ISMIP6 Projections Greenland

Overview: Experimental protocol for Greenland projections

This page describes the experimental protocol for the ISMIP6 projections that target the upcoming IPCC AR6 assessment. Due to the delay in CMIP6 climate simulations, the initial set of ISMIP6 simulations are based on CMIP5 projections. These CMIP5 models were chosen following the assessment presented in Barthel et al. (2020). As CMIP6 model outputs became available, ISMIP6 included simulations based on these new models. The experimental framework was revised in September 2018 during an ISMIP6 workshop held in Sassenheim (NL).

The revised protocol – described in Nowicki et al. (2020) and summarized in **Figure 1** allows for:

- *Sampling CMIP scenarios*: main focus is on the high emission RCP8.5, but ice sheet evolution in response to low emission RCP2.6 is also investigated.

- *Sampling CMIP models*: 6 AOGCMs have been selected from the CMIP5 model ensemble. The AOGCMs were identified based on the following steps:

1. Present plausible climates near Greenland (evaluated by model biases over the historical period);
2. Have the data at the temporal resolution needed for RCM downscaling;
3. Sample a diversity of forcing (evaluated by differences in projections and code similarities); and
4. Allow only models with RCP8.5 and ideally with RCP2.6. The sampling methodology for the CMIP5 models is described in Barthel et al. (2020). As CMIP6 models became available, ISMIP6 prepared dataset for CNRM-CM6 (ssp585 and ssp126), CESM2 (ssp585) and UKEM1-CM6 (ssp585). Unlike for the rigorous analysis for the CMIP5 models, the CMIP6 models were selected because of their availability.

- *Sampling ice sheet model uncertainty*: "standard" and "open" experiments. The "standard" experiments are based on parameterizations developed by the ocean focus group, while "open" experiments utilize the parameterizations already in use by respective ice sheet models. The open experiments are an important contribution as the use of different parameterizations reflect the uncertainty in our current understanding of ice-ocean interactions.

- ***Sampling ocean forcing uncertainty***: the standard experiments include "high", "mid" and "low" parameters (see **Slater et al.** 2019 and **Slater et al.** 2020).

- ***Experiment ranking***: This experimental framework results in a series of projections (divided into core and targeted experiments), a historical run and a control run. Not every ice sheet model will be able to carry out the full set of experiments, but they are strongly encouraged to participate in the full suite of core experiments (Table 1, which uses both the "open" and "standard" experiments/parameterizations). Given that the standard experiments requires new implementations, it is OK to only participate with only the open experiments. Similarly, it is OK to only participate with the "standard" experiments. Groups are encouraged to work through the lists presented below (see Table 1 for core experiments, and targeted experiments will follow soon), starting from the top, and complete as many experiments as possible. This approach of combining core and targeted experiments is based on Shannon et al. (2013): it ensures that all groups do a subset of identical experiments, while it also allows faster models to explore the targeted experiment space more fully.
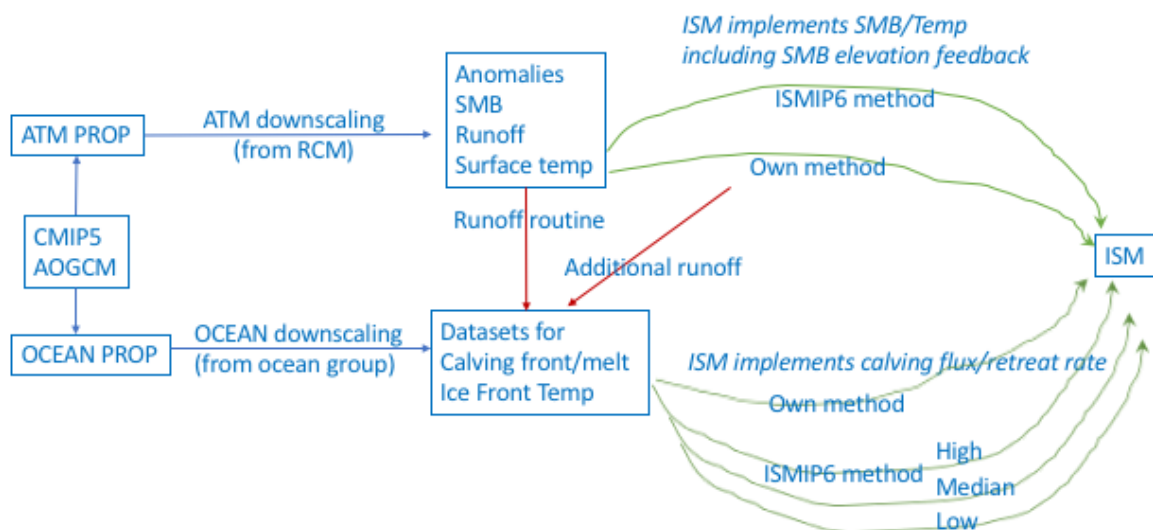

Figure 1: Overview of the Greenland experimental framework

List of Projections

With the help of the atmosphere and ocean focus groups, a number of CMIP5 AOGCMs have been selected for ISMIP6 standalone ice sheet model projections. Table 1 lists the *core*

experiments which are the minimum contribution expected from ISMIP6 models, in addition to the initialization experiments listed in **Table 2**.

All groups are encouraged to contribute to the "standard" experiments. Groups that have their own methods for implementing ocean and atmosphere forcing, are encouraged to do the suite with "open" experiments (1-4), but these are not compulsory. Models that perform the "open" experiments can use the parameterization of their choice to simulate atmospheric and oceanic forcings, but these parameterizations must use the given CMIP5 AOGCM outputs.

Modeling groups that can run many simulations will be encouraged to further explore the ice sheet response using *targeted experiments* (See Table and **Nowicki et al.** (2020)). These include three additional CMIP5 AOGCMs under RCP8.5, and experiments that explore the ocean forcing uncertainty. As CMIP6 AOGCMs became available, a selected number of CMIP6 AOGCMs were also prepared. Because there is value in both completing the 6 CMIP5 AOGCMs (to sample the uncertainty in CMIP) and simulations with CMIP6 models, we encourage groups do to as many experiments as possible.

Table 1: Core Experiments based on MIROC5, NorESM1-M and HadGEM2-ES

Exp	RCP	AOGCM	Std/open	Ocean Forcing Unc.	Note
1	8.5	MIROC5	Open	Medium	Expected largest response to SMB, median ocean warming
2	8.5	NorESM	Open	Medium	Low atmosphere change, low ocean warming
3	2.6	MIROC5	Open	Medium	Expected largest response to SMB, median ocean warming
4	8.5	HadGEM2-ES	Open	Medium	Expected median response to SMB, median ocean warming
5	8.5	MIROC5	Standard	Medium	Expected largest response to SMB, median ocean warming
6	8.5	NorESM	Standard	Medium	Low atmosphere

					changes, low ocean warming
7	2.6	MIROC5	Standard	Medium	Expected largest response to SMB, median ocean warming
8	8.5	HadGEM2-ES	Standard	Medium	Expected median response to SMB, median ocean warming
9	8.5	MIROC5	Standard	High	Ocean Forcing Uncertainty
10	8.5	MIROC5	Standard	Low	Ocean Forcing Uncertainty

Initial state, control run, historical run and projections set up

The core and targeted experiments all start on January 2015 and end in December 2100. The start date follows the CMIP6 protocol for projections, while the end date is constrained by the availability of forcing. In many cases, modelers will need to run a short historical run to bring their models from the "initialization date" to the "projection start date" of January 2015.

The "initialization date" (or initial state) is left to the modeling groups discretion and can be any time prior to January 2015. The "initialization date" corresponds to the date assigned to the initialization procedure. Groups can reuse their initMIP initialization configuration or generate a new initial state. In the later case, it is important to redo the initMIP schematic experiments 'asmb' (see initMIP Greenland and **Goelzer et al.** 2018), as it will help understanding how a novel initial state contributes to the uncertainty in ice sheet evolution.

Note that ISMIP6 has a new standard grid (horizontal resolution of 1 km on projection EPSG:3413), which is different than that used in initMIP-Greenland. The revised datasets for the initMIP 'asmb' forcing for the new grid can be obtained from Ghub Globus endpoints. We have changed to the new grid because its projection is standardized and used by many observational datasets that are key input for ice sheet models.

A control run ('ctrl') is also needed to evaluate model drift. As for initMIP, the control run is obtained by running the model forward, keeping the surface mass balance and ocean forcing used in the initialization technique unchanged. The control run starts from the initial state (typically before 2015) and should last a minimum of 100 years, the same duration as the schematic initMIP experiments. The control run should also be sufficiently long to reach 2100. (See examples in **Table 2**).

Note that in the event that initMIP schematic experiments and control run are redone as part of the projection setup, then consistency with the projections protocol is more important than

consistency with the original initMIP setup. For example, in initMIP bedrock was not allowed to evolve. However, an ISM planning to run the projection with evolving bedrock AND planning to redo the initial state, would also rerun initMIP (ctrl, asmb) with bedrock change. Similarly, the original initMIP requested 2D output every 5 years, whereas the projections protocol request for yearly values. Therefore if rerunning initMIP, the schematic experiments should be saved yearly.

A **single "historical run"** is required for each ice sheet model, from which all the projections will branch off. The historical run starts at the initMIP state and ends in December 2014. Groups are free to choose how to run the "historical run", using a reanalysis, a historical run from an RCM, a historical run from an AOGCM or combination of multiple datasets.

However, we reject multiple historical runs for each individual AOGCM, because this would very much complicate the forcing strategy and interpretation. As a consequence, in case AOGCM data is used, please decide for one. ISMIP6 provides a climatology for the SMB and surface temperature for each of the AOGCMs used to generate the projection dataset, as well as anomalies. Groups that would like to use an ISMIP6 Greenland dataset for initialization and historical run are recommended to use MIROC5.

Note that the SMB and temperature climatology corresponds to January 1960-December 1989 because the ice sheet is assumed in steady state with the climate during this period. To give a concrete example of a historical run that seems to work well: The ice sheet is initialized to a steady state in 1960. RCM anomalies (here RACMO) are applied from 1960 – 2014 on top of the SMB assumed during initialization (here RACMO average 1960-1990). Other SMB products forced with reanalysis data (e.g. MAR) are expected to work equally well.

The **"projection control"** (ctrl_proj) is an unforced simulation that starts at the same ice sheet state as the projections. It will run until 2100, and is implemented with zero anomalies. It is meant to capture how much drift arises from the historical run.

In most cases the same historical run (and potentially spin-up) can be used for both the standard and open experiments. However, if the implementation of the open and standard experiments requires changes to the ISM that are substantially different (in terms of physics in the ISM), then modelers are allowed to carry out an historical run for the open experiments and an historical run for the standard experiments.

Table 2: Initialization experiments and examples of different initialization start date

Experiment	Note	start 1 (duration)