Application for CMIP6-Endorsed MIPs

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The recently proposed, revised CMIP structure (see information on the CMIP Panel website at http://www.wcrp-climate.org/index.php/wgcm-cmip/about-cmip) provides for a small set of experiments to be routinely performed by modeling groups whenever they develop a new model version. The output from these so-called *ongoing CMIP Diagnostic, Evaluation and Characterization of Klima (DECK)* experiments and the *CMIP6 Historical Simulation* will be distributed for community use via the ESGF infrastructure. Other Model Intercomparison Projects (MIPs) will build on the CMIP DECK experiments and the CMIP6 Historical Simulation and augment them to address a broad range of scientific questions. Additionally proposed MIP experiments together with the CMIP DECK experiments and the CMIP6 Historical Simulation will constitute the suite of simulations for the next phase of CMIP.

MIPs are invited to request endorsement for the next phase of CMIP (i.e., CMIP6). Applications from MIPs requesting status as a CMIP6-Endorsed MIP should be sent to the CMIP Panel Chair. The current set of MIP proposals is now complete and will be revised on the agreed timeline. We will review any additional proposals in a year from now at the next WGCM meeting in October 2015. A MIP may propose that a subset or even all of their experiments be included as part of the suite of simulations constituting CMIP6. The CMIP Panel will, together with the WGCM co-chairs, decide whether a MIP and its experiments meet the criteria for endorsement for CMIP6. Note that it is expected that all additional experiments proposed for CMIP6 will be scientifically analyzed and exploited by the MIP.

CMIP6-Endsored MIPs can make full use of the ESGF infrastructure. In order to minimize the burden imposed on modeling groups wishing to participate, the MIPs seeking to be part of CMIP Phase X must agree to comply with the CMIP standards in terms of experimental design, data format and documentation. In general the WGCM encourages adhering to the standards in place for CMIP.

The main criteria for MIPs to be endorsed for CMIP6 are

1. The MIP and its experiments address at least one of the key science questions of CMIP6.
2. The MIP demonstrates connectivity to the DECK experiments and the CMIP6 Historical Simulation.
3. The MIP adopts the CMIP modeling infrastructure standards and conventions.
4. All experiments are tiered, well-defined, and useful in a multi-model context and don't overlap with other CMIP6 experiments.
5. Unless a Tier 1 experiment differs only slightly from another well-established experiment, it must already have been performed by more than one modeling group.
6. A sufficient number of modelling centers (~8) are committed to performing all of the MIP's Tier 1 experiments and providing all the requested diagnostics needed to answer at least one of its science questions.
7. The MIP presents an analysis plan describing how it will use all proposed experiments, any relevant observations, and specially requested model output to evaluate the models and address its science questions.
8. The MIP has completed the MIP template questionnaire.
9. The MIP contributes a paper on its experimental design to the CMIP6 Special Issue.
10. The MIP considers reporting on the results by co-authoring a paper with the modelling groups.

Proposals from MIPs should include the following information:

* *Preliminary information used to determine whether a MIP should be endorsed for CMIP6 or not.*

** *Information that must be provided later (and before the panel can determine which experiments, if any, will be incorporated in the official CMIP6 suite).*

- Name of MIP*: Polar Amplification MIP (PAMIP)*
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- Link to website (if available)*
- Goal of the MIP and a brief overview

Goal of PAMIP

The overall aim of PAMIP is to investigate the causes and global consequences of polar amplification, through creation and analysis of an unprecedented set of coordinated multi-model experiments and strengthened international collaboration. The broad science objectives are:

- *Provide new multi-model estimates of the global climate response to Arctic and Antarctic sea ice changes.*
- *Determine the robustness of the responses between different models and the physical reasons for differences.*
- *Improve physical understanding of the mechanisms causing polar amplification and its global effects.*
- *Harness increased process understanding and new multi-model ensembles to constrain projections of future climate change in the polar regions and associated global climate impacts.*

PAMIP addresses all three of the CMIP6 scientific questions:

1. *How does the Earth system respond to forcing? This will be addressed through coordinated multi-model experiments to understand the causes and consequences of polar amplification.*
2. *What are the origins and consequences of systematic model biases? Specific experiments are proposed to investigate the role of model biases in the atmospheric response to sea ice.*
3. *How can we assess future climate changes given climate variability, predictability and uncertainties in scenarios? Analysis of PAMIP experiments will focus on process understanding in order to constrain future projections.*

PAMIP will contribute to the following WCRP Grand Challenges:

- *Near-term Climate Prediction*
- *Melting Ice and Global Consequences*
- *Weather and Climate Extremes.*

Brief overview

Warming in response to increasing greenhouse gases is projected to be amplified in polar regions compared to lower latitudes. Polar amplification appears to be occurring already in the Arctic, and Arctic sea ice extent has reduced by more than 10% per decade in late summer/early autumn over the last few decades. Model simulations of the Arctic are broadly consistent with the observations, although they perhaps underestimate the rate of sea ice loss. However, polar amplification in the Antarctic has not yet been observed, with Antarctic sea ice extent actually increasing slightly over recent decades in contrast to most model simulations. Changes in the southern annular mode have likely played a role in recent Antarctic climate change, but the details are not well understood. Coordinated experiments proposed in PAMIP will further our understanding of the physical processes that control the rate of polar amplification in both poles and the reasons for apparent differences between the model simulations and the observations.

There is mounting evidence that polar amplification will affect the global climate system, but the precise details and physical mechanisms are poorly understood. For example, polar amplification will reduce the equator to pole surface temperature gradient, potentially weakening the mid-latitude westerly winds and promoting a negative North Atlantic Oscillation (NAO). However, modelling studies currently simulate a full range of NAO responses to reduced Arctic sea ice. Some of the discrepancies likely arise from differences in the experimental design, including the magnitude and pattern of applied sea ice changes, the use of atmosphere only or coupled models, and whether other changes are applied, for example from greenhouse gases which are expected to oppose the effects of Arctic sea ice loss by enhancing the temperature gradient between the tropics and middle latitudes. The coordinated experiments proposed by PAMIP will eliminate these sources of differences, enabling a better understanding of the physical processes that give rise to the spread of model responses. Analysis of the experiments will take advantage of this spread to define "emergent constraints" to narrow the uncertainties in future projections.

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- An overview of the proposed experiments*

PAMIP will investigate the causes and consequences of polar amplification through numerical experiments that address the following primary questions:

- *What are the relative roles of local sea ice and remote sea surface temperature (SST) changes in driving polar amplification?*
- *How does the global climate system respond to changes in Arctic and Antarctic sea ice?*

These questions will be answered by taking differences between numerical simulations that are forced with different combinations of SST and/or sea ice concentration (SIC) representing present day, pre-industrial and future (2 degree warming) conditions. Pairs of simulations with the same SSTs but different SICs provide estimates both of the contribution of sea ice changes to polar amplification and of the climate response to sea ice changes. Pairs of simulations with the same SICs but different SSTs provide estimates of the contribution of SST changes to polar amplification.

The full list of experiments is given in Table 1, and various combinations that address the primary questions are suggested in Table 2. All experiments provide a large ensemble to obtain robust results (Mori et al 2014). The Tier 1 experiments are atmosphere only, and build on similar experiments that have previously been performed by at least two groups to investigate the effects of present-day sea ice loss and SST changes (Screen et al 2012, 2014; Perlwitz et al 2015), and future Arctic (Deser et al 2010; Peings and Magnusdottir 2014; Screen et al., 2015) and Antarctic (Menendez et al 1999; Kidston et al., 2011; Bader et al 2013) sea ice loss.

Lower tier experiments are proposed to investigate additional aspects and provide further understanding of the physical processes. Ocean-atmosphere coupling potentially amplifies the response to sea ice and produces impacts in remote regions including the tropics (Deser et al 2015; Smith et al 2017). This will be investigated with coupled ocean-atmosphere experiments (2.1-2.5). The sensitivity of the atmospheric response to the pattern of sea ice forcing (Sun et al 2015; Screen 2017) and to the model background state (i.e. bias, Balmaseda et al 2010; Smith et al 2017) will be investigated with atmosphere-only experiments (3.1-3.2 and 4.1-4.2). AMIP simulations (5.1-5.2) provide a more detailed analysis of the recent period, including individual years of interest, and enable the transient response to sea ice loss to be investigated. Centennial coupled ocean-atmosphere experiments (6.1-6.3) are particularly aimed at diagnosing oceanic responses to sea ice loss, including changes in the overturning circulations (Tomas et al 2016; Sévellec et al 2017).

A key goal of PAMIP is to determine the real world situation from the spread of model simulations. This will be achieved by considering "emergent constraints" (Hall and Qu 2006; Collins et al 2012; Bracegirdle and Stephenson 2013) in which model uncertainty may be reduced by using an observable quantity that physically explains the inter-model spread. For example, results using a single model suggest that the NAO response to Arctic sea ice loss can to be explained by the climatological planetary wave refractive index (Smith et al 2017). This hypothesis will be tested using the multi-model PAMIP simulations.

Table 1: Coordinated model experiments. The contributions of local sea ice and remote sea surface temperature (SST) to polar amplification, and the response to sea ice, are diagnosed from atmosphere-only and coupled atmosphere ocean model experiments using different combinations of SST and sea ice concentration (SIC) representing present day (pd), pre-industrial (pi) and future (fut, representing 2 degree warming) conditions. The signals of interest are obtained by differencing experiments, as shown in Table 2.

No.	Experiment name	Description	Notes	Tier	Start year	Number of years	Minimum ensemble size
1. Atmosphere-only time slice experiments							
1.1	pa-pdSSTpdSIC	Time slice forced by climatological monthly mean SST and SIC for the present day (pd)[1,2]	Present day SST and SIC	1	1860	1	100
1.2	pa-piSSTpiSIC	Time slice forced by climatological monthly mean SST and SIC for pre-industrial (pi) conditions[3]	Pre-industrial SST and SIC	2	1860	1	100
1.3	pa-piSSTpdSIC	Time slice forced by pi SST and pd SIC[3]	Different SST relative to 1.1 to investigate the role of SSTs in polar amplification	1	1860	1	100
1.4	pa-futSSTpdSIC	Time slice forced by pd SIC and future SST representing 2 degree global warming (fut)[3]		2	1860	1	100
1.5	pa-pdSSTpiSIC-Arctic	Time slice forced by pd SST and pi Arctic SIC[3]	Different Arctic SIC relative to 1.1 to	1	1860	1	100

1.6	pa-pdSSTfutSIC-Arctic	Time slice forced by pd SST and fut Arctic SIC[3]	investigate the impacts of present day and future Arctic sea ice, and the role of Arctic SIC in polar amplification	1	1860	1	100
1.7	pa-pdSSTpiSIC-Antarctic	Time slice forced by pd SST and pi Antarctic SIC[3]	Different Antarctic SIC relative to 1.1 to investigate the impacts of present day and future Antarctic sea ice, and the role of Antarctic SIC in polar amplification	2	1860	1	100
1.8	pa-pdSSTfutSIC-Antarctic	Time slice forced by pd SST and fut Antarctic SIC[3]		1	1860	1	100
1.9	pa-pdSSTfutSICSIT-Arctic	Time slice forced by pd SST and fut Arctic SIC and sea ice thickness (SIT)	Investigate the impacts of sea ice thickness changes	3	1860	1	100
2. Coupled ocean-atmosphere time slice experiments							
2.1	pa-cpld-pdSIC	Coupled time slice constrained by pd SIC[2,4]		2	1860	1	100
2.2	pa-cpld-piSIC-Arctic	Coupled time slice with pi Arctic SIC[3]	As 1.5 and 1.6 but with coupled model	3	1860	1	100
2.3	pa-cpld-futSIC-Arctic	Coupled time slice with fut Arctic SIC[3]		2	1860	1	100
2.4	pa-cpld-piSIC-Antarctic	Coupled time slice with pi Antarctic SIC[3]	As 1.7 and 1.8 but with coupled model	3	1860	1	100
2.5	pa-cpld-futSIC-Antarctic	Coupled time slice with fut Antarctic SIC[3]		2	1860	1	100
3. Atmosphere-only time slice experiments to investigate regional forcing							
3.1	pa-pdSSTfutSIC-Arctic-Okhotsk	Time slice forced by pd SST and fut Arctic SIC only in the Sea of Okhotsk	Investigate how the atmospheric response depends on the pattern of Arctic sea ice forcing	3	1860	1	100
3.2	pa-pdSSTfutSIC-Arctic-BKSeas	Time slice forced by pd SST and fut Arctic SIC only in the Barents/Kara Seas		3	1860	1	100
4. Atmosphere-only time slice experiments to investigate the role of the background state							
4.1	pa-cpldSSTpdSIC	Time slice forced by pd SIC and pd SST from coupled model (2.1) rather than observations	In conjunction with experiments 1 and 2, isolate the effects of the background state from the effects of coupling	3	1860	1	100
4.2	pa-cpldSSTfutSIC-Arctic	Time slice forced by fut Arctic SIC and pd SST from coupled model (2.1) rather than observations		3	1860	1	100
5. Atmosphere-only transient experiments							
5.1	pa-amip-climSST-transientSIC	Repeat CMIP6 AMIP (1979-2014) but with climatological monthly mean SST	Use CMIP6 AMIP as the control. Investigate transient response, individual years, and the contributions of SST and SIC to recent climate changes	2	1860	36	3
5.2	pa-amip-transientSST-climSIC	Repeat CMIP6 AMIP (1979-2014) but with climatological monthly mean SIC		2	1860	36	3
6. Coupled ocean-atmosphere transient experiments							
6.1	pa-cpld-control-transient	Coupled model simulation constrained with pd sea ice[5]	Experiments to investigate the decadal and longer	3	1860	100	1

6.2	pa-cpld-futSIC-Arctic-transient	Coupled model simulation constrained with fut Arctic sea ice[5]	impacts of Arctic and Antarctic sea ice on the ocean.	3	1860	100	1
6.3	pa-cpld-futSIC-Antarctic-transient	Coupled model simulation constrained with fut Antarctic sea ice[5]		3	1860	100	1

Notes:
Radiative forcing to be set to pre-industrial levels for all experiments except AMIP (5.1 and 5.2) where the CMIP6 protocol should be used.
[1] All necessary SST and sea ice fields will be provided to participants.
[2] Time slice simulations to begin on 1st April and run for 14 months. One year long runs are required to isolate short-term atmospheric responses from longer timescale ocean responses, which will be investigated separately (experiments 6).
[3] Past and future SIC and SST will be computed from the ensemble of CMIP5 projections (full details will be given in GMD paper). Sea ice thickness should be specified according to the CMIP6 AMIP protocol.
[4] Sea ice concentration to be nudged into coupled model with a relaxation time-scale of 6 hours
[5] Present day and future sea ice to be the same as used in experiments 1.1, 1.6 and 1.8. It is recommended to constrain sea ice by nudging[4]. However, appropriate calibrated long-wave fluxes applied to the sea ice model (following Deser et al 2015) may also be used.

Table 2: Suggested analysis of experiments to diagnose the causes and consequences of polar amplification. The role of SST in polar amplification is obtained by differencing experiments that have the same SIC but different SST (e.g. 1.1 and 1.3). The role of SIC in polar amplification, and the response to SIC, is obtained by differencing experiments that have the same SST but different SIC (e.g. 1.1 and 1.5).

	Polar amplification		Response to sea ice		
	Role of SST	Role of sea ice	Past	Future	Total
Arctic	**[1.1-1.3],** [1.4-1.1], [1.4-1.3], [1.5-1.2], [AMIP-5.2]	**[1.1-1.5], [1.6-1.1],** [1.6-1.5], [1.3-1.2], [AMIP-5.1]	**[1.1-1.5],** [1.3-1.2], <u>[2.1-2.2]</u>, [5.1-AMIP]	**[1.6-1.1],** <u>[2.3-2.1]</u>, [3.1-1.1], [3.2-1.1], [4.2-4.1], <u>[6.2-6.1]</u>, <u>[1.9-1.1]</u>	[1.6-1.5], <u>[2.3-2.2]</u>
Antarctic	**[1.1-1.3],** [1.4-1.1], [1.4-1.3], [1.7-1.2], [AMIP-5.2]	**[1.8-1.1],** [1.1-1.7], [1.8-1.7], [1.3-1.2], [AMIP-5.1]	[1.1-1.7], [1.3-1.2], <u>[2.4-2.1]</u>, [5.1-AMIP]	**[1.8-1.1],** <u>[2.5-2.1]</u>, <u>[6.3-6.1]</u>	[1.8-1.7], <u>[2.5-2.4]</u>

Notes:
Experiments are defined in Table 1. AMIP is part of the CMIP6 DECK simulations
Tier 1 experiments are in **bold**
Coupled model experiments are <u>underlined</u>

- An overview of the proposed evaluation/analysis of the CMIP DECK and CMIP6 experiments*
  The CMIP DECK experiments will provide valuable additional information on the characteristics of the models used in PAMIP, including climate sensitivity and simulated internal variability. This will aid the interpretation of the PAMIP results. Furthermore, the CMIP DECK AMIP experiments will serve as the control for some of the PAMIP experiments (5, atmosphere-only transient experiments).
- Proposed timing*
  Ideally experiments will start in spring 2018 and be completed in 2019 in time for papers to contribute to the IPCC sixth assessment report. The forcing data has already been prepared, and some groups are starting to run some test simulations. However, we recognize that setting up a new MIP, including the data request, is a substantial undertaking and delays could be expected. We note that there will not be any new diagnostics that are not already in the existing CMIP6 data request, so groups could potentially run experiments now with the same diagnostics as in their DECK simulations and then publish the data once the PAMIP data request has been finalized.

- For each proposed experiment to be included in CMIP6**
  - the experimental design;

    See Table 1.

- the science question and/or gap being addressed with this experiment;

1. *Atmosphere-only time slice experiments address the following questions: (1) what are the roles of local sea ice and remote sea surface temperature (SST) changes in polar amplification? (2) How does the atmosphere respond to Arctic and Antarctic sea ice changes?*
2. *Coupled ocean-atmosphere time slice experiments: how does coupling affect the atmospheric response to Arctic and Antarctic sea ice changes?*
3. *Atmosphere-only time slice experiments to investigate regional forcing: what is the atmospheric response to sea ice changes in the Sea of Okhotsk and the Barents/Kara Seas?*
4. *Atmosphere-only time slice experiments to investigate the role of the background state: what is the role of model bias in the atmospheric response to Arctic sea ice?*
5. *Atmosphere-only transient experiments: what are the contributions of sea ice and SST to climate change and variability over the period 1979 to 2014?*
6. *Coupled ocean-atmosphere transient experiments: how does the ocean respond to Arctic and Antarctic sea ice loss?*

- possible synergies with other MIPs;
- potential benefits of the experiment to (A) climate modeling community, (B) Integrated Assessment Modelling (IAM) community, (C) Impacts Adaptation and Vulnerability (IAV) community, and (D) policy makers.

➢ If possible, a prioritization of the suggested experiments, including any rationale**

All experiments are tiered. Tier 1 experiments enable a basic multi-model assessment of the roles of local sea ice and remote sea surface temperatures (SSTs) in driving polar amplification, and of the response to Arctic and Antarctic sea ice changes. Tier 2 experiments build on the DECK AMIP simulations to investigate transient responses to sea ice and assess individual years. The remaining tier 3 experiments build on the tier 1 experiments to investigate different aspects including the roles of coupling, model biases and the pattern of sea ice changes, as well as responses in the ocean.

➢ All model output archived by CMIP6-Endorsed MIPs is expected to be made available under the same terms as CMIP output. Most modeling groups currently release their CMIP data for unrestricted use. If you object to open access to the output from your experiments, please explain the rationale.**

➢ List of output and process diagnostics for the CMIP DECK/CMIP6 data request**

- whether the variable should be collected for all CMIP6 experiments, or only some specified subset and whether the output is needed from the entire length of each experiment or some shorter period or periods;
- whether the output might only be relevant if certain components or diagnostic tools are used interactively (e.g. interactive carbon cycle or atmospheric chemistry, or only if the COSP simulator has been installed);
- whether this variable is of interest to downstream users (such as impacts researchers, WG2 users) or whether its principal purpose is for understanding and analysis of the climate system itself. Be as specific as possible in identifying why the variable is needed.
- whether the variables can be regridded to a common grid, or whether there is essential information that would be compromised by doing this;
- the relative importance of the various variables requested (indicated by a tiered listing) is required if the data request is large.

Diagnostics list is being developed. It will likely contain most of the diagnostics from the DCPP but with selected additional diagnostics from DynVarMIP to provide enhanced process understanding of atmospheric variability and from Sea-Ice MIP for in-depth analysis of the evolution of sea ice. There will not be any new diagnostics that are not already in the existing CMIP6 data request.

➢ Any proposed contributions and recommendations for**

- model diagnostics and performance metrics for model evaluation;

- observations/reanalysis data products that could be used to evaluate the proposed experiments. Indicate whether these are available in the obs4MIPs/ana4MIPs database or if there are plans to include them;
- tools, code or scripts for model benchmarking and evaluation in open source languages (e.g., python, NCL, R).

- Any proposed changes from CMIP5 in NetCDF metadata (controlled vocabularies), file names, and data archive (ESGF) search terms.**
- Explanation of any proposed changes (relative to CMIP5) that will be required in CF, CMOR, and/or ESGF.**