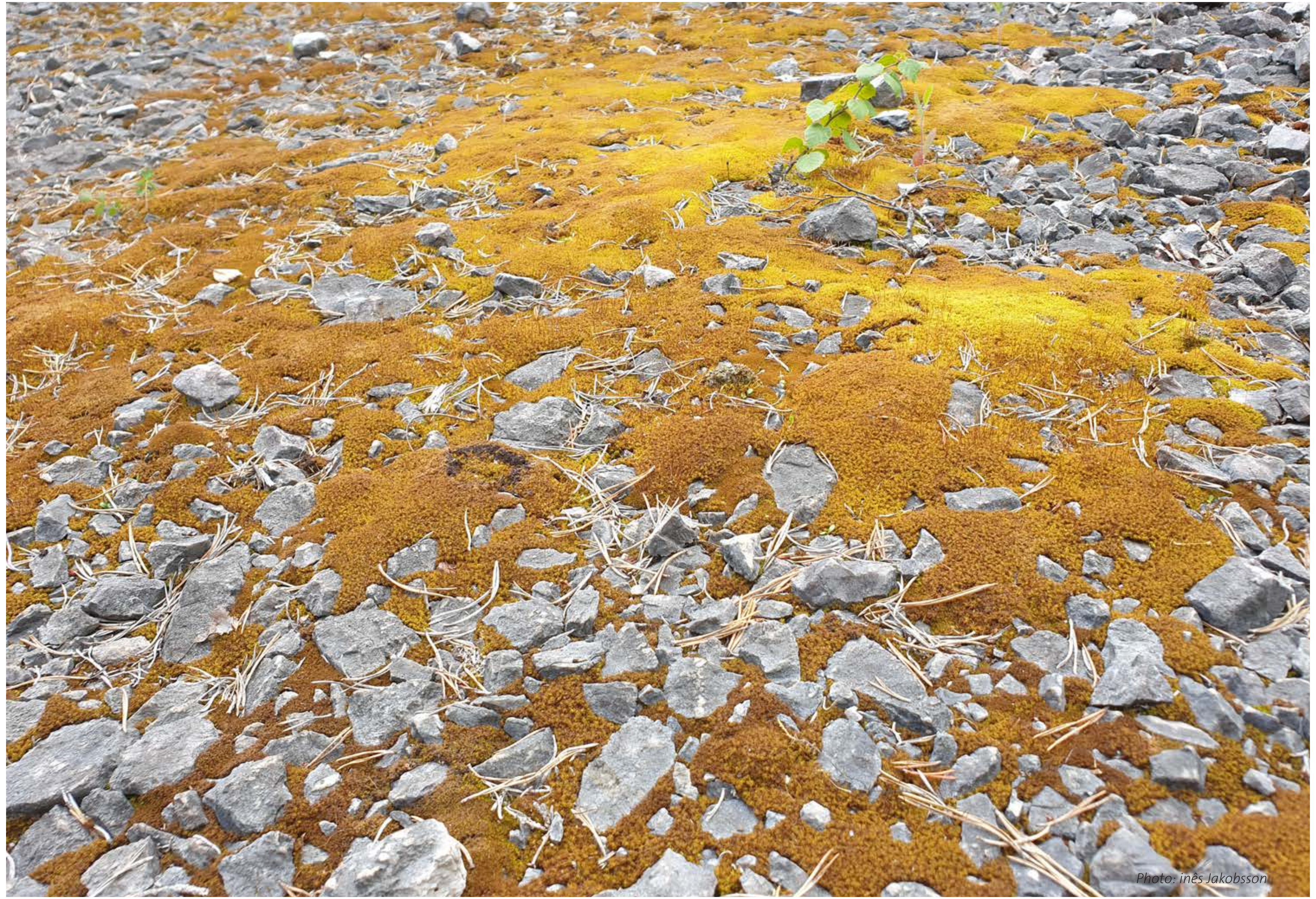


Photo: Ines Jakobsson

The External Science Advisory Group

The Bolin Centre has appointed an ESAG composed of leading national and international scientists working 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 to increase the Bolin Centre's contacts with international networks and research groups within the climate research area.

Professor Jay Famiglietti

Global Futures Professor at Arizona State University, and a science communicator. Director Emeritus of the Global Institute for Water Security at the University of Saskatchewan.

Professor Karen Kohfeld

Professor, resource and environmental management (primary) and environmental science, Simon Fraser University, Canada.

Professor Ulrike Lohmann

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

Professor Camille Parmesan

Adjunct Professor, Department of Geological Sciences, Jackson School of Geosciences, The University of Texas at Austin, USA.


Photo: Inés Jakobsson

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. Apart from a few brief absences, 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 a natural leader. He initiated several research programmes focusing on the global environment including the World Climate Research Programme and the International Geosphere-Biosphere Programme.

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 the IPCC has been confirmed by many. The IPCC received the Nobel Peace Prize in 2007.

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

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

Henning Rodhe
Bert Bolin's student, colleague and friend

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

Photo: Martin Jakobsson

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

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