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PRIMAVERA

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PRocess-based climate sIMulation: AdVances in high resolution modelling and European climate Risk Assessment

Deliverable D6.4

Stream 1 control and historic coupled runs

Deliverable Title	*Stream 1 control and historic coupled runs*	
Brief Description	*Stream 1 coupled runs, both control and historic, completed at both high and low resolution*	
WP number	*6*	
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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
		CO - Confidential, only for members of the consortium, including the Commission services

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1. Executive Summary

The coupled Stream1 simulations provide an unprecedented collection of quality-controlled, single-protocol simulations applying high-resolution grid configurations. Together with the atmosphere-only Stream1 simulations, they are PRIMAVERAs contribution to CMIP6 HighResMIP. They encompass a 100-year long 1950-control simulation, a historical simulation covering the period 1950 to 2014 and a scenario simulation covering the period 2015 to 2050. All simulations are carried out in two different grid configurations, allowing to assess the impact of increased model resolution on simulated climate variability and change. The delay in the coupled Stream1 simulations is due to the delay in the availability of the CMIP6 external forcing datasets. By now, the 1950-control and historical simulations have been completed; a small annex will be provided once the scenario forcing datasets are available and the scenario simulations have also been completed.

The CMORized and quality-checked output from the coupled Stream1 simulations will be made publicly available on the Earth System Grid Federation (ESGF) data nodes as soon as possible, providing the basis for publications which will enter the IPCC AR6 report. Currently, the coupled Stream1 simulations are available to all PRIMAVERA project members as well as selected individuals from the CLIVAR project working closely with PRIMAVERA scientists. One important aspect of preliminary analysis is the reduced cold bias in the North Atlantic with higher model resolution, which should positively affect the simulated air-sea interactions and thus the simulated climate in the North Atlantic / European sector.

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)*	X	
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)*		X
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)*	X	
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)*		X
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)*	X	
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)*		X
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)*		X

3. Detailed Report

Coupled Stream1 simulations

The coupled Stream1 simulations are dedicated to CMIP6 HighResMIP and are performed with seven coupled climate models (Table 1). They encompass a spin-up initialized from EN4 temperature and salinity, a 100 year long 1950-control simulation (fixed external forcing corresponding to year 1950), a historical simulation covering the period 1950 to 2014 and a scenario simulation covering the period 2015 to 2050 (Table 2). Models are documented individually in journal publications (see reference list). The contribution to CMIP6 HighResMIP is fulfilled with one ensemble member per simulation type and model. However, to investigate internal variability and increase the signal to noise ratio, some project partners have performed (will perform) more than one ensemble member. All simulations are carried out in two different grid configurations, a low-resolution (corresponding to CMIP5 standard) and a high-resolution one, allowing to assess the impact of increased model resolution on simulated climate variability and change. Within PRIMAVERA, the focus will be on the North Atlantic / European sector.

Delay of coupled Stream1 simulations

The delay in the availability of the CMIP6 external forcing datasets has delayed the coupled Stream1 simulations. In the original PRIMAVERA Description of Action, completing the coupled Stream1 simulations was foreseen by April 2017. By now, the 1950-control and historical simulations have been completed for all PRIMAVERA models, and the CMORized output has been uploaded to the JASMIN server. The scenario simulations could not be performed so far, as some of the CMIP6 scenario forcing datasets have only be provided in early 2019. We note that the delay in the CMIP6 external forcing datasets is out of the hands of the project partners. The scenario simulations, however, are only a minor part of the coupled Stream1 simulations (35 out of 200 plus spin-up integration years per model). Therefore, this deliverable is submitted now and it will be stated in the reports once the coupled scenario simulations have been completed.

Institution	MOHC, UREAD, NERC	EC-Earth KNMI,SHMI, BSC, CNR	CERFACS	MPI-M	AWI	CMCC	ECMWF
Model name	HadGEM3 GC3.1	EC-Earth3	CNRM-CM6	MPIESM-1-2	AWI-CM 1.0	CMCC-CM2	ECMWF-IFS
Model components	UM NEMO CICE	IFS NEMO LIM	ARPEGE NEMO GELATO	ECHAM6.3 MPIOM1.63 MPIOM1.63	ECHAM6.3 FESOM FESIM	CAM4 NEMO CICE	IFS cycle43r1 NEMO3.4 LIM2
Atmos dynamical scheme (grid)	Grid point (SISL, lat-long)	Spectral (linear, reduced Gaussian)	Spectral (linear, reduced Gaussian)	Spectral (triangular, Gaussian)	Spectral (triangular, Gaussian)	Grid point (finite volume, lat-long)	Spectral (cubic octohedral, reduced Gaussian)
Atmos grid name	N96 , N216, N512	Tl255, Tl511	Tl127, Tl359	T127, T255	T63, T127	1x1, 0.25x0.25	Tco199, Tco399
Atmos mesh spacing 0N	208, 93, 39	78, 39	156, 55	104, 52	200, 100	100, 28	50, 25
Atmos mesh spacing 50N	135, 60, 25	71, 36	142, 50	67, 34	129, 64	64, 18	50, 25
Atmos nominal res (CMIP6)	250, 100, 50	100, 50	250, 50	100, 50	250, 100	100, 25	50, 25
Atmos model levels (top)	85 (85km)	91 (0.01 hPa)	91 (78.4 km)	95 (0.01 hPa)	95 (0.01 hPa)	26 (2 hPa)	91 (0.01 hPa)
Ocean grid name	ORCA	ORCA	ORCA	TP	FESOM (unstructured)	ORCA	ORCA
Ocean nominal res (km)	100, 25	100, 25	100, 25	40, 40	50, 25	25, 25	100, 25
Ocean levels	75	75	75	40	47	50	75

Table 1: *Overview of PRIMAVERA coupled climate models.*

CMIP6 experiment name	Experiment description
spinup-1950	Spin-up initialized from EN4 temperature and salinity, applying fixed CMIP6 external forcing corresponding to year 1950; length model-dependent
control-1950	100 year long control simulation applying fixed CMIP6 external forcing corresponding to year 1950, initialized from end of spinup-1950
hist-1950	Historical simulation (1950 – 2014) applying transient CMIP6 external forcing, initialized from end of spinup-1950
highres-future	Scenario simulation (2015 – 2050) applying transient CMIP6 external forcing, initialized from end of hist-1950

Table 2: *Overview of CMIP6 HighResMIP simulations.*

Output of coupled Stream1 simulations

The coupled Stream1 simulations provide (most of) the standard quantities requested within CMIP6. In addition, the output encompasses variables specific to HighResMIP and PRIMAVERA needs. One such example are the products of oceanic velocity components and hydrographic properties (uT, uS, vT, vS, wT, wS, u^2, v^2, w^2). These allow to quantify the

contribution of ocean eddies to volume, heat and freshwater transports without the need to write out the 3-dimensional ocean variables at daily (instead of monthly) frequency. Another example is very high frequency (1-hourly) output of atmospheric quantities such as near-surface air temperature and wind speed, which provides the basis for user engagement within PRIMAVERA.

All model output is CMORized following the CMIP6 metadata standards, and the CMORized output is uploaded to the UK server JASMIN. All data received at JASMIN is checked using the primavera-val tool (https://github.com/PRIMAVERA-H2020/primavera-val). This checks that the essential metadata is correct and that a random data point can be read, ensuring that the file has not been corrupted during transfer. Additionally, data is checked using the CMIP6 PrePARE validation tool. PrePARE ensures that a file fully complies with the CMIP6 metadata standards. Software has been developed to correct any metadata issues that are identified by PrePARE.

As soon as possible, the CMORized output will be made publicly available on the Earth System Grid Federation (ESGF) data node located in UK. This is important given the tight deadlines for publications entering the IPCC AR6 report as well as the extensive data volumes. Top-level DOIs have already been made available for some of the project partners.

Currently, the coupled Stream1 simulations are available to all PRIMAVERA project members. Additionally, selected individuals from the CLIVAR project are working closely with PRIMAVERA scientists and have been granted access to the model output at JASMIN. A guidance note on data sharing has been developed. The note states that data will only be released to institutes who are actively collaborating with the analysis of PRIMAVERA data, all analysis work is performed at JASMIN and that the project will be acknowledged in results. Work package 10 is currently collaborating with some energy companies using this guidance note. This data sharing as well as the publication on ESGF is consistent with the data policy in the PRIMAVERA project proposal.

Preliminary analysis of coupled Stream1 simulations

Detailed assessment of the benefits of increased model resolution is dedicated to WP2 and deliverables therein. However, one example is shown here to underline the importance of CMIP6 HighResMIP.

Figure 1 shows the sea surface temperature bias averaged over the last ten years of the spinup-1950 simulation, using EN4 1950-54 mean as observations (corresponding to the initial condition). Common features include models being warmer at higher ocean resolution, thus reducing cold biases, in particular in the North Atlantic, while the Southern Ocean typically has an increased warm bias. Regarding the PRIMAVERA focus, the reduced cold bias in the North Atlantic should positively affect the simulated air-sea interactions and thus the simulated climate in the North Atlantic / European sector.

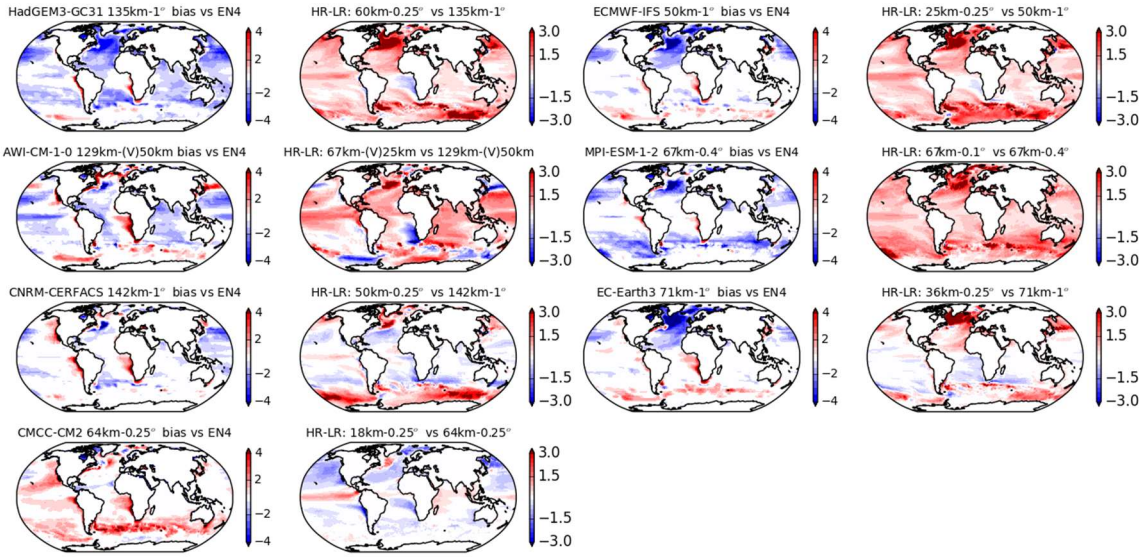

Figure 1: *Sea surface temperature bias (using EN4 1950-54 mean as observations) averaged over the last ten years of the high-resolution spinup-1950 simulations (1st and 3rd column), and sea surface temperature difference between high (HR) and low (LR) resolution version (2nd and 4th column). We note that for MPI-ESM-1-2 low- and high-resolution version of the Stream1 simulations apply the same ocean grid configuration, thus a simulation from WP4 applying a higher-resolution ocean grid configuration is used as high-resolution version. Figure provided by Malcolm Roberts (Met Office).*

Reference papers for coupled Stream1 simulations

Details of the CMIP6 HighResMIP protocol are given in Haarsma et al. (2016).

Haarsma RJ et al. (2016) High Resolution Model Intercomparison Project (HighResMIP v1.0) for CMIP6. Geoscientific Model Development, 9, 4185-4208, https://doi.org/10.5194/gmd-9-4185-2016

The CMIP6 HighResMIP simulations performed with the different models are described in the following publications:

Cherchi, A., et al. (2019): Global mean climate and main patterns of variability in the CMCC-CM2 coupled model. JAMES, 11, 185-209

Gutjahr, O., et al. (2019): Max Planck Institute Earth System Model (MPI-ESM) for High-Resolution Model Intercomparison Project (HighResMIP). Geosci. Model Dev., accepted

Haarsma et al.: HighResMIP versions of EC-Earth: EC-Earth3P and EC-Earth3P-HR. Description, model performance, data handling and validation. In preparation

Menary, M.B., et al. (2018): Preindustrial control simulations with HadGEM3-GC3.1 for CMIP6. JAMES, 10, 3049–3075

Roberts, C., et al. (2018): Climate model configurations of the ECMWF Integrated Forecast System (ECMWF-IFS cycle 43r1) for HighResMIP. Geosci. Model Dev., 11, 3681-3712

Roberts, M., et al.: Description of the resolution hierarchy of HadGEM3-GC3.1 model as used in HighResMIP coupled experiments. In preparation

Sidorenko, D., et al.: Evaluation of FESOM2.0 coupled to ECHAM6.3: Pre-industrial and HighResMIP simulations. JAMES, submitted

Voldoire, A., et. al.: Evaluation of CMIP6 DECK experiments with CNRM-CM6-1. JAMES, submitted

High-resolution modelling is a time and resource extensive exercise. Vidale et al. analyse the current performance of the PRIMAVERA models under the HighResMIP protocol. They show that performance varies strongly, depending on dynamical core formulation, IO strategy, output data intensity, as well as workflow choices, such as history file dumping frequency.

Vidale PL et al. (in preparation) Performance of multi-resolution GCMs under the HighResMIP protocol.

4. Lessons Learnt

Performance of coupled Stream1 simulations

Generally, an increase in model resolution is expected to reduce model biases. However, this is not always the case as shown here by an example from the MPI-ESM model: When increasing the atmospheric resolution from 1° to 0.5° in MPI-ESM1.2, we encountered the problem of a strong decline in the strength of the Atlantic meridional overturning circulation (AMOC) caused by the relatively weak surface winds in the high-resolution atmospheric component (via spin-down of North Atlantic gyre circulation and related northward heat and salt transport → strong cold and fresh bias in subpolar North Atlantic → large extension of subpolar sea ice cover → complete shut-down of subpolar deep convection). Tuning attempts to sufficiently strengthen the surface winds over the North Atlantic have failed. However, within WP3, the vertical mixing scheme in the ocean component of MPI-ESM1.2 has been replaced to the so-called KPP scheme, which increases the sensitivity of the mixing to the winds. This indeed avoids the subpolar cold and fresh bias and keeps the strength of the AMOC stable. Therefore, experience gained within WP3 is already applied to the coupled Stream1 simulations with MPI-ESM1.2.

Data transfer

Ideally, the CMIP6 data request and PrePARE validation tool would have been finalised before the coupled Stream1 simulations began. The changing data request created additional work for every PRIMAVERA partner as they adapted their simulations to match the changes. Additional work has been required by work package 9 to update the metadata in some of the first results so that they can be published through the ESGF.

5. Links Built

Links with other work packages

The coupled Stream1 simulations are the heart of PRIMAVERA, and are linked with almost all other work packages, most importantly

- The (coupled and atmosphere-only) Stream1 simulations provide the basis to assess the benefits of increased model resolution within WP2.
- The coupled Stream1 simulations provide reference simulations to assess the impact of new parameterizations developed within WP3 and applied in the coupled Stream2 simulations.

- The high-resolution coupled Stream1 simulations also provide reference simulations to assess the benefits of even higher model resolution attempted within WP4.
- Model climatology and initial conditions needed for the sensitivity experiments performed within WP5 are taken from the 1950-control simulations.

Links with other projects / endusers

- The coupled Stream1 simulations will, as CMIP6 HighResMIP simulations, be made publicly available on the ESGF data nodes, providing the basis for publications which will enter the IPCC AR6 report.
- Scientists within the CLIVAR project working closely with PRIMAVERA scientists have shown interest in analysing the coupled Stream1 simulations. Their ideas have been presented at the PRIMAVERA General Assembly in November 2017.
- The very high frequency output of atmospheric quantities such as near-surface air temperature and wind speed provides the basis for user engagement such as energy companies.