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PRIMAVERA

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

Deliverable D*8.1*

Progress summary following review of WPs

Deliverable Title	Progress summary following review of WPs	
Brief Description	*Taking a review of the project research to date, this report aims to describe the relevance and impact that the PRIMAVERA results have had to date. It also looks at this work in the context of future climate research directions*	
WP number	8	
Lead Beneficiary	*Met Office*	
Contributors	*Malcolm Roberts, Pier-Luigi Vidale, Jon Seddon, Paul van der Linden, Erika Palin*	
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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

This report is a brief summary of project progress to date, including significant outcomes, for the following:

- specific project successes and their policy / societal relevance,
- the key importance of JASMIN as a central platform,
- scientific benefits from the choices made for the Stream 2 model simulations,
- interactions with international bodies and at international meetings

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)*	y	
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)*	y	
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)*		n
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)*		n
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)*		n
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)*	y	

3. Detailed Report on Progress

This report focuses on the relevance and utility of PRIMAVERA research progress for furthering understanding of the climate system, for use in downstream applications and for its relevance to policy formulation.

The outcomes of the Fourth General Assembly (GA4) held in Barcelona in March 2019, together with the CMIP6 workshop, have been provided in the project's Quarterly Reports, and additional results through the Periodic Reporting and Independent Reviews provided to the Commission. This includes the detailed scientific motivation for the choices of the Stream 2 round of additional simulations. That information will not be repeated here, but it gives the context for what it has allowed us to plan and accomplish in in the project to date, as it enters its final stage.

3.1 International Science engagement and its outcomes

Coordination between PRIMAVERA and the UK programme ACSIS (Atlantic Climate System Integrated Study) was ensured through several joint meetings organised and attended by Adrian New in the context of ACSIS WP3.6. This aims to study internal decadal variability in the climate system using a range of models including the highest resolution UK models participating in PRIMAVERA and others undertaken in ACSIS. Specific discussion meetings to coordinate work in this area were held on June 5th, 2017 and April 2nd, 2019, both at the National Oceanography Centre in the UK.

As noted above, our GA4 meeting was held in conjunction with the WGCM CMIP6 workshop, which enabled a large amount of our science to be shown to a wider community. Several new collaborations were initiated and will produce manuscripts in future. There are also an increasing number of modelling groups who have completed the HighResMIP experiments and uploaded data to the Earth System Grid Federation to share, and some of this has been used in multi-model analysis (see later).

Engagement with various CLIVAR groups, including Climate Dynamics and Atlantic panels, is ongoing. This has so far produced one submitted manuscript on explosively developing extra-tropical cyclones (Gao et al., 2019) using our multi-model dataset. M Roberts has also joined a new US CLIVAR "Air-sea interactions working group" which will further exploit our multi-model datasets for improved understanding of atmosphere-ocean interactions.

We have also maintained a significant presence at international meetings such as EGU and AGU, being co-chairs of several sessions dedicated to high resolution modelling and data analysis.

3.2 Engagement with climate data users and its outcomes

Through WP10/11, PRIMAVERA is engaging with users of climate data in several key sectors – principally energy and insurance, but also transport. The progress of this work has inevitably been delayed by the delays to the delivery of the PRIMAVERA future simulations; it was challenging to engage users about the project during the period when no future outputs were available. Nonetheless, through mechanisms such as the User Interface Platform (D11.2), the Twitter account (223 followers currently) and attendance at events and conferences (examples below), and by using the historical simulations, we have endeavoured to engage users and maintain their interest in the project. Now that almost all the data are available, it has been possible to develop our engagement further. A data viewer (D11.4, forthcoming) is being produced which will provide a selection of PRIMAVERA data for users to view.

WP10 has explored the impact of high resolution on user-relevant metrics, including low-wind days (wind energy sector); characteristics of extratropical cyclones (ETCs; insurance and transport sectors); and heavy precipitation days (multiple sectors). This builds on the work done by other WPs to explore resolution impact on more fundamental processes and parameters. It is key to link process, metric and user-relevant impact (e.g. ETCs, widespread strong winds, insurance losses).

We have attended a range of conferences and events spanning users across the climate data spectrum – from those who are aware of climate variability and change but not yet managing the associated risks, through to technically adept and data-hungry users. The Met Office contingent of WP10/11 alone has attended twelve conferences for PRIMAVERA to date. Recently, for example, we led a workshop at the European Transport Conference where user-relevant PRIMAVERA research was presented, followed by a short group discussion about user needs in the sector. As a result of this workshop, one organisation who attended has asked us to lead a workshop exploring their climate change resilience and their ability to assess the risks posed to them by climate change.

We are preparing storm footprints data to share with insurance sector users in the hope of providing “better” information for them to use in their own catastrophe models. We have also worked closely with energy sector (hydropower) users who require high-resolution data to drive their hydrological models. The final stages of the project are expected to involve further user-focused engagement; the forthcoming deliverables D11.5 and D11.7 will evaluate the project from users’ perspectives, and detail the interactions with users against the various KPIs set in D11.1, respectively.

3.3 Policy relevant meetings and their outcomes

Meeting in Norway – bringing together various European and international projects to discuss common interests.

PL Vidale attended the “Climate Prediction workshop” in Bergen, June 2019, coordinated by the Bjerknes Climate Prediction Unit and the EU Climate Modelling Cluster in Bergen, Norway, where representatives from Blue-Action, PRIMAVERA, APPLICATE, CRESCENDO

were present. A key message was the importance of improving understanding of fundamental climate processes, which requires sustained, long-term ocean and atmospheric observation networks. Observational data such as that provided by the OSNAP programme are critical to improving model resolution and reducing errors, as well as continuing to monitor real-world climate change. Climate modellers and observational scientists are working together to define and provide these data in large-scale partnerships that will improve knowledge transfer between disciplines.

Massive investment in computing infrastructure is also required for the next generation of high-resolution climate models. Computing is rapidly evolving, and future researchers will need to respond by adopting a community approach, working on shared infrastructure in large teams, and allowing simulation data to be analysed by the wider scientific community. These new ways of working throw up a range of challenges, from effective funding and knowledge sharing, to data storage and management.

Overall, the underlying theme of both workshops was the importance of cooperation: between research teams, across scientific disciplines, and between the scientific community and other stakeholders. The EU Climate Modelling Cluster promotes cooperation among EU funded projects to boost their impact and optimize use of resources, avoiding potential overlaps as well. Improving the predictive capacity of the models goes hand in hand with targeting the results to where they can have the most impact, working with stakeholders to design climate services for the benefit of both science and society.

Lisbon meeting – bringing together modelling and observational communities.

Pier Luigi Vidale (Science Co-Coordinator) attended the “EuroGEOSS” workshop in Lisbon, 3-5 July 2019, where he presented a synthesis of PRIMAVERA achievements to date, together with examples of the use of environmental data for model assessment. Two of the main points highlighted were: i) high-resolution models increasingly pose a challenge for assessment, as they produce information at a resolution higher than observations and ii) there is a strong need for observational data and model data to be confronted on a like-to-like basis, which means inserting observational emulators into climate models. During the roundtable discussion, ways to collect and process higher and more specialised environmental data, suitable for broad range of decision-making models, were also considered. Recommendations for the future include one for EuroHPC to support deep learning from large datasets (e.g. from climate models) rather than just the simulation aspects (traditional HPC).

Malcolm Roberts (Science Co-Coordinator) attended a workshop on “Convergent Use of EU HPC, Cloud, Data & AI Resources for Earth System Modelling & EU Sustainability Policy Support” in Brussels on 27 November 2019. It raised some interesting ideas on producing a digital representation of Earth, derived from using extreme scale data and analysis as well as cloud computing and machine learning. There may be opportunities for PRIMAVERA and any successor project to follow up.

3.4 Reach of the scientific research

We have been closely involved in the initial drafts of the IPCC AR6 report, with some PRIMAVERA members on the Coordinating or Lead Author list, or as contributing authors.

For Chapter 3 on mean climate, we are contributing our HighResMIP simulations, a manuscript was submitted on some baseline performance of the PRIMAVERA models, and as part of this we are helping to produce multi-model figures via ESMValTool (Bock et al. 2019). Our work in adding new metrics to ESMValTool, which is one of the standard assessment packages for CMIP, will enable us to contribute more standardised plots to the report. A more detailed manuscript (Caron et al.) is in preparation.

For Chapter 9 on ocean processes, we submitted a manuscript (Roberts et al., 2019a) on the Atlantic Meridional Overturning Circulation, both mean state and future change at different model resolutions, and one of its figures should appear in the Chapter. The ensemble members produced in Stream 2 were essential to look at the range of response in the future and check that these are robust.

In Chapter 10 linking global to regional changes, we helped to coordinate a manuscript comparing PRIMAVERA global simulations (specifically precipitation over Europe) with regional CORDEX simulations, and we have agreed a figure for the chapter (Demory et al. 2019). A manuscript on European summer warming trends and links to large-scale circulation has also been submitted (Boé et al. 2019).

We were encouraged to submit at manuscript on future tropical cyclone changes for Chapter 11 on climate extremes (Roberts et al. 2019b), as well as describing their present-day simulation, which is in an accepted manuscript (Roberts et al. 2019c). The future changes make extensive use of data from the Stream 2 simulations, as an enhanced ensemble size is key to producing more robust results given the relative rarity of intense tropical cyclones. A manuscript on global extreme precipitation was submitted (Bador et al. 2019). This chapter is also making use of other extreme indices derived from the PRIMAVERA ensemble.

3.5 Common data platform

Having a common data and analysis platform (CEDA JASMIN) continues to be a key resource for the project - indeed the project would not function without it. As well as enabling cross-project communication and sharing of data, code and results, it has allowed us to involve a wide variety of external groups (IPCC authors and contributors, CLIVAR members, other international and European collaborating projects) to work with us on analysing our data. The topics of these collaborations include:

Marine heat waves, tropical cyclones, mid-latitude cyclones and explosive intensification, Atlantic Ocean circulation and AMOC, storm and surge, Antarctic Circumpolar Current and the Southern Ocean, North Atlantic Oscillation and mid-latitude storms.

Groups: IPCC, CLIVAR, Blue-Action, APPLICATE, various universities.

It also means that publication of our data to the CMIP archive via ESGF is made easier, since CEDA hosts the UK node of ESGF. Currently we are aiming at publishing about 5 TB of data per day to CMIP, which should allow us to complete the process before the end of the project.

The aforementioned workshop in Brussels introduced some developing European infrastructure that may be useful in future projects but does not yet have all the qualities

of JASMIN. We were also unable as a group to use EU PRACE supercomputing resource due to the lack of coordination and differing timescales between funding scientists (via H2020) and compute. We hope that future developments may help to make this possible, since to run fully complex Earth System Models at appropriate resolutions will require Tier 0 supercomputing and analysis infrastructure.

3.6 Extending the boundaries – Stream 2

Our choices for the Stream 2 simulations gave an emphasis on increasing our ensemble size, since for a variety of our scientific questions the internal variability in the models is such that distinguishing the forced signal is difficult. A variety of manuscripts described in 3.4 are already using these ensemble members, and a subset of this data will also be made available to the community via the CMIP ESGF data nodes. The additional ensemble members, together with targeted high frequency diagnostics, were a key demand of our user-facing work packages (WP10,11), to allow them to produce climate information relevant to those users.

4. Future directions

We will continue to write up and publish our work over the rest of the project. We had 19 published papers in 2019, with a further 25 either submitted or accepted and at least 30 more in preparation. Many of these submitted by the end-Dec 2019 IPCC AR6 submission deadline will appear in the IPCC AR6 report, where PRIMAVERA and HighResMIP are likely to have a significant profile in Chapters 3, 8, 9, 10 and 11.

There is work to do to summarise these many strands of work into high level overview papers, with a view to future opportunities. We have explored much new ground in the project, producing the first multi-model dataset at high resolution. Some of the results, particularly at the extreme edges of resolution (8 km in the ocean and 10 km in the atmosphere), suggest productive future avenues of research specifically in the influence of the mesoscales onto the larger scales and the promise of improving model variability.

References

Bador et al., 2019: Global extreme precipitation, in preparation.

Bock et al., 2019, Baseline performance of the PRIMAVERA models, in preparation.

Boé et al., 2019: European summer warming trends and links to large-scale circulation, in preparation.

Caron et al., 2019, Performance evaluation of the PRIMAVERA models, in preparation.

Demory et al., 2019, Comparison of PRIMAVERA simulations of precipitation over Europe with regional CORDEX simulations, in preparation.

Gao et al., 2019: Explosively developing extra-tropical cyclones, in preparation.

Roberts et al., 2019a: Mean state and future change at different model resolutions of Atlantic Meridional Overturning Circulation, in preparation.

Roberts et al., 2019b, Future tropical cyclone changes, in preparation.

Roberts et al., 2019c, The present day simulation of tropical cyclones, in preparation.