SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2022
Project Title:	The Impact of Stochastic Parametrisations in Climate Models: EC-EARTH System Development and Application
Computer Project Account:	spgbtpsp
Principal Investigator(s):	T. N. Palmer K. J. Strommen H. M. Christensen S. Juricke D. MacLeod A. Weisheimer
Affiliation:	University of Oxford Physics Department Parks Rd, Oxford OX1 3PU
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Antje Weisheimer
Start date of the project:	2021
Expected end date:	2023

Computer resources allocated/used for the current year and the previous one

(if applicable)
Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	15,000,000	12,563,211	10,000,000	0
Data storage capacity	(Gbytes)	10,000	2000	10,000	0

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 (10 lines max)

No problems were encountered so far in this incarnation of the project.

Summary of plans for the continuation of the project (10 lines max)

In the remainder of this year, two sets of experiments are planned. One set will assess what effect the humidity fix to the SPPT scheme has on observed changes to equilibrium climate sensitivity when using SPPT in EC-Earth3. The second will be to add further ensemble members with stochastic sea-ice and ocean schemes active, including ones simulating future climate change, to assess what impact these schemes have on future trends.

In the final year of the project, ensemble experiments will be carried out with only one of the stochastic sea-ice and ocean schemes active, in order to understand which of the schemes (ice or ocean) are crucial to obtain the impact on Arctic-midlatitude teleconnections found when using both at once.

List of publications/reports from the project with complete references

A manuscript on the impact of stochastic sea-ice and ocean schemes on Arctic-midlatitude teleconnections in EC-Earth3 has undergone two rounds of revision and is now likely close to acceptance. The full review process and the preprint of the manuscript can be found here:

https://wcd.copernicus.org/preprints/wcd-2021-61/

Summary of results

The project has been focused in two directions so far. We describe current results of both in turn.

<u>Climate sensitivity</u>

As detailed in the previous progress report, experiments were carried out to assess the impact of the SPPT scheme on equilibrium climate sensitivity (ECS) in EC-Earth3, as well as on individual climate feedbacks using radiative kernel methods. These consisted of abrupt4xCO2 experiments with and without SPPT, and pre-industrial control counterparts, which are the CMIP standard experiments used for estimating ECS. Some preliminary analysis is Gregory plots of net top-of-atmosphere flux imbalance versus global mean surface temperatures are shown for in Figure 1a (DET: no SPPT) and 1b (STO: with SPPT). These suggest that the inclusion of SPPT has lowered the ECS in EC-Earth3 by about 7%. This is consistent with what was found for transient simulations in Strommen et al. 2019, but not consistent with the follow-up study Meccia et al. (2020).

To understand this better, individual climate feedbacks have been computed following the same methods as described in Zelinka et al. (2020), which the reader should consult for details. A summary of these are shown in Figure 2, while a spatial map of the long and short-wave cloud feedbacks are shown in Figure 3. Notable differences in cloud feedbacks can be seen when adding SPPT, comparable to the difference between two CMIP6 model by comparison to Zelinka et al. (2020). However, Figure 2 also suggests a lot of the difference with SPPT may be accounted for by the residual term, pointing to subtler differences than those diagnosed by the standard climate feedback breakdown. This is currently being studied further: in particular, we next aim to apply the climate feedback decomposition to the transient simulations to ascertain if the non-linear behaviour of the impact of SPPT can be seen as a time-varying climate feedback shift.

<u>Arctic mid-latitude teleconnections</u>

Two 6-member ensembles of EC-Earth3 were carried out covering the historical period 1950-2015, one control (no stochastic schemes) and one with stochastic sea ice and ocean schemes active. The inclusion of stochasticity to these components was found to notably improve the representation of the observed teleconnection between November Barents-Kara sea ice and the winter North Atlantic Oscillation. No such teleconnection was apparent in the control ensemble, nor in the CMIP6 ensemble as a whole, but is robustly there with stochastic sea ice and ocean schemes: see Figure 4.

These results have been written up into a paper, currently under review. The paper, which includes all details and comprehensive analysis and discussion, can be viewed publicly here:

https://wcd.copernicus.org/preprints/wcd-2021-61/

FIGURES

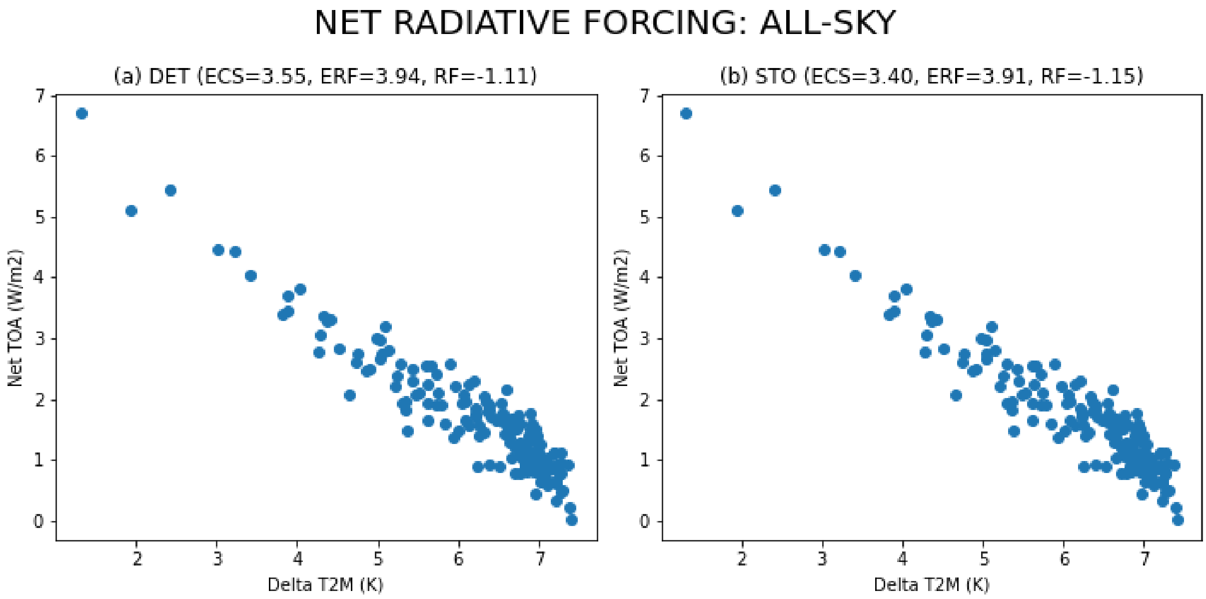

Figure 1: Gregory plots of net top-of-atmosphere (TOA) fluxes versus the amount of surface global warming (relative to the pre-industrial control mean) in the abrupt4xCO2 simulations, for (a) DET (no SPPT), and (b) STO (with SPPT). The caption gives estimates of the ECS, effective radiative forcing (ERF) and climate feedback (RF) based on fitting a straight line to the data.

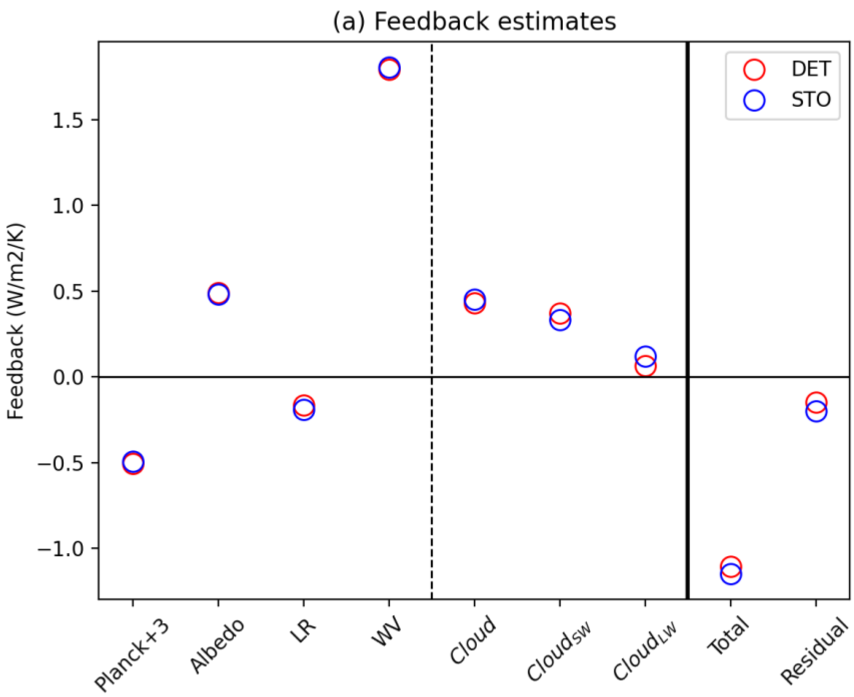

Figure 2: Climate feedback estimates for EC-Earth3, with SPPT (STO) and without (DET). The methodology, terminology and abbreviations follow those of Zelinka et al. (2020).

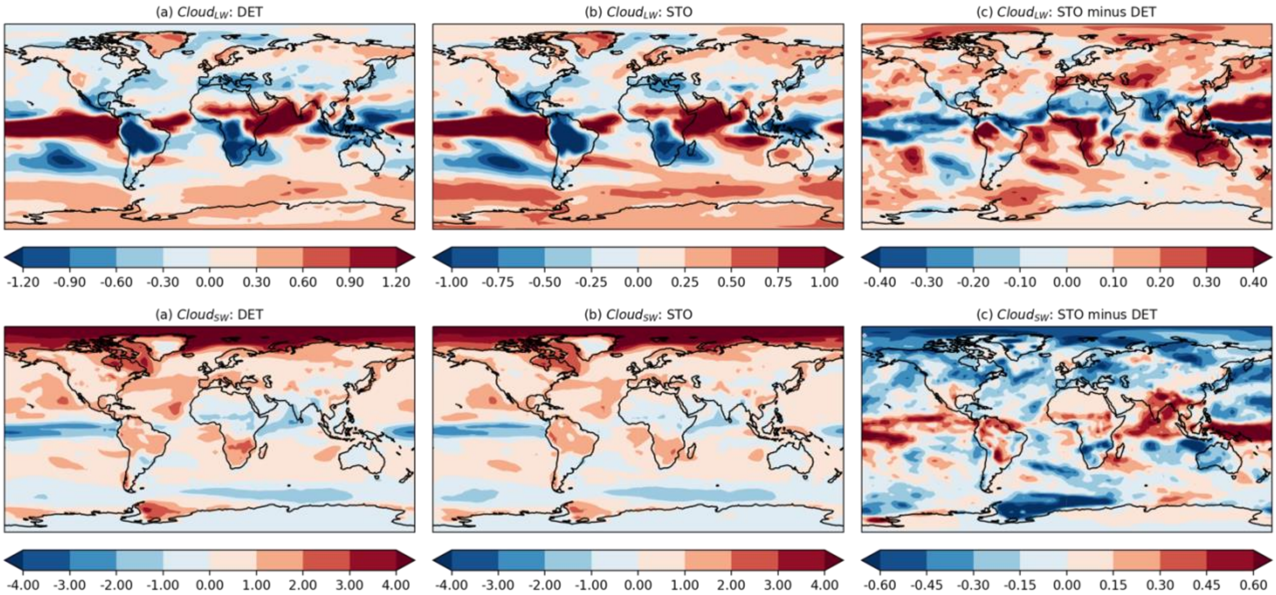

Figure 3: Top row: the long-wave cloud feedback in (a) DET, (b) STO, and (c) STO minus DET. Bottom row: same but the short-wave cloud feedback.

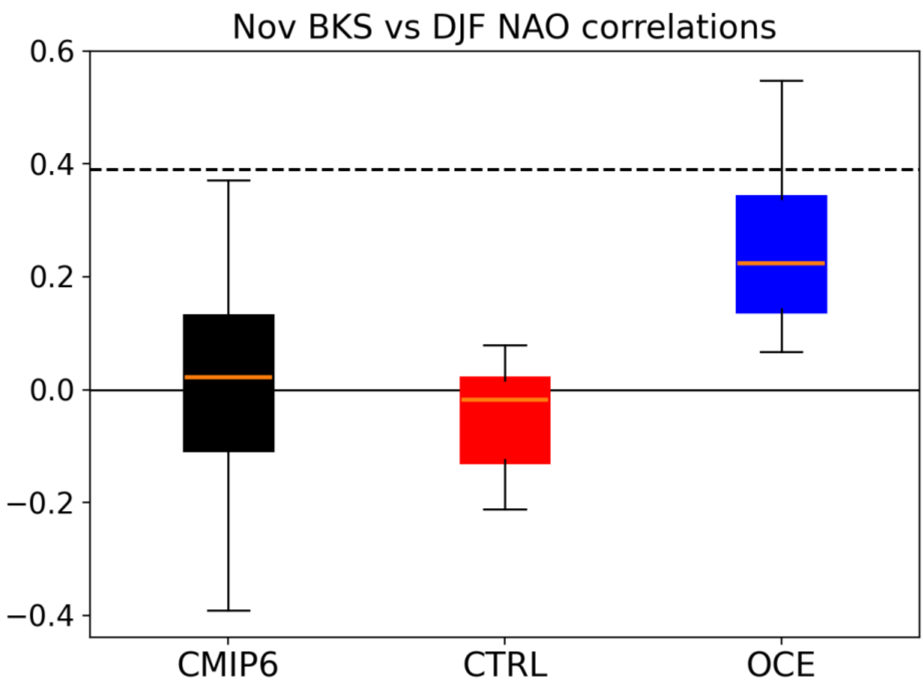

Figure 4: Box and whisker plots of correlations between November Barents-Kara sea ice concentration and the winter (DJF) North Atlantic Oscillation (NAO), over the period 1980-2015; for CMIP6 (the full historical ensemble), CTRL (the deterministic EC-Earth3 control ensemble), and OCE (the stochastic EC-Earth3 ensemble).

REFERENCES

Meccia, V. L., Fabiano, F., Davini, P., & Corti, S. (2020). Stochastic Parameterizations and the Climate Response to External Forcing: An Experiment With EC-Earth. Geophysical Research Letters. https://doi.org/10.1029/2019GL085951

Strommen, K., Watson, P. A. G., & Palmer, T. N. (2019b). The Impact of a Stochastic Parameterization Scheme on Climate Sensitivity in EC-Earth. Journal of Geophysical Research: Atmospheres. https://doi.org/10.1029/2019JD030732

Zelinka, M. D., Myers, T. A., McCoy, D. T., Po-Chedley, S., Caldwell, P. M., Ceppi, P., et al. (2020). Causes of higher climate sensitivity in CMIP6 models. *Geophysical Research Letters*, 47, e2019GL085782. https://doi.org/10.1029/2019GL085782