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PRIMAVERA

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Deliverable D*5.1*

Document protocol for forced and coupled sensitivity experiments

Deliverable Title		*Protocol for forced and coupled sensitivity experiments*
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WP number		5
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		PP - Restricted to other programme participants, including the Commission services
		RE - Restricted to a group specified by the consortium, including the Commission services
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Version 1	3-09-2016	L. Terray	
Version 2	25-09-2016	L. Terray	Updated version with additional details about sea-ice and snow experiments

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1. Executive Summary

The following note provides the protocol needed to perform the forced and coupled sensitivity experiments needed in WP5. There are two kinds of experimental protocols that will be described here. The first kind concerns the experiments regarding the influence of low-frequency oceanic modes, namely the Atlantic Multidecadal Variability (AMV) and Interdecadal Pacific Variability (IPV) modes, on the global and European Climate. The second concerns the experiments dedicated to the influence of Arctic sea-ice loss on the European climate and atmospheric circulation. While the first protocol has been discussed extensively and the protocol set in marble, the second one is still under discussion among the WP5 partners. A final decision on the agreed protocol will be made before or at the general assembly.

2. Project Objectives

With this deliverable, the project has contributed to the achievement of the following objectives (DOA, Part B Section 1.1) WP numbers are in brackets:

No.	Objective	Yes	No
A	To develop a new generation of global high-resolution climate models. *(3, 4, 6)*		
B	To develop new strategies and tools for evaluating global high-resolution climate models at a process level, and for quantifying the uncertainties in the predictions of regional climate. *(1, 2, 5, 9, 10)*		
C	To provide new high-resolution protocols and flagship simulations for the World Climate Research Programme (WCRP)'s Coupled Model Intercomparison Project (CMIP6) project, to inform the Intergovernmental Panel on Climate Change (IPCC) assessments and in support of emerging Climate Services. *(4, 6, 9)*		
D	To explore the scientific and technological frontiers of capability in global climate modelling to provide guidance for the development of future generations of prediction systems, global climate and Earth System models (informing post-CMIP6 and beyond). *(3, 4)*		
E	To advance understanding of past and future, natural and anthropogenic, drivers of variability and changes in European climate, including high impact events, by exploiting new capabilities in high-resolution global climate modelling. *(1, 2, 5)*		
F	To produce new, more robust and trustworthy projections of European climate for the next few decades based on improved global models and advances in process understanding. *(2, 3, 5, 6, 10)*		
G	To engage with targeted end-user groups in key European economic sectors to strengthen their competitiveness, growth, resilience and ability by exploiting new scientific progress. *(10, 11)*		
H	To establish cooperation between science and policy actions at European and international level, to support the development of effective climate change policies, optimize public decision making and increase capability to manage climate risks. *(5, 8, 10)*		

3. Detailed Report

3.1. *Protocol for the AMV and IPV experiments*

It has been decided to adopt the CMIP6 DCPP-C protocol for both forced and coupled experiments. Here we only provide a short summary of the main features, **full details of the experiments and implementation can be found in the attached papers and technical notes** (Boer et al. 2016; Cassou et al. 2016a, b; they are also on the wiki).

3.1.1. The PRIMAVERA coordinated experiments

The ***wish*** list of the coordinated PRIMAVERA coupled experiments is the following: (***AMV-CTRL***) a control experiment where the North Atlantic is constrained to follow the model control run climatology; (***AMV+***) a perturbed ensemble where one restores North Atlantic SSTs to positive AMV anomaly (see below) superimposed on model climatology; (***AMV-***) a perturbed ensemble where one restores North Atlantic SSTs to negative AMV anomaly superimposed on model climatology. (***IPV-CTRL), (IPV+), (IPV-)***, defined as in the AMV case but for the Pacific. All the experiments must be run for ~10 years and ~25 members. PRIMAVERA teams will have to decide how many of the experiments they will be able to perform, especially in the costly high resolution case (some compromise between CPU time and the number of members may need to be found). **It is mandatory to perform the selected experiments at both low (LR) and high (HR) spatial resolution** in order to be used in the main PRIMAVERA objectives and deliverables. Groups that have the capability may run additional tier1 and tier2 DCPP-C experiments. All the details related to the experimental set-up can be found in the DCPP-related GMD paper (Boer et al. 2016).

3.1.2. The AMV and IPV SST patterns used in PRIMAVERA experiments

We now describe the methodology used to produce the anomalous sea surface temperature (SST) pattern from observations that are representative of the Atlantic Multidecadal Variability and the Interdecadal Pacific Variability (hereafter AMV and IPV, respectively). The AMV and IPV SST anomalies that are imposed in the proposed experiments correspond to an estimation of the internal component of observed decadal variability. To get these SST anomalies, the externally forced signal, both natural (solar+volcanoes) and anthropogenic (GHG and aerosols), must be *a priori* removed. There are multiple ways of estimating the externally forced signal. Here we follow the approach proposed by Ting et al (2009) that uses a signal-to-noise maximizing EOF analysis (Venzske et al. 1999) applied to global annual mean SST derived from the CMIP5 multi-model ensemble. Historical simulations and Representation Concentration Pathway 8.5 (RCP8.5) simulations are used for the 1870-2005 and the 2006-2013 periods, respectively (Cassou et al. 2016a). The time series associated to the AMV and IPV patterns are then defined as residuals of the forced components over the 1870-2013 period. The AMV and IPV SST patterns are then obtained by regression using the sub period of 1900-2013 during which observations are more reliable (***Fig. 1***).

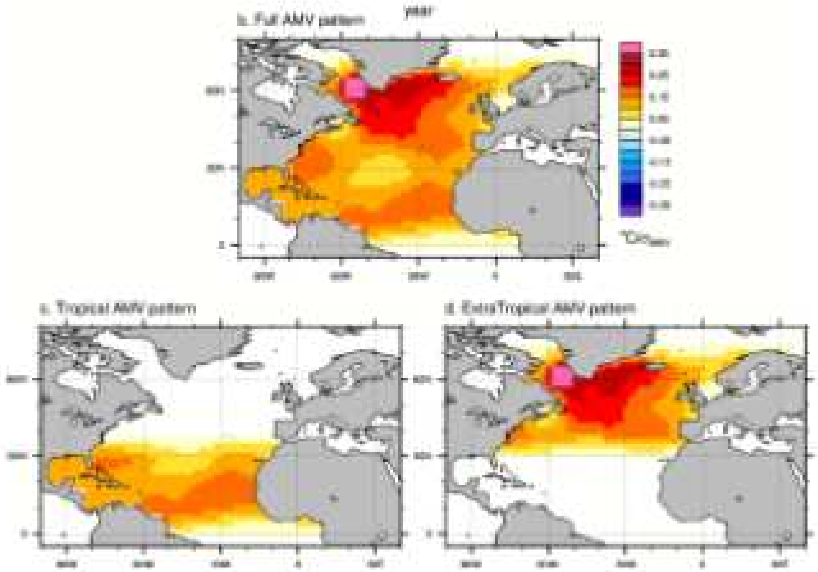

***Figure1**: AMV SST anomalies obtained from regression of ERSST4 annual residual SSTs (i.e. the forced component removed) on the AMV time series. Units are K/sigma where sigma is the standard deviation of the AMV time series (sigma varies between -2 and 2 throughout the 20th century).Full, tropical, and extratropical AMV SST patterns are shown. From Cassou et al. 2016a*

A similar approach has been followed for the IPV SST patterns (***Fig. 2***).

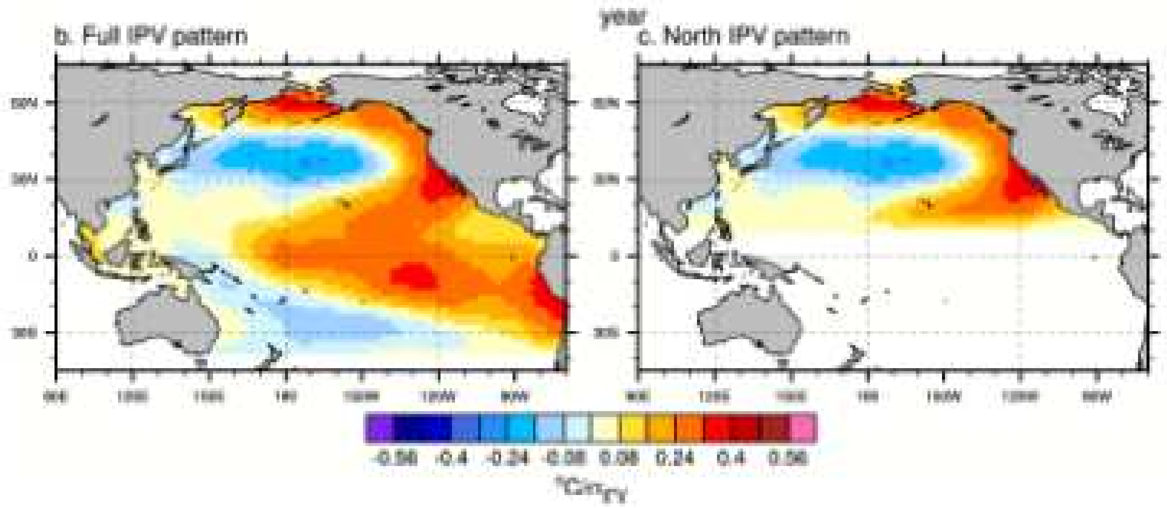

***Figure 2**: Same as Figure 1 but for the IPV SST patterns. From Cassou et al. 2016a*

A number of sensitivity studies have been performed to test the robustness of the procedure to observed SST datasets, filtering procedures, time periods (see the technical notes). The above patterns were found to be very robust among the different tests. The netcdf files containing the AMV and IPV SST anomalies are on the wiki (also available on request to terray@cerfacs.fr) and will be put on JASMIN.

IMPORTANT Warning: please make sure you read attentively the two technical notes as they contain recommendations on some subtle points that do matter in the implementation of the protocols.

Major outcomes of the work

AMV and IPV WP5 sensitivity experiments defined

3.2. Protocol for the Arctic ice loss experiments

The starting idea was to favour a simple forced (AMIP-type) protocol for the core sea-ice loss experiments (remembering that they have to be performed at both LR and HR). The suggested protocol was aiming at a simple framework where we prescribe the observed sea-ice decline for 1979-2015 with climatological SSTs and constant external forcing (for instance at values typical of the early 1980s) and compare that with a reference experiment.

A consultation has been performed across all WP5 partners to discuss the protocol for sea-ice loss experiments. A lot of different protocols based on both forced and coupled frameworks have been documented in the literature. Key findings are the following:

- In case where one is interested in the influence of the recent (since 1979) impact of Arctic sea-ice loss on the global and European climate based on AMIP-type ensembles of atmospheric simulations, a number of studies have demonstrated that the signal-to-noise ratio is likely to be low, requiring a very large number of atmospheric members to significantly detect the signal due to sea-ice loss.
- In studies looking at isolating the effect of sea-ice at the end of the 21st century under the RCP8.5 scenario, the use of a coupled framework (as in Deser et al. 2016, Oudar et al. 2016, Blackport et Kushner 2016) has been shown to give different results than those based on the standard time-slice atmospheric protocol.

Here is a short summary of the key recommendations emerging from the consultation:

1. Sea ice AMIP-experiments: Similar experiments have already been made in the GREENICE-project (https://greenice.b.uib.no) with 6 global AGCMs. The difference was that GREENICE-runs did not keep external forcings at 1980-level and of course other models and model-versions and probably different SST/ice forcing data have been used (NOAA-data, which turned out to be not perfect since the ice trends are smaller in the NOAA-data then in other ice data sets).
2. Sea-ice AMIP experiments: There were concerns about the implications of using a climatological SST in the proposed original protocol: in earlier experiments, sea-ice variations seemed to produce a response in phase with the observed anomalies only when the SSTs were appropriate for the period under consideration. Also, the use of climatological SST will reduce the SST gradients, especially in the Western Boundary Current regions, and may reduce the advantage of using a high-resolution model. A possible alternative is use the standard stream-1 AMIP ensemble as control, and run experiments where SST and radiative forcings are as in the standard AMIP, but the prescribed sea-ice concentration (SIC) is modified in such a way to remove the downward trend.
3. Sea-ice AMIP experiments: the GREENICE multi-model shows a limited impact of the long-term declining trends in sea-ice on atmospheric circulation trends, in agreement with results by Perlwitz et al. (2015, JCLIM 28:2154-2167) with two other models, i.e. CAM4 and ECHAM5. The protocol in Perlwitz et al. is actually the same as the one just mentioned above (two sets of AMIP-type simulations, obs_SST+obs_SIC and obs_SST+clim_SIC 1979-89). However, the fact of not

having a distinguishable impact on atmospheric circulation trends shouldn't imply that there is no impact on atmospheric variability or a potential influence in the case of an extreme event. Another idea about a coordinated sensitivity experiment would be to perform a sensitivity experiment similar to the one in Honda et al. (2009, GRL 36:L08707) or in Screen et al. (2013 JCLIM 26:1230-1248, 2014 CLIMDYN 43:333-344). One could do a perturbed experiment where one prescribes 1-year-long, seasonally-evolving SIC anomalies computed as the mean sea-ice concentration difference between two 10-year periods such as 2006/2015 - 1979/1988. This perturbed simulation would then be compared with a control run with climatological SIC for the earlier period. Indeed, the number of years or size of the ensemble will have to be quite large. The advantage of using different AGCMs would be to evaluate the distinct atmospheric sensitivity to the same boundary forcing, which could yield monthly/seasonally-locked responses according to each model mean-state. The advantage of running LR and HR experiments would be to assess the impact of varying resolution on both the mean-flow and the sensitivity to sea-ice reduction with a single set of experiments. Concerning the use of climatological SST, it could be done everywhere but in the marginal zones around the climatological sea-ice edge (as in Screen et al. (2013 JCLIM 26:1230-1248).

4. Impact of regional sea ice anomalies: We could focus on Barents/ Kara Seas (e.g. 30-70E, 70-80N) and Chukchi/ East Siberian Seas (e.g. 160E-160W,65-80N). Experiments for both regions with climatology in this specific region and fully variable in the rest. As comparison, we would need AMIP with fully varying SST, sea ice everywhere. This type of experiment could be tier 2.
5. Coupled experiments: there is an interest by all groups to go towards a coupled framework. The focus could be on the long term/climatic response (Deser et al., 2016, Oudar et al. 2016) or the short-term response (in the following winters after an abrupt reduction to low SIC) to sea ice loss. (***Note: the long-term will be too costly to achieve with the HR model.***). The sea ice reduction can be achieved either through perturbations (flux corrections) of the longwave radiative flux, non-solar fluxes or of the albedo, starting from a control run. The consensus seems to be in favour of studying the short term response (because it is more computationally tractable, and that will allow both **HR** and **LR** to be performed) and using the albedo perturbation technique (as in Blackport and Kushner, 2016a, b). The latter framework is much more easily implemented than the one relying on flux correction (the latter would be very costly at **HR** as the restoring flux coefficients have to be estimated with a non-negligible number of sensitivity tests). **The PRIMAVERA protocol could be as follows**: we use as reference the 1950 CTRL coupled HiResMIP 100-year simulation (note that it means that groups have to do it also for LR). At selected dates, we then branch off perturbed experiments with reduced albedos (the number of experiments/dates should be at least 3 and preferably between 5 and 10). The length of the perturbed experiments should be ~5-10 years as the sea-ice melt consists of an abrupt change during the first couple of years followed by a very long and small amplitude adjustment (see Figure 1 of Blackport and Kushner, 2016b). Here, we want to focus on the ultra-fast (weeks to month) and fast responses (month to year) and not on the long time scale one due to the **HR** computing cost.
6. Snow experiments: these experiments are of interest for a few groups. Others may join in if they wish. The idea is to use the same baseline experiments as for the AMIP-sea ice. Then the following steps are performed: 1. Calculate snow climatology

from these simulations; 2. Perform a new set of simulations with snow-climatology instead of interactive snow. The difference between the sets with and without interactive snow indicates the effect of the varying and decreasing snow on climate. Ensemble size should be at least 10 members.

In terms of sea-ice experiments, we thus seem to converge towards two types of experiments **(these are the current propositions that we have to discuss among ourselves before making a final decision no later than the PRIMAVERA GA)**:

- Sea ice *tier 1* **coordinated forced experiments** based on **one** of the protocols described in paragraph 3 above. The first one is simply based on modified AMIP experiments and use the fact that reference AMIP simulations (both LR and HR) between 1950-2015 are required anyway for HiResMIP. The idea is then to replicate the AMIP experiments on the 1991-2015 period (25 years) but with SIC fixed at the 1979-1990 period climatology. It will be necessary as mentioned above to have the SST modified when sea-ice strongly differs between the reference and modified AMIP simulations.

  The second one is the one relying on a repeated 1-year perturbed SIC. The needed input files are the SIC and SST files needed to force the AGCMs. It is proposed to derive them from the HadISST2 daily data used in the AMIP HiResMIP experiments. Here is the proposed method:

  - ✓ Get smoothed (first two harmonics) SST and SIC daily climatology for the 1979-1988 and 2006-2015 periods based on HadISST2.
  - ✓ Make the 2006-2015 - 1979-1988 SST and SIC differences (see ***Fig.3***). Then add the SIC difference to the 1979-1988 smoothed SIC daily climatology. Constrain the final results to be within [0-1]: if sic < 0, sic = 0; if sic >1, sic = 1 (see ***Fig.4.***). Note that both **Figure 3 and 4** are now based on 2006-2015 for the later period (Note that the two figures only show monthly means whereas the SIC and SST data files will be provided at the daily frequency).
  - ✓ If relative SIC change (2006-2015 - 1979-1988) exceeds 10% of the 1979-1988 climatology, add the SST (2006-2015 - 1979-1988) difference to the smoothed (1979-1988) SST daily climatology.
- Sea ice *tier 1* **coordinated coupled experiments** based on the protocol mentioned in paragraph 5 above**.** Starting from the 1950 control experiment, sea ice loss for our perturbation experiments will be accomplished by instantaneously altering the albedo parameters (such as albedo of the sea ice, snow on top of the sea ice, and the ice that forms on top of melt ponds) in the sea ice model code. These changes will increase the amount of shortwave radiation absorbed, thus directly driving ice and snow-on-ice to melt. This change could be applied either globally or just for the Arctic. Again, computing constraints du to HR requirements suggest that compromises will have to be made in terms of simulated years and ensemble members. As an initial guess, we propose 5- or 10-year long perturbed simulations and between 5 and 10 starting dates (with a minimum of 3).

The *tier 1* snow AMIP experiments will be performed only by the interested groups. Tier 2 experiments are not mandatory and include regional sea ice anomalies and subtropical/subpolar AMV and IPV pattern experiments. Note also that, as required by the

HiResMIP protocol, we will have 1950-2015 AMIP experiments with varying SST and sea-ice everywhere as a basis for comparison with tier 1 and tier 2 forced atmospheric simulations.

Figures:

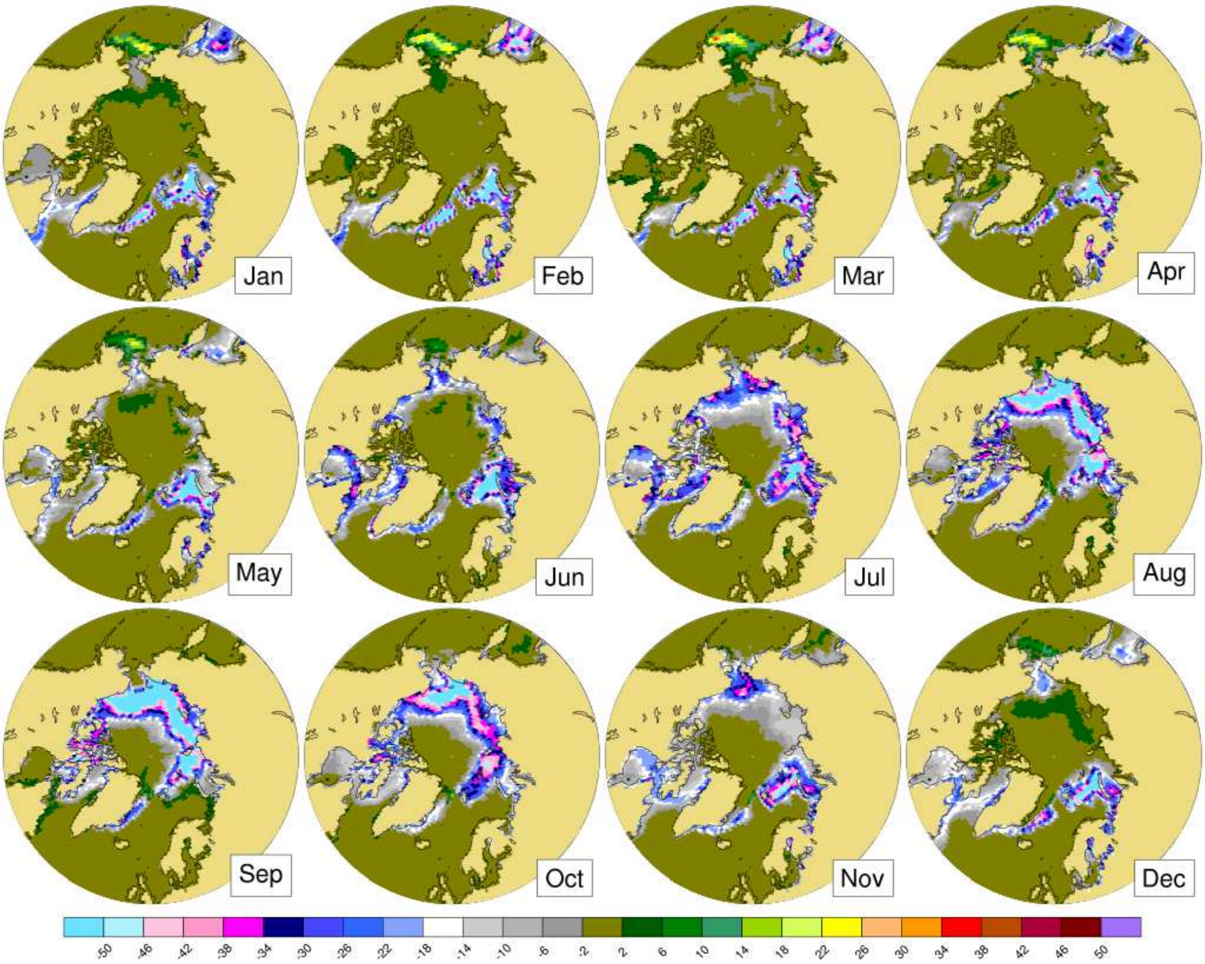

***Figure 3**: Seasonal cycle of Arctic SIC difference (in percent) between 2005-2009 and 1979-1988. See text for details.*

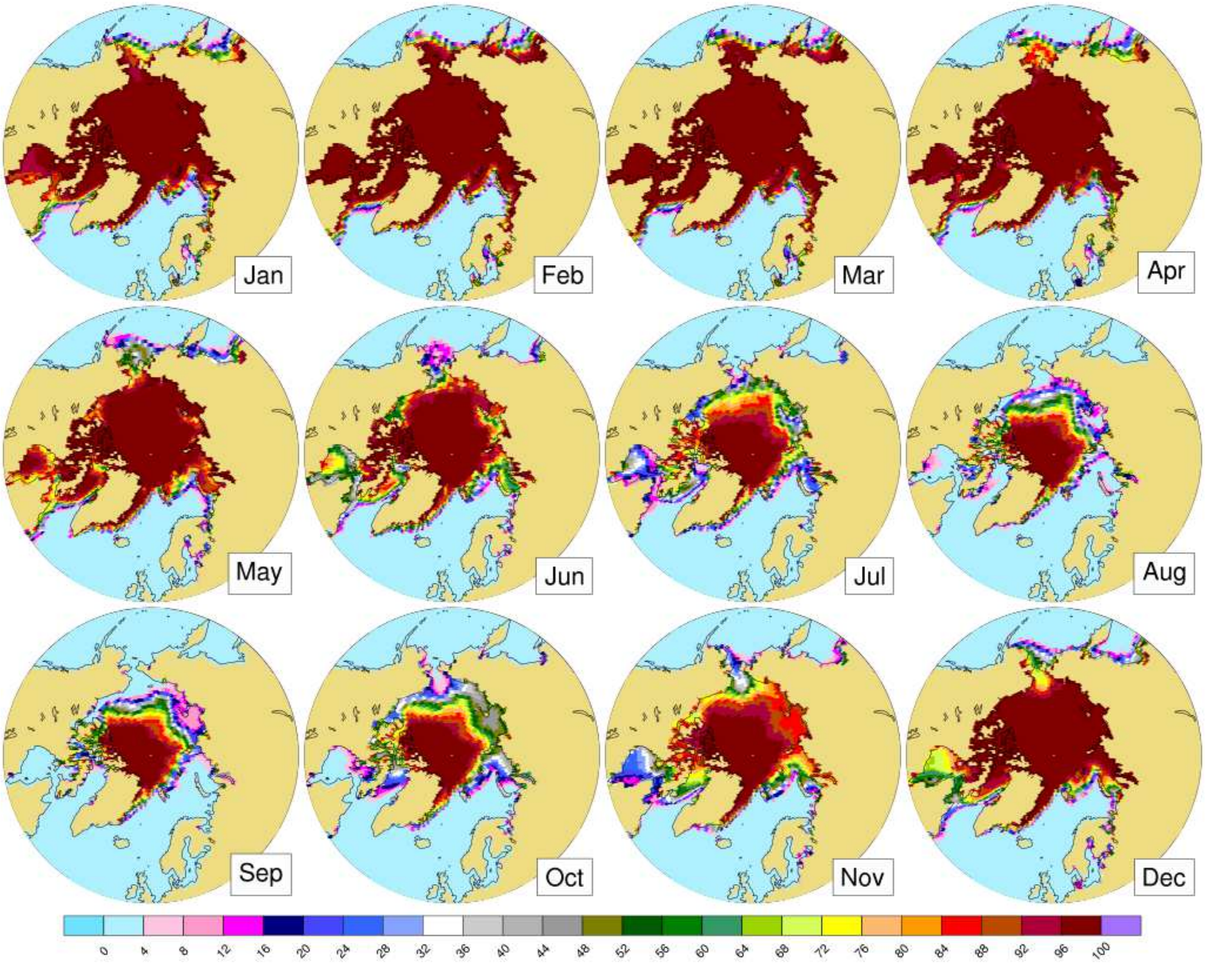

Figure 4: *Monthly mean SIC (unit in percent) climatology for the sea-ice AGCM-PERT PRIMAVERA experiment. See text for details.*

Summary Table for *tier 1* WP5 sensitivity experiments and minimum length and number of members required:

Exps \ Groups	**AMV**:CTRL, AMV+,AMV- (**HR** 5 mem, 10 years	**IPV:** CTRL, IPV+, IPV- (**HR**, 5 mem, 10 years)	**Sea-ice** (AGCM): CTRL, PERT (10 Mem, 5 years)	**Sea-ice** (CGCM): PERT (5-10 dates, 5-10 years)	**Snow** PERT 10 mem AMIP
Cerfacs	X	X	X	X	
SMHI			X	X	X
MPI	X	X			
UCL			X	X	
U.Read	X	X			
BSC	X	X	X	X	
ECMWF	X	X	X		X

Note that they all have to be done for both HR and LR. The 1950 CTRL HiResMIP simulation will serve as control simulation (and initialization) for the coupled sea-ice PERT simulations. The AMIP HiResMIP simulations will serve as CTRL for the snow-PERT simulations.

4. Links Built

There is a strong link with the CMIP6 DCPP activities meaning that in the end the PRIMAVERA results will be analysed by a much larger community, that of CMIP6. In particular, the presence of both low and high resolution simulations will certainly generate a wide interest beyond the PRIMAVERA teams.

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