



Climate and Cryosphere (CLIC) Strategic Plan 2022–2031

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ORGANIZATION



United Nations
Educational, Scientific and
Cultural Organization



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Oceanographic
Commission



International
Science Council



World Climate Research Programme

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Climate and Cryosphere

Strategic Plan

2022–2031

Spegazzini glacier, in the South Patagonia ice field, flows into Lake Argentino – at the border of Chile and Argentina. It is a major tourist attraction in this area (Photo: Shin Sugiyama, Hokkaido University, Japan).



About Clīc

Who we are

The Climate and Cryosphere (Clīc) Core Project is a global community of dedicated and enthusiastic researchers with expertise and knowledge of the cryosphere and its interactions with the climate system. Clīc expertise spans simulation, modelling, field observations, process studies, and includes cross-disciplinary work and stakeholder engagement. Clīc is one of the Core Projects of the World Climate Research Program (WCRP, www.wcrp-climate.org).

What we do

Clīc 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 help address them. Clīc highlights emerging issues, facilitates exchanges amongst scientists and, with relevant external stakeholders, promotes international cooperation. Clīc also communicates

cryosphere related science to policymakers, funding agencies, and the general public. To ensure that we are preparing for the future, Clīc takes a leading role in promoting early career researcher development, including through fellowships.

How we work

Clīc 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. Clīc's activities are overseen by the Clīc Scientific Steering Group (SSG) which has the overall responsibility for planning and guiding the work of the Core Project. The Clīc International Project Office supports the SSG and the wider Clīc community in their work and is the main point of contact for Clīc (www.climate-cryosphere.org).



Icebergs in Sermilik Fjord, West Greenland, are part of the exchange of freshwater between the ice sheets and the ocean (Photo: Fiammetta Straneo, Scripps Institution of Oceanography, USA).



Climate and Cryosphere

Introduction

The Climate and Cryosphere (CliC) Project identifies, articulates, and coordinates activities aimed at improving our understanding of the cryosphere (polar seas, frozen and snow-covered land and glaciated regions, including ice sheets and mountainous areas) and its interaction with the climate system. Over the last decades, CliC has pursued this goal by leading and supporting efforts aimed at improving our ability to model and observe the different cryosphere components. This includes modeling intercomparison projects for ice sheets, snow, glaciers and coordinated observations of sea ice for the Arctic and Antarctica. CliC modelling projects were largely organized under the umbrella of WCRP's Grand Challenge on Melting Ice and Global Consequences and/or through joint activities with other WCRP Core Projects. Through these efforts, CliC has fostered the growth of collaborative, international scientific communities and has provided key inputs to the Intergovernmental Panel on Climate Change.

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 the clearest planet-wide response to human-induced global warming (SROCC, 2019; IPCC, 2021). 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, ecosystems, societies, economies and are triggering feedbacks within the climate system (Figure 1). Related impacts include loss of access and mobility due to sea ice melt, reduced water supply for populations reliant on glaciers in high mountain areas, land destabilization from permafrost melting, inundation of low-lying coastal regions by rising



Sediment released from glaciers into lakes and oceans is part of the cycle of nutrients and material exchange between the cryosphere and other components of the climate system. (Photo: Fiammetta Straneo, Scripps Institution of Oceanography, USA).

seas, and the displacement of people and loss of habitat for many land- and marine-based species. These “grand challenges” in cryospheric science are at the interface of science and policy and require a transdisciplinary, system-based approach that involves extensive engagement between natural and social scientists and key stakeholder groups.

To address this requirement, CLiC is broadening its mission to include research that is co-designed and executed with relevant stakeholder groups, while continuing to support research that advances an understanding of processes within the cryosphere components of the climate system. In doing this, CLiC will promote research to determine what a ‘safer cryosphere’ may look like in a ‘safe landing

climate’ and will investigate how the cryosphere may continue to provide the same services to society as it has done in the past – including provision of drinking water from glaciers, transport routes over sea ice, solid building ground on permafrost, snow for leisure activities and grazing reindeer herds, and a relatively stable sea level that requires stable ice sheets in Antarctica and Greenland. In this regard, CLiC’s new strategic plan aligns with the vision of the WCRP Strategic Plan 2019-2028 (WCRP JSC, 2019) aimed at “using sound, relevant, and timely climate science to ensure a more resilient present and sustainable future for humankind”, and directly addresses its fourth Scientific Objective of “bridging climate science and society.”

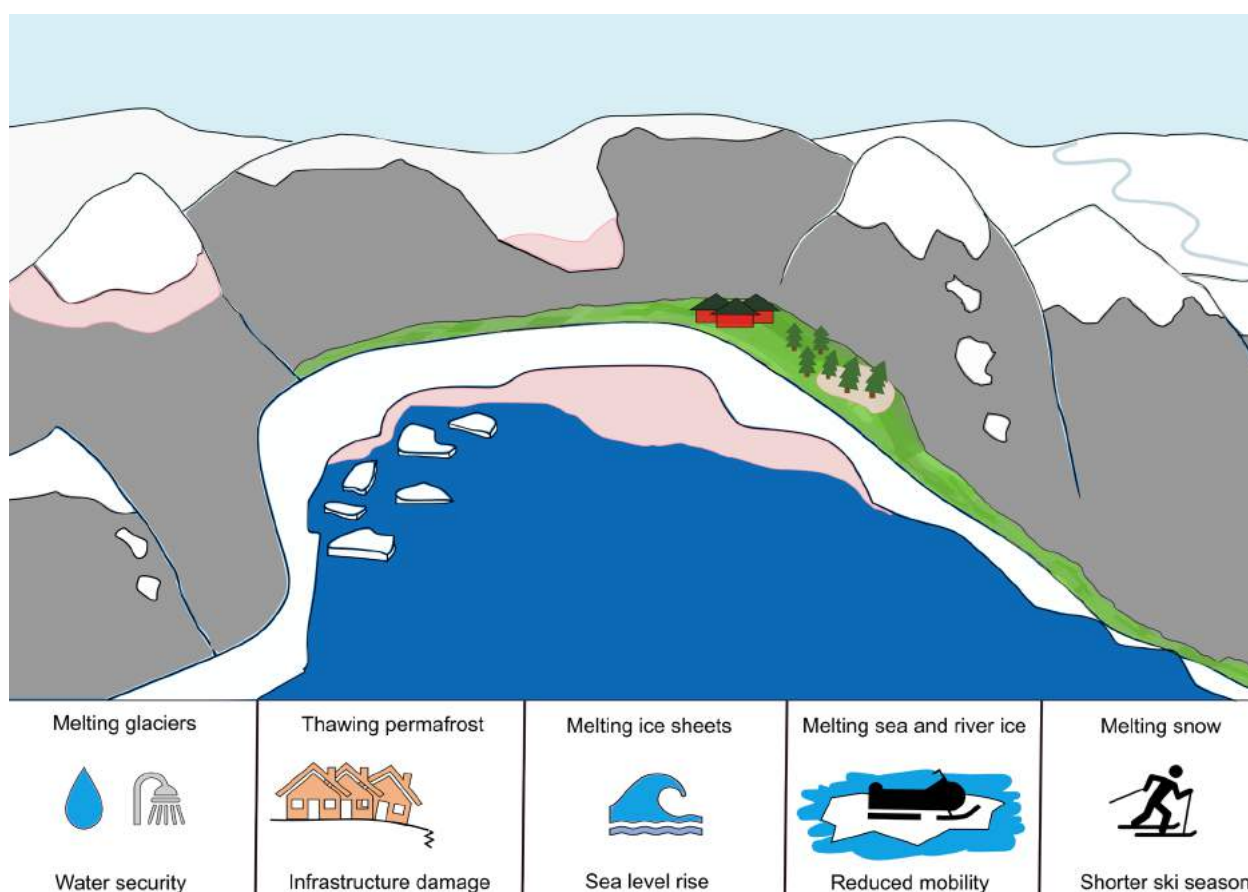


Figure 1 - Cryosphere changes impact both global and local communities by affecting services provided by the cryosphere. Pink shading indicates areas gradually becoming ice and snow free in a warming climate (Source: Helene Asbjørnsen, Bjerknes Centre for Climate Research, Norway).

The cryosphere: an Earth system component and a provider of services

Heat gain by the planet as a result of increased greenhouse gases has resulted in the warming of the ocean, land, and atmosphere, and the melting of ice. It is estimated that 4% of the additional heat absorbed by the Earth since 1971 has been taken up by melting ice with profound effects on sea-ice extent in the Arctic, ice loss from Greenland and Antarctica and the reduction of glaciers world-wide (von Shuckmann et al., 2020).

These changes, in turn, affect global climate via a number of processes and feedbacks with regional and global consequences. Sea-ice reduction leads to increased solar absorption and ocean warming and resulting in a positive feedback on sea-ice melt. Increased freshwater discharge into the ocean from both land- and sea-ice melt can affect ocean stratification, and by altering the exchange of heat between the atmosphere and the ocean, the regional and large-scale ocean circulation. Modern ice loss from the large polar ice sheets is a major influence on current sea level rise and, over glacial cycles, is responsible for changes in sea level exceeding 100 m that modified ocean basins and passageways.

In addition to the impact of cryosphere change on the physical Earth and the climate system, ice is a provider of services to the scientific community which include, for example, climate records retrieved for ice cores or a platform that supports instrumentation aimed at probing the atmosphere and the ocean in sea-ice covered regions (for example ice-tethered profilers and ice mass buoys).

In parallel to these climate and research services, the cryosphere provides multiple services to humans and society that extend beyond its role

in climate regulation (Su et al., 2019). As a result, a diminishing cryosphere impacts both local and global communities. Mountain glaciers provide a source of freshwater for hundreds of millions of people, e.g., in the Himalayas and the Andes, and changes in climate are likely to result in water shortages and floods to downstream regions (Yao et al. 2012).

Arctic sea-ice serves as a platform for travel, especially for Indigenous communities (Eicken et al., 2009) while its reduction opens up transport routes as well as access to fisheries and mineral resources both in the open ocean and in coastal regions (e.g., Stephenson et al., 2013, Olsen et al., 2021). Changes in the frozen coastal margins and rivers affect communities for which these can represent major travel ways for much of the year (e.g., hunting and fishing trails, community to community visits, and emergency travel). Changes in air temperatures affect transportation on roads built in winter by freezing of water pumped onto land which are used to supply “roadless areas” or move oil industry rigs and materials (Raynolds et al., 2014).

Frozen places are locations of enculturation and sustenance for, primarily, Indigenous peoples who have tightly coupled relationships with their surroundings (Schuur and Mack, 2018). Both herders (e.g., the Sami) and hunters (e.g., Inuit) rely on the cold for food security (Crate et al., 2017). In addition, non-Indigenous peoples are users of the annual cycles of cold for different activities (e.g., ice fishing, recreation, livelihoods) (Melvin et al., 2016). Finally, sea level rise from the melting of land-ice, compounded by the increasingly frequent extreme events, can have major impacts

on coastlines around the world, including shoreline recession, the loss of coastal infrastructure, natural resources and biodiversity, and the displacement of communities (Bronen, 2013). By the end of the 21st century, it is very likely that a large fraction of the world's coasts will be affected by climate-induced sea level rise, impacting nearly 1 billion people.

Existing studies of the drivers and climate impacts of change in the cryosphere have been largely decoupled from studies of the impact of the loss of cryosphere services for global societies. Furthermore, climate research on the cryosphere facilitated by CLiC has largely focused on the physical climate with limited integration of other natural sciences and of the social sciences. The growing impact of humans on the planet, including on the cryosphere, and the associated impact that climate change is having on communities

worldwide, means we can no longer ignore the interconnectedness of the Earth System. Relevant information and projections for adaptation, mitigation, and sustainable development require systems approaches, international collaboration, and a multitude of perspectives and engagement with diverse stakeholders. CLiC's new mission and vision, as well as this strategic plan, have therefore been developed to facilitate progress on cryosphere research within this context.

Given the increasing impact of changes in the cryosphere on global societies and the need to integrate physical cryosphere research into a system description of cryosphere regions (Arctic and Southern oceans, Greenland and Antarctic ice sheets and neighboring polar caps, high mountain regions - including the Himalayas and the Andes, and frozen land), we propose a new vision and mission for CLiC.



Melting, due to rising air temperatures, makes travel over sea-ice in late spring more challenging near Qaanaaq, NW Greenland (Photo: Steffan M. Olsen, Danish Meteorological Institute, Denmark).

New vision and mission

The new CliC mission and vision expand the scope of the Core Project beyond the valuable, discipline-based research that it has facilitated for many years. The objective now is to integrate this research into a system description of cryosphere regions that spans all natural sciences, includes relevant social sciences, and takes into account stakeholder needs.

This expansion of the vision and mission does not preclude CliC from continuing to facilitate and promote research which addresses fundamental science questions. Indeed, society relies on this fundamental science to provide the basis for decision-making. This is in line with the new WCRP Strategic Plan, which has a more outward-looking focus and seeks to maintain excellent science whilst better serving societal needs. In particular, the new Lighthouse Activities within WCRP all have cryosphere components.

CliC's new strategic plan is also aligned with complementary activities being undertaken by the international research community, such as:

- The Scientific Committee on Antarctic

Research (SCAR) new strategic research program Instabilities & Thresholds in Antarctica (INSTANT), focused on future contributions of Antarctica to sea level rise (SCAR, 2020).

- The International Science Arctic Committee (IASC) 2018-2023 Strategic Plan, which aims to facilitate Arctic research co-operation, promote engagement and ensure knowledge exchange (IASC, 2018).
- The goals of the International Cryosphere Climate Initiative (ICCI) that promote integrated projects across regions and disciplines, bringing together a range of organizations and individuals not normally in contact (ICCI, 2021).

In this regard, CliC endorses and promotes activities that follow a best practices code of conduct for conducting research in the Arctic (e.g., IARPC, 2018) and produce knowledge in line with the United Nations Sustainable Development Goals (United Nations Sustainable Development Goals, 2015) and the Decade of the Ocean (United Nations Decade of the Ocean Science for Sustainable Development, 2021).

Our Vision

A system understanding of the global and regional cryosphere that includes the physical climate, ecosystems and inhabitants of cryosphere regions, and cryosphere connections and feedbacks to global climate and society.

Our Mission

CliC will promote collaborative, international research and its communication, targeting the global and regional cryosphere, bridging across climate, ecosystems and human society, and their change, from local to regional to global scales, to address societal needs.

Through this new strategic plan, CLiC will broaden its scope beyond the regional focus of many of its projects/activities to facilitate communication on cryosphere science, across national boundaries, across diverse of regions and between the science community, stakeholders and wider society. This will be facilitated by cooperation between Future Earth, as described in newly signed Future Earth – WCRP Joint Statement that commits both programs to future joint activities, convening, and products to increase their combined global impact to the challenges that society faces in the next decade.

Since its inception in WCRP almost 30 years ago, CLiC has strived to serve as a connector and integrator among the numerous cryosphere research groups worldwide in order to facilitate a sharing of knowledge and resources and the avoidance of duplication of effort. For CLiC to continue succeeding in this role it will be decisive for the community not only to strengthen existing relationships but also to expand the liaisons with partners and agencies working on the societal impacts of climate change in the cryosphere.

Training an international team of early career scientists in ice coring as part of an Arctic Glacier Field Course in Western Greenland (Photo: Kerim H. Nisancioglu, Bjerknes Centre for Climate Research, Norway).





Ice-wedge polygons in Adventdalen, Svalbard, a widespread ice-rich permafrost landform in lowlands (Photo: Kolibri Geo Services).

Five priorities for CLiC for the next decade

CLiC’s top five priorities seek to advance understanding and coordination in cryosphere science from regional to global scales through the productive engagement of the global research community and the acknowledgment of the needs of a wide range of stakeholders.

1 Engagement of a broad and diverse community in cryosphere research

CLiC will engage in, promote and coordinate efforts aimed at ensuring that scientific progress in cryosphere research, including research on the impacts of a changing cryosphere, benefits from a diversity of experience, knowledge and perspective that includes researchers, Indigenous communities and residents of cryosphere regions currently under-represented in groups supported by CLiC’s activities. An example of how CLiC can do

this is shown in Box 1. In promoting research and building relations, CLiC acknowledges the need to respect indigenous knowledge and cultures and to follow responsible environmental stewardship. Indigenous knowledge offers a “unique way of knowing” and it can identify research needs and be applied to them, which will ultimately inform decision-makers (ICC 2015; ICC 2021).

Delayed sea-ice melt means a delayed fishing season for fishermen in Tasiilaq, SE Greenland, who have to wait for thaw before their boats can travel safely (Photo: Mattias R. Cape, Bigelow Laboratory for Ocean Sciences, USA).



Box 1: The Pikialarsorsuaq (North Water Polynya) project

The Pikialarsorsuaq, also known as the North Water Polynya (Figure B1), located between Ellesmere Island (CA) and Northwest Greenland, is a highly productive region and a habitat for Arctic and migratory species including birds, marine mammals, and fish. Its high productivity is associated with the upwelling of nutrient rich-waters, driven by winds and ocean currents in the polynya's ice-free waters. The resulting marine ecosystem is key to the sustenance of local communities in Greenland and Canada. Recognition that climate change and other external factors, such as an increase of cargo- and cruise-ship traffic through the Northwest Passage, are posing a major threat to this region led to the establishment of Inuit-led Pikialarsorsuaq Commission aimed at identifying sustainable strategies for the conservation and management of this region. The report from the commission made several key recommendations that take into account evidence based Indigenous and western knowledge to define a sustainable use, development and protection of this area and its resources (Pikialarsorsuaq Report, 2017).

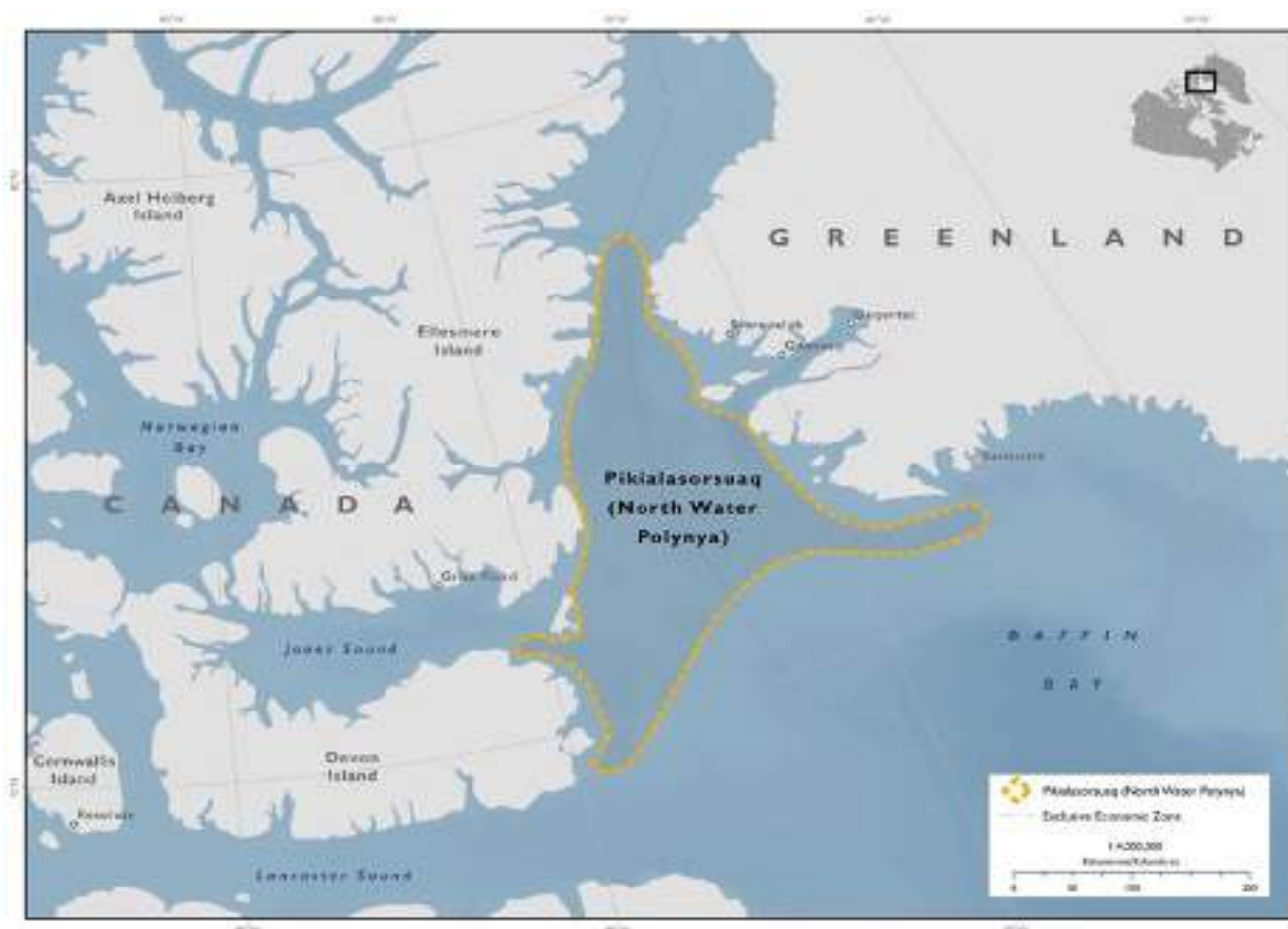


Figure B1: The Pikialarsorsuaq (The North Water Polynya), a highly productive region that is key to the sustenance of Inuit communities both in Greenland and Canada, is threatened by climate change and other external factors. An international, Inuit led commission has made a series of recommendations for the sustainable management of this region. Map: Pikialarsorsuaq (North Water Polynya) ©DFO, the reproduction is a copy of the version available on the [DFO website](#).

2 Cryosphere ice loss - assessment and impacts

CLiC will facilitate global and regional assessments of cryosphere loss and of its impacts. This requires identifying services provided by ice, in its different forms, and integrating societal cost in estimates of ice loss. Societal costs such as loss of services as well as a cultural loss for many

Indigenous residents of cryosphere regions are not traditionally included in economic assessments. Arctic communities should be involved when estimating a decreasing cryosphere. Box 2 shows an example of how CLiC can pursue such assessments by involving affected communities.

Box 2: The Siku-Inuit-Hila / sea ice project: community-based sea-ice monitoring

This project examined sea ice, sea ice use, and sea ice change in the Arctic communities of Qaanaaq, Greenland, Barrow, Alaska, and Clyde River, Nunavut. One project legacy was a handbook available as a resource for anyone wishing to establish a local sea ice monitoring program (Figure B2). Methods were chosen with remote communities of the Arctic in mind, allowing communities to acquire high quality data without requiring specialist training or experience. Equipment was selected to be robust and simple to build or repair (Mahoney & Gearheard 2008).



Figure B2: Clyde River residents install a sea ice monitoring station near Clyde River in Nunavut, Canada (Photo: Nina Palituq).

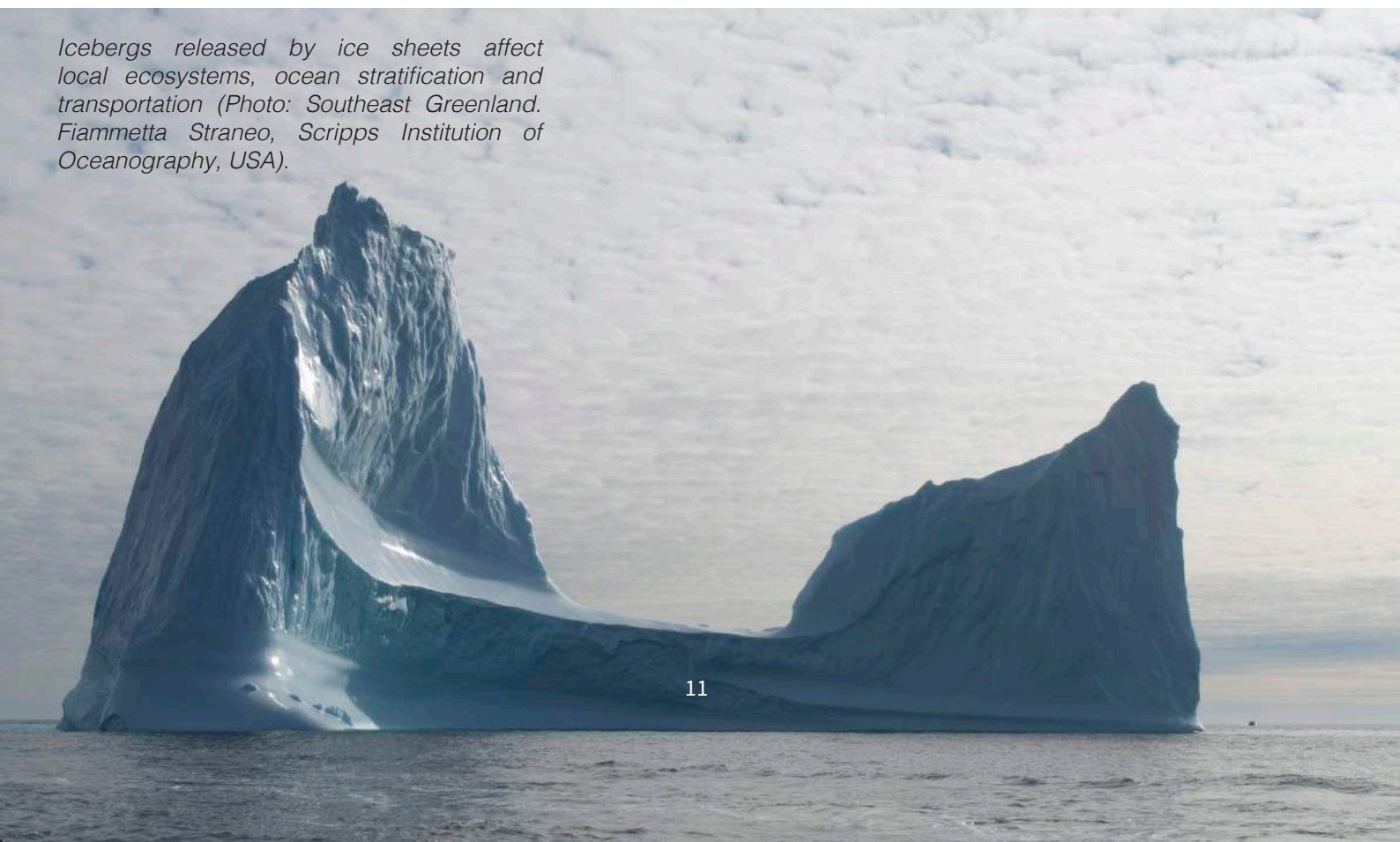
3 Projection of future ice loss and impacts

CliC will continue to promote the improvement of projections of future ice loss at global and regional scales and for each cryosphere component, through CliC’s Ice Sheet Model Intercomparison Project6 (ISMIP6) (Box 3). ISMIP6 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 timescales.

In parallel, CliC will promote efforts aimed at evaluating and projecting the impact of future ice loss and the development of mitigation strategies and adaptation plans. This effort will include identifying short- and long-term impacts as well

as tipping points for both the physical climate, the biosphere, and communities. In this regard, it will be directly tied to several of the WCRP Lighthouse Activities that are currently under development, including “My Climate Risk” (aims to develop and mainstream a ‘bottom-up’ approach to regional climate risk, which starts with the requirements of decision-makers), “Safe Climate Landings” (an exploration of the routes to “safe landing” spaces for human and natural systems) and “Explaining and Predicting Earth System Change “ (aims to design, and take major steps toward delivery of, an integrated capability for quantitative observation, explanation, early warning, and prediction of Earth System change on global and regional scales, with a focus on multi-annual to decadal timescales).

Icebergs released by ice sheets affect local ecosystems, ocean stratification and transportation (Photo: Southeast Greenland. Fiammetta Straneo, Scripps Institution of Oceanography, USA).



Box 3: Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6)

Examples of ISMIP6 projections of sea level for Greenland and Antarctica. These changes come in addition to the sea level that is already locked in due to past climatic change. For the Greenland ice sheet (Figure B3.1), projections over the 21st century show that the spread in sea-level in the CMIP5 experiments is due to ice sheet models themselves (40%), CMIP models (40%) and ocean forcing uncertainty (20%) (Goelzer et al. 2020). For Antarctica (Figure B3.2), projections over the 21st century show strong regional differences (West vs East Antarctica Ice Sheet) with larger uncertainties in the West Antarctic Ice Sheet. Main sources of uncertainties are the physics of ice flow models, the climate conditions used to force the ice sheet and the representation of ocean-induced melt at the base of ice shelves. (Seroussi et al., 2020). ISMIP6 is working on extensions of projections beyond 2100, and will continue to improve projections, through a better representation of the historical changes in recent decades and stronger links between the modeling and observations community, as well as renewed focus on ice-ocean interactions. ISMIP6 will benefit, and contribute to, upcoming activities such as the paleo and marine ice sheet ocean model intercomparison projects (e.g., PMIP & MISOMIP), ISMASS, the European PROTECT effort, and the new SCAR INSTANT initiative.

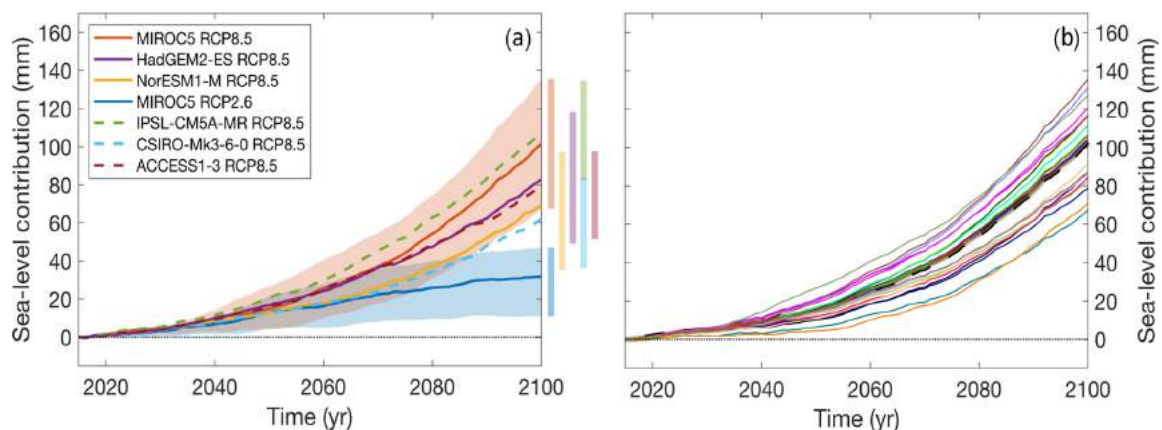


Figure B3.1: Ensemble sea-level projections of the Greenland Ice Sheet (Goelzer et al., 2020)

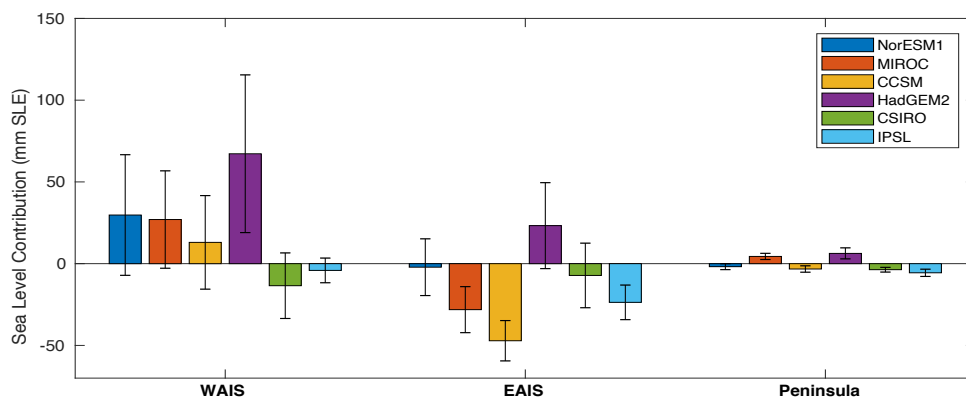


Figure B3.2: Regional change in volume above flotation of the Antarctic Ice Sheet (in mm SLE) for 2015–2100 from six CMIP5 model forcings under the RCP 8.5 scenario with median forcing, relative to ctrl_proj (historical experiment control run). Black lines show standard deviations (Seroussi et al. 2020).

4

CliC will facilitate interdisciplinary and transdisciplinary research that contributes to an integrated description of cryosphere systems across multiple components and disciplines and that bridges the natural and social sciences. See example in Box 4.

Box 4: ANDEX Hydroclimate Research Program

The ANDEX hydroclimate research program for the Andes region (Figure B4), a prospective WCRP WCRP Global Energy and Water Exchanges (GEWEX) Regional Hydroclimate Project, deals with understanding and prediction of climate, and hydrology along the Andes cordillera. ANDEX will integrate atmospheric and hydrologic models, and assimilate local and remotely sensed data products. Scientific advances of ANDEX will be transferred to operational centers, decision-makers and society in general.

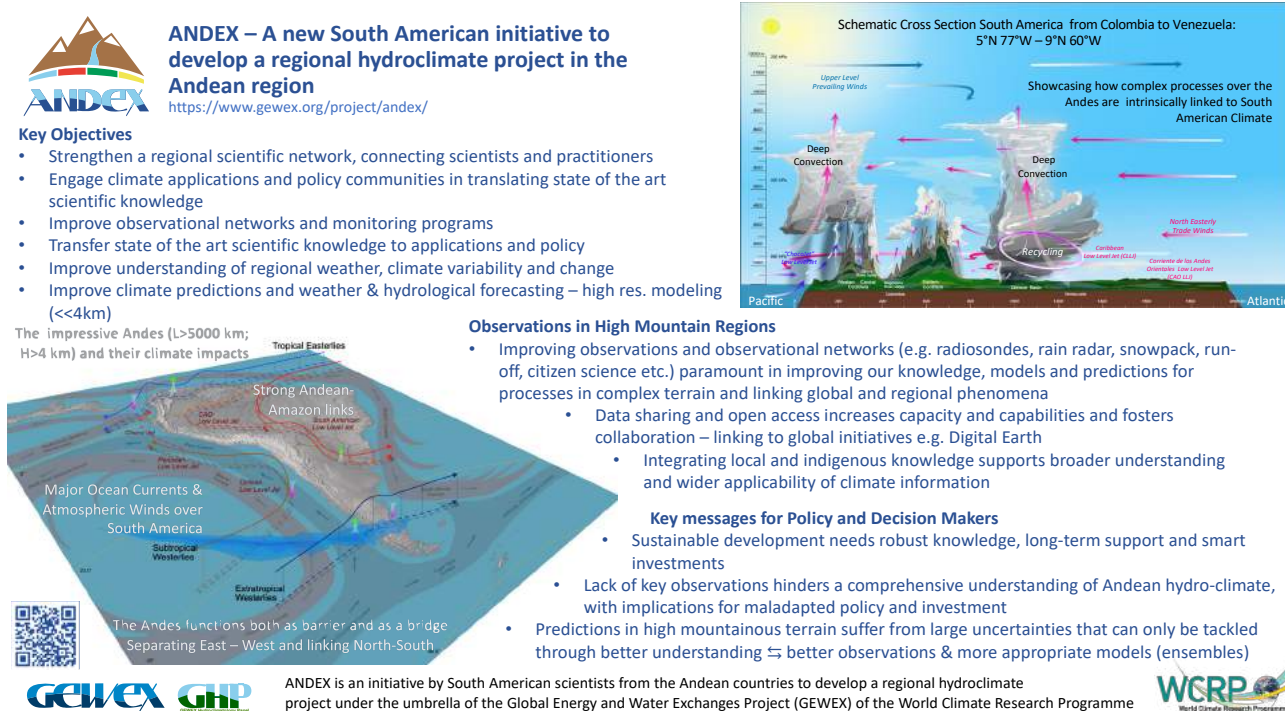


Figure B4: ANDEX Hydroclimate Research Program (van Oevelen et al., 2020).

5 Knowledge syntheses and communication to stakeholders

cliC will encourage the synthesis and communication of cryosphere-related research, knowledge and projections developed through interactions with stakeholders (Allen et al. 2020). CliC will cooperate closely with the new WCRP Core See Box 5). This will include the integration of indigenous knowledge and diverse perspectives from under-represented communities within cryosphere and climate research. In this regard, CliC will cooperate closely with the new WCRP Core Project “Regional Information for Society.”

Box 5: Arctic Report Card

The Arctic Report Card, from NOAA’s Arctic Program, has grown since 2006 to become the leading assessment of the state of the Arctic environment, building on the work of a wide range of researchers, and reaching many stakeholders inside and beyond the science community (e.g., educators, policy makers and the wider public). As well as a scientific record, it has become an excellent vehicle for outreach and for communication through a range of channels (a selection of graphics tell clear stories of change across the Arctic, such as the figure below). Currently, no other cryospheric region has such regular and comprehensive public reporting. By supporting such report cards for other cryospheric regions, such as the Antarctic and the Third Pole, CliC will help disseminate information on the broader state of the cryosphere to stakeholders and to society at large. The report cards can bring together physical climate information with impacts on communities, such as implications of glacier melt for water availability across South Asia.

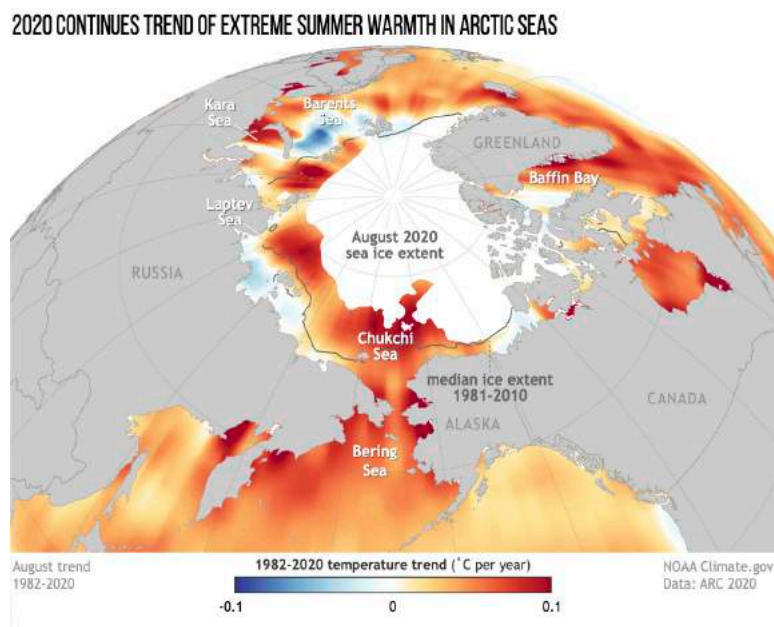


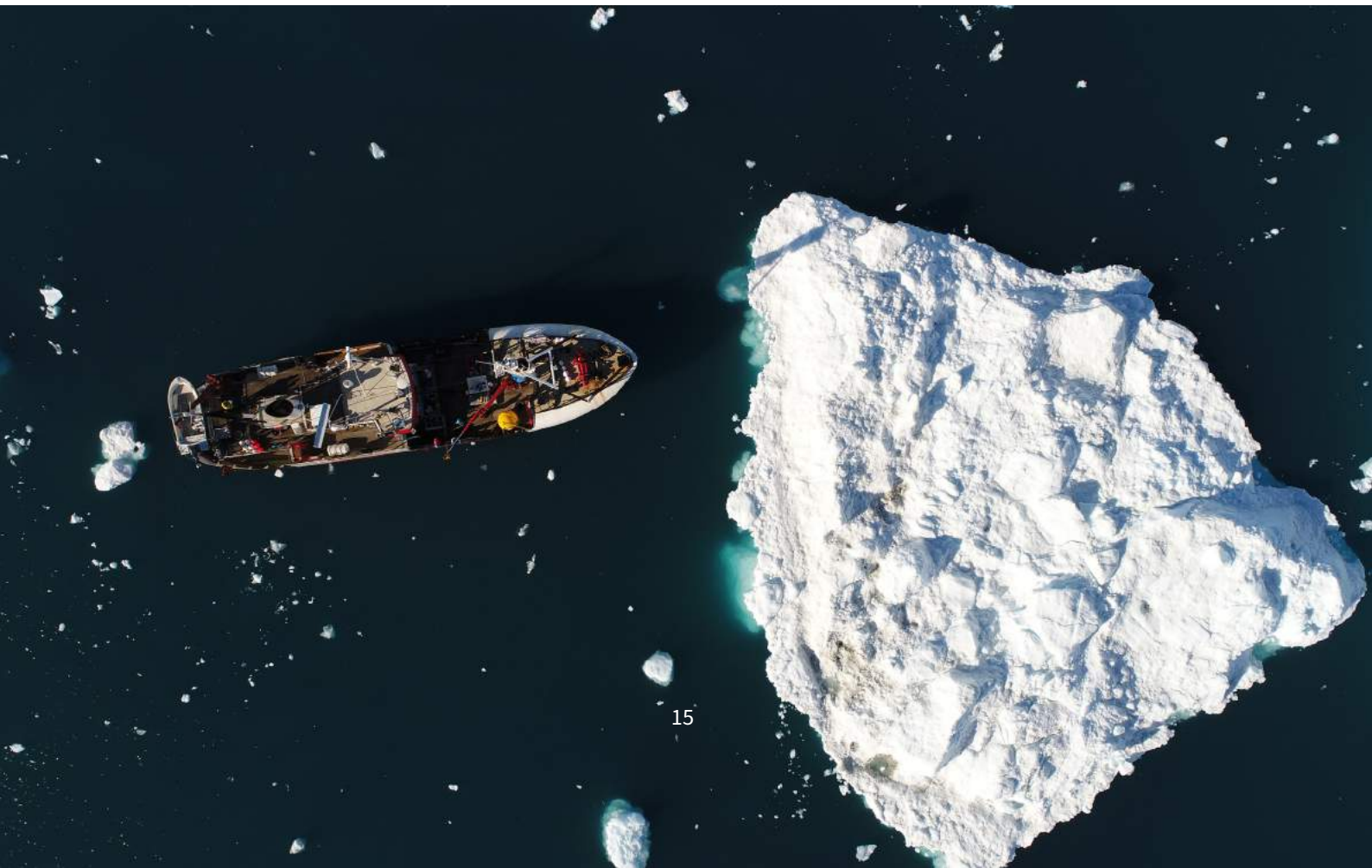
Figure B5: Sea surface temperature trends in the Arctic from 1982–2020, showing where waters are warming (red and orange) and where they are cooling (blue). The gray line shows the median August sea ice extent, and the white areas show the ice extent in August 2020. NOAA Climate.gov, based on data from Timmermans and Labe, 2020 Arctic Report Card.

CliC Activities and Objectives (2022-2026)

CliC will engage in activities that seek to advance progress on the five scientific priorities identified in the preceding pages by:

1. Soliciting proposals for new working groups that address aspects of the identified priorities and by providing support and training for the launch of new activities by these working groups.
2. Leveraging partnerships with other national and international organizations to promote the funding and coordination of activities aimed at addressing the scientific priorities.
3. Establishing CliC fellowships and grants aimed at engaging early career scientists and scientists from under-represented regions and groups in CliC activities.
4. Engaging with the WCRP Lighthouse Activities and Core Projects in ways that complement CliC's research activities and priorities.
5. Promoting the adoption of best practice protocols for conducting and disseminating research that are attentive to societal and community needs and expectations.

Owing to the challenges posed by ice and its remoteness, many cryosphere regions are under observed (Photo: Southeast Greenland. David Sutherland, University of Oregon, USA).



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Acronyms

AMAP	Arctic Monitoring & Assessment Programme
CMIP	Coupled Modelling Intercomparison Project
CMIP5	CMIP Phase 5
CMIP6	CMIP phase 6
GEWEX	WCRP Global Energy and Water Exchanges Core Project
IASC	International Science Arctic Committee
ICC	Inuit Circumpolar Council
ICCI	International Cryosphere Climate Initiative
INSTANT	Instabilities & Thresholds in Antarctica AMAP
ISMASS	cliC Ice-sheet Mass Balance and Sea Level
ISMIP6	cliC Ice Sheet Model Intercomparison of CMIP6
JSC	Joint Scientific Committee (WCRP)
MISOMIP	cliC Marine Ice Sheet-Ocean Model Intercomparison Project
PMIP	Paleoclimate Modelling Intercomparison Project
PROTECT	Projecting sea level rise: from ice sheets to local implications
SCAR	Scientific Committee on Antarctic Research
UNESCO-IOC	UNESCO Intergovernmental Oceanographic Commission
WCRP	World Climate Research Programme
WMO	World Meteorological Organization



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