2020
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. CliC 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).

Report edited by Beatriz Balino, IPO, with contributions from:
Steve Ackley, John Cassano, Jan de Rydt, Chris Derksen, Heiko Goelzer, Edward Hanna, Petra Heil, Regine Hock, Alexandra Jahn, Julie Jones, Nicolas Jourdain, Hyungiun Kim, Gerhard Krinner, Torge Martin, Ben Marzeion, Ruth Mottram, Tim Naish, Dirk Notz, Sophie Nowicki, Taikan Oki, James E. Overland, Tony Payne, Don Perovich, Marilyn Raphael, James Renwick, Annette Rinke, Catherine Ritz, Christina Schaedel, Ted Schuur, Sonia Seneviratne, Inga Smith, Amy Solomon, Mike Sparrow, Jackeline Stefels, Nadja Steiner, Fiamma Straneo, Barrt van den Hurk, Melinda Webster and Andrew Orr

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Front page: Arctic fox (*Vulpes lagopus*). Photo: Jan Helge Fosså

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Overview from the CliC and the Melting Ice & Global Consequences Grand Challenge Co-Chairs

2020 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. The report also covers the outputs resulting from the WCRP Grand Challenge on *Melting Ice and Global Consequences.*

CliC supported projects have made major contributions to the *Melting Ice and Global Consequences* Grand Challenge primarily through a series of modelling intercomparison projects. These include the Ice Sheet Modelling Intercomparison Project (ISMIP6) which has produced some of the first community-wide projections of sea level rise from Greenland and Antarctica using stand-alone ice sheet models forced by Coupled Model Intercomparison Project (CMIP) models and projections of ice loss from glaciers (GlacierMIP; Model Intercomparison of Global Scale Glacier Models) – both of which provided estimates for the upcoming Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Additional important contributions to our ability to model ice loss were made by the new Marine Ice Sheet Ocean Model Intercomparison Project 2 (MISOMIP2), the Earth System Model-Snow Model Intercomparison Project (ESM-SnowMIP) and the Land Surface, Snow and Soil Moisture Model Intercomparison Model (LS3MIP). These projects reflect a strategy aimed at connecting cryosphere scientists with the modelling communities. Beyond the intercomparison modelling projects cited above, CliC supported activities focused on ice sheets, sea-ice variability, mid-latitude-polar region linkages and permafrost that spanned across multiple disciplines and Earth System Components. Finally, it engaged in joint activities with other WCRP Core projects aimed at the coordination of observations and modelling efforts.

The Co-Chairs would like to thank the cryosphere community for continuing their efforts even in the challenging circumstances posed by COVID-19. A special thanks goes to Gwen Hamon, Executive Office of CliC International Project Office (IPO) from 2014 to 2020, for her essential and extensive contributions to CliC. We also heartily welcome Beatriz Balino (Executive Director) on board and very much look forward to working with her. We are also very grateful to the Bjerknes Center for Climate Research (BCCR), for hosting the CliC IPO, and the BCCR and the Research Council of Norway for their financial support to the IPO.

James Renwick & Fiamma Straneo, CliC co-chairs
Tim Naish, chair *GC Melting Ice and Global Consequences*

The Scientific Steering Group (SSG)

In 2020 six new members were appointed to the SSG. Membership and appointed periods are shown below.

Chairs

James Renwick, Victoria University of Wellington, New Zealand	1/2017-12/2020
Fiammetta Straneo, Scripps Inst. Oceanography, UCSD, USA	1/2018-12/2020

Members

Jason Box, Geological Survey of Denmark & Greenland , Denmark	1/2020-12/2023
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, NASA JPL, 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

Support

WCRP Joint Scientific Committee liaisons:

Jens Hesselbjerg Christensen, University of Copenhagen, Denmark
Igor Shkolnik, Voeikov Main Geophysical Observatory, Russia

International Project Office

Gwénaëlle Hamon, Executive Officer (2014-Sept 2020). WCRP Secretariat, WMO
Beatriz Balino, Executive Director (from August 2020), c/o Bjerknes Centre, Norway

WCRP Secretariat

Mike Sparrow, Head of office, WMO, Switzerland

The International Project Office

A new host

In the period Jan 2019-August 2020, the CliC project office lacked a host institution so the project´s activities were coordinated by Executive Officer Gwenaelle Hamon from the WCRP Secretariat, at WMO headquarters. Hamon was hired as part-time consultant to work closely with Head of WCRP Secretariat and CliC liaison Mike Sparrow. Hamon left CliC in September 2020.

In August 2020, the Bjerknes Centre for Climate Research (BCCR) in Bergen, Norway, became the new host of the IPO. CliC´s science aligns well with the science strategy of the BCCR which gathers one of the largest polar research communities in the natural sciences in Norway and it is the largest climate research community in the Nordic countries (230 scientists, postdocs and PhD students from 39 countries). The IPO is jointly supported with a grant from the Research Council of Norway and in-kind funding from the BCCR. Dr. Beatriz Balino was appointed Executive Director of the IPO. Balino is a marine biologist with more than 25 years of experience in coordination and management of large international research programmes and projects in global environmental and climate change. She has previously held positions as Assistant Executive Officer at the International Project Office of the *Joint Global Ocean Flux Study* (JGOFS); Deputy Director at the secretariat of the *International Geosphere-Biosphere programme* (IGBP) in Stockholm.

2020 Activities

The IPO helped the projects to re-organize most of the original planned meetings and workshops not cancelled or postponed to 2021, into online events. It also worked with the SSG in revising CliC Strategy and Action Plan by mapping CliC´s activities onto WCRP new structure (e.g., participation in the Lighthouse Activities), and how the MIPs will fit after the sunset of the Grand Challenge Melting Ice. The IPO also kept regular teleconferences with the International Offices from GEWEX, SPARC, CLIVAR and CORDEX, other WCRP supporting activities CORA[1], S2S[2] and CLIVAR Monsoon Office, as well as invited representative from the YESS[3] network. As WCRP plans to start implementing its new structure in 2021, the future role of the IPOs was discussed during an extraordinary meeting of the Joint Scientific Committee (JSC) in December 2020. The issue was on whether the IPOs could assist in the integration and communication among the Core Projects/Homes and the new Lighthouse Activities.


Gwen Hamon


Beatriz Balino


Mike Sparrow

[1] WCRP Coordination Office for Regional Activities

[2] Sub-seasonal to Seasonal predictions project, a joint activity of the WCRP and the World Weather Research Programme (WWRP)

[3] Young Earth System Scientists network

CliC organisation

Scientific Steering Group (SSG)
Co-chairs:
Fiamma Straneo
James Renwick

International Project Office
Executive Director: Beatriz Balino

WCRP Grand Challenge: Melting Ice and Global Consequences

- Earth System Model-Snow MIP (ESM-Snow MIP)
- Ice Sheet MIP endorsed CMIP6 (ISMIP6)
- Marine Ice Sheet-Ocean MIP (MISOMIP)
- Diagnostic Sea Ice MIP (SIMIP) of the Sea Ice and Climate Modelling Forum
- Glacier MIP
- Land Surface, Snow and Soil Moisture MIP (LS3MIP)
- CliC/SPARC Polar Climate Predictability Initiative (PCPI)

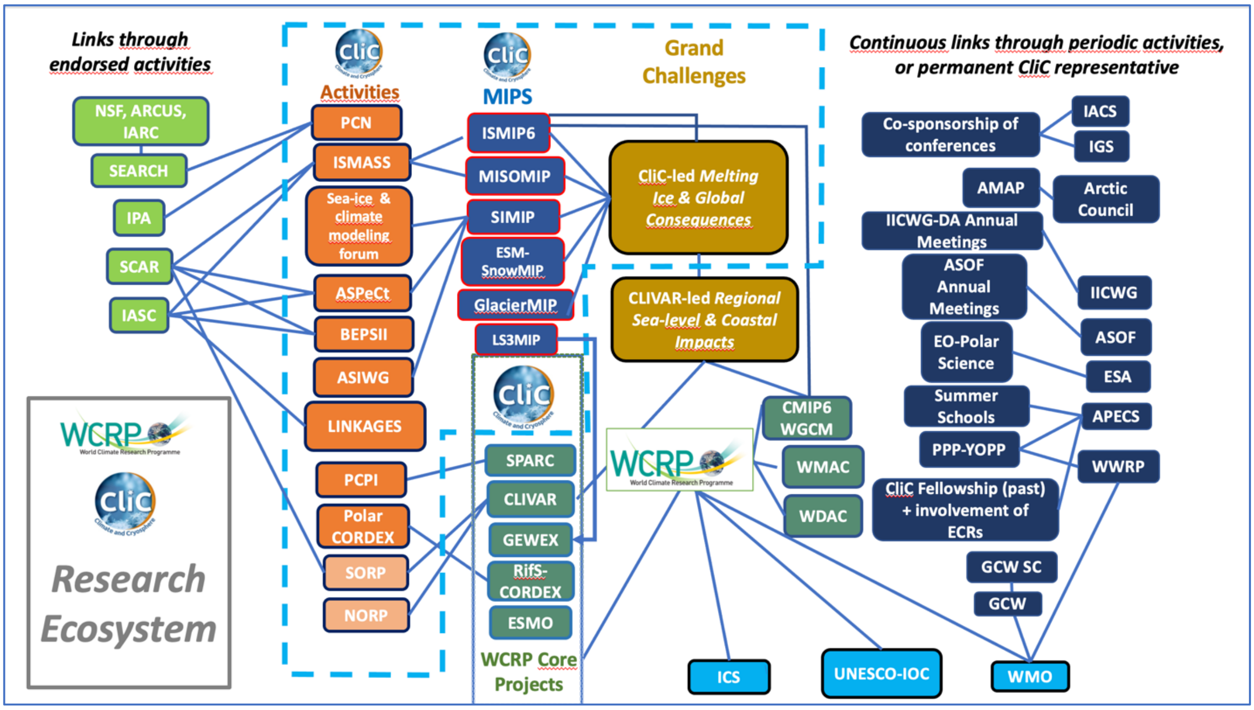
Research Projects

- Antarctic Sea Ice Processes & Climate (ASPeCt, joint with SCAR)
- Arctic Sea Ice Working Group (ASIWG)
- Biogeochemical Exchanges Processes at sea ice interfaces (BEPSII)
- Linnkages between Arctic Climate Change and Mid-latitude Weather Extremes (LINKAGES)
- Ice-Sheet Mass Balance and Sea Level (ISMASS, joint with SCAR and IASC)

Interdisciplinary Activities & Networkds

- CliC/CLIVAR Northern Oceans Regional Panel
- CliC/CLIVAR/SCAR Southern Ocean Regional Panel
- Polar CORDEX
- Permafrost Carbon Network

The CliC Research Ecosystem



CliC Activities 2020

WCRP Grand Challenge: *Melting Ice and Global Consequences*

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). 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. ISMIP6 experimental protocol explores the uncertainty in sea level projections due to ice sheet model initialization and ice sheet models, climate scenario uncertainty and uncertainty in the representation of ice-ocean interactions on centennial timescale. ISMIP6 was designed to deliver projections for use in the IPCC 6th Assessment report.

2020 Highlights

ISMIP6 coupled climate-ice sheet CMIP6 experiments were performed by CESM2.1-CISM2.1 and are on-going by other groups. ISMIP6 standalone ice sheet experiments (RCP2.6, RCP8.5, SSP116, SSP585) were performed by the majority of existing ice sheet models. Because of the delay in CMIP6, CMIP5 RCP became the focus of the ISMIP6 projections framework (Nowicki et al., 2020). For the Greenland ice sheet, the spread in sea-level in the CMIP5 experiments (Fig 1 top and Goelzer et al. 2020) is due to ice sheet models themselves (40%), CMIP models (40%) and ocean forcing uncertainty (20%).

The use of CMIP6 SSPs instead of CMIP5 RCP results in higher sea level by 2100 due in part to the more negative surface mass balance in the CMIP6 models used to drive the ice sheet models (Payne et al. 2020, Hofer et al. 2020). For the Antarctic ice sheet (Seroussi et al., 2020; Payne et al., in press), the largest source of uncertainty comes from climate forcing, ice shelf basal melt and dynamic response to ocean forcing. Large snowfall over the East Antarctic ice sheet can mitigate mass loss in the West Antarctic ice sheet (Fig 1 bottom).

2020 Peer review publications (a selection)

ISMIP6 spawned additional research on ocean and atmospheric forcing for ice sheets, resulting in over 20 publications in 2020 as well as three publications accepted in January 2021 in *Nature*, *GRL*, and *The Cryosphere*. Additional publications will result from the on-going analysis of the ISMIP6 ensemble, as well as publications from individual members on their own model simulations. ISMIP6 resulted in community building between ice sheet modelers and climate modelers The full list of publication is available at http://www.climate-cryosphere.org/wiki/index.php?title=ISMIP6_Publication_List&redirect=no

Goelzer, H. et al. 2020. The future sea-level contribution of the Greenland ice sheet: a multi-model ensemble study of ISMIP6, 14, 3071-3096 *The Cryosphere*, https://doi.org/10.5194/tc-14-3071-2020.

Hofer, S., C Lang, C Amory, C Kittel, A Delhasse, A Tedstone, X Fettweis (2020). Greater Greenland Ice Sheet contribution to global sea level rise in CMIP6 Nature communications 11 (1), 1-11

Jourdain, N. et al. 2020. A protocol for calculating basal melt rates in the ISMIP6 Antarctic ice sheet projections, 14, 3111-3134, *The Cryosphere*, https://doi.org/10.5194/tc-14-3111-2020.

Nowicki, S. et al 2020. Experimental protocol for sea level projections from ISMIP6 stand-alone ice sheet models, *The Cryosphere*, 14, 2331–2368, https://doi.org/10.5194/tc-14-2331-2020.

Payne et al. Future sea level change under coupled model intercomparison project phase 5 and phase 6 scenarios from the Greenland and Antarctic ice sheets. Geophysical Research Letters, *in press*

Seroussi, H. et al.. ISMIP6 Antarctica: a multi-model ensemble of the Antarctic ice sheet evolution over the 21st century, 14, 3033-3070, *The Cryosphere*, https://doi.org/10.5194/tc-14-3033-2020.

Slater, D., et al. 2020. Twenty-first century ocean forcing of the Greenland ice sheet for modelling of sea level contribution, *The*

Cryosphere, 14, 985–1008, https://doi.org/10.5194/tc-14-985-2020.

Sun, S. et al. 2020. Antarctic ice sheet response to sudden and sustained ice shelf collapse (ABUMIP), 1-4, *Journal of Glaciology*, https://doi.org/10.1017/jog.2020.67

2020 Presentations at academic meetings

ISMIP6 steering committee members gave a number of presentations in 2020 at EGU, AGU, IARPC, NASA Sea Level Change Team 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 in order to refine the protocol for future efforts. ISMIP6 is starting 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. Key candidates are extensions of the projections to beyond 2100, which are planned to be proposed to the ISMIP6 participant in 2021. ISMIP6's effort will have a strong focus on how to improve simulations over the historical and last decades, as well as renewed focus on ice-ocean interactions. As ISMIP6 plans its follow-on activities, we are also aware of new activities that we can either contribute to or benefit from such as other MIPs (eg; MISOMIP, PMIP) or the European PROTECT effort, ISMASS or the new SCAR INSTANT initiative.

Meetings

No meetings or workshops organised in 2020 due to COVID-19. We aim to organise a virtual meeting with our members in 2021.

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Websites:

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

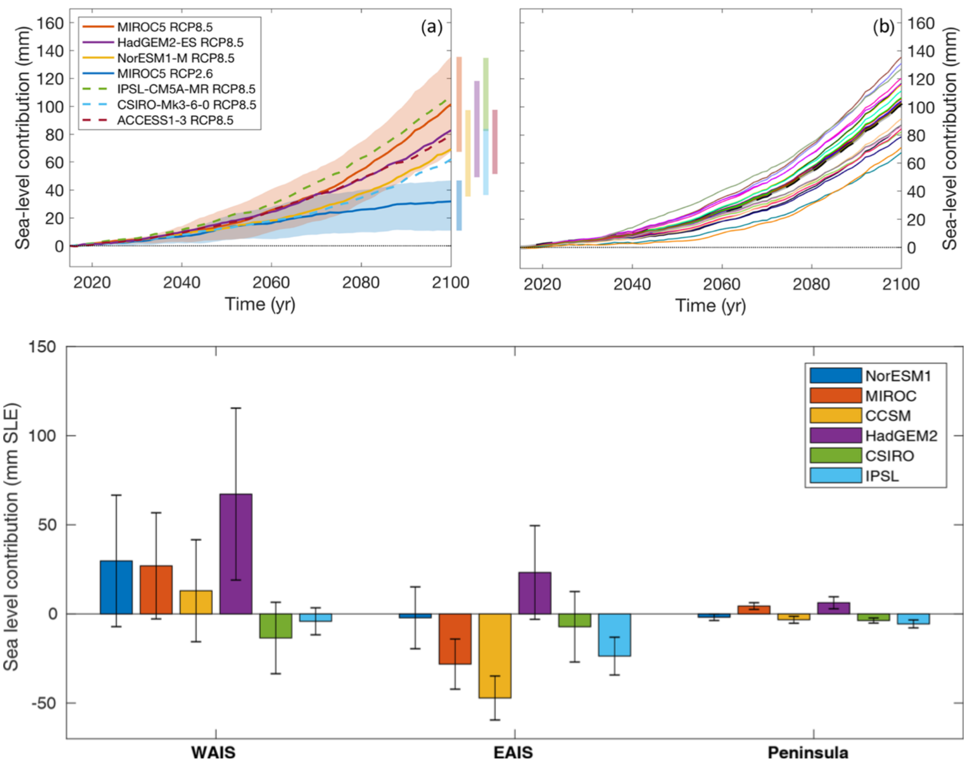

Fig 1: Example of sea level contribution over the 21st century from the Greenland (top) and Antarctic (bottom) ice sheets under CMIP5 RCPs. This sea level is in addition to the sea level that is already locked in due to past climatic change. Figures from Goelzer et al. (2020) and Seroussi et al. (2020)

MARINE ICE SHEET OCEAN MODEL INTERCOMPARISON PROJECT 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.

While MISOMIP1 was solely based on the intercomparison of highly-idealized experiments with strict constraints on the model domain and parameters, MISOMIP2 focuses on realistic simulations and comparisons to common sets of observations at interannual time scales. There will be two target regions: the Amundsen Sea and the Weddell Sea. These regions are chosen because they describe two extremely different environments (warm and small vs cold and large cavities) that all models should be able to represent, and because numerous observational products are available in these two regions.

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

The project has just started. In 2020, we have worked on the definition of the experimental design, and we still need to finalize it and publish it. Here is an overview of the MISOMIP2 tasks planned so far (A=Amundsen, W=Weddell):

- **Ocean-A1&W1** experiments are designed to compare multiple ocean simulations with fixed ice shelf cavities (and parameterizations) to a common set of observations.
- **Ocean-A2&W2** experiments are designed to compare the responses of simulated melt rates to an imposed modification of the ice-shelf geometry.
- **Ice-A1&W1** experiments: same as Ocean-A1&W1 but for the ice. Work on initialization in the mid 1990s and sensitivity to idealized positive and negative melt anomalies (through melt parameterization).
- **IceOcean-A1&W1** experiments: same as Ocean-A1&W1 but with coupled models (possibly including "intermediate-complexity coupling" through parameterizations). Attempt to compare to recent changes.

Meetings and workshops

We organized two online meetings to outline the aims of MISOMIP2, to inform potential participants about the timeline and to discuss the experimental protocol:

- 1 September 2020, 6-7pm CEST
- 3 September 2020, 9-10am CEST

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Website: https://www.climate-cryosphere.org/mips/misomip (to be updated)

Earth System Model-Snow Model Intercomparison Project (ESM-SnowMIP)

The Land Surface, Snow and Soil Moisture Intercomparison Project (LS3MIP) is an endorsed subproject 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.

Highlights

A provocative new paper was published in early 2021 (Menard et al., 2021; full citation below), highlighting lessons learned (or the lack thereof) from ESM-SnowMIP reference site simulations generated by 27 participating models. Importantly, the paper concludes that "*….evaluating models against more variables and providing evaluation datasets extended temporally and spatially does not facilitate identification of key new processes requiring improvement to model snow mass and energy budgets, even at point scales. In fact, the same modelling issues identified by previous snow MIPs arose: albedo is a major source of uncertainty, surface exchange parameterizations are problematic, and individual model performance is inconsistent*." The process of drafting this manuscript with input from across the snow modelling community was instructive in identifying the required adaptations for future snow MIPs.

Following on from the first set of ESM-SnowMIP reference site simulations, an experiment using global reanalyses downscaled to the reference sites showed reasonable consistency in long-term trends of simulated and observed annual snow cover duration. In contrast to the established phenomenon of "slower snowmelt in a warmer world" for regions where snow is tending to melt earlier in spring, these simulations identified a mechanism for enhanced sensitivity to warming at sites where snow currently persists late into the summer (Essery et al., 2020).

Despite the challenges identified in Menard et al. (2021), ESM-SnowMIP analyses continued to advance with additional reference site simulations. A key activity was the preparation of forcing data from *in situ* observations for ESM-SnowMIP experiments at tundra study sites (for example, Trail Valley Creek in the Northwest Territories, Canada). The tundra climate class of snow was not considered in the initial set of ESM-SnowMIP reference site simulations. Preparations were also made for an ESM-SnowMIP experiment with downscaled driving data over Marmot Creek Research Basin, Alberta, Canada. New observational datasets were explored for ESM-SnowMIP evaluation, including new snow cover fraction (SCF) and snow water equivalent (SWE) dataset from the European Space Agency (ESA) Climate Change Initiative – Snow project. The use of Snow CCI products will provide a bridge between ESM-SnowMIP reference site (point) simulations and ESM grid scales.

Analysis was initiated on the set of historical land simulations (land-hist) from the Land Surface, Snow and Soil Moisture Intercomparison Project (LS3MIP). A paper is in preparation on the validation and benchmarking of snow and permafrost within the land-hist simulations, including investigation of emerging constraints for snow and permafrost projections. The land-hist simulations were produced for the first time within CMIP6, so a key issue to address is the value of these uncoupled simulations in providing additional insight relative to the historical (coupled) simulations.

An important advancement in diagnosing climate simulations of snow was the inclusion of new snow extent and snow water equivalent reference datasets (as described in Mudryk et al., 2020) within The International Land Model Benchmarking (ILAMB) project. This represents the first inclusion of hemispheric-scale snow datasets within ILAMB

Peer review publications

Essery, R, et al. 2020. Snow cover duration trends observed at sites and predicted by multiple models. The Cryosphere, 14, 4687–4698. https://tc.copernicus.org/articles/14/4687/2020

Menard, C. B., 2021. Scientific and Human Errors in a Snow Model Intercomparison, Bulletin of the American Meteorological Society, 102(1), E61-E79.

Mudryk, L., et al. 2020. Historical Northern Hemisphere snow cover trends and projected changes in the CMIP-6 multi-model ensemble, The Cryosphere. 14, 2495–2514, DOI: 10.5194/tc-14-2495-2020.

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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

A GlacierMIP community paper was completed and published in *Earth's Future*, analyzing data submitted to GlacierMIP and complying to prescribed, standardized boundary conditions, with a total of 288 transient simulations of 21st century glacier mass changes based on 11 glacier models, 10 GCMs and 4 emission scenarios (Marzeion et al., 2020). Results indicate that glaciers will lose 18±13% (RCP2.6) to 36±20% (RCP8.5) of their 2015 mass by 2100, corresponding to 79 ± 56 mm sea-level equivalent (SLE) and 159 ± 86 mm SLE, respectively. Projected mass losses are slightly less, but within error margins of the previous GlacierMIP projections (Hock et al., 2019). Emission scenario is the largest uncertainty in the projections by the end of the century, but glacier model uncertainty dominates the uncertainty in the coming decades. Results have been requested by IPCC AR6 lead authors for inclusion into the upcoming report.

A new GlacierMIP activity was launched aiming to determine the equilibrium response of glaciers to various temperature increases above pre-industrial. Standardized experiments were developed in multiple telecons by a core GlacierMIP team. An open call for the GlacierMIP equilibrium experiments will be issued in early 2021, once details have been finalized. All data submissions will then be analyzed, and submission of a paper is targeted within the coming 12 months

Peer review publications

Hock, R., B. Marzeion, A. Bliss, et al. 2019. GlacierMIP - A model intercomparison of global-scale glacier mass-balance models and projections, 2019. *J. Glaciol.,* doi:10.1017/jog.2019.22.

Marzeion, B., R. Hock, B. Anderson, et al. 2020. Partitioning the Uncertainty of Ensemble Projections of Global Glacier Mass Change. *Earth's Future* 12, doi: 10.1029/2019EF001470

Meetings and workshops

The new GlacierMIP results (Marzeion et al., 2020) were presented at several conferences and international webinars in 2020. A virtual GlacierMIP meeting was held on 6 November 2020 with 13 participants, including three new GlacierMIP members

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Sea Ice and Climate Modelling Forum - Diagnostic Sea Ice Model Intercomparison Project (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

Analysis using newly available sea ice output requested by SIMIP shows that biases in melt onset can compensate for a too thin winter sea ice cover, leading to September sea ice area consistent with observations (Smith et al., 2020, Figure 1). Furthermore, a mass budget analysis of Arctic sea ice showed that the relative amounts of frazil and basal ice formation varies between the models, while the time of year where different mass budget processes are important are largely consistent between models (Keen et al., 2021). Both of these studies highlighting the importance of using more process-based metrics to assess sea ice simulations in climate models, going beyond September sea ice extent or area

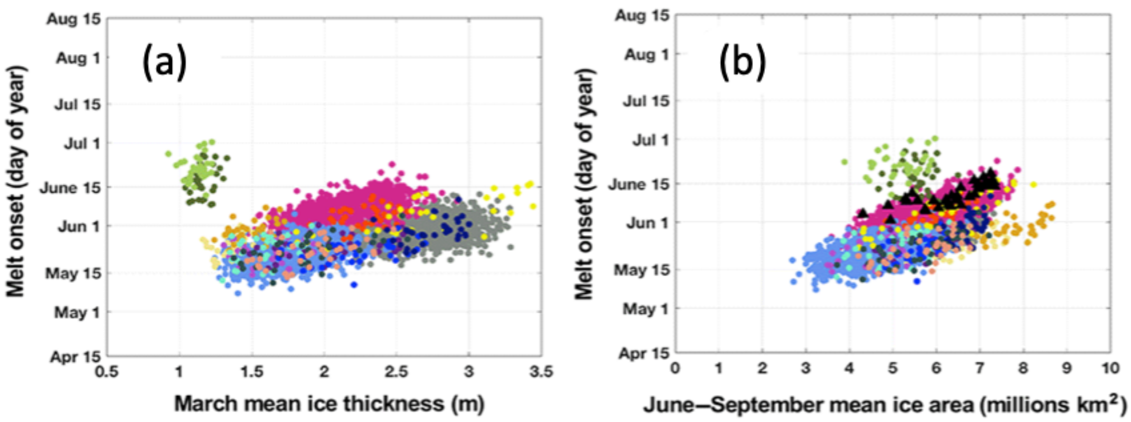

Figure 1: Figure 1: CMIP6 (colours) simulated melt onset dates versus (a) March ice thickness and (b) June to September average sea ice area. In (b), observations are shown in black. CMIP6 models with clear biases in green. From Smith et al., 2020.

The Community SIMIP paper about Arctic sea ice in CMIP6 models was published (SIMIP Community 2020, GRL) and received significant press attention. Several additional papers by SIMIP members and related to SIMIP targeted efforts were submitted and published, including an overview on Antarctic Sea ice in CMIP6 models (Roach et al., 2020, GRL), an analysis of melt season dates in CMIP6 models (Smith et al., 2020, The Cryosphere), a mass budget analysis of Arctic sea ice (Keen et al., 2021) and an essay on integrating models and observations for predictions of a changing Arctic (Holland et al. 2020, Arctic report Card). We are currently in the process of adding a publication list to the SIMIP website to collect SIMIP related publications and ensure these results are well publicised within the SIMIP community to enable rapid scientific progress.

Peer review publications

SIMIP Community (2020), Arctic sea ice in CMIP6. *Geophysical Research Letters*, 47, e2019GL086749. https://doi.org/10.1029/2019GL086749

Roach, L. A., et al. 2020. Antarctic sea ice in CMIP6. *Geophysical Research Letters*, 47, e2019GL086729. https://doi.org/10.1029/2019GL086729

Smith, A., et al. 2020. Seasonal transition dates can reveal biases in Arctic sea ice simulations, *The Cryosphere*, 14, 2977–2997, https://doi.org/10.5194/tc-14-2977-2020.

Holland, M.M., 2020. Integrating Models and Observations to Better Predict a Changing Arctic Sea Ice Cover, *Arctic Report Card 2020*, R. L. Thoman, J. Richter-Menge, and M. L. Druckenmiller, Eds., https://doi.org/10.25923/bx13-ja71

Keen, A.,.: An inter-comparison of the mass budget of the Arctic sea ice in CMIP6 models (2020), The Cryosphere, *in press*. Discussion paper at https://doi.org/10.5194/tc-2019-314.

Meetings and workshops

No meetings or workshops were held in 2020 due to the pandemic.

Future plans

Further CMIP6 sea ice analysis is expected to be published in 2021, with several currently under review and more in preparation. We hope to convene an in-person SIMIP workshop after the pandemic, in 2022 or 2023, to discuss next steps and outstanding analysis efforts that should be taken by the sea ice modelling community to make further progress under the aims of the project

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Website

http://www.climate-cryosphere.org/mips/simip

LS3MIP is a joint model intercomparison (and improvement) project from WCRP´s Coupled Model Intercomparison Project (CMIP6), the Global Energy and Water Exchanges (GEWEX) and the Climate and Cryosphere (CliC). Its goals are to (i) assess the performance of current land surface modules of Earth System Models, and (ii) quantify land surface feedbacks in a changing climate

In particular, LS3MIP provides a comprehensive assessment of land surface-, snow-, and soil moisture-climate feedbacks, and to diagnose systematic biases in the land modules of current ESMs using constrained land-module only experiments. The solid and liquid water stored at the land surface has a large influence on the regional climate, its variability and predictability, including effects on the energy and carbon cycles. Notably, snow and soil moisture affect surface radiation and flux partitioning properties, moisture storage and land surface memory. They both strongly affect the atmospheric conditions, in particular air temperature, but also large-scale circulation patterns and precipitation. Climate models, however, show divergent responses and representations of these feedbacks as well as systematic biases due to simplifications or missing parameterizations of key the underlying processes.

LS3MIP provides the means to quantify the associated uncertainties and to better constrain climate change projections, of particular interest for highly vulnerable regions (densely populated regions, polar regions, agricultural areas, land ecosystems).

Meetings
Teleconference on Hist Papers, July 17, 2020

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

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The Polar Climate Predictability Initiative (PCPI) is an initiative of the WCRP, whose goal is to improve the understanding of the predictability of climate and the effect of human activities on climate. The PCPI focus on polar regions and their role in the global climate system, and aims to improve predictability of the climate system on all time scales by improving our understanding of the underlying physical mechanisms and their representation in climate models. The PCPI is supported by both CliC and the Stratosphere-troposphere Processes And their Role in Climate Project (SPARC) of WCRP, and is an activity of the *Grand Challenge Melting Ice and Global Consequences*

Science highlights

In a paper led by PCPI lead Kyle Clem, the authors explored the recent warming over the South Pole, which at 0.61 ± 0.34 °C per decade is more than three times the global average. This warming resulted from a strong cyclonic anomaly in the Weddell Sea caused by increasing sea surface temperatures in the western tropical Pacific. The results show how closely linked the interior Antarctic climate is to tropical variability. The study also showed that any anthropogenic warming signal over the Antarctic interior during the twenty-first century has been masked by atmospheric internal variability, which can induce extreme regional climate change over the Antarctic interior.

Due to the Covid-19 pandemic, there has been no coordinated PCPI activity during 2020. Both co-leads hold teaching positions, and so dealing with the ever-changing circumstances, and to converting courses to online teaching, meant that time for research activities was severely limited, and needed to be focussed on core research.

Future plans

In 2020 we planned to continue the reorganization of PCPI, which was begun in 2019. This included planning for activities (workshops, etc.) to advance the goals of the new structure. This plan was not "completed" because of the effect that the pandemic had on the leadership and membership of the group. As the pandemic eases, we expect that we will continue the work of PCPI in 2021. This will be done through online meetings and science meetings of opportunity.

Peer review publications

Clem, K. et al. 2020 Record warming at the South Pole during the past three decades. *Nature Climate Change*, 10. 762-770. 10.1038/s41558-020-0815-z

Fogt, R. et al. 2020 The Southern Annular Mode: variability, trends, and climate impacts across the Southern Hemisphere. *WIREs Climate Change*, 11. 10.1002/wcc.652

Fogt, R. L., et al. 2020, An assessment of early 20th Century Antarctic pressure reconstructions using historical observations. International *Journal of Climatology*, 22, E672-E689, https://doi.org/10.1002/joc.6718.

Handcock, M. S. & Raphael, M. N.: Modelling the annual cycle of daily Antarctic sea ice extent, The Cryosphere, 14, 2159–2172, https://doi.org/10.5194/tc-14-2159-2020, 2020.

Roach, L. A., et al. 2020. Antarctic sea ice area in CMIP6. *Geophysical Research Letters*, 47, e2019GL086729. https://doi.org/10.1029/2019GL086729

Marshall, G. et al. 2020 The role of atmospheric circulation patterns in driving recent changes in indices of extreme seasonal precipitation across Arctic Fennoscandia. *Climatic Change*, 162. 741-759. 10.1007/s10584-020-02747-w

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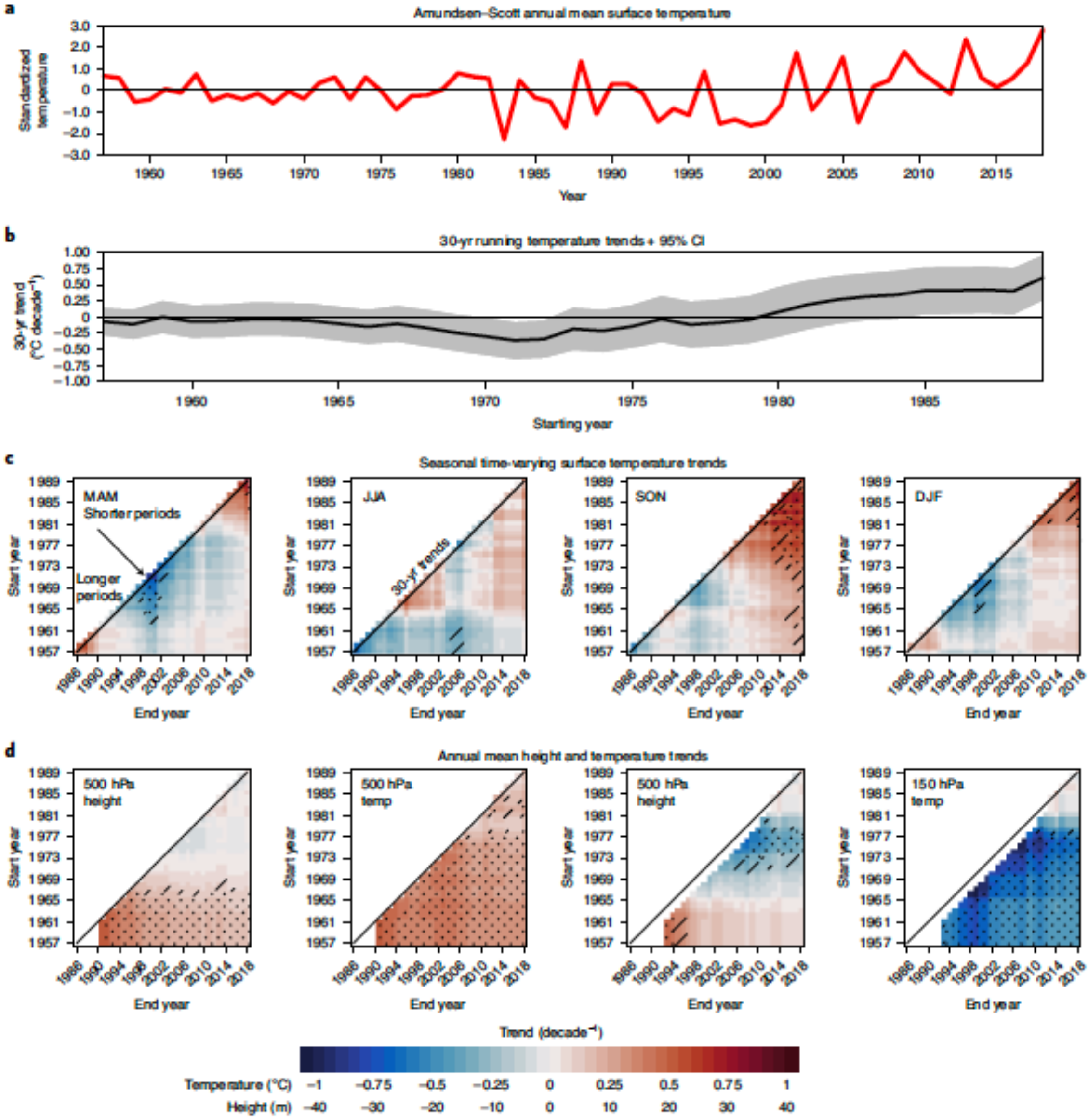


Fig. 1 | Temperature and pressure changes at the South Pole during the modern instrumental record. a,b, Time series of the standardized South Pole annual-mean SAT (**a**) and running 30-yr SAT trends (°C decade⁻¹) (**b**), with the 95% CI shaded in grey. **c,d**, The time-varying South Pole seasonal-mean SAT trends (**c**) and annual-mean geopotential height and temperature trends at 500 hPa and 150 hPa from South Pole radiosonde data (**d**). In **c** and **d**, the starting year of trend is on the left axis and ending year of trend is on the bottom axis; the $x = y$ axis is exactly 30 yr, and longer periods are in the bottom right corner. Cross-hatching in **c** and **d** indicates trends different from zero at $P < 0.10$ and stippling $P < 0.05$. MAM, March–April–May; JJA, June–July–August; SON, September–October–November; DJF, December–January–February.

Research Projects

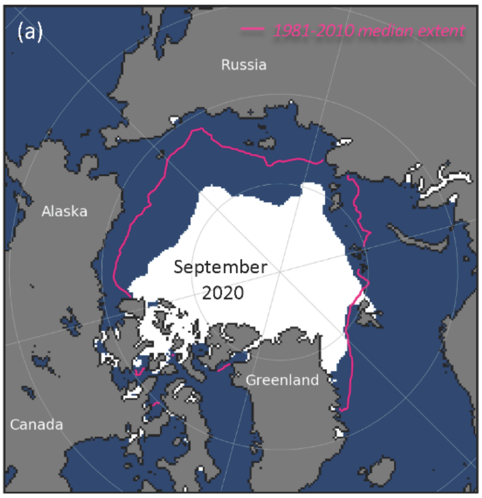
The goals of the Climate and Cryosphere Arctic Sea Ice Working Group are to:
(i) develop, standardize, and implement measurement protocols for Arctic sea ice in coastal, seasonal, and perennial ice zones; (ii) integrate surface-based observations with remote sensing and modelling efforts, and (iii) foster 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.

Highlights
The primary science highlight of the year was participation in the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) field experiment. Members of the ASIWG participated in the planning and execution of MOSAiC. Many of the MOSAiC protocols for sea ice observations were developed by the ASIWG. These protocols included the Ice Watch and measurements of albedo, snow depth, mass balance, melt ponds and ice core stratigraphy. Early results from MOSAiC are currently being presented in conferences and published in journals.

ASIWG members took a leading role in writing the Arctic sea ice section of the 2019 Bulletin of the American Meteorological Society's State of the Climate Report. They also coordinated and led the sea ice portion of the 2020 Arctic Report Card. This was the fifteenth year of the Arctic Report Card, and ASIWG members have led the sea ice portion for most of that period. Sea ice extent is a critical parameter that is reported in the Report Card (Figure 2). The time series demonstrates the considerable loss of sea ice in the past four decades.

In the coming year 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.

Figure 1. Ice dynamics on Leg 5 of the MOSAiC expedition.
Photo credit: Lianna Nixon



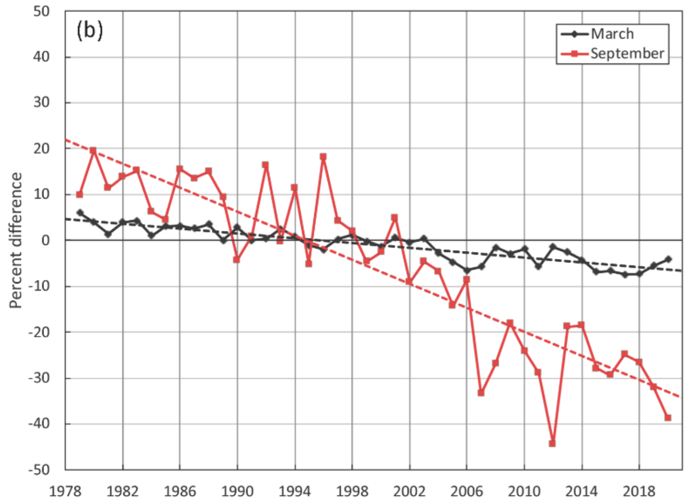


Figure 2. (a) Sea ice extent map for September 2020, with ice concentration >15% in white; the magenta contour indicates the median extent for 1981 – 2010. (b) Percent anomaly of March (black) and September (red) extent for 1979 – 2020; the dashed lines indicate the linear trend.

Meetings

No annual meeting was held this year, due to travel restrictions associated with COVID-19.

In addition, the MOSAiC field campaign was from September 2019 to October 2020. The sea ice community was actively involved in MOSAiC and spent large amounts of time in the field.

We hope that in-person meetings will be possible in the coming year. If so, we will arrange for an annual meeting at the Fall Meeting of the American Geophysical Union. In case in-person meetings are not possible, we will host an online virtual meeting in the coming year.

Outreach

We performed extensive outreach activities in 2020, many of which were associated with the MOSAiC field experiment. These included:

- Contributed nine modules on sea ice to the Massive Online Open Course “Frozen in the ice exploring the new Arctic.”
- Performed numerous media interviews associated with MOSAiC and the Arctic Report Card.
- Worked with schools across the globe, including the US National Ocean Sciences Bowl, to discuss MOSAiC, data, and climate change.
- Continued our work with citizen scientists using the ASSIST ice watch software.

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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.

Highlights

ASIWG published 2 collective papers, one in *Nature Climate Change* by D. Lannuzel L. Tedesco, M. van Leeuwe, K. Campbell, H. Flores, B. Delille, L. Miller, J. Stefels, P. Assmy, J. Bowman, K. Brown, G. Castellani, M. Chierici, O. Crabeck, E. Damm, B. Else, A. Fransson, F. Fripiat, N.-X. Geilfus, C. Jacques, E. Jones, H. Kaartokallio, M. Kotovitch, K. Meiners, S. Moreau, D. Nomura, I. Peeken, J.-M. Rintala, N. Steiner, J.-L. Tison, M. Vancoppenolle, F. Van der Linden, M. Vichi, P. Wongpan. The future of Arctic sea-ice biogeochemistry and ice-associated ecosystems. Natu (Nature Climate Change, 2020) "The future of Arctic sea-ice biogeochemistry and ice-associated ecosystems », and the other in EOS, by L. Miller F. Fripiat, S. Moreau, D. Nomura, J. Stefels, N. Steiner, L. Tedesco, M. Vancoppenolle. Implications of sea ice management forArctic biogeochemistry. EOS: "Implications of Sea Ice Management for Arctic Biogeochemistry

Peer review publications

Lannuzel, D. et al. 2020. The future of Arctic sea-ice biogeochemistry and ice-associated ecosystems. Nature Climate change https://doi.org/10.1038/s41558-020-00940-4

Miller, L., et al. 2020. Implications of sea ice management forArctic biogeochemistry. EOS, *101*, https://doi.org/10.1029/2020EO149927.

L. Duprat, L. D. Lannuzel M. Corckill, C. Genovese, K. M. Meiners, A. T., Townsend, S. Moreau. Iron distribution in East Antarctic summer sea ice: a potential contribution from glacier basal melt. Journal of Geophysical Research: Oceans

Nomura, D., 2020. Saroma-Ko Lagoon observations for sea ice physico-chemistry and ecosystems 2020 (SLOPE2019). *Bulletin of Glaciological Research*, Japanese Society of Snow and Ice 38, 1-12, doi:10.5331/bgr.19R02.

Hayashida, H., et al. 2020. Spatiotemporal variability in modeled bottom ice and sea surface dimethylsulfide concentrations and fluxes in the Arctic during 1979–2015. *Global Biogeochemical Cycles*, 34, e2019GB006456. https://doi.org/10.1029/2019GB006456

Mortenson, E., et al. 2020. Modeled impacts of sea ice exchange processes on Arctic Ocean carbon uptake and acidification (1980–2015). *Journal of Geophysical Research: Oceans*, 125, e2019JC015782. https://doi.org/10.1029/2019JC015782.

Hayashida, H., 2020. Ice Algae Model Intercomparison Project phase 2 (IAMIP2), Geosci. Model Dev. in revision

Meetings and workshops

COVID locked many of our projects in 2020. Yet we managed to organise a very successful, 24-28 August 2020. The meeting included plenary sessions and poster displays. The workshop was preceded by an Early Career Scientist session on Aug 21st.

Future plans

Some plans are delayed because of the pandemic. We hope for a rapid restart in 2021.

- We have in preparation a review/position analysis paper, on Antarctic sea ice biogeochemistry (Meiners et al)
- Collaborative discussions among BEPSII and CATCH include a SCOR-WG proposal and a

potential joint CATCH-BEPSII cruise

- A BEPSII ECS fields school is still in planning but dependent on Covid19 related re-opening of the Canadian North
- New BEPSII special issue started in Elementa
- Community paper on changes in sea-ice ecosystems and ecosystem services (submitted to Elementa BEPSII special issue)
- Cambridge Bay intercalibration experiment (Spring 2022)
- We will investigate how to position ourselves with the new organisation of WCRP. We'd love to exchange with Clic regarding that matters.

Outreach

Crabeck, K. Campbell, S. Moreau, M. Thomas. 2021. The movement of CO2 through the frozen world of sea ice. Frontiers for Young Minds. 9:516072. doi: 10.3389/frym.2020.516072

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https://sites.google.com/site/bepsiiwg140/home

Participants of the BEPSII/ECVice 2020 workshop, 24-28 August 2020

ASPeCt is an expert group on multi-disciplinary Antarctic sea ice zone research with the key objective of improving our understanding of the Antarctic sea ice zone and its response to climate change. This understanding is to be achieved through focused field programs, systematic monitoring of the ice cover, analysis of remote sensing and numerical modelling.

Highlights

- Major outcomes of the 2017 PIPERS cruise, led by ASPeCt Immediate Past Chair Steve Ackley, on N. B. Palmer into the early winter Ross Sea, have been presented at scientific conferences and are in varying stages of publications. Details of the cruise found here: http://www.utsa.edu/LRSG/PIPERS/index.htm
- ASPeCt is continuing development of the ASPeCt ship-based observation system and database for sea ice measurements taken by remote vessels (airborne and under ice), ship-based instruments and surface-based instruments and sampling. – This is an ongoing ASPeCt activity.
- ASPeCt continued updating its database with data from the 2019/2020 research season. This includes quality control of poor data and compilation of seasonal metadata records as prerequisite to obtaining DOIs.
- ASPeCt has continued the process of visualization of its current database in order to increase the accessibility of the data and to publicize its existence.
- ASPeCt scientists have continued hydrographic timeseries of high-salinity shelf water
- (HSSW) production, wind and sea ice in Terra Nova Bay. This is done as part of the NZ Antarctic Science Platform & Deep South Challenge.
- Under the Japan-Australia-New Zealand Antarctic Partnership during the 61st Japanese Antarctic Research Expedition (JARE61), ASPeCt scientists deployed 5 wave-ice interaction buoys, extending coverage to 64S and achieving longer term observations.

Peer review publications and in press

Arndt, S., et al. 2020. Seasonal and interannual variability of landfast sea ice in Atka Bay, Weddell Sea, Antarctica, The Cryosphere, 14, 2775–2793, https://doi.org/10.5194/tc-14-2775-2020, 2020.

Ackley SF, et al. 2020. Surface flooding of Antarctic summer sea ice. Annals of Glaciology 1–10. https://doi.org/10.1017/aog.2020.22

Dai L., et al. 2020. Ice Production in Ross Ice Shelf Polynyas during 2017–2018 from Sentinel–1 SAR Images, Remote Sens., 12, 1484; doi:10.3390/rs12091484

Fraser, A. D., et al.2020. High-resolution mapping of circum-Antarctic landfast sea ice distribution, 2000–2018, Earth Syst. Sci. Data, 12, 2987–2999, https://doi.org/10.5194/essd-12-2987-2020, 2020.

Hoppmann M, et al. 2020. Platelet ice, the Southern Ocean’s hidden ice: a review. Annals of Glaciology 1–28. https://doi.org/10.1017/aog.2020.54

Kohout A.L. et al. 2020. Observations of exponential wave attenuation in Antarctic sea ice during the PIPERS campaign. Annals of Glaciology, 1–14.

Mackie, S., et al. 2020. Sea ice formation in a coupled climate model including grease ice. Journal of Advances in Modelling Earth Systems (in press)

Tison, J., et al. 2020. Physical and biological properties of early winter Antarctic sea ice in the Ross Sea. *Annals of Glaciology,* 1-19. doi:10.1017/aog.2020.43

Yoon, S.-T., et al. 2020. Spatio-temporal variations in High-Salinity Shelf Water production in Terra Nova Bay polynya, Antarctica, *Ocean Sci. Discuss* (in press)

Meetings

ASPeCt sponsored **Session #5: Antarctic sea ice variability and change: physical links with the Southern Ocean,** at the SCAR2020 Online meeting in July 2020.

Antarctic Sea ice Processes and Climate 2020 Workshop Report.

ASPeCt held an online Workshop, supported by CliC's GoToMeeting platform, on July 31st 2020. This workshop was supported by CliC and SCAR and was formerly planned to be a part of SCAR 2020 in Hobart, Australia. Over the four hours of meeting a maximum of 36 people participated. At the Workshop, the work that ASPeCt has been doing over the last 2 – 4 years was highlighted. This was followed by extensive discussion on updating ASPeCt's sea ice measurement protocol, database management, identifying critical Antarctic sea ice areas for targeted observations, and the Group's science objectives for the next five to ten years. Representatives from SOOS (Southern Ocean Observing System) and SORP (Southern Ocean Region Panel) were also present to discuss mutual interests and to plan for collaborative projects.

Future plans

- ASPeCt will continue active enlistment of cruises going into the ice zone in order to increase contributions to the ship sea ice observation database. ASPeCt is using DUE SOUTH to access information on upcoming cruises.. – This is an ongoing ASPeCt activity.
- ASPeCt is continuing development of the ASPeCt ship-based observation system and database for sea ice measurements taken by remote vessels (airborne and under ice), ship-based instruments and surface-based instruments and sampling. – This is an ongoing ASPeCt activity.
- Updating the ASPeCt database: This includes quality control and entering new data, making the database accessible to the larger public and formatting the data to make it easier for incorporating into climate models, and finally, analyzing the data writing up the results. This project is underway supported by limited funding and new funding avenues being explored.
- ASPeCt scientists plan a project on Platelet Ice in the McMurdo Sound, to better understand the role of sub-ice platelet layers in supporting the Ross Sea ecosystem 2021/22, 2022/23 & 2023/24. This is part of the NZ Antarctic Science Platform & Deep South Challenge.
- ASPeCt scientists have a planned campaign into the Weddell Sea for January 2022. The project title is *Ocean-ice-atmosphere connection*

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LINKAGES

The assessment of the potential for recent Arctic changes to influence broader hemispheric weather is a difficult and controversial topic, with considerable skepticism. 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 were merely random events or were 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.

Highlights and publications

Resulting from our Linkages workshop held at NOAA/PMEL in September 2019, a paper was published as follows: Overland, J.E. et al. 2021. *How do intermittency and simultaneous processes obfuscate the Arctic influence on midlatitude winter extreme weather events? Environmental Research Letters* in January 2021. https://iopscience.iop.org/article/10.1088/1748-9326/abdb5d

Abstract
"Pronounced changes in the Arctic environment add a new potential driver of anomalous weather patterns in midlatitudes that affect billions of people. Recent studies of these Arctic/midlatitude weather linkages, however, state inconsistent conclusions. A source of uncertainty arises from the chaotic nature of the atmosphere. Thermodynamic forcing by a rapidly warming Arctic contributes to weather events through changing surface heat fluxes and large-scale temperature and pressure gradients. But internal shifts in atmospheric dynamics — the variability of the location, strength, and character of the jet stream, blocking, and stratospheric polar vortex (SPV) — obscure the direct causes and effects. It is important to understand these associated processes to differentiate Arctic-forced variability from natural variability. For example, in early winter, reduced Barents/Kara Seas sea-ice coverage may reinforce existing atmospheric teleconnections between the North Atlantic/Arctic and central Asia, and affect downstream weather in East Asia. Reduced sea ice in the Chukchi Sea can amplify atmospheric ridging of high pressure near Alaska, influencing downstream weather across North America. In late winter southward displacement of the SPV, coupled to the troposphere, leads to weather extremes in Eurasia and North America. Combined tropical and sea ice conditions can modulate the variability of the SPV. Observational evidence for Arctic/midlatitude weather linkages continues to accumulate, along with understanding of connections with pre-existing climate states. Relative to natural atmospheric variability, sea-ice loss alone has played a secondary role in Arctic/midlatitude weather linkages; the full influence of Arctic amplification remains uncertain

Outreach

A press release relating to our ERL paper was published by the University of Lincoln: *«Research Sheds Light on Extreme Winter Weather Events»*. Published: 29th January 2021

This year a 'sudden stratospheric warming' event could reportedly plunge parts of the northern hemisphere into extreme cold, reminiscent of the infamous 'Beast from the

East' weather event experienced in the UK in 2018.

These warming events occur naturally every other year or so, disrupting the upper-level winds high over the Arctic. While often difficult to predict, their effects can be highly disruptive to transportation, infrastructure, agriculture and other human activities.

Now an international team of researchers, including from the University of Lincoln, UK, and the US National Oceanographic and Atmospheric Administration, has shed light on how these weather events in the Arctic can have knock-on effects for extreme winter weather in Europe, North America and Asia.

They found that disruptions of the stratospheric polar vortex, located 30 kilometres above the North Pole, compound with other factors including the impact of Arctic sea-ice loss, ocean temperature patterns, tropical fluctuations, and natural variations in the atmosphere. The combination of these factors and connections between them can all impact on weather in the northern hemisphere.

Edward Hanna, Professor in Climate Science and Meteorology at the University of Lincoln, and co-author of the study, said: "It's a complex story but it's clear that the changing climate, particularly in the Arctic, is affecting winter weather patterns in Europe, Asia, and North America. Lead author, Dr. James Overland of NOAA, notes that the new paper shows that each event is composed of multiple factors. Cases show a weather connection to loss of sea ice north of Alaska and north of Norway and Russia in recent years.

"The winter of 2020/21 is an amazing case study, as we witness loss of sea- ice, record-breaking Arctic warmth, a major stratospheric disruption, and a combination of record-breaking weather features: an exceptionally high-pressure centre over eastern Asia along with a record low-pressure storm near the Aleutian Islands. "Recent studies suggest these types of events are connected, and they may happen

more often as the Arctic continues to melt and warm faster than elsewhere. We may see stratospheric disruptions like the present one happening more frequently."

The researchers note the atmosphere is complex and it can be difficult to identify which factors may be responsible for any given extreme event.

Despite this, they state that the loss of three-quarters of the Arctic sea-ice volume in the last 40 years is one of the clearest indicators of human- caused climate change, and weather patterns will be affected. But there is still a challenge to figure out when, where, how, and how much.

The paper was published in the journal *Environmental Research Letters*

Contacts

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Website

https://www.climate-cryosphere.org/activities/linkages/about

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

Frank Pattyn and Guðfinna Aðalgeirsdóttir (both representing ISMASS) co-hosted a CliC-sponsored (with SCAR and IASC) session CR1.1 on Ice sheet mass balance and sea-level: ISMASS/ISMIP6" at the EGU General Assembly 2020 Sharing Geoscience Online during 4-8 May 2020. The session explored improvements in understanding and quantification of past, present and future ice sheet and sea-level changes. While the focus is on present and future (multi-centennial) Greenland and Antarctic ice sheets, paleo-studies are encouraged if they shed light on above topics. Due to COVID-19, the session was an online chat session and 194 people attended.

Frank Pattyn and Guðfinna Aðalgeirsdóttir (both representing ISMASS) co-hosted a session during the SCAR 2020 Online conference 3-7 August 2020. The session was titled "Critical challenges in modelling past and future evolution of the Antarctic and Greenland ice sheets - scales, uncertainty, processes, implications for sea level". An abstract book is available online:

https://az659834.vo.msecnd.net/eventsairseasiaprod/production- leishman-public/e8899af7571a486685cbb9ce710a7842.

A model intercomparison of the surface mass balance of the Greenland ice sheet was finalised and published (Fettweis et al., 2020). GrSMBMIP was suggested and initiated by ISMASS during a SSC meeting in June 2018.

The Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6), with ISMASS chair Heiko Goelzer taking a leading role in the Greenland projections, has delivered its major scientific result in 200. Several key publications, from experimental protocol to results of centennial time-scale projections for both ice sheets have come out of this community effort and fed into the current IPCC assessment cycle (AR6).

Peer review publications

Hanna, E., et al. 2020. Mass balance of the ice sheets and glaciers - progress since AR5 and challenges. Earth Science Reviews. 201, https://doi.org/10.1016/j.earscirev.2019.102976.

Pattyn, F. & M. Morlighem (2020) The uncertain future of the Antarctic ice sheet. Science 367 (6484): 1331-1335; https://doi.org/10.1126/science.aaz5487. This review paper that is part of three papers published in Science in March 2020 for the 200th anniversary of the first sighting of Antarctica.

Fettweis, X., et al. 2020.GrSMBMIP: intercomparison of the modelled 1980–2012 surface mass balance over the Greenland Ice Sheet, The Cryosphere, 14, 3935–3958, https://doi.org/10.5194/tc-14-3935-2020

Goelzer, H., et al. 2020. Brief communication: On calculating the sea-level contribution in marine ice-sheet models, The Cryosphere, 14, 833–840, https://doi.org/10.5194/tc-14-833-2020.

Nowicki, S., et al. 2020. Experimental protocol for sea level projections from

ISMIP6 standalone ice sheet models, Cryosphere, 14, 2331–2368, https://doi.org/10.5194/tc-14-2331-2020

Goelzer, H.,et al. 2020. The future sea-level contribution of the Greenland ice sheet: a multi-model ensemble study of ISMIP6 Cryosphere, 14, 3071–3096, https://doi.org/10.5194/tc-14- 3071-2020

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Meetings and workshops

ISMASS Steering Committee Meeting, June 4th 2020, online (zoom), 12 participants. Discussed topics: report on last year's activities, changes to the SSC members, change of chair, operation under ongoing pandemic, future activities.

Future plans

- **Ice sheets change: "climate" versus "weather",** led by E. Hanna. Focus on signal-to-noise ratio of recent (last 2-3 decades) ice-sheet changes, perhaps linking this topic with thresholds, extreme events (e.g. the near-record Greenland Ice Sheet melt of summer 2019) and relevant climate feedbacks. Workshop planned in spring/summer 2022 in Lincoln, UK / review paper.
- **Involvement in future 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. Exchanges with INSTANT will be beneficial for both parties. Ritz has proposed a sub-committee to work on ice sheet models bridging different time and spatial scales.
- **North-South feedback** (Led by T. Aðalgeirsdóttir). This activity reflects the two poles of ISMASS (co-supported by SCAR and IASC) which was also exemplified by a session at the SCAR ONLINE 2020 and EGU 2020.
- **Model intercomparisons and ISMIP6**. ISMASS has a strong expertise in model intercomparisons and will contribute to ISMIP6 and other intercomparison exercises.
- **EGU 2021 session on ice sheet mass balance and sea-level.** ISMASS will organise a joint session with ISMIP6 titled "Integrating models and observations for the estimation of ice sheet mass balance and sea level, incorporating ISMASS/ISMIP6" at the upcoming EGU21: Gather Online, 19–30 April 2021

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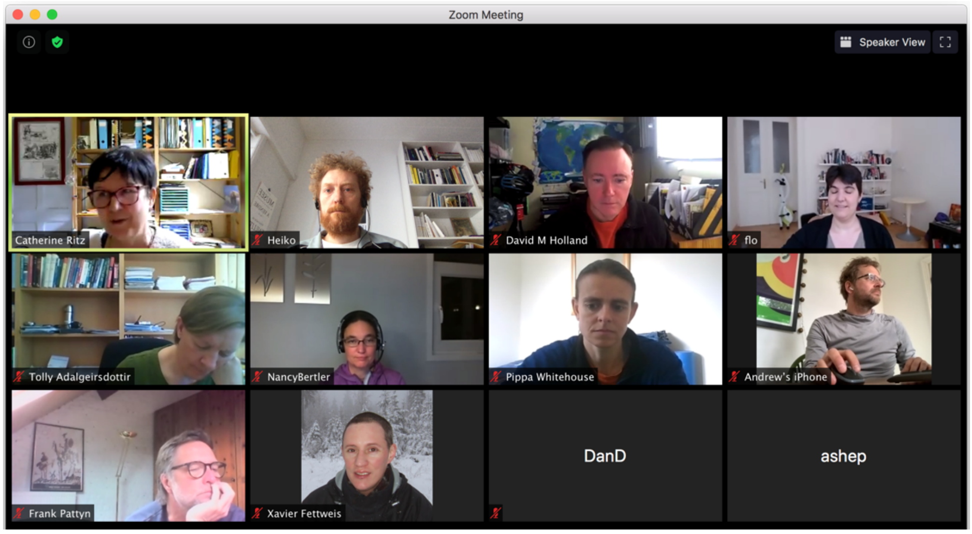

The ISMASS Steering Committee at their meeting on June 4th

Interdisciplinary Activities & Networks

The goal of SORP is to serve as a forum for the discussion and communication of scientific advances in the understanding of climate variability and change in the Southern Ocean. To advise CLIVAR, CliC, and SCAR on progress, achievements, new opportunities and impediments in internationally-coordinated Southern Ocean research.

Highlights
Member´s participation in the OcPean Science meeting in San Diego, February 2020

Peer review publications

Bromwich, D. H., K. Werner, B. Casati, J. G. Powers, I. V. Gorodetskaya, F. Massonnet, V. Vitale, V. J. Heinrich, D. Liggett, S. Arndt, E. Bazile, B. Barja, Y. Choi, S. R. Colwell, R. R. Cordero, M. Gervasi, T. Haiden, J. Inoue, T. Jung, H. Kalesse, M. A. Lazzara, K. W. Manning, K. Norris, S.-J. Park, I. Rigor, P. M. Rowe, P. Seifert, M. Zannoni and X. Zou (2020) The Year of Polar Prediction in the Southern Hemisphere (YOPP-SH). Bull. Amer. Meteor. Soc. 101 (10): E1653–E1676. doi:10.1175/BAMS-D-19-0255.1

This paper is a summary of the 2018-2019 Special Observing Period (16 Nov to 14 Feb 2019) during the Year of Polar Prediction in the Southern Hemisphere (YOPP-SH). The paper was led by SORP members David Bromwich in his YOPP-SH role, and Francois Massonet, in his capacity as liaison between SORP and the YOPP-SH.

Meetings and workshops
Due to the COVID-19 pandemic all workshops were cancelled. The initiative to reschedule the SORP-14 meeting alongside other meetings in 2021 was not successful yet. Workshops were typically rescheduled for 2021 without particular adjustments. As the situation remains uncertain, a growing number of organizing committees considers online meetings or hybrid versions with limited local participants for next year.

SORP held regular panel meetings every (other) month using video calls. While this was sufficient to provide input to incoming requests and interaction with other panels, it hindered reinvigoration of ongoing but somewhat dormant tasks. New members have a hard time to get to know the panel. We thus sought successfully to renew/extend memberships instead of issuing a call for new members hoping that the group will more easily succeed in carrying on with already defined tasks. The discussion on the WCRP LHA yielded promising perspectives for 2021.

Future Plans
<u>Restructuring tasks to match upcoming WCRP LHA</u>:

- improve exchange between observational and modelling communities; planning strategy workshop; include other panels [LHA 1]
- support countries in strengthening their non- or under-developed Antarctic and Southern Ocean programs; creating list of available programs for international exchange [LHA 2]; in this context: promote international data storage to improve sharing of data from less developed countries [LHA 1]
- planning session/workshop on “Sources and consequences of Southern Ocean freshening: Toward synthesizing observations and modelling” in conjunction with a (white) paper [LHA 3]
- report on how the Southern Ocean is

perceived as a place for mitigating global warming (including potential geoengineering options as well as nature-based solutions to increase resilience) [LHA 3]
- list polar ocean quantities and definitions needed to provide stakeholders with key information on polar climate change (together with NORP) [LHA 4]
- assess demand for downscaling products of ocean boundary conditions from global and regional models as input for ice sheet/ice shelf as well as ice-ocean interaction process modelling (collaboration with ISMIP and SCAR INSTANT community) [LHA 4]
- Detailed ideas and contributions to the new structure of WCRP were provided through CLIVAR channels.

Workshops:

1. SORP-14 options (will be held in 2021 one way or the other):
- In-person meeting (or hybrid):
    - CLIVAR multi-region-panel Observing Systems Workshop, Trieste, Italy
    - WAMC/YOPP-SH meeting in Ohio, USA
- Virtual meeting, likely split over a couple of days
2. Joint SORP/NORP 2-day workshop planned following the OOCP/CLIVAR workshop on "Ocean Heat and Freshwater Storage and Transports in Observations and Climate Models" in Exeter, co-organized by SORP member Neil Swart.
3. Preliminary planning for a "Fluxes in the sea-ice zone" workshop (ASPeCt, SOOS, YOPP, SORP)
4. Submit session proposal "Sources and consequences of Southern Ocean freshening: Toward synthesizing observations and modelling" to a large conference (was unfortunately not successful at last AGU fall meeting)

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NORP serves as an international forum for coordinating and strategizing activities 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. NORP plays a central role in coordinating, monitoring, and evaluating the progress of such activities during and beyond the Year of Polar Prediction.

Highlights

Scientific results from activities

- Contributed section on "Observational challenges and needs in the polar oceans" to CLIVAR OceanObs19 Community White Paper
- Contributed to OceanObs19 Community White Paper, "A Critical Gap in the Observing System and its effect on Environmental Prediction"

Scientific capacity building and career support

Summer school

- Discussed the NORP 2021 Summer School via SLACK and telecon. This summer school will provide opportunities to early career scientists and students to get access to the frontier knowledge of Arctic science.

Knowledge exchange

- FAMOS 2020 Talk on NORP activities and near-term scientific objectives
- Presentations on NORP activities at US CLIVAR Summit, IASC Annual Meeting, FAMOS Annual Meeting, CLIVAR SSG, and CliC Annual report-out.

Peer review publications

Smith, G., et al. 2019. Polar Ocean Observations: A Critical Gap in the Observing System and its effect on Environmental Prediction. *Frontiers*, doi:10.3389/fmars.2019.00429.

Stammer, D., et al. 2019. Ocean climate observing requirements in support of Climate Research and Climate Information. *Frontiers*, doi:10.3389/fmars.2019.00444

In addition, NORP completed a publication (currently under review in Ocean Sciences) entitled, "*Freshwater in the Arctic Ocean 2010-2019".* This paper assesses to what extent observations during the 2010-2019 period are sufficient to estimate the Arctic freshwater budget with greater certainty than previous assessments and how this budget has changed relative to the 2000-2010 period. The paper includes discussions of processes not included in previous assessments, such as redistribution between basins, run off from the Greenland Ice Sheet, the role of snow on sea ice, and vertical redistribution. It is shown that the trend in Arctic freshwater in the 2010s has stabilized relative to the 2000s due to an increased compensation between a freshening of the Beaufort Gyre and a reduction in freshwater in the Amerasian and Eurasian basins. Notably, the Arctic system has shifted to an increasingly seasonal and mobile sea ice cover, a shift in mass loss from the western to the eastern Greenland ice sheet, and an increased import of subpolar waters into the Arctic.

Meetings and workshops

- Co-sponsored 2020 EGU Session: Changes in the Arctic Ocean, sea ice and subarctic seas systems: Observations, Models and Perspectives
- Co-organized OOPC Workshop on Ocean Heat and Freshwater Storage and Transports in Observations and Climate Models【POSTPONED】
- Organized 2nd session of CLIVAR/CliC Northern Ocean Region Panel【POSTPONED】
- Co-sponsored session on Sea ice, ocean and climate connections in the Northern Oceans and the Southern Oceans at IGS 2019
- Co-sponsored session on 'Changes in the Arctic Ocean, sea ice and subarctic seas systems: Observations, Models and Perspectives' at EGU 2019
- Co-sponsored AGU 2020 sessions on "Sea Ice–Ocean–Atmosphere Interactions in the "New" Arctic and Southern Oceans" and "Extratropical and High-latitude Storms,

Teleconnections, Extreme Events, and the Rapidly Changing Polar Climate"

- Co-sponsored The Aspen Global Change Institute workshop on "Arctic Climate and Weather Extremes: Detection, Attribution, and Future Projection" in spring 2020 【POSTPONED】
- Monthly telecons with reports of international Arctic collaborations and campaigns, updates on scientific studies, planning for future activities.

Future plans

1. Organize session at ASSW2021 on "Marine ecosystems in the New Arctic"
2. Co-organize OOPC Ocean Heat and Freshwater Storage and Transports in Observations and Climate Models workshop
3. Organize workshop with SORP on "Role of Freshwater in Polar Ocean Climate Change and Global Linkages" (in parallel with OOPC Ocean Heat and Freshwater Storage and Transports in Observations and Climate Models workshop)
4. Work with national representatives to secure support for Arctic ocean-sea ice state estimates
5. Advance studies on Greenland ice sheet – ocean interactions: Advocate for inclusion in CMIP7 and Sea level call in Horizon2020
6. Coordinate archiving/mirroring of past/future campaign/in-situ data for assimilation and analysis with CLIVAR Global Synthesis and Observations Panel
7. Continue monthly telecons
8. Plan NORP 2021 Summer School in coordination with NORP MOSAiC activities to:
    - learn/improve big data management skills; from writing the algorithm to visualizing the results;
    - get an Earth system perspective by working with students from a different topic;
    - improve critical skills: know why models are not perfect and how to detect biases;
    - Provide an introduction to current MIPs and SSPs

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

Highlights

Accomplished research related to Arctic CORDEX: improvement in simulation of temperature at the snow/ice surface, new modelling efforts, key drivers of Arctic cyclones, simulations of future climate change, and teleconnections.

Accomplished research related to Antarctic CORDEX: new modelling efforts (e.g. climate model NHM-SMAP from JMA), improved understanding of clouds, efforts to model surface mass balance.

Peer review publications

Inoue, J., et al. 2021. Clouds and radiation processes in regional climate models evaluated using observations over the ice-free Arctic Ocean, J. Geophys. Res., 126, e2020JD033904, doi:10.1029/2020JD033904

Sedlar, J., et al. 202.: Confronting Arctic troposphere, clouds and surface energy budget representations in regional climate models with observations, J. Geophys. Res., 124, doi:10.1029/2019JD031783

Fettweis, X., et al. 2020. GrSMBMIP: intercomparison of the modelled 1980–2012 surface mass balance over the Greenland Ice Sheet, The Cryosphere, 14, 3935–3958, doi:10.5194/tc-14-3935-2020

Meetings and workshops

Polar CORDEX Workshop 5-7 October 2020: This was the annual joint Arctic and Antarctic CORDEX workshop and was held as an online Zoom meeting. 30 participants.

Future plans

- Polar CORDEX simulations will be used for the IPCC Interactive Atlas.
- Initial plans have been made for coordinate simulations and analysis using MOSAiC and YOPP supersite observations.
- Antarctic CORDEX simulations at 0.11 deg resolution will be used to understand atmospheric temperature thresholds over Antarctic ice shelves.
- The Polar CORDEX community will explore closer links to the satellite community e.g. via the ESA Climate Change Initiative (CCI).
- The size of the Antarctic CORDEX domain will be increased to encompass more of the Southern Ocean

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CLIC´S CONTRIBUTION TO THE UPDATE OF THE EARTH´S ENERGY IMBALANCE

Understanding how much and where the extra heat (due to increased greenhouse gases) is distributed in the Earth system is fundamental to understanding the impact of anthropogenically driven climate change on the oceans, atmosphere and land, and associated sea level rise, which are fundamental concerns for society.

In this regard, CliC contributed to the Global Climate Observing System (GCOS) concerted international effort to update the Earth's Energy Imbalance (EEI) over the period 1960–2018.

The study shows a consistent long-term Earth system heat gain over the period 1971–2018, with a total heat gain of 358±37 ZJ, which is equivalent to a global heating rate of 0.47±0.1 W m^{-2}. Almost 90% of the heat gained since 1971 ends up in the global ocean, half of which in the upper 700 m. Heat gain over land amounts to 6 % over these periods, 4 % is absorbed by the cryosphere, and 1 % is available for atmo-spheric warming.

Stabilization of climate, the goal of the universally agreed United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and the Paris Agreement in 2015, requires that EEI be reduced to approximately zero to achieve Earth's system quasi-equilibrium. The amount of CO_2 in the atmosphere would need to be reduced from 410 to 353 ppm to increase heat radiation to space by 0.87 W m^{-2}, bringing Earth back towards energy balance.

The most practical way to monitor climate state, variability and change is to continually assess the energy, mainly in the form of heat, in the Earth system. This simple number, EEI, is the most fundamental metric that the scientific community and public must be aware of as the measure of how well the world is doing in the task of bringing climate change under control. The authors of the study thus call for an implementation of the EEI into the global stocktake based on best available science.

Co-chair Fiammetta Straneo was invited by GCOS to lead a team to prepare the inventory for the cryosphere for the period 1979 to 2017. Their systematic estimate of ice loss show that Earth has lost 407 00 ± 5800 Gt of ice with a corresponding energy uptake of 13.8 ± 2.0 ZJ, between 1979 and 2017, larger than previous estimates and equivalent to the energy uptake by the deep ocean, the land and the atmosphere. The total loss is due to approximately equal contributions from Arctic sea-ice, the Antarctic and Greenland ice sheets, and glaciers. However, only half of it contributed to sea level rise. From 1980s to the 2010s, the rate of ice loss has almost tripled. The ice inventory is included in the planetary inventory (von Shuckmann et al. 2020) and the data can be found at Straneo et al. (2020) and is a contribution to the upcoming IPCC AR6.

References

Von Schuckmann, K., et al. (2020). Heat stored in the Earth System: where does the energy go?" Earth Syst. Sci. Data, 12, 2013–2041. This Earth heat inventory is published at the German Climate Computing Centre (DKRZ, https://www.dkrz.de/ under the DOI https://doi.org/10.26050/WDCC/GCOS_EHI_EXP_v2

Straneo, F., et al. (2020). Data from: "Inventory of Earth's Ice Loss and Associated Energy Uptake from 1979 to 2017" (Version 1.0) [Data set]. Zenodo. http://doi.org/10.5281/zenodo.4119129. Python code to read the data is available at: https://github.com/sioglaciology/energy_imbalance_cryosphere

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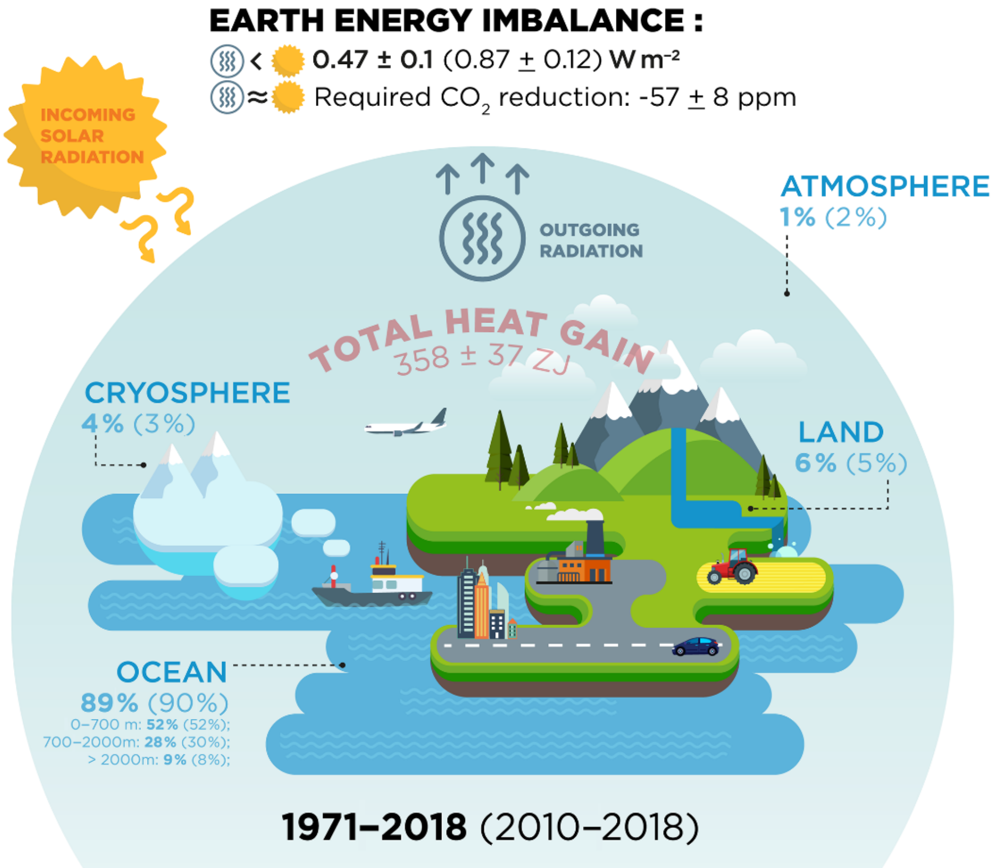

Schematic representation on the Earth heat inventory for the current anthropogenically driven positive Earth energy imbalance at the top of the atmosphere (TOA). Source: von Schuckmann et al. 2020

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

Highlights

The science highlights of the Permafrost Carbon Network include a synthesis with a first estimate of thermokarst (abrupt thaw) carbon emissions using numerical models (Turetsky et al. 2020). Abrupt thaw occurs in <20% of the permafrost zone but could double permafrost carbon emissions.

Another science highlight from 2020 shows that widely-used land models project near-surface drying of the terrestrial Arctic despite increases in the net water balance driven by climate change (Andresen et al. 2020). Drying was generally associated with increases of active-layer depth and permafrost thaw in a warming climate.

A third synthesis product assessed the potential for mobilization of old soil carbon after permafrost thaw (Estop-Aragones et al. 2020). This synthesis suggests widespread but not universal release of permafrost soil organic carbon following thaw.

An expert assessment published in December of 2020 (Sayedi et al. 2020) provides the first circum arctic assessment of the quantity and climate sensitivity of organic matter and methane hydrates on the continental shelves of the Arctic Ocean (Figure 1). The assessment suggests slow but substantial greenhouse gas release from submarine permafrost

Peer review publications

Andresen CG**,** et al. 2020. Soil moisture and hydrology projections of the permafrost region – a model intercomparison. *The Cryosphere*, *14*(2), 445–459. https://doi.org/10.5194/tc-14-445-2020

Estop-Aragonés C**,** et al. 2020. Assessing the Potential for Mobilization of Old Soil Carbon after Permafrost Thaw: A Synthesis of 14C Measurements from the Northern Permafrost Region. *Global Biogeochemical Cycles*, e2020GB006672. https://doi.org/10.1029/2020GB006672

Sayedi SS, et al. 2020. Subsea permafrost carbon stocks and climate change sensitivity estimated by expert assessment. Environmental Research Letters, 15(12), 124075 https://doi.org/10.1088/1748-9326/abcc29

Turetsky MR, et al. 2020. Carbon release through abrupt permafrost thaw. Nature Geoscience, 13(2), 138–143. https://doi.org/10.1038/s41561-019-0526-0

Meetings

Virtual Meeting of the Permafrost Carbon Network, November 10 2020.

The Permafrost Carbon Network welcomed more than 200 participants from across the globe for its 10th Annual Meeting held in a virtual format (Fig. 2). We discussed in four different panels the following questions: What is the current, bottom line provided by science synthesis on topics central to the permafrost carbon-climate feedback? The four panels were structured around the following questions and issues:

1) How much carbon is stored in the permafrost region and how vulnerable is it.
2) How much carbon will be released through gradual climate warming and abrupt permafrost thaw?
3) Are increases in Arctic carbon emissions already occurring?
4) Integrating permafrost science into climate policy

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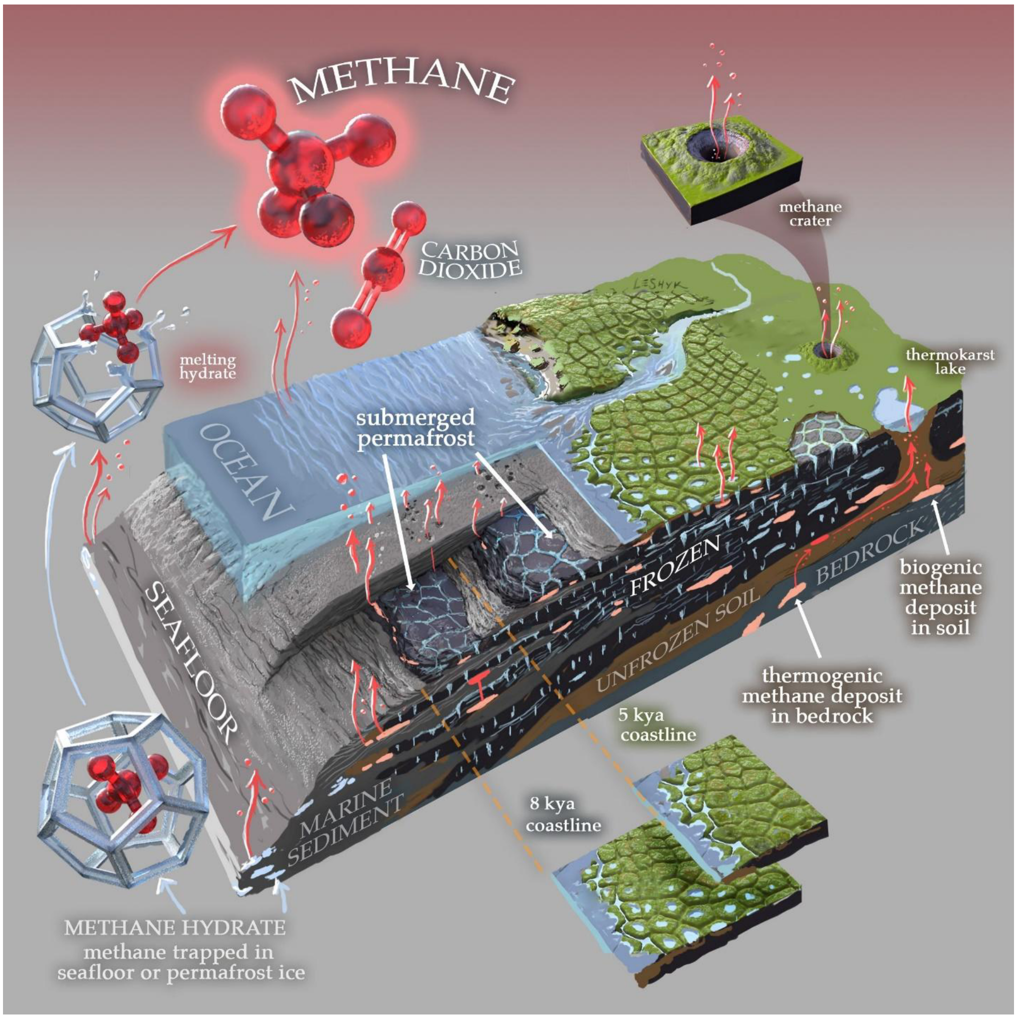

Fig. 1. Artistic diagram of the subsea and coastal permafrost ecosystems including greenhouse gas production and release. Credit: Victor O. Leshyk, Northern Arizona University.

Virtual Meeting of the Permafrost Carbon Network, November 10 2020

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