BAMS
Meeting Summary

Toward Effective Collaborations between Regional Climate Modeling and Impacts-Relevant Modeling Studies in Polar Regions

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Toward Effective Collaborations between Polar Regional Climate and Impacts Modelers

What: The aim of this workshop was to discuss the needs and challenges in using high-resolution climate model outputs for impacts-relevant modeling. Development of impacts-relevant climate projections in the polar regions requires effective collaboration between regional climate modelers and impacts-relevant modelers in the design stage of high-resolution climate projections for the polar regions.

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Where: Online

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There is growing scientific evidence that the Arctic and parts of Antarctica are warming considerably faster than other parts of the world. As well as impacting the lives and livelihoods of millions of people who live in these regions, warming has implications for global climate, ecosystems, and economies. Assessing the impacts of climate change in the polar regions is essential to inform regional and global adaptation and mitigation options. Such assessments depend on high-resolution regional climate models and modeled projections of their impacts.

Despite this, challenges remain in quantifying the impacts of polar climate change using the current available suite of high-resolution regional climate model simulations, which vary in resolution from 10 to 50 km (Mottram et al. 2021). Much of this is due to the inadequacy of currently available climate simulations for specific impact studies in the polar regions (e.g., in their spatiotemporal scales or their resolution of key dynamical processes). This is largely owing to a lack of dialogue between the two research communities (i.e., those involved in regional climate modeling and those involved in impacts studies). Better knowledge sharing is therefore needed to facilitate understanding of the requirements, limitations, capabilities, and challenges of both.

The main objective of this workshop was to initiate and build close collaboration between groups developing and running the next generation of high-resolution regional climate models and impacts modelers to deliver more impacts-relevant climate projections for the polar regions. The sessions were organized around practical questions so that the information arising from the workshop could be implemented into decision-making processes regarding the configuration of high-resolution regional climate models to ensure their applicability for impact studies before regional model simulations are set up and run with the latest CMIP6 model forcing. The main theme of the workshop covered the needs and limitations between regional climate modeling and impacts modeling.

We invited regional climate modelers who intend to deliver open-access, state-of-the-art, high-resolution polar climate projections (i.e., at a grid spacing of around 10 km) for international projects and initiatives such as the European Commission–funded Horizon 2020 project PolarRES (https://www.polarres.eu/) and Polar CORDEX (https://climate-cryosphere.org/polar-cordex/) as well as impacts modelers that focus on polar regions. The impacts on the polar regions represented at the meeting include permafrost thaw and human infrastructure, boreal forest wildfires, ocean ecosystems relevant for fish production in the Arctic and the Antarctic, trans-Arctic shipping routes, and radionuclide dispersion in the Arctic Ocean.

Prior to the workshop, the impacts modelers were invited to fill in a data table describing the necessary parameters for impacts modeling. Refer to Table A1 in the appendix for details.

Impacts on land

Terrestrial-based impacts of climate change include permafrost and boreal forest fires, which can be simulated with land surface and vegetation models (i.e., CTSM, LPJ-GUESS, and CryoGrid3 models discussed in this workshop, among others). These models share many similarities to the land surface models used in regional climate modeling but differ in complexity and capabilities. There are seven key parameters to force land surface and vegetation models participating in this workshop. These include 2-m air temperature, 2-m specific humidity, 10-m wind speed, surface pressure, total precipitation, surface downward solar radiation, and surface downward longwave radiation flux. These parameters are standard outputs from regional climate models [refer to Table A1 in Fita et al. (2019)] and recommended outputs for CORDEX model runs. Some additional parameters that are also standard regional climate model outputs would be beneficial (e.g., daily maximum/minimum temperature and separating precipitation into rain and snow) for these impact modeling studies. Other parameters such as runoff or soil moisture were discussed to be less useful in the impacts modeling as these models have their own hydrological modules.

The preferable temporal frequency for the previously described variables is at 3- or 6-hourly, which is needed to represent meteorological diurnal cycles. It is possible for regional climate models to produce these variables at this frequency. It is also possible to conduct land surface model simulations using the daily mean for the land surface models. In this case, daily minimum and maximum are necessary. However, a 3- or 6-hourly output frequency is very common for regional climate models, but it is often not shared widely due to the size of files produced. We therefore urge regional climate modeling groups to store appropriate variables at subdaily frequency for impacts studies.

As a starting point, the group discussed the Arctic CORDEX domain (https://climate-cryosphere.org/arctic/). This domain (Fig. 1) excludes large areas of the Siberian boreal forest zone (Fig. 1b, blue area in eastern Russia). Additional concerns were raised, including the need to extend the domain further to ensure that the areas of interest for impact models are not in the "relaxation" or "buffer" zone of the climate models (i.e., the other boundary of the domain, where the lateral boundary conditions interact with the interior of the model). This extension may be necessary to include land area and regions important in impacts-relevant studies, particularly the coastal areas in northern Siberia. The impacts modelers strongly argue for having a stable forcing dataset within this domain (Fig. 1, land areas within the yellow box) at a minimum.

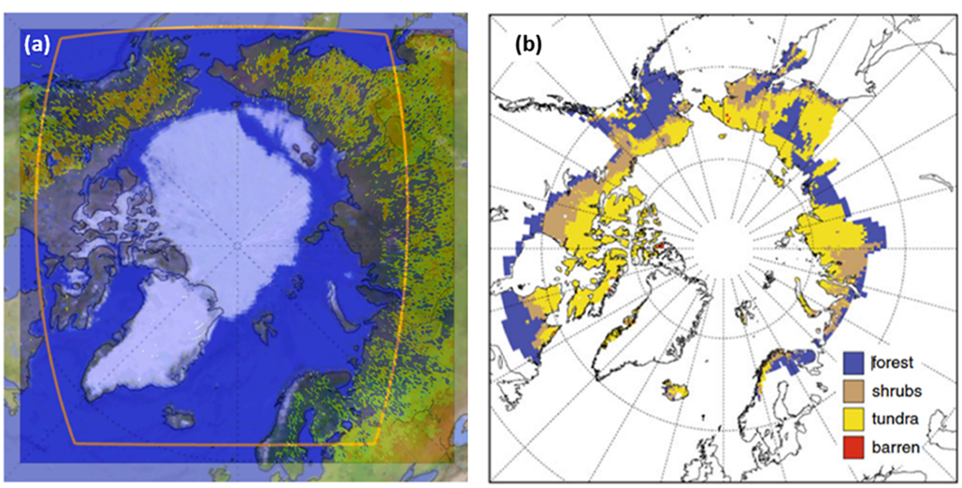

Fig. 1. (a) Global Fire Emissions Database (GFED 4.1; Giglio et al. 2013) burned area 1997–2016 mean and boundaries of the CORDEX domain (yellow line; WCRP CORDEX 2015). (b) Boreal dominant vegetation classification described in LPJ-GUESS dynamic vegetation model at 0.5° × 0.5° resolution. This figure was shown to describe the importance of keeping the minimum boundary of the yellow line to cover important impacts such as boreal forest wildfires.

It was suggested to be very useful if the domain can include a larger area if feasible for the regional climate modelers. If resources allow, impacts modelers recommended extending the domain southward, particularly in Siberia, to cover larger areas of boreal forest and permafrost region, where permafrost thaw and boreal forest wildfire impacts are most important.

The standard resolution at which the land surface and vegetation models operate are 10–100-km horizontal resolution. Upcoming regional climate model simulations for the polar regions will operate at around 10 km, but additional very high-resolution or kilometer-scale regional climate simulations could be useful for other models such as CryoGrid3, which is a permafrost model capable of simulating permafrost thaw risks and ice roads. Models such as CryoGrid3 can conduct simulations at kilometer-scale resolutions.

The land surface and vegetation models will need inputs/forcing from 30 years of historical climate model outputs for the models to adapt to spinup. This is of great importance, particularly for dynamic vegetation models like the LPJ-GUESS model, which needs to build up soil carbon. Additionally, model simulations till the end of the century will require continuous climate model outputs as inputs/forcing for this period (i.e., ~100 years). It is not possible for these models to use short or decade-long time slices at the end of the twenty-first century to investigate this period.

Impacts on Greenland and Antarctic ice sheet

Ice sheet melting can cause sea level rise, which will have a global-scale climate change impact. The ice sheet model discussed in this workshop was CISM, which, as is typical of most ice sheet models, requires 2-m air temperature, precipitation, surface mass balance, sea surface temperature, and salinity at monthly to yearly time resolution for Greenland ice sheet. Subshelf basal melt is also necessary for Antarctic ice sheet modeling. Variables such as salinity are only available from either coupled atmosphere–ocean regional climate models or regional oceanographic models, although they can also be obtained from coarse-resolution CMIP6 outputs. Ice sheet models can conduct simulations at a range of resolutions from the subkilometer to tens of kilometers. High resolution is desired for resolving fast flow and complex ice dynamics in particular, as well as for resolving the relatively narrow ablation zone at the margins of the ice sheets; CISM simulations, for example, are typically conducted at 4-km resolution. A 30-yr historical forcing dataset (ideally 1960–90 for Greenland) is sufficient to spin up CISM and 100 years into the future will be useful to conduct impacts-relevant simulations. Since both Arctic and Antarctic CORDEX domains include Greenland and Antarctica (Figs. 1 and 2), the CORDEX domain and output is sufficient for whole ice sheet modeling.

Impacts on marine and maritime

The marine and maritime impacts discussed in this workshop include impacts on marine ecosystems in relation to ecosystem structure and functioning (including food production), dispersal of radionuclide in the Arctic Ocean, and trans-Arctic shipping.

Marine ecosystem modeling. To examine these impacts the marine ecosystems modeling group requests a three-tier variable list. Primary parameters include sea surface temperature, sea ice concentration, oceanographic circulation, and changes in seasonality (increasingly recognized as important drivers at high latitude). A complete list of secondary and tertiary parameters requested by the marine ecosystem modelers are listed in Table A1. Although some of these variables are available from atmosphere-only regional climate models, many (e.g., oceanographic circulation) are outputs from regional ocean models such as NEMO and ROMS and/or coupled regional models such as MAR-NEMO-LIM and HCLIM-NEMO-CICE, or have to be derived from the atmospheric reanalysis data. Additionally, there are coupled climate–oceanographic models that incorporate biogeochemistry, which are currently being developed by various international groups.

The regions of interest identified for marine ecosystems modeling in the Arctic include the Atlantic sector of the Arctic (area of the Barents Sea north of Norway and Svalbard), the North Atlantic, Fram Strait, and the Barents Sea. Areas within these regions of interest may change seasonally. For example, the Greenland Sea and Norwegian Sea are important overwintering habitats for some zooplankton species. There is already a lot of summer surface data, but obtaining deep, wintertime climate model outputs and projections of their impacts would be beneficial, particularly for ecosystem impacts and fisheries management purposes.

The region of interest in the Antarctic encompasses the southwest Atlantic sector of the Southern Ocean (west of the Antarctic Peninsula, 90°–100°W out to 0°, from as far south in the Weddell Sea as possible to approximately 45°S, encompassing the Antarctic Circumpolar Current Front; Fig. 2). This is a region of high primary productivity and biomass of Antarctic krill (*Euphausia superba* and other zooplankton) which support populations of fish, squid,

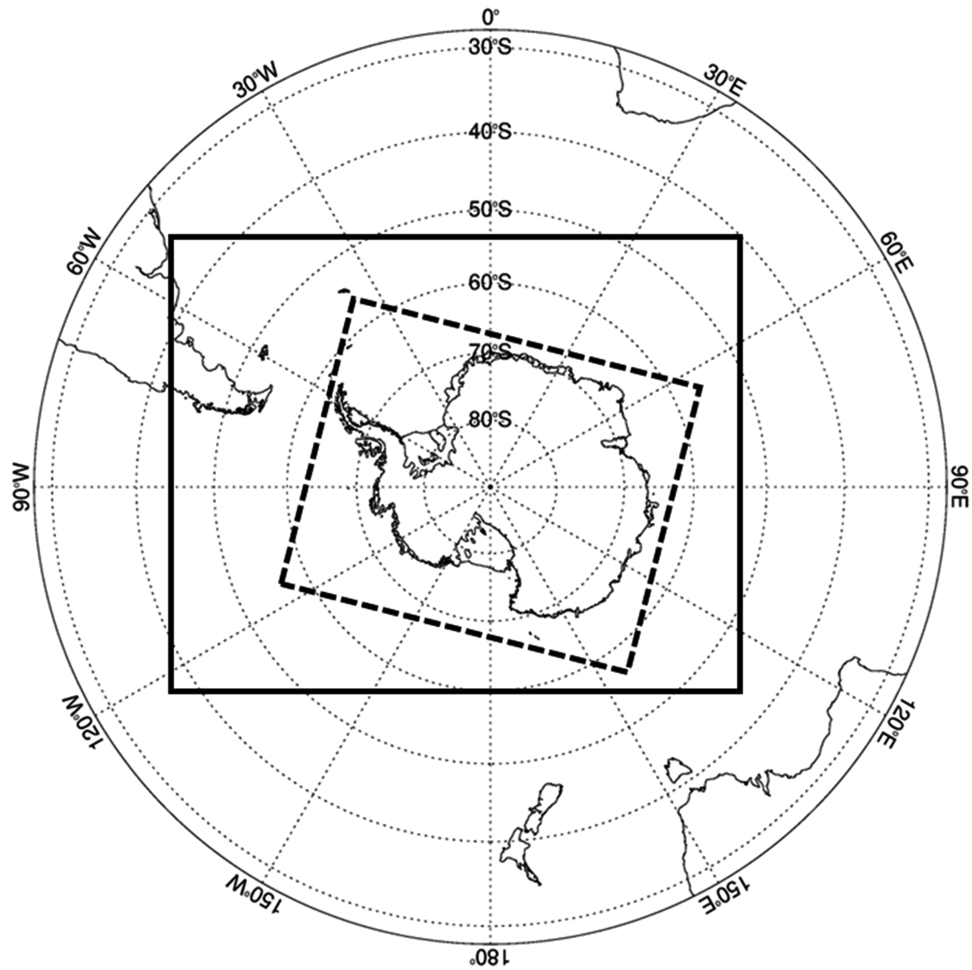

Fig. 2. Map of high-latitude Southern Hemisphere showing four model domains of interest to the impact modeling community. The small black box represents the current Antarctic CORDEX domain; regional climate modeling groups have already identified that this domain is too small for atmospheric dynamics to be properly represented. The outer black box represents a much-extended Antarctic CORDEX domain that would be of use to the international community examining climate impacts on ecosystems within the region of the Southern Ocean that includes the Antarctic Circumpolar Current, but it is also computationally very expensive at high spatial resolution (~10 km). The mid-sized box represents an extension of the current Antarctic CORDEX domain that would be useful to modeling impacts in the southwest Atlantic sector of the Southern Ocean, as well as the Scotia Sea and Drake Passage (which will likely be used by the PolarRES project). The dashed box represents a domain for oceanographic models that also includes these regions.

and vast populations of seals, penguins, seabirds, and whales. This is also a key area for international fisheries for Antarctic krill, mackerel icefish and Patagonian and Antarctic toothfish, and wildlife tourism.

The marine ecosystem modelers request forcing resolution to be as high as possible. Interannual (seasonal) changes in the environmental variability of near-surface winds and air temperatures, sea ice, ocean circulation, and ocean temperature (as well as ocean acidification and nutrient availability) are important drivers of change in marine ecosystem productivity, structure, and functioning. The current Antarctic CORDEX domain (small box in Fig. 2) does not extend out far enough to capture the key biological region of focus. Rather than extending out to the computationally expensive larger domain in Fig. 2 (large box), a compromise could be to extend the left side of the Antarctic CORDEX domain (mid-size box), which would cover the ocean area of most interest for these impacts. The larger box would also be better for the atmospheric modeling community as it captures the storm track regions and Southern Ocean clouds and allows models to represent synoptic-scale systems better. For the longer-term value of the Antarctic CORDEX work for the Southern Ocean community, the larger domain would inevitably be better as it covers the full Antarctic Circumpolar Current region, whereas the smaller extended domain would cut in and out across the main circumpolar current in some areas.

Radionuclide dispersion in Arctic Ocean. The only model output requirement for these simulations is 3D field of ocean circulation, which is a standard output of NEMO. The spatial resolution of the simulations is usually higher than 10 km and 100 years toward the year 2100 is preferable.

Trans-Arctic shipping route. The model simulations require many economic and geopolitical parameters, and sea ice extent and thickness are the only two model variables required. They require relatively coarse spatial and temporal resolution data for simulations. Sea ice extent can be divided into 8 different zones within the Arctic Ocean, and usually weeks to months temporal frequency is sufficient for modeling.

Outlook and future meeting suggestion

The main outcome of this workshop was the identification of the importance of co-designing high-resolution regional climate projections by both the impact modelers (downstream users) and regional climate modelers, to ensure that regional climate simulations (including atmosphere-only, ocean-only, and coupled simulations) are useful for modeling and assessing impacts of change in the polar regions. Creating information on environmental changes in the coming decades/over the century is important for providing advice to policy-makers and stakeholders to support adaptation and mitigation options.

The challenges in achieving such collaborations include computational resources/costs for the impact related simulations. For example, the large domain in Fig. 2 that includes all the Southern Ocean is very computationally expensive at high spatial resolution (~10 km), making it unfeasible for projections till the end of the twenty-first century. To maximize the value from the improvements in the spatial resolution in the regional climate modeling, it is important to identify the necessity of high-resolution model outputs as some of the impacts-relevant modeling does not operate at such high resolutions.

Additional associated impacts were also identified, such as the implications of snow and rain-on-snow for tourism. Although these impacts were not explicitly discussed in this workshop, they can still be quantified using the standard output from regional climate models and do not require separate impacts models or additional effort from the regional climate modelers.

This workshop identified the need to further discuss more impacts beyond the topics discussed at this workshop. We therefore plan to organize a follow-up workshop and invite different groups working on impacts modeling and impacts studies in the polar regions as well as statistical downscaling. The future workshop will include discussions on how impacts modeling could help support local communities and shape future policymaking. Interested groups should contact Priscilla Mooney (priscilla.mooney@norceresearch.no).

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APPENDIX

Table A1. Summary table of climate model variables needed for impacts-relevant modeling.

Simulation topic	Model name	Model resolution	Simulation region or area	Forcing parameters	Units	Levels	Forcing frequency	Time coverage	Notes
Permafrost thaw risks simulation	CTSM	0.1°–2°	60°–90°N, land	Air temperature	K	2 m	3 hourly	30 yr historical, 100 yr future	Instantaneous
				Specific humidity	kg kg^{-1}	2 m			
				Wind speed	m s^{-1}	10 m			
				Surface pressure	Pa	Surface			
				Precipitation	mm s^{-1}	Surface	6 hourly		Average
				Surface downward solar radiation	W m^{-2}	Surface			
				Downward longwave radiation flux	W m^{-2}	Surface			
High-latitude fire regime assessment	LPJ-GUESS	0.1°–0.5°	60°–90°N, land	Air temperature	K	2 m	Daily	30 yr historical, 100 yr future	Maximum
				Air temperature	K	2 m			Minimum
				Wind speed	m s^{-1}	10 m			Average
				Relative humidity	frac	Surface			Average
				Precipitation	mm s^{-1}	Surface			Total
				Surface dowelling shortwave radiation	W m^{-2}	Surface			Total
Permafrost infrastructure/ ice road	CryoGrid	No resolution limit	60°–90°N, land	Air temperature	K	2 m	3 hourly	30 yr historical, 100 yr future	Instantaneous
				Specific humidity	kg kg^{-1}	2 m	3 hourly		
				Wind speed	m s^{-1}	10 m	3 hourly		
				Surface pressure	Pa	Surface	3 hourly		
				Precipitation	mm s^{-1}	Surface	6 hourly		Average
				Surface downward solar radiation	W m^{-2}	Surface	6 hourly		
				Downward longwave radiation flux	W m^{-2}	Surface	6 hourly		
Ice sheet modeling	CISM	4 km	Greenland, land	Air temperature	K	2 m	Monthly, yearly	10 yr historical, 100 yr future	Average
				Precipitation	mm s^{-1}	Surface			
				Surface mass balance					
			Around Greenland, ocean	Temperature	K	Surface			
				Salinity	g kg^{-1}	Surface			
			Antarctica, land and ice shelves	Air temperature	K	2 m			
				Precipitation	mm s^{-1}	Surface			
				Surface mass balance		Surface			
			Around Antarctica, ocean	Temperature	K	Surface			
				Salinity	g kg^{-1}	Surface			
				Subshelf basal melt		Surface			

Table A1. (Continued)

Marine ecosystems modeling	Unspecified	Highest possible	Arctic (Atlantic Arctic, N. Atlantic) and Antarctic (southwest Atlantic sector of Southern Ocean)	Sea surface temperature	K	Surface	Highest possible	100 yr future (particularly decadal stage for conservation and management purposes)	
				Sea ice concentration	% or proportion	Surface			
				Light irradiance (including under sea ice) (e.g., PAR)	?				
				Phytoplankton biomass	chl-*a* mg m^{-3}	Subsurface			
				Sea ice plankton biomass (or some other measure of under ice productivity)	chl-*a* mg m^{-3}				
				Upper-ocean temperature[a]	K	Model levels			
				Temperature at depths (beyond surface)[a]	K	Model levels			
				Velocity fields at depth (beyond surface)[a]	—	Model levels			
				Salinity[a]	—	Model levels			
				Sea ice thickness[a]	m	Surface			
				Light/climate irradiance levels[a]					
				Sea surface height (observational, used to derive velocity fields)[b]	—	Surface			
				Dynamic height (observational, used to derive velocity fields)[b]	dynamic meters ($m^2\ s^{-2}$)			100 yr future (including internal data for conservation and management purposes, and to differentiate signal from noise)	
				Wind speed (near surface)[b]	m s^{-1}	10 m			
				Air temperature (near surface)[b]	K	2 m			
				Surface pressure[b]	Pa	Surface			
				Surface downward solar radiation[b]	W m^{-2}	Surface			
				Downward longwave radiation flux[b]	W m^{-2}	Surface			
				pH[b]	n/a	Water column			
				Water column nutrient concentration (iron, nitrate, phosphate, silicate)[b]	μmol kg^{-1}	Water column			
Radionuclide dispersion in the Arctic	LagrRad	Unspecified	Arctic Ocean	3D field of velocity	m s^{-1}	All model levels	Monthly	100 yr future	Month averaged
Trans-Arctic shipping	Unspecified	Zones	Arctic Ocean	Sea ice extent	Zones (8–27 zones)	Surface	Weeks to months	100 yr future	
				Sea ice thickness	m	Surface			

[a] Optional (highly desirable).

[b] Optional (desirable).

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