SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	The Impact of Stochastic Parametrisations in Climate Models: EC-EARTH System Development and Application
Computer Project Account:	spgbtpsp
Start Year - End Year :	2018 - 2020
Principal Investigator(s)	T. N. Palmer K. J. Strommen H. M. Christensen S. Juricke D. MacLeod A. Weisheimer
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Other Researchers (Name/Affiliation):	Paolo Davini (ISAC-CNR).

Summary of project objectives

(10 lines max)

The central aim of the project is to implement stochastic parametrisation schemes in multi-year integrations of the EC-Earth climate model and investigate their impacts on the modelled climate. Stochastic schemes are developed for all components of the EC-Earth model (atmosphere, ocean, sea-ice and land) and tested in different combinations. Model evaluation is focused both on basic mean state biases, long-term climate dynamics (e.g. ENSO), response to forcing (i.e. climate sensitivity) and the representation of key regional phenomena crucial for modulating local climate (e.g. Euro-Atlantic weather regimes, the Indian summer monsoon etc.)

Summary of problems encountered

The main technical problems encountered throughout the project were all related to the large volume of data associated with the production of an ensemble of climate model simulations. The basic challenge was to create a pipeline that allowed us to run as many ensemble members concurrently as possible without exceeding the SCRATCH limitations; because of the need to both transfer data elsewhere and validate the transferred data, these limitations were frequently being rubbed up against for extended periods of time. Due to delays in the delivery of the PRIMAVERA forcing files, this need for an efficient pipeline became particularly crucial. Thanks to frequent consultation with both ECMWF Support and Oxford Physics IT Support these problems were ultimately surmounted in a very satisfactory manner.

Experience with the Special Project framework

The experience of progress reports and applications has been perfectly smooth and transparent.

Summary of results

The aims of this project were to build on the efforts of the previous incarnation of the Special Project (SP) with the same name. In that SP, new stochastic schemes were developed for the atmosphere, ocean, sea-ice and land-scheme components of EC-Earth3, and testing was carried out of the atmospheric and land schemes in AMIP-style experiments. One of the primary goals of this follow-up SP was therefore to evaluate all the schemes individually in coupled simulations, as well as configurations with stochasticity active in all 4 components at once. Based on the results of this testing, a recommendation was to be made to the EC-Earth Consortium concerning the potential inclusion of stochasticity in the next version of EC-Earth, i.e., EC-Earth4.

The experimental framework of our main experiments were carried out in the context of the Horizon 2020 Project PRIMAVERA. This project ended successfully in the summer of 2020, and the Deliverable Reports have since been published following approval by the EU H2020 coordinators. Full details of the project can be found on the project website:

https://www.primavera-h2020.eu/

The results of our experiments and analysis was summarised in two such Deliverable Reports. The first, for which we were the lead authors, assessed the impact of stochasticity on the diurnal cycle of convection. A comparison was made against the impact of increased horizontal resolution, and the potential changes in diurnal cycle under an RCP8.5 forcing scenario were examined in EC-Earth3 with and without stochastic physics. The published report can be found here:

https://www.primavera-h2020.eu/primavera/static/media/uploads/Documents/project/primavera_deliverable_4-4.pdf

The second Deliverable Report to which we contributed contains a comprehensive assessment of the impact of the various stochastic schemes in coupled experiments, and can be found here:

https://www.primavera-h2020.eu/primavera/static/media/uploads/Documents/project/primavera_deliverable_4-1.pdf

Besides the results described in these published reports, we would like to comment on 3 additional sets of experiments carried out using the SP units that did not strictly fall within the umbrella of PRIMAVERA.

Firstly, while stochastic sea-ice perturbations appear to be able to generate a big impact (c.f. the results described in the above report), the impact of stochasticity in the ocean appears to be more limited. This is likely due to the fact that the 1 degree NEMO used in the PRIMAVERA experiments does not resolve eddies, and there is therefore not much variability available to be perturbed. We therefore carried out a short 10 year simulation of the high-resolution (T511+0.25deg NEMO) version of EC-Earth3 with stochastic ocean schemes turned on. At this resolution the stochastic perturbations appear to have significantly more impact, as suggested in Figure 1. Indeed, the magnitude of the impact on sea-surface temperature variability appears to be comparable to the impact of moving from a 1 degree ocean to a 0.25 degree ocean. These results are being actively studied in collaboration with Alessio Bellucci (CNR) and longer experiments are being planned.

Secondly, our plan to carry out abrupt 4xCO2 runs with SPPT, as outlined in the last progress report, was successfully carried out. A preindustrial control, 4xCO2 and 1-percent-CO2 simulation were all run on CCA, and are currently being analysed. Example output of the 4xCO2 run can be viewed at http://wilma.to.isac.cnr.it/ecearth/diag/REFORGE/s4co/

Finally, several short experiments were carried out to test a new, more physically consistent, water conservation fix for the SPPT scheme. This fix involves adding perturbations also to the surface water quantities (precipitation and evaporation), and had previously been found to work well in experiments using IFS cycle 40r3. Our testing in EC-Earth3 (cycle 36r4) was so far unsuccessful, as can be seen in Figure 2, showing the P-E imbalance for a number of different implementations. Our work suggests this is due to the tapering of SPPT at the surface. Adding perturbations to the surface quantities is only guaranteed (in theory) to create a consistent water budget under the assumption that there is no tapering of the perturbations near the surface. However, in cycle 36r4, removing the tapering of the perturbations does not seem to behave as expected from the experiments carried out with the later cycle 40r1. Based on this we have decided to rather work to implement the fix in EC-Earth4 (cycle 43r3), where the tapering of the perturbations can be more safely turned off.

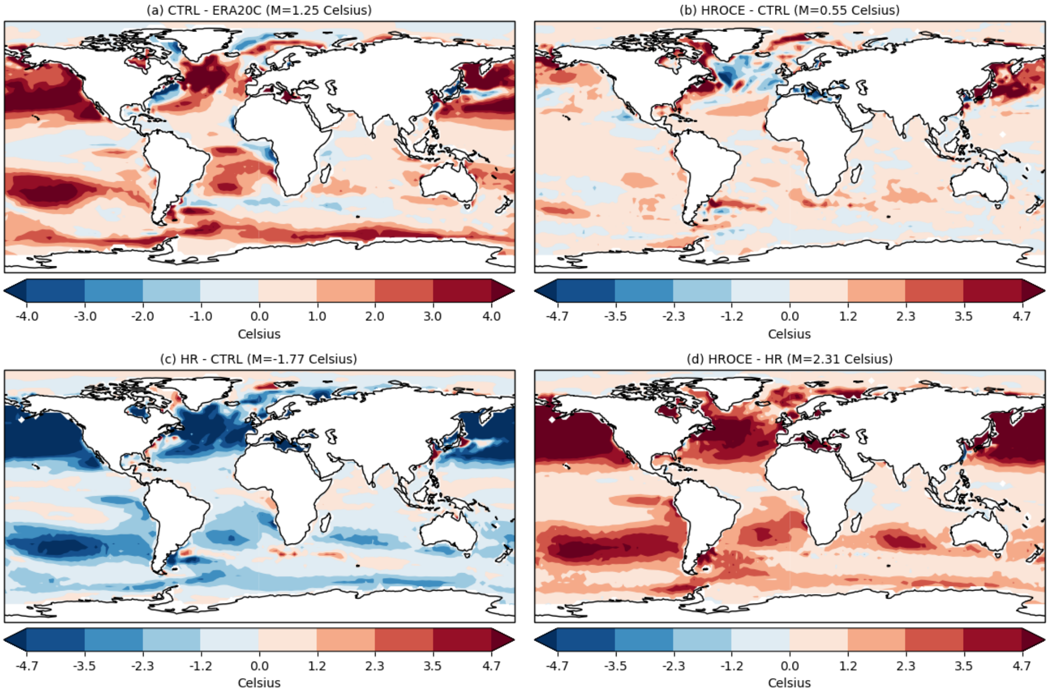

Figure 1: Monthly sea-surface temperature variance for a) CTRL-ERA20C, b) HROCE-CTRL, c) HR-CTRL and d) HROCE-HR. Here CTRL is a deterministic low-resolution (T255ORCA1) simulation, HR a deterministic high-resolution simulation (T511ORCA025) and HROCE a high-resolution simulation with stochastic ocean and sea-ice schemes active. The period covered is 1950-1959.

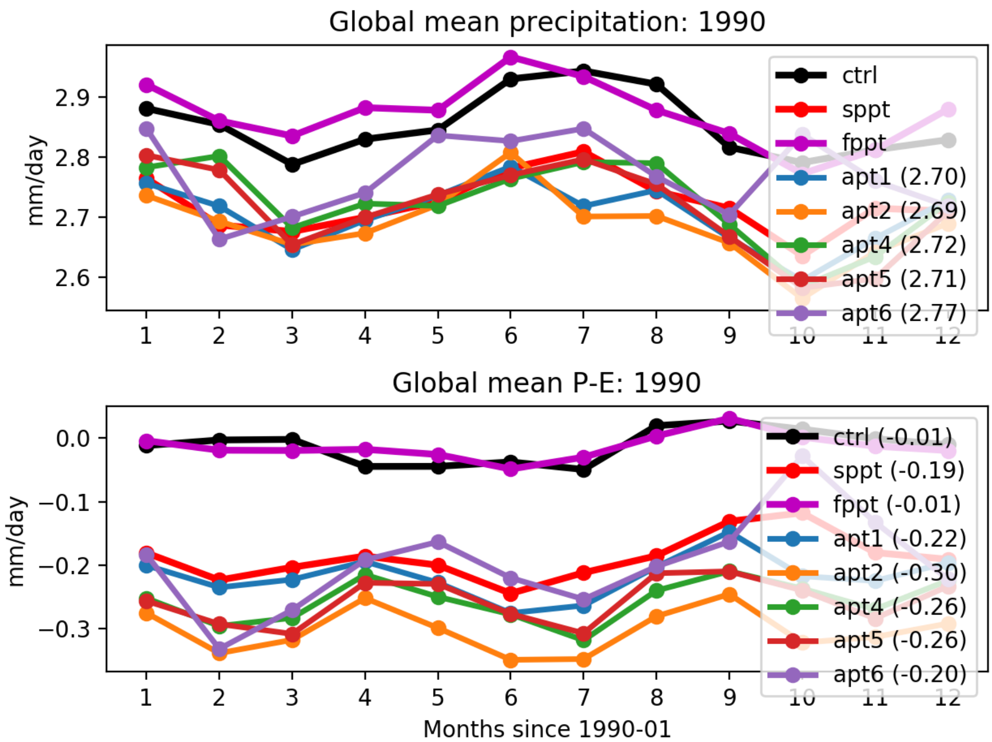

Figure 2: Timeseries of (top) global mean precipitation and (bottom) global mean precipitation minus evaporation for a number of different experiments covering 1990. CTRL (black) is the deterministic model, SPPT (red) is default SPPT, FPPT (purple) is SPPT with the global mass

balancer (as developed by J.von Hardernberg), and the APT* experiments are all different attempts at adding consistent perturbations to the surface, with and without tapering near the surface.

List of publications/reports from the project with complete references

https://www.primavera-h2020.eu/primavera/static/media/uploads/Documents/project/primavera_deliverable_4-4.pdf

https://www.primavera-h2020.eu/primavera/static/media/uploads/Documents/project/primavera_deliverable_4-1.pdf

Vidale, P. L., Hodges, K., Vannière, B., Davini, P., Roberts, M. J., Strommen, K., Weisheimer, A., Plesca, E., & Corti, S. (2021). Impact of Stochastic Physics and Model Resolution on the Simulation of Tropical Cyclones in Climate GCMs, *Journal of Climate*, *34*(11), 4315-4341.

Strommen, K., Juricke S. and Palmer, T. (2021). Improved Arctic-Midlatitude Teleconnections Through Stochastic Sea-ice Parameterisations. *In preparation.*

Dorrington J., Fabiano, F. and Strommen, K. (2021). Geopotential Jet Regimes in the CMIP6 and PRIMAVERA Ensemble: Model Performance and the Impact of Model Biases. *In preparation.*

Future plans

This Special Project has already been renewed under the same identifier (spgbtpsp). The main plans are broadly as follows:

- Better understand the impact of SPPT on climate sensitivity using targeted experiments and radiative kernel analysis to diagnose the feedbacks directly.
- Evaluate the impact of stochastic ocean schemes when using a 0.25 degree ocean.
- Development towards a stochastic EC-Earth4, including the implementation of the water conservation fix.

For further details we refer to the application for the renewed project.