2021
WCRP CliC
Annual Report

ABOUT CliC

Who we are…

The Climate and Cryosphere (CliC) is a global community of dedicated and enthusiastic researchers with expertise and knowledge of the cryosphere and its interactions with the climate system. CliC expertise spans simulation modelling, field observations, process studies and cross-cutting workers who engage with other disciplines and stakeholders. CliC is one of the Core Projects of the World Climate Research Program (WCRP, https://www.wcrp-climate.org)

What we do…

CliC identifies key research questions, priorities, gaps and challenges pertaining to the cryosphere and its interaction with the global climate system, and coordinates international activities to promote activities that address these matters. CliC highlights emerging issues, facilitates exchanges amongst scientists, and with relevant external stakeholders, promotes international cooperation. The project also communicates cryosphere related science to policymakers, funding agencies, and the general public. To ensure that we are preparing for the future, CliC takes a leading role in promoting early career researcher development, including through fellowships

How we work…

CliC achieves its mission by bringing together scientists and stakeholders from all over the world to plan and take part in activities targeting the scientific priorities in cryosphere science. CliC activities are overseen by the CliC Scientific Steering Group (SSG) which has the overall responsibility for planning and guiding the work of the Core Project. The CliC International Project Office supports the SSG and the wider CliC community in their work and is the main point of contact for CliC (www.climate-cryosphere.org).

The Annual Report 2021 was edited by Beatriz Balino with contributions from:
John Cassano, Jan de Rydt, Chris Derksen, Heiko Goelzer, Edward Hanna, Petra Heil, Regine Hock, Alexandra Jahn, Nicolas Jourdain, Hyungiun Kim, Chris Kittel, Gerhard Krinner, Torge Martin, Ben Marzeion, Ruth Mottram, Dirk Notz, Sophie Nowicki, James E. Overland, Tony Payne, Don Perovich, James Renwick, Annette Rinke, Catherine Ritz, Christina Schaedel, Ted Schuur, Sonia Seneviratne, Amy Solomon, Jackeline Stefels, Nadja Steiner, Fiammetta Straneo, Barrt van den Hurk, Melinda Webster and Andrew Orr

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Photo front page: Tuna Glacier with Bearded seal (*Erignathus barbatus*), Svalbard, Norway. Photo: Jan Helge Fosså

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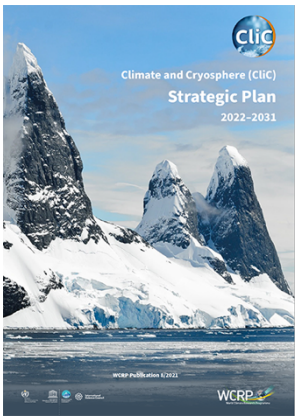
Summary

2021 was a productive year for the CliC community, even amidst the pandemic, and we are pleased to share this annual report highlighting some of our progress and achievements during the past year. In this summary, we would like to highlight the following:

The *Ice Sheets Modelling Intercomparison Project 6* (ISMIP6) succeeded in generating projections of the future sea-level contribution of ice sheets for use in the 6th Assessment Report of the IPCC. This was the result of a seven-year international collaboration involving over 40 institutions and represents the first ever coordinated effort to make fully process-based predictions of the ice sheets' future. The collaboration generated well over 25 scientific papers including key publications on the responses of Greenland and Antarctica to climate change, as well as a statistical analysis focussed on high-end estimates of sea level rise. It involved very significant interdisciplinary collaborations with oceanographers, meteorologists, glaciologists and statisticians in developing the first framework for the use of climate projections from Earth System Models by the ice sheet modelling community and saw worldwide scientific engagement in the development and application of this framework. The project has created a lasting legacy based around this framework and the community of international researchers brought together to trace the complex ways in which future climate change will impact the ice sheets and their all-important contribution future sea level rise.

CliC Strategic Plan 2022-2031



Our improved understanding of the cryosphere has developed in parallel with an increased awareness of the large impact that human activities are having on the planet and how these changes, in turn, are affecting human and natural systems. For the cryosphere, in particular the rate of loss of land-ice, sea ice, and permafrost, has rapidly increased over the last few decades, representing some of the clearest planet-wide response to human-induced global warming and has in turn helped to accelerate climate change. Moreover, future ice loss will be strongly influenced by present and future human activities. These changes, in turn, are having major consequences on local and global communities and ecosystems, societies, economies as well as triggering feedbacks within the climate system. This prompted the SSG to start working on a new science strategy for the upcoming decade, to broaden CliC´s vision and mission to include research that is co-designed and executed with relevant stakeholders and user communities, while continuing to support the research that advances understanding of processes within the cryosphere components of the climate system. This work culminated with the publication of the *CliC Strategic Plan 2022-2031*. CliC´s approach to achieve a system understanding of the cryosphere and its services, will be the co-design of research among natural and social scientists, stakeholders and affected communities. CliC´s new strategy aligns with the vision of WCRP Strategic Plan 2019-2028, "*…sound, relevant, and timely climate science to ensure a more resilient present and sustainable future for humankind",* and addresses directly the fourth strategic objective of *"bridging climate science and society*". As first steps in the implementation of the Strategic Plan, it was decided to increase the engagement of senior scientists and Early Career Scientists from regions currently underrepresented in CliC, such as South America, Asia and Africa. For this, open calls were launched for (i) SSG membership and (ii) CliC Grants and Fellowships that target CliC´s new priority research areas.

As WCRP is proceeding to implement its Science Plan, CliC ensured representation of the cryosphere community at the Science Plan Writing Teams of all new bodies of WCRP: Lighthouse Activities: MyClimate Risk, Safe Landing Climates, Digital Earths, Explaining and Predicting Earth System Change and Academy and Core Projects: Regional Information for Society (RifS) and Earth System Modelling and Observations (EMSO).

We thank the cryosphere community for continuing their efforts even in the challenging circumstances posed by COVID-19.

CliC co-chairs Fiammetta Straneo & James Renwick

James Renwick

Fiammetta Straneo

The end of 2021 saw the termination of serving terms of co-chair **James Renwick**, SSG member **Lars H. Smedsrud** and leader of the Grand Challenge *Melting Ice and Global impacts* **Timothy Naish**. The CliC community extends a special thanks to all of them for long service and invaluable contributions to the project.

The Scientific Steering Group 2021

Chairs

James Renwick, Victoria University of Wellington, New Zealand	1/2017-12/2021
Fiammetta Straneo, Scripps Inst. Oceanography, UCSD, USA	1/2018-12/2022

Members

Hanne Christiansen, University Centre in Svalbard, Norway	1/2020-12/2023
Amy Lovecraft, University of Alaska Fairbanks, USA	1/2020-12/2023
Camille Lique, IFREMER LOPS, France	1/2020-12/2023
Helene Seroussi, Dartmouth College, USA	1/2019-12/2022
Lars H. Smedsrud, University of Bergen, Norway	1/2016-12/2021
Shin Sugiyama, Hokkaido University, Japan	1/2020-12/2023
Martin Vancoppenolle, CNRS LOCEAN, France	1/2019-12/2022
Tingjun Zhang, Lanzhou University, China	1/2020-12/2023


H.Christensen


A. Lovecraft


C. Lique


M. Vancoppenolle


H. Seroussi


L.H. Smedsrud


S. Sugiyama


T. Zhang

WCRP Support

JSC liaison


Jens Hesselbjerg Christensen, University of Copenhagen, Denmark

JSC liaison


Igor Shkolnik, Voeikov Geophysical Observatory, Russia

Secretariat


Narelle van der Wel, WMO, Switzerland

The International Project Office

The CliC International Project Office (IPO) assisted the SSG in the organisation of two virtual meetings in March and August as well as in the reporting of CliC activities to the WCRP Joint Scientific Committee. The IPO prepared presentation material to SSG members attending science meetings of relevance to CliC.

Balino and van der Wel at WCRP secretariat coordinated the design, edition and publication of the CliC Strategy Plan 2022-2023:
https://climate-cryosphere.org/wp-content/uploads/2022/01/CliC_StrategicPlan_2022-2031.pdf

The IPO co-organised the virtual PolarCORDEX Annual meeting and edited this annual report. It assisted in the first call for CliC grants and fellowships as well as in the call for nominations for CliC co-chairmanship.

The IPO kept regular teleconferences with the International Offices from WCRP Core Projects and other supporting activities. In 2021 WCRP continued the implementation of its new structure and the future role of the IPOs in assisting the new bodies continues to be a topic of discussion.

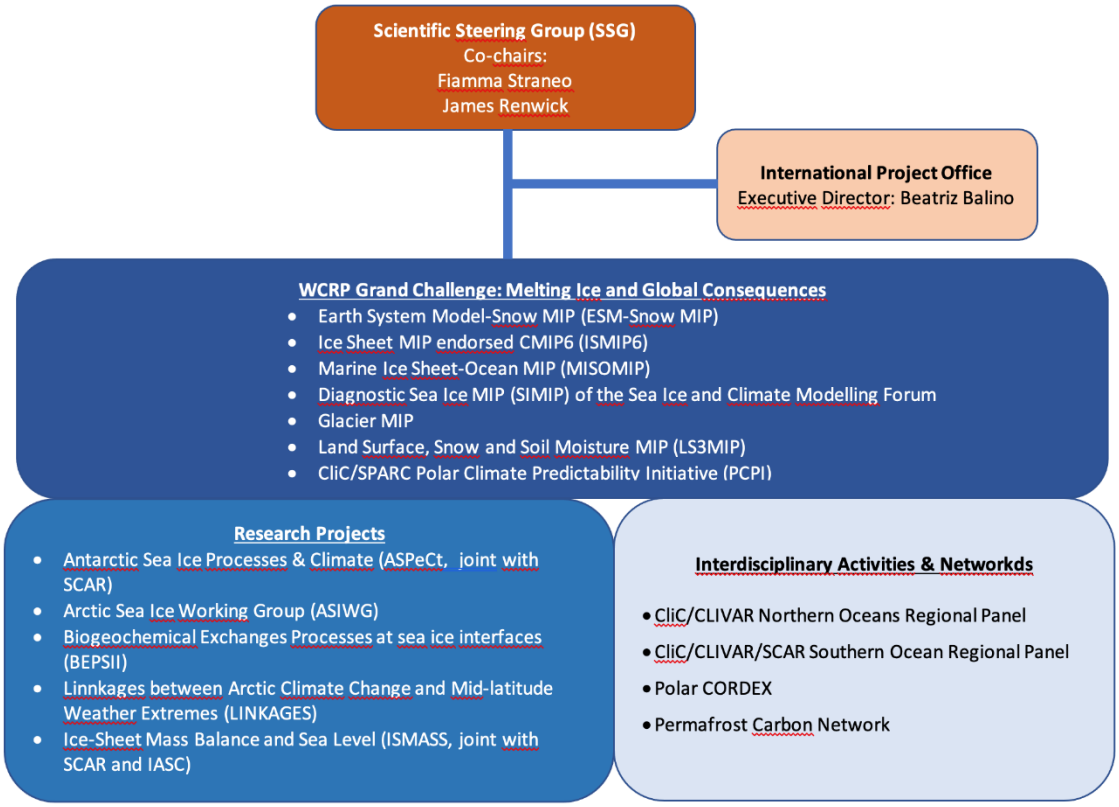
Executive Director Balino was on sick-leave part of 2021, so Dr Helene Asbjørnsen was hired during Balino´s absence. Asbjørnsen is an oceanographer at the Geophysical Institute, University of Bergen with expertise in modelling the interactions between the Arctic and Atlantic oceans. She was well acquainted with CliC from before and took over the day-to-day management of the office right away. We thank Helene for her contribution to the project.

The IPO is hosted by the Bjerknes Centre for Climate Research (BCCR) and is co-sponsored by BCCR and the Research Council of Norway.


Beatriz Balino


Helene Asbjørnsen

CliC organisation 2021



Modelling Intercomparison Projects (MIPs)

ICE SHEET MODEL FOR CMIP6 (ISMIP6)

The Ice Sheet Model Intercomparison for CMIP6 (ISMIP6) has the key objective of improving projection of sea level from the Greenland and Antarctic ice sheets, and our understanding of the cryosphere in a changing climate. These goals map into both "Melting Ice and Global Consequences" and "Regional Sea-level Change" Grand Challenges relevant to CliC and the World Climate Research Program (WCRP) which was sunset in 2021. As uncertainties in future sea level arise due to both the climate forcing and the response of the ice sheets, a primary focus for ISMIP6 was to become better integrated in the CMIP6 initiative. ISMIP6 became an endorsed activity of CMIP6 in 2015 allowing for the first time in CMIP for ice sheets to be considered as a component of the Earth system.

HIGHLIGHTS

ISMIP6 succeed in its primary goal of generating projections of the future sea-level contribution of ice sheets for use in the 6th Assessment Report of the IPCC (AR6). The analysis of these simulations suggested the need for extending Antarctic projections beyond 2100. A primary focus for the project in 2021 was the development of a protocol and dataset for Antarctic projections to 2300. This new effort will be launched in early 2022.

The on-going analysis of the ISMIP6 ensemble resulted in two community papers (Payne et al. 2021 and Edwards et al., 2021) and multiple ISMIP6 members publications (see publication list below for a selection). Payne et al. (2021) explored future sea level change under CMIP5 and CMIP6 scenarios from the Greenland and Antarctic ice sheets. Edwards et al. (2021) combined ISMIP6 simulations with statistical techniques to make projections for the latest emission scenarios and further estimate uncertainty in sea level projections from ice sheets. Both Payne et al. (2021) and Edwards et al. (2021) showed that the response of the two ice sheets in a warming world is different: whereas Greenland loses mass with warming temperature (Figure 1), Antarctica is more complex as it depends on how increased temperature translate into local climate. The ISMIP6 member publications ranged from describing their models and ISMIP6 simulations (Quiquet and Dumas, 2021a, 2021b) to building on the ISMIP6 protocol with additional ice-ocean interactions (Lipscomb et al., 2021), the use of emulators in 23rd century projections (Lowry et al. 2021), or projections to year 3000 (Chambers et al., 2021).

Community building between ISMIP6 ice sheet modelers, as well as ice sheet modelers and climate modelers remained a key focus for ISMIP6 despite the pandemic. These efforts are illustrated in the multiple presentations given by ISMIP6 steering committee members to EGU, AGU, IARPC, NASA Sea Level Change Team, TIPMIP, SCAR INSTANT and many other virtual workshops.

FUTURE PLANS

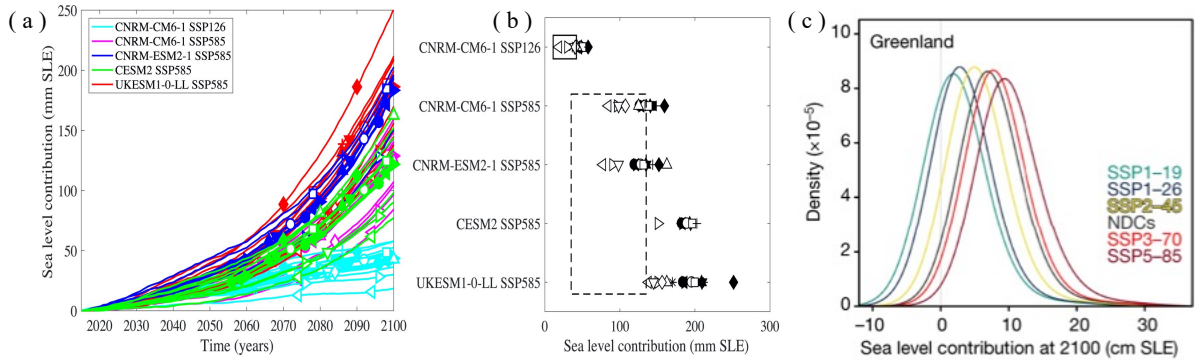
ISMIP6 is continuing the analysis of the rich dataset with the goal of understanding the uncertainty in the sea level projections and to refine the protocol for future efforts. ISMIP6 will continue to plan simulations that can be built on the existing protocol (for simulations that can occur in the next year) or protocol for ISMIP6 follow on effort. Our goals for both the standalone and coupled aspects of ISMIP6 are to develop MIP ideas and highlight areas for development that need to be addressed by the time of CMIP7. As ISMIP6 plans its follow-on activities, we will continue to interact with other activities from which we can either contribute to or benefit from such as other MIPs (eg: MISOMIP, PMIP, TIPMIP) or initiatives (eg: GRISO, PROTECT, ISMASS, SCAR INSTANT)

In addition to the launch of Antarctic projections to 2300 and subsequent analysis, a focus for 2022 is how to improve simulations over the historical and last decades. It is

anticipated that very significant interdisciplinary collaborations with oceanographers, meteorologists, glaciologists, and statisticians in developing this new framework will be required. ISMIP6 is also planning to interact with GlacierMIP and the glacier community to develop a strategy for delineating between ice sheets and glaciers to avoid double counting or omission of ice in observational and modelling studies. Our primary focus for community building in the near term will be with the climate modelling community that is coupling dynamic ice sheets to climate models. The project plans to facilitate these interactions with a series of focused virtual workshops and focus groups throughout the year. We hope to convene an in-person workshop linked with AGU or another large conference to review and discuss next steps in these activities.

MEETINGS

The annual meeting was cancelled, and no workshops were organised due to COVID-19.



Global mean sea level rise contribution from the Greenland ice sheet to 2100. (a) Time series of contribution between 2015 and 2100 (in mm) for whole ice sheet as a function of experiment (legend) and ice sheet model (symbol). (b) Contribution at 2100. Symbols refer to ice sheet models while boxes refer to ranges from equivalent CMIP5-forced experiments. (c) Probability density function for CMIP6 scenarios obtained from statistical emulation of ISMIP6 ensemble. Panels (a-b) are from Payne et al. (2021) and (c) is from Edwards et al. (2021).

PEER REVIEW PUBLICATIONS (A SELECTION)

Edwards, T. L., Nowicki, S., Marzeion, B., Hock, R., Goelzer, H., Seroussi, H., ... & Zwinger, T. (2021). Projected land ice contributions to twenty-first-century sea level rise. Nature, 593(7857), 74-82, https://doi.org/10.1038/s41586-021-03302-y.

Payne, A. J., Nowicki, S., Abe-Ouchi, A., Agosta, C., Alexander, P., Albrecht, T., ... & Zwinger, T. (2021). Future sea level change under CMIP5 and CMIP6 scenarios from the Greenland and Antarctic ice sheets. Geophysical Research Letters, e2020GL091741, https://doi.org/10.1029/2020GL091741.

Lipscomb, W. H., Leguy, G. R., Jourdain, N. C., Asay-Davis, X., Seroussi, H., and Nowicki, S.: ISMIP6-based projections of ocean-forced Antarctic Ice Sheet evolution using the Community Ice Sheet Model, The Cryosphere, 15, 633–661, https://doi.org/10.5194/tc-15-633-2021

Quiquet, A. and Dumas, C.: The GRISLI-LSCE contribution to ISMIP6, Part 1: projections of the Greenland ice sheet evolution by the end of the 21st century, The Cryosphere, 15, 1015–

1030, https://doi.org/10.5194/tc-15-1015-2021, 2021a.

Quiquet, A. and Dumas, C.: The GRISLI-LSCE contribution to ISMIP6, Part 2: projections of the Antarctic ice sheet evolution by the end of the 21st century, The Cryosphere, 15, 1031–1052, https://doi.org/10.5194/tc-15-1031-2021, 2021.b

Lowry, D.P., Krapp, M., Golledge, N.R. and Alevropoulos-Borrill, A.: The influence of emissions scenarios on future Antarctic ice loss is unlikely to emerge this century. Commun Earth Environ 2, 21, https://doi.org/10.1038/s43247-021-00289-2, 2021.

Chambers, C., Greve, R., Obase, T., Saito, F., and Abe-Ouchi, A.: Mass loss of the Antarctic ice sheet until the year 3000 under a sustained late-21st century climate, Journal of Glaciology, https://doi.org/10.1017/jog.2021.124, 2021.

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- http://www.climate-cryosphere.org/wiki/index.php?title=ISMIP6_wiki_page
- https://climate-cryosphere.org/about-ismip6/

MARINE ICE SHEET OCEAN MIP 2 (MISOMIP2)

The aim of MISOMIP2 is to keep strong interactions between the ocean and ice-sheet modelling communities and to further investigate the robustness and biases of ocean and/or ice-sheet models in a range of Antarctic environments.

MISOMIP2 is a natural progression of previous and ongoing model intercomparison projects that have focussed on the simulation of ice-ocean processes in Antarctica. Previously, the ISOMIP (ISOMIP and ISOMIP+) and MISMIP (MISMIP, MISMIP3D, MISMIP+) exercises have used idealized geometries and forcings to test and compare the ability of ocean models to simulate ice shelf melt rates, and to assess the corresponding ice dynamic response. MISOMIP1 was the first intercomparison exercise to bring the ice-dynamics and ocean communities together and provide a framework to compare outputs from a range of coupled ice-ocean models.

The aim of MISOMIP2 is not to build emission-based coupled ocean/ice-sheet projections because this is the task of ISMIP6 (their initial protocol includes regional configurations). Rather, we aim to provide a platform to assess the ability of ocean models to simulate melt rates for different realistic forcings and variable cavity geometries and assess the sensitivity of ice dynamics to various perturbations in a realistic environment.

HIGHLIGHTS

In 2021, the core team continued to work on the experimental design, as follows:

- Test-simulations were run for each of the proposed experiments. Results were analysed, discussed, and refined.
- Post-processing routines for model output were coded and tested.
- Oceanographic and glaciological data were gathered and processed to serve as a 'MIPkit' for comparison to model output.
- A first draft of a manuscript outlining the MISOMIP2 protocol was completed

FUTURE PLANS

The community will be consulted on the final MISOMIP2 protocol, and a manuscript will be submitted to Geoscientific Model Development in 2022. We will organise an informative Splinter session during EGU22, and a writing workshop in Autumn 2022 with the core team and selected members of the wider community including 5 CliC-sponsored ECRs.

MEETINGS

Tha annual meeting was cancelled due to the pandemic. Planned to take place in Autumn 2022.

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LAND SURFACE, SNOW AND SOIL MOISTURE MIP (LS3MIP) AND THE EARTH SYSTEM MODEL-SNOW MIP (ESM-SNOWMIP)

The Land Surface, Snow and Soil Moisture Intercomparison Project (LS3MIP) is an endorsed sub-project of CMIP6. The ESM Snow Model Intercomparison (ESM-SnowMIP) is an extension to LS3MIP focusing on the evaluation of the representation of snow in global and dedicated process models. In addition to global land surface and coupled simulations similar to LS3MIP, ESM-SnowMIP also includes site-scale simulations designed to evaluate model performance at local scales.

SCIENCE HIGHLIGHTS

- The suite of northern hemisphere snow extent and snow water equivalent reference datasets was updated to reflect advancements in satellite-derived products (through the European Space Agency Snow CCI project) and the newest generation of physical snow models driven by reanalysis meteorology.
- Preparations continued for a set of reference site experiments for ESM-SnowMIP experiments at tundra sites. The tundra climate class of snow was not considered in the initial set of ESM-SnowMIP reference site simulations. These are challenging sites because of limited availability of forcing data over a full seasonal cycle, and the high degree of spatial heterogeneity in tundra snow properties.
- Analysis continued the set of historical land simulations (land-hist) from LS3MIP. The focus is on the validation and benchmarking of snow and permafrost within the land-hist simulations, compared to the historical CMIP6 coupled simulations.

MEETINGS

AGU Fall meeting 2021 to present the work of Mudryk, L., E. Burke, G. Krinner, N. Collier, C. Derksen, and D. Lawrence. 2021. Simulation of cold processes in the CMIP6 land-historical simulations.

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Barrt van den Hurk, Koninklijk Nederlands Meteorologisch Instituut, Bart.vandenHurk@deltares.nl

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https://climate-cryosphere.org/esm-snowmip/

https://wiki.c2sm.ethz.ch/LS3MIP/LS3MIPObjectivesDesign

The Model Intercomparison of Global Scale Glacier Models (GlacierMIP) is a model intercomparison project focusing on all glaciers in the world outside the ice sheets. It provides a framework for a coordinated intercomparison of global-scale glacier evolution models, to foster model improvements and reduce uncertainties in global glacier projections and related sea-level projections

HIGHLIGHTS

After the successful completion of the initial phase of GlacierMIP (comparison of 21st century global glacier projections based on previously published works; Hock et al., 2019) and GlacierMIP2 (288 transient simulations of 21st century glacier mass changes based on prescribed, standardized boundary conditions; Marzeion et al., 2020), in 2021 we designed the experimental setup for GlacierMIP3 and launched a call for participation.

In GlacierMIP3 we aim to determine the equilibrium response of glaciers to various temperature increases above pre-industrial levels. For this, participants are requested to start simulations from glacier geometries at year 2000 (the approximate date of the Randolph Glacier Inventory (RGI) and simulate their equilibration, using the climatic forcing from the eight repeat-periods : 1851-1870, 1901-1920, 1951-1970, 1995-2014, 2021-2040, 2041-2060, 2061-2080 and 2081-2100. The climatic forcing is taken from the latest phase of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP3b). All the necessary documentation for potential participants to join (including protocol, FAQs and template files for submission) is provided on
https://github.com/GlacierMIP/GlacierMIP3

FUTURE PLANS

The deadline for submitting results to GlacierMIP3 was set on February 1st 2022, and to date (March 15) we have received submissions from five different glacier evolution models. We are in close contact with other groups that have not yet submitted results but who have indicated their willingness to participate in GlacierMIP3. In the coming months, we expect to receive contributions from about five additional groups, bringing our glacier model ensemble size to approx. 10.

A framework to rapidly scan the submitted results has been setup and is already operational to check for potential errors/biases when participants submit results. In the coming months, when new results are submitted, they will be checked immediately through this framework. As additional results progressively come in, we will also start to perform more detailed analyses on these simulations. For a fruitful and in-depth analysis of the results, besides meeting online regularly, we will also organize two in-person meetings during the Cryosphere 2022 Symposium (International Symposium on Ice, Snow and Water in a Warming World) in Reykjavík, Iceland. All GlacierMIP3 core members, as well as the majority of GlacierMIP3 participants, have confirmed participation. The plan is to submit a paper that summarizes the results of GlacierMIP3 by the end of 2022.

For 2023& 2024, we plan to initiate new GlacierMIP activities, including:

1. An updated estimate of the future sea-level contribution from glaciers and related uncertainties, thereby partly relying on new approaches (new methods since GlacierMIP2) and datasets (CMIP6 vs. CMIP5, new glacier outlines and ice thickness reconstructions)
2. Reconstruction of past glacier changes, including detection and attribution experiments.

MEETINGS

Our initially planned annual meeting at the Cryosphere 2021 conference in Iceland had to be postponed as the conference was cancelled. Instead, we organized several online meetings throughout the year which mainly focused on GlacierMIP3. While most meetings included the core team of GlacierMIP3, we also held online meetings open to all participants to provide opportunities for feedback on the evolving experimental design.

Additionally, the experimental design of GlacierMIP3 was presented at EGU2021 (https://presentations.copernicus.org/EGU21/EGU21-7775_presentation.pdf). GlacierMIP results were also presented by R. Hock in the weekly webinar by the International Glaciological Society (IGS) in March 2021 and at an international 1-day online workshop by the Working Group on ¨Regional Assessments of Glacier Mass Change (RAGMAC)¨ in June 2021, and by B. Marzeion at the UK Sea Level Workshop in September 2021.

PEER REVIEW PUBLICATIONS

Fox-Kemper, B., H. T. Hewitt, C. Xiao, G. Aðalgeirsdóttir, S. S. Drijfhout, T. L. Edwards, N. R. Golledge, M. Hemer, R. E. Kopp, G. Krinner, A. Mix, D. Notz, S. Nowicki, I. S. Nurhati, L. Ruiz, J-B. Sallée, A. B. A. Slangen, Y. Yu, 2021: *Ocean, Cryosphere and Sea Level Change*. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. doi:10.1017/9781009157896. *In Press.*

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SEA ICE & CLIMATE MODELLING FORUM/ DIAGNOSTIC SEA ICE MIP (SIMIP)

The CliC Sea Ice and Climate Modelling Forum contributes to a better understanding of the role of sea ice for the changing climate of our planet. To reach this aim, we coordinate large-scale model simulations and facilitate the exchange of ideas between modelers and observers through joint workshops. As part of that effort, the Diagnostic Sea Ice Model Intercomparison Project (SIMIP) facilitates process-based model analysis of sea ice in CMIP6, through an updated variable request, community coordination, and workshops. SIMIP is an endorsed diagnostic MIP for CMIP6 that defines a list of variables to understand the evolution of sea ice in any experiment using the sea ice model as part of CMIP6.

HIGHLIGHTS

SIMIP analyses contributed to the sea-ice assessment in IPCC AR6.

SIMIP showed in all scenarios that the Arctic will likely be practically sea-ice free in summer before 2050 (SIMIP Community (2020), Arctic sea ice in CMIP6. *Geophysical Research Letters*, 47, e2019GL086749). By 2100, simulations show that the open-water period lengthens by 63 days (on average), 3 and 6 months with 2 °C, 3 °C and 5 °C global warming respectively, above the 1850-1900 average. Model bias compared to satellite data suggests that even such dramatic projections may be conservative.

MEETINGS

A planned SIMIP in-person meeting to discuss the next steps and outstanding analysis efforts was cancelled due to COVID-19 restrictions

FUTURE PLANS

Preparations for CMIP7 from a sea-ice perspective to be discussed at the International Glaciology Society Symposium in 2023.

PEER REVIEW PUBLICATIONS

Crawford, A., Stroeve, J., Smith, A., Jahn. A, Arctic open-water periods are projected to lengthen dramatically by 2100. *Commun Earth Environ* **2,** 109 (2021). https://doi.org/10.1038/s43247-021-00183-x

Chen, S., Liu, J., Ding, Y., Zhang, Y., Cheng, X., Hu, Y. (2021), Assessment of Snow Depth over Arctic Sea Ice in CMIP6 Models Using Satellite Data. Adv. Atmos. Sci. https://doi.org/10.1007/s00376-020-0213-5

Keen, A., Blockley, E., Bailey, D. A., Boldingh Debernard, J., Bushuk, M., Delhaye, S., Docquier, D., Feltham, D., Massonnet, F., O'Farrell, S., Ponsoni, L., Rodriguez, J. M., Schroeder, D., Swart, N., Toyoda, T., Tsujino, H., Vancoppenolle, M., and Wyser, K (2021), An inter-comparison of the mass budget of the Arctic sea ice in CMIP6 models, The Cryosphere, 15, 951–982, https://doi.org/10.5194/tc-15-951-2021

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WEBSITE

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Research Projects

The goals of the Climate and Cryosphere Arctic Sea Ice Working Group are to:
(i) develop, standardize, and implement measurement protocols for Arctic Sea ice in coastal, seasonal, and perennial ice zones; (ii) integrate surface-based observations with remote sensing and modelling efforts, and (iii) foster connections between international groups involved in sea ice observations, modelling, and remote sensing. The ASIWG has organized workshops, participated in programs, and produced documents addressing these goals.

SCIENCE HIGHLIGHTS

Ice Watch: Ice Watch has been active through the pandemic. Even while shipping was reduced in the Arctic, we were participating in the MOSAiC field campaign and running bridge ice watch on resupply cruises and at the MOSAiC ice camp. This has resulted in collecting a data set in winter, which is unusual. We worked to collect data to validate the representation of the sea ice topography observations. These were found to be rather subjective. We are writing a data paper for Nature Scientific Data, as part of the MOSAiC special issue, to document the data set and the verification work done during MOSAiC. Penny Wagner at Met Norway is still leading the Ice Watch program and has been very active in Global Cryosphere Watch ensuring Ice Watch maintains its adherence to WMO sea ice standard and is leading in widening participation of collecting standardized observations. Met Norway also participates in the Ice Chart Working Group, and Ice Watch data is used internationally in ice charts and data shared by Met Norway. Met Norway is also facilitating the citizen science Ice Watch program and expanding this via a collaboration with Lauren Farmer and Alex Cowen to more tourist cruises. This citizen science was not active during the pandemic; however, we are anticipating new data collection this coming boreal summer. Ice Watch data has been archived at AWI Pangaea. Following previous efforts to build this data portal, it is now streamlined that transfer of data from the Ice Watch database at Met Norway to the permanent Pangaea archive simply requires uploading the csv data files to the Pangaea portal.

MOSAiC: The MOSAiC field campaign has facilitated work on data standardization within the sea ice community. A showcase example is that MOSAiC standardized how sea ice cores are documented across physics, biological and chemical scientists. This coordination was a large effort and Mark Oggier developed documentation and spreadsheets to facilitate the data recording. We wish to support this effort and provide a forum to ensure a legacy in such efforts during MOSAiC. We would like to support scientists with the provision of their documentation to the community and to support uptake in the community of collected standardized observations. This is vital to ensure legacy of our data collection and that the data is accessible, comparable to data collected in other campaigns, and can be utilized by other researchers. We are in dialogue with early career scientists active in these efforts, leading them to determine a way forward to support standardization of sea ice observational methods and how to disseminate information about the utility and limitations of the data sets. It is anticipated that a workshop next year would greatly support this dialogue and provide support for these scientists to maintain this effort so that it can live longer than the MOSAiC field campaign.

MEETINGS AND FUTURE PLANS

No annual meeting was held this year. This was due to the travel restrictions associated with COVID-19. We hope that in-person meetings will be possible in the coming year. If so, we will arrange an annual meeting at either the MOSAiC workshop in Boulder,

Colorado (USA) on 13-17 February 2023 or the IGS meeting *International Symposium on Sea Ice Across Spatial and Temporal Scales* in Bremerhaven, Germany on 4-9 June 2023. If in-person meetings are not possible, we will host a virtual meeting in the coming year. In 2022 we plan to i) host an ASIWG meeting (COVID permitting), ii) continue to work on MOSAiC results, and iii) reach out to other CliC groups for collaborative activities.

PEER REVIEW PUBLICATIONS

ASIWG members took a leading role in writing the Arctic Sea ice section of the 2020 Bulletin of the American Meteorological Society's State of the Climate Report: https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/.

ASIWG members also coordinated and led the sea ice portion of the 2021 Arctic Report Card. This was the 16th year of the Arctic Report Card, where ASIWG members have led the sea ice section. Sea ice age, an indicator of sea ice thickness is a critical parameter reported in the Report Card (Figure 1). The time series demonstrates the considerable loss of older, thicker sea ice over the past four decades.

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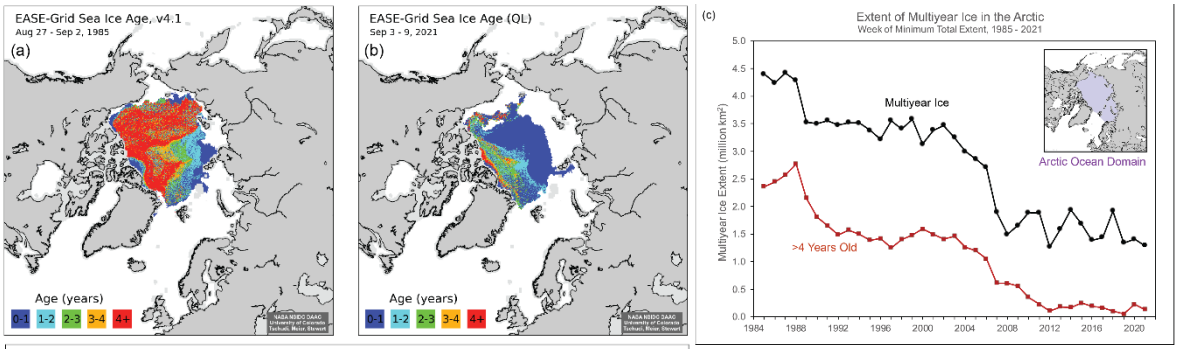

Figure 1. *Sea ice age coverage map for the week before minimum total extent (when age values are incremented to one year older) in (a) 1985, and (b) 2021; (c) extent of multiyear ice (black) and ice >4 years old (red) within the Arctic Ocean for the week of the minimum total extent. Adapted from Figure 3 in the 2021 Arctic Report Card: https://arctic.noaa.gov/Report-Card.*

BEPSII was launched in 2011 as a SCOR working group from 2012 until September 2018. In 2016 it was endorsed as a SOLAS-CliC forum as well as as a SCAR Action Group. BEPSII is now coordinating some community activities linked to the biogeochemistry of sea ice-influenced environments, involving about 120 scientists.

SCIENCE HIGHLIGHTS

The 2021 synthesis of the sea-ice ecosystem and associated ecosystem services highlights that:

- The sea-ice ecosystem supports all four ecosystem service categories
- Sea-ice ecosystems meet the criteria for ecologically or biologically significant marine areas (EBSAs);
- Global emissions driving climate change are directly linked to the demise of sea-ice ecosystems and its ecosystem services
- The sea-ice ecosystem deserves specific attention in the evaluation of marine protected area planning.

The ongoing changes in the polar regions have extreme impacts on sea-ice ecosystems and associated ecosystem services. While the response of sea-ice associated primary production to environmental change is regionally variable, the effect on ice-associated mammals and birds are predominantly negative, subsequently impacting human harvesting and cultural services in both polar regions. Conservation can help protect some species and functions. However, the key mitigation measure that can slow the transition to a strictly seasonal ice cover with climate change, reduce the overall loss of sea-ice habitats from the ocean, and thus preserve the unique ecosystem services provided by sea ice and their contributions to human well-being is a reduction in carbon emissions.

POLICY BRIEF AND SEA-ICE ECOSYSTEM SERVICES PAPER:

Following detailed evaluations, data collations, observation and model studies, BEPSII applied its collective expertise to compile several policy relevant community science papers:

1. A position analysis on the future of Arctic sea-ice biogeochemistry in *Nature Climate Change* (Lannuzel et al. 2020);
2. an evaluation of implications of sea-ice management for Arctic biogeochemistry in EOS (Miller et al. 2020),
3. in 2021 a synthesis of climate change impacts on sea-ice ecosystems and associated ecosystem services in Elementa (Steiner et al. 2021).

The main outcomes of the three publications have been compiled into a policy brief (https://doi.org/10.5281/zenodo.5595254) which has been circulated widely and received significant international attention including at the COP26 Cryosphere Pavilion.

Meetings and workshops

COVID-19 locked many of our project's meetings in 2021 as well.

PUBLICATIONS

Lannuzel, D., S. Moreau, K.M. Meiners, & F. Fripiat. The future of Arctic sea-ice biogeochemistry and ice-associated ecosystems. (2020). Nature Climate Change https://doi.org/10.1038/s41558-020-00940-4

Miller, L. et al. (2020). Implications of sea ice management for Arctic biogeochemistry. Eos, 101, https://doi.org/10.1029/2020EO149927.

Steiner, N.. et al (2021) BEPSII Arctic Policy Brief. Doi:10.5281/aenodo.5595254

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LINKAGE BETWEEN ARCTIC CLIMATE CHANGE AND MID-LATITUDE WEATHER EXTREMES

The assessment of the potential for recent Arctic changes to influence broader hemispheric weather is a difficult and controversial topic, with considerable scepticism. There is little agreement on problem formulation, methods, or robust mechanisms in the research community. Several case studies do show the importance of three linkage mechanisms: local surface heating, temperature advection, and prior jet stream blocking physics (Tachibana et al. 2019, Overland et al. 2021).

An intriguing and increasingly important question from scientists and the broader community is whether recent extreme weather in North America, eastern Asia and northern Europe merely random events were or related to recent global or Arctic climate change. CliC, the Atmospheric Working Group of IASC, other IASC Working Groups and multiple programs have prioritized the challenge: CliC, WMO/Polar Prediction, NOAA, UK Met Office, and the Icelandic Met Office.

SCIENCE HIGHLIGHTS

Both the North America and eastern Asia show examples of a causal connection from global warming through atmospheric and ocean physics to ecosystem disruption and human impacts. Warming influences are more than a local heating response but follow a chain of events involving disruption of the jet stream.

FUTURE PLANS

- The team stays in contact regarding new extreme events that are beyond previous records, such as the winter 2020 Siberian heat wave, the winter 2021 US cold event and the summer 2021 northwest USA/west Canada heat dome. Midlatitude events are not only forced by the Arctic but can result from natural Arctic variability such as polar vortex disruptions and from tropical/local forcing. Discussions are ongoing for the theme of a follow-on workshop as the topic continues to increase in international importance.
- Modest size discussion hybrid meetings proposed for summer/autumn 2022
- Plot the way forward: new mid-latitude weather linkages events, Arctic climate change shown by extremes, dynamic mechanisms such as those relating to the polar vortex and high-latitude blocking; communication of science and impacts.

MEETINGS

No in-person meetings were held due to travel restrictions due to COVID-19.

PEER REVIEW PUBLICATIONS

Hanna, E., T.E. Cropper, R.J. Hall, R.C. Cornes, M. Barriendos (2022) Extended North Atlantic Oscillation and Greenland Blocking indices 1800-2020 from new meteorological reanalysis. *Atmosphere* 13, 436.

Overland, J.E., B.-M. Kim, Y. Tachibana (2021) Communicating Arctic-midlatitude weather and ecosystem connections: direct observations and sources of intermittency. *Environmental Research Letters* 16, 10506.

Overland, J., T.J. Ballinger, J. Cohen, J.A. Francis, E. Hanna, R. Jaiser, B.-M. Kim, S.-J. Kim, J. Ukita, T. Vihma, M. Wang, X. Zhang (2021) How do intermittency and simultaneous processes obfuscate the Arctic influence on midlatitude winter extreme weather events? *Environmental Research Letters* 16, 043002.

OUTREACH

A press release relating to our ERL (043002) paper was published by University of Lincoln: https://news.lincoln.ac.uk/2021/01/29/researc

h-sheds-light-on-extreme-winter-weather-events/

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The goals of ISMASS are to promote the research on the estimation of the mass balance of ice sheets and its contribution to sea level, to facilitate the coordination among the different international efforts focused on this field of research, to propose directions for future research in this area, to integrate the observations and modelling efforts, as well as the distribution and archiving of the corresponding data, to attract a new generation of scientists into this field of research, and to contribute to the diffusion, to society and policy makers, of the current scientific knowledge and the main achievements in this field of science.

HIGHLIGHTS

ISMASS organised a joint session with ISMIP6 at EGU 2021 entitled "Integrating models and observations for the estimation of ice sheet mass balance and sea level, incorporating ISMASS/ISMIP6" (Gather Online, 19–30 April 2021.

ISMIP6 and ISMASS chair Heiko Goelzer, took a leading role in the Greenland projections and delivered key publications making an important basis for the IPCC AR6.

FUTURE PLANS

Workshop: "Ice Sheets: Weather versus Climate", led by E. Hanna. This 1.5-day workshop will explore the degree to which short-term fluctuations and extreme events in the ice sheets (both Greenland and Antarctica) in the last two decades reflect their longer-term evolution and response to ongoing climate change. Workshop planned in summer 2022 / review paper.

Involvement in SCAR SRP INSTANT (Led by F. Pattyn, C. Ritz, H. Goelzer, F. Colleoni). ISMASS has a strong expertise in ice sheet modelling and INSTANT plans to investigate the link between past and future ice sheet changes on long and on short timescales in Antarctica. Exchanges with INSTANT will be beneficial for both parties. Ritz is leading a subcommittee to work on ice sheet models bridging different time and spatial scales.

Model intercomparisons and ISMIP6. ISMASS has a strong expertise in model intercomparisons and will contribute to ISMIP6 and other intercomparison exercises. H. Goelzer is leading ongoing Greenland ice sheet intercomparisons in ISMIP6. F. Pattyn is leading the CalvingMIP project, which is part of EU-project PROTECT.

EGU 2022 session on ice sheet mass balance and sea-level. ISMASS will organise a joint session with ISMIP6 titled "Ice sheet mass balance and sea level: ISMASS/ISMIP6 and beyond" at the upcoming General Assembly 2022, 23–27 May 2022.

MEETINGS AND WORKSHOPS

Due to ongoing Covid-19, ISMASS meeting activities were reduced during this reporting period.

PEER REVIEW PUBLICATIONS

Edwards, T. L., Nowicki, S., Marzeion, B., Hock, R., Goelzer, H., Seroussi, H., Jourdain, N. C.,Slater, D. A., Turner, F. E., Smith, C. J., McKenna, C. M., Simon, E., Abe-Ouchi, A., Gregory,J. M., Larour, E., Lipscomb, W. H., Payne, A. J., Shepherd, A., Agosta, C., Alexander, P.,Albrecht, T., Anderson, B., Asay-Davis, X., Aschwanden, A., Barthel, A., Bliss, A., Calov, R.,Chambers, C., Champollion, N., Choi, Y., Cullather, R., Cuzzone, J., Dumas, C., Felikson, D.,Fettweis, X., Fujita, K., Galton-Fenzi, B. K., Gladstone, R., Golledge, N. R., Greve, R.,Hattermann, T., Hoffman, M. J., Humbert, A., Huss, M., Huybrechts, P., Immerzeel, W.,Kleiner, T., Kraaijenbrink, P., Le clec'h, S., Lee, V., Leguy, G. R., Little, C. M., Lowry, D. P.,Malles, J. H., Martin, D. F., Maussion, F., Morlighem, M., O'Neill, J. F., Nias, I., Pattyn, F.,Pelle, T., Price, S. F., Quiquet, A., Radić, V., Reese, R., Rounce, D. R., Rückamp, M., Sakai,A., Shafer, C., Schlegel, N. J., Shannon, S., Smith, R. S., Straneo, F., Sun, S., Tarasov, L.,Trusel, L. D., Van Breedam, J., van de Wal,

R., van den Broeke, M., Winkelmann, R.,Zekollari, H., Zhao, C., Zhang, T., and Zwinger, T.: Projected land ice contributions to 21stcentury sea level rise, Nature, 593(7857), 74–82, 2021
https://doi.org/10.1038/s41586-021-03302-y

Payne, A. J., Nowicki, S., Abe-Ouchi, A., Agosta, C., Alexander, P., Albrecht, T., Asay-Davis, X.,Aschwanden, A., Barthel, A., Calov, R., Chambers, C., Choi, Y., Cullather, R., Cuzzone, J.,Dumas, C., Edwards, T., Felikson, D., Fettweis, X., Goelzer, H., Golledge, N. R., Gregory, J.M., Greve, R., Hatterman, T., Hoffman, M. J., Humbert, A., Huybrechts, P., Jourdain, N. C.,Kleiner, T., Larour, E., clec'h, S. L., Lee, V., Leguy, G., Lipscomb, W. H., Little, C. M., Lowry,D., Morlighem, M., Nias, I., Pattyn, F., Pelle, T., Price, S., Quiquet, A., Reese, R.,Rueckamp, M., Schlegel, N.-J., Seroussi, H., Shepherd, A., Simon, E., Slater, D., Smith, R.,Straneo, F., Sun, S., Tarasov, L., Trusel, L. D., Breedam, J. V., van de Wal, R., van denBroeke, M., Winkelmann, R., Zhao, C., Zhang, T., and Zwinger, T.: Future sea level change under CMIP5 and CMIP6 scenarios from the Greenland and Antarctic ice sheets, Geophys. Res. Lett., 2021
https://doi.org/10.1029/2020GL091741

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Interdisciplinary Activities and Networks

SORP serves as a forum for the discussion and communication of scientific advances on the understanding of climate variability and change in the Southern Ocean. It also advises CLIVAR, CliC, and SCAR on progress, achievements, new opportunities and impediments in internationally coordinated Southern Ocean research.

SCIENCE HIGHLIGHTS

- SORP members actively participated in the development of the action plan for the Southern Ocean as part of the United Nations Decade of Ocean Science for Sustainable Development. The Southern Ocean (SO) is one of nine ocean basins designated and endorsed by the UN for an individual action plan. As part of this effort coordinated by SCAR the Southern Ocean Task Force was set up to develop the Southern Ocean Action Plan. SORP worked with other members, many from affiliated committees (https://www.sodecade.org/about/) to create seven working groups aligned with the seven outcomes of the Ocean Decade (https://www.sodecade.org/working-groups/). These working groups identified research, logistical and technical challenges and actions needed. These were presented in a public forum on Antarctica day (Dec 1, 2021). The plan will be finalized in the first quarter of 2022.
- Contributed to the new SO Observing System (SOOS) science plan
- Co-edited a special volume in *Frontiers in Marine Science* on interbasin exchanges between the SO and South Atlantic Ocean.

MEETINGS

The SORP-14 business meeting followed a new online format including open discussion spaces and time for re-evaluation and planning. Two-hour long conferences spread over 4 days (October 6-7 & 13-14) were held across a range of times zones. The panel discussed its current state as well as future goals and connections to related groups, such as NORP, SOOS, Ocean Observations Physics and Climate (OOPC) and Ocean Model Development Panel (OMDP). From the meeting emerged the following 3 task teams:

1. A group of 10 current and former SORP members will work on ocean and climate responses to freshwater released from Antarctica. For this they will create a protocol and run first exemplary model experiments for a community wide *Southern Ocean Freshwater-release model experiments Initiative* (SOFIA). The team meets monthly; a draft protocol exists, and the first model experiments are being performed.
2. A team will work on a proposal for a CLIVAR Exchanges issue on SO/Antarctic research from less developed programs/nations, about their (lack of) networking opportunities and obstacles they encounter. At present, the abstract and online questionnaire for participation is being drafted.
3. A team discusses the possibility to use unspent travel funds (due to the pandemic) to enhance scientific exchanges and provide networking opportunities targeted to Early Career Researchers from countries with less developed Antarctic programs. Examples are: “travelling lecturer fund” or a network of coordinated, simultaneous but locally held hackatons.

SORP co-organized a virtual workshop, lead by OMDP, on the Future Development of High-Resolution Ocean Modelling on 29 Sept–1 Oct. It dealt with opportunities and challenges of using advances in high-resolution modelling to simulate the ocean climate system. Interaction with the growing availability and capabilities of observations as

well as new observing systems was sought not only for model validation but also for using high-resolution models for the planning of observations. Scientific questions addressed were (i) robustness of decadal variability signals over the last 6-7 decades, (ii) hindcast modelling strategies including spin-up, grid resolution (mesoscale to sub-mesoscale) and physical parameterizations, (iii) identification of physical processes that deserve more attention, such as sub-mesoscale dynamics, internal and surface gravity waves, and tides, (iv) the importance of coupling the ocean with the atmosphere and cryosphere (beyond sea ice) to detect global warming impacts on the ocean. Visit the workshop website: https://www.clivar.org/events/future-directions-high-resolution-ocean-modelling

FUTURE PLANS

- Organize a workshop together with NORP on polar fresh water: *Sources, Pathways* and *ImpaCts of frEsh water in northern and soUthern Polar oceans and seas* (SPICE UP) planned for the fall of 2022.
- Continue the SOFIA MIP activity for Southern Ocean freshwater model experiments
- Co-lead a townhall on the SO decade and chair a SO freshwater session at the Ocean Science Meeting 2022
- Continue the involvement in the UN Ocean Decade efforts
- Run a CLIVAR Exchanges issue on research and diversity in emerging Antarctic programs

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CLIVAR/CLIC NORTHERN OCEANS REGIONAL PANEL (NORP)

NORP serves as an international forum to coordinate activities and strategies on the role of the Arctic Ocean in the context of the global climate system from a coupled perspective. NORP facilitates progress in the development of tools and methods to monitor and assess climate variability and change and evaluate climate predictability of the ocean-atmosphere-ice system in the Arctic and Subarctic Ocean. NORP coordinates efforts to enhance the ability to monitor the coupled system, understand the driving mechanisms of the system change from a coupled process perspective, and predict the evolution of the emerging New Arctic climate. This forum plays a central role in coordinating, monitoring, and evaluating the progress of activities during and beyond the Year of Polar Prediction.

HIGHLIGHTS

- Science: Solomon is serving on the EU H2020 *Climate relevant interactions and feedbacks: the key role of sea ice and snow in the polar and global climate system research project (CRiceS),* and the *Polar Regions in the Earth System* (PolarRES) International Advisory Committees.
- Capacity building and career support: Solomon had a virtual site visit to Pennsylvania State University and meet with the Department of Meteorology graduate students to provide feedback on their research and careers on April 21, 2021.
- Knowledge exchange: Solomon made a presentation about model experiments on coupled atmosphere-sea ice-ocean interactions during the MOSAiC campaign to the US CLIVAR PSMI Panel on Feb 23, 2021.

MEETINGS

- Sessions at EGU 2021: OS1.3 Changes in the Arctic Ocean, sea ice and subarctic seas systems: Observations, Models and Perspectives
- The 2nd Session of the CLIVAR/CliC Northern Oceans Region Panel https://www.clivar.org/news/2nd-session-clivarclic-northern-oceans-region-panel-took-place-online
- Monthly Panel telecons

PEER REVIEW PUBLICATIONS

Solomon, A., Heuzé, C., Rabe, B., Bacon, S., Bertino, L., Heimbach, P., Inoue, J., Iovino, D., Mottram, R., Zhang, X., Aksenov, Y., McAdam, R., Nguyen, A., Raj, R. P., and Tang, H.: Freshwater in the Arctic Ocean 2010–2019, Ocean Sci., 17, 1081–1102, https://doi.org/10.5194/os-17-1081-2021, 2021

FUTURE PLANS

- Arctic Processes in CMIP6 bootcamp, Oct 5-21, 2022, Helgoland, Germany
- NORP/SORP Workshop on sources, pathways and impacts of fresh water in northern and southern polar seas, planned for June 2022 (supported by IASC and potentially WWRP/PPP)
- Sessions at 2022 AGU and EGU annual meetings
- Review paper on seasonality of the Arctic freshwater
- Review paper on Arctic Ocean heat flux

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Polar CORDEX aims at improving the understanding of polar processes and generation of regional climate change projections

HIGHLIGHTS

Antarctic: Mottram et al. (2021) compared the performance of five different regional climate models, available through the Antarctic CORDEX project, in simulating the present-day near-surface climate and surface mass balance (SMB) of Antarctica. This study showed that all models simulate Antarctic climate well when compared with daily observed temperature and pressure. Over a 30-year climatological mean period (1980-2010), the ensemble mean SMB over the Antarctic ice sheet is 2483 Gt yr^{-1}. However, individual model estimates vary from 1961±70 to 2519±118 Gt yr^{-1}. The largest spatial differences between modelled SMB are in West Antarctica, the Antarctic Peninsula, and around the Transantarctic Mountains.

Arctic: Inoue et al. (2021) performed an Arctic CORDEX coordinated evaluation of six RCMs with nine model runs using an in-situ meteorological observation data set obtained over the ice-free Arctic Ocean by the Japanese Research Vessel Mirai. The main sources of surface energy budget uncertainty were quantified: reduced occurrence of unstable stratification with low-level cloud water in all models in comparison to observations, significant differences in cloud water representations between single- and double moment cloud schemes, differences in partitioning of hydrometeors including solid/liquid precipitation, and lower-tropospheric air temperature biases.

MEETINGS

Polar CORDEX annual workshop, 13-15 October 2021, online / Zoom. Around 50 people registered. Organised by Andrew Orr (co-chair) and Beatriz Balino (CliC IPO).

PEER REVIEW PUBLICATIONS

Mottram, R., et al. (2021), What is the surface mass balance of Antarctica? An intercomparison of regional climate model estimates, *The Cryosphere*, https://doi.org/10.5194/tc-15-3751-2021.

Heinemann, G., and R. Zentek (2021), A model-based climatology of low-level jets in the Weddell Sea Region of the Antarctic, *Atmosphere*, https://www.mdpi.com/2073-4433/12/12/1635.

Verjans, V., et al. (2021), Uncertainty in East Antarctica firn thickness constrained using a model ensemble approach, Geophysical Research Letters, https://doi.org/10.1029/2020GL092060.

Gilbert, E., and C. Kittel (2021), Surface melt and runoff on Antarctica ice shelves at 1.5C, 2C, and 4C of future warming, Geophysical Research Letters, https://doi.org/10.1029/2020GL091733.

Kittel, C., et al. (2021), Diverging future surface mass balance between the Antarctic ice shelves and grounded ice sheet, The Cryosphere, https://doi.org/10.5194/tc-15-1215-2021.

Akperov et al. (2021), Responses of Arctic cyclones to biogeophysical feedbacks under future warming scenarios in a regional Earth system model, Env. Res. Lett., https://doi.org/10.1088/1748-9326/ac0566

Inoue et al. (2021), Clouds and radiation processes in regional climate models evaluated using observations over the ice-free Arctic Ocean, J. Geophys. Res. Atm., https://doi.org/10.1029/2020JD033904

Heinemann et al. (2021), Observations and simulations of meteorological conditions over Arctic thick sea ice in late winter

during the Transarktika 2019 expedition, Atmosphere, https://doi.org/10.3390/atmos12020174

Lee et al. (2021), Causes and Evolution of Winter Polynyas over North of Greenland, The Cryosphere Discuss., https://doi.org/10.5194/tc-2021-279

FUTURE PLANS

- Contribute simulations to the coordinated MOSAiC and YOPPsiteMIP activities (e.g. https://www.polarprediction.net/key-yopp-activities/yoppsitemip/ and https://www.polarprediction.net/organization/yopp-task-teams/southern-hemisphere/).
- Work closely with the EU Horizon 2020 funded project PolarRES, which involves downscaling multiple regional climate models over the Arctic and Antarctic CORDEX domains.
- Organize the Polar CORDEX annual workshop 28-30 September 2022 in Bergen, Norway.

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The Permafrost Carbon Network (PCN) produces new knowledge through research synthesis to quantify the role of permafrost carbon in driving future climate change.

SCIENCE HIGHLIGHTS

PCN co-sponsored a synthesized Arctic-Boreal carbon flux database (ABCflux) that includes historic and contemporary CO2 flux measurements from tundra and boreal forest sites located across the northern high latitudes (Virkkala et al. 2022). In particular, the database synthesizes whole-ecosystem CO2 fluxes from both clear chamber and eddy tower measurements along with site meta-data.

Another science highlight of 2021 is the publication of the Boreal–Arctic Wetland and Lake Dataset (BAWLD), a land cover dataset based on an expert assessment. BAWLD provides maps of upland environments, five wetland types, seven lake types, and three river types across the north, split by their methane-emitting land cover characteristics. BAWLD will be suitable for many hydrological and biogeochemical modelling and upscaling efforts for the northern boreal and arctic region (Olefeldt et al. 2021).

PEER REVIEW PUBLICATIONS

Virkkala A-M, Natali SM, Rogers BM, Watts JD, Savage K, Connon SJ, Mauritz M, Schuur EAG, Peter D, Minions C, Nojeim J, Commane R, Emmerton CA, Goeckede M, Helbig M, Holl D, Iwata H, Kobayashi H, Kolari P, López-Blanco E, Marushchak ME, Mastepanov M, Merbold L, Parmentier F-J W, Peichl M, Sachs T, Sonnentag O, Ueyama M, Voigt C, Aurela M, Boike J, Celis G, Chae N, Christensen TR, Bret-Harte MS, Dengel S, Dolman H, Edgar CW, Elberling B, Euskirchen E, Grelle A, Hatakka J, Humphreys E, Järveoja J, Kotani A, Kutzbach L, Laurila T, Lohila A, Mammarella I, Matsuura Y, Meyer G, Nilsson MB, Oberbauer SF, Park S-J, Petrov R, Prokushkin AS, Schulze C, St. Louis VL, Tuittila E-S, Tuovinen J-P, Quinton W, Varlagin A, Zona D and Zyryanov VI 2022 The ABCflux database: Arctic–boreal CO2 flux observations and ancillary information aggregated to monthly time steps across terrestrial ecosystems Earth System Science Data 14 179–208 https://doi.org/10.5194/essd-14-179-2022

Olefeldt D, Hovemyr M, Kuhn M A, Bastviken D, Bohn T J, Connolly J, Crill P, Euskirchen E S, Finkelstein S A, Genet H, Grosse G, Harris L I, Heffernan L, Helbig M, Hugelius G, Hutchins R, Juutinen S, Lara M J, Malhotra A, Manies K, McGuire A D, Natali S M, O'Donnell J A, Parmentier F-J W, Räsänen A, Schädel C, Sonnentag O, Strack M, Tank S, Treat C, Varner R K, Virtanen T, Warren R K and Watts J D 2021 The Boreal-Arctic Wetland and Lake Dataset (BAWLD) Earth System Science Data, 13, 5127–5149, https://doi.org/10.5194/essd-13-5127-2021

MEETINGS

PCN hosted a session at the American Geophysical Union in New Orleans entitle 'Vulnerability of Permafrost Carbon to Climate Change'

PCN hosted its 11th Annual Meeting in a virtual format on November 16 & 17, 2021. We welcomed more than 200 participants from across the globe and discussed on the first day the representation of permafrost carbon in the IPCC AR6 s well as the communication of permafrost carbon in the media and to decision makers. The second day breakout discussions dealt with the following topics: (i) remote permafrost change detection, (ii)) model intercomparisons, (iii) paleo carbon evidence, (iv) carbon flux timeseries and upscaling, (v) ground ice across spatial scales, (vi) nutrient interactions

with carbon and climate. The breakout discussions will lead to several smaller workshops on some of these topics (modelling, carbon fluxes) in 2022.

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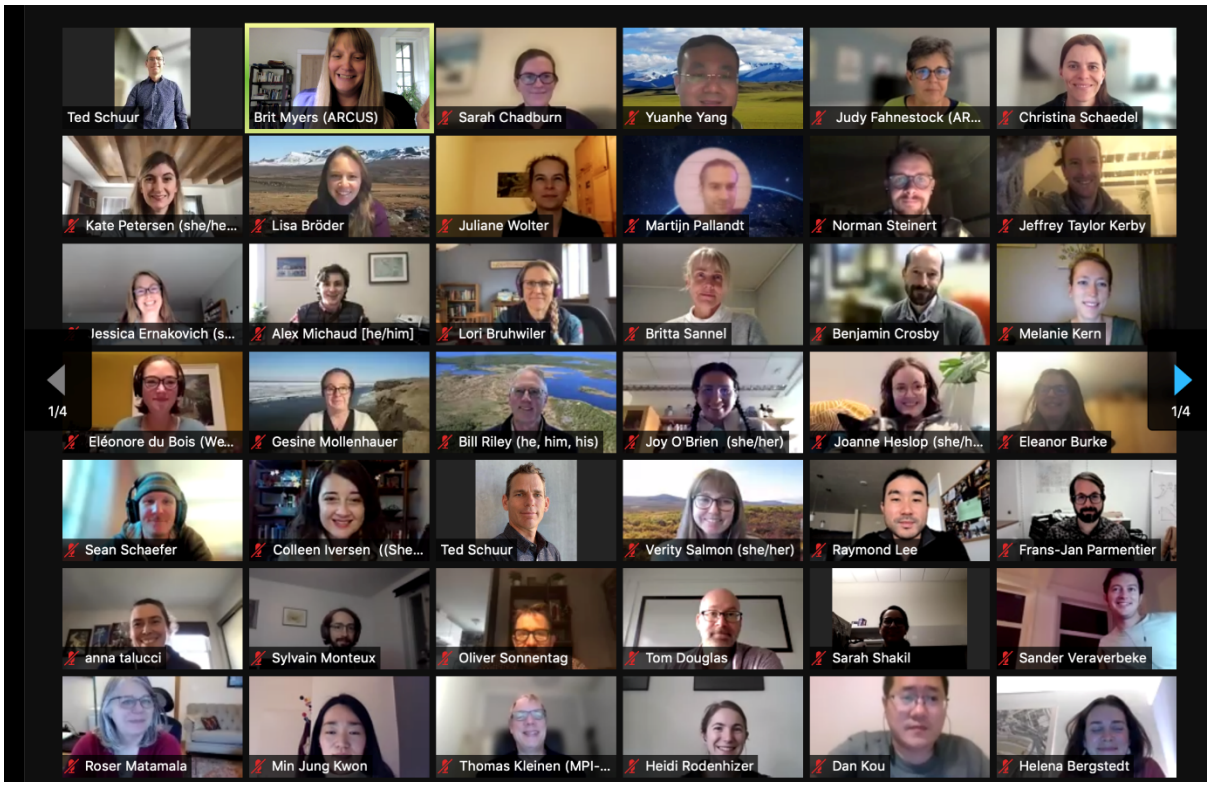
2021 Permafrost Carbon Network Annual Meeting



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