SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2017
Project Title:	The Impact of Stochastic Parameterisations in Climate Models: EC-EARTH System Development and Application
Computer Project Account:	spgbtpsp
Principal Investigator(s):	Prof Tim Palmer Dr Hannah Christensen Dr Andrew Dawson Dr Stephan Juricke Dr Dave MacLeod Dr Aneesh Subramanian Dr Peter Watson Dr Kristian Strommen
Affiliation:	University of Oxford
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Antje Weisheimer
Start date of the project:	Jan 2015
Expected end date:	Dec 2017

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)			9600000	6063740

Data storage capacity	(Gbytes)			7000	

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. Oxford University recently joined the EC-Earth Consortium. Because the EC-Earth model is based on System 4, all development done so far at Oxford for System 4 will be tested and implemented within the EC-Earth system. Once the stochastic parametrisations have been implemented, the impact of these on the coupled model mean state and variability can be investigated.

Summary of problems encountered (if any)

Official development of the new EC-Earth version 3.2 was (and is) severely delayed due to difficulties of satisfactory tuning and in alleviating a deficient AMOC in coupled mode. As a result, no coupled testing at all has been possible so far, and AMIP testing was delayed until a tuned version was ready for use. This seriously constrained our ability to use computing units in a timely fashion.

Summary of results of the current year (from July of previous year to June of current year)

Brief summary:

1. Primary simulations of new stochastic schemes
2. Water conservation experiments
3. Stochastic ocean development

Primary experiments

The main goal of this reporting period was to carry out a number of simulations in EC-Earth 3.2 to test the impact of the two new stochastic schemes, ‘independent SPPT’ (ISPPT; see Christensen et al 2017) and stochastic land (Land-scheme; see MacLeod et al 2016) on the model climate. The schemes had essentially been implemented already at the start of this reporting period, though a few new features were added, including proper restart capacity which respected the stochastic patterns. Additionally, the mass fix was implemented in the schemes, mimicking that in operational SPPT to ensure the global average tendency was preserved after perturbation. This simple fix (described in Leutbecher et al 2017) computes the global average of each tendency before and after the perturbations, and adds the correction back on (with a simple spatial weighting) to ensure the mean stays the same. A bug which led to incorrect generation of stochastic patterns was also identified and resolved.

We first performed a number of preliminary experiments for tuning purposes. These comprised of 10 and 20 year atmosphere only runs initialized at 1990 (using the default EC-Earth initial conditions). The output was then post-processed and energy fluxes were analysed at both the top of the atmosphere (TOA) and the surface, comparing against observational estimates from the literature. Standard tuning parameters (RPRCON, RVICE, RLCRITSNOW, RSNOWLIN2, ENTRORG, DETRPEN and ENTRDD) were then altered in order to bring the TOA and surface net energy fluxes in line with observational estimates in the integration period. We also used these experiments to tune the strength of the stochastic perturbations themselves, as these do significantly impact on the net fluxes. With ISPPT, we tested the impact of making certain tendencies have the same perturbations. Finally, we also implemented proper restart capabilities of the stochastic schemes to ensure no discontinuities in the stochastic patterns upon restarting the model.

The final tests in atmosphere only mode were performed with the default parameters for EC-Earth 3.2.1, a version that had been tuned for AMIP simulations, so that we could assess the raw impact of the schemes, even if they then suffered from a poor net TOA energy balance, as was the case with ISPPT in particular. For these simulations, we tested four different EC-Earth configurations: the default deterministic set-up, regular SPPT, ISPPT and the Land-scheme (all stochastic schemes with the mass fix turned on). For ISPPT, we opted to make the perturbations of the two convective tendencies identical, and the rest of them completely independent of each other. The strength of the perturbations for the different time and length-scales were the same as for SPPT. For the Land-scheme, the strength of the perturbations was set to 0.33 for all time and length-scales. A series of ensemble simulations were then carried out for each configuration. We had 5 initial conditions from different years (1980, 1975, 1970, 1965, 1960) in order to sample different ocean states. From each initial condition a 20 year simulation was carried out for each scheme. Initial conditions were obtained from the EC-Earth group at the Barcelona Supercomputing Centre (BSC). Output was automatically processed and stored on ECFS for analysis.

Figures below show the net impact of ISPPT and the land-scheme on precipitation and soil temperature (level 1) respectively. Here, ICA1, ICA2, …, ICA5 are the 5 simulations with ISPPT, LCA1, …, LCA5 the 5 simulations with the land-scheme and DCA1, …, DCA5 the 5 deterministic simulations. The top left in each plot shows the mean of all the differences where changes that are not statistically significant have been masked out.

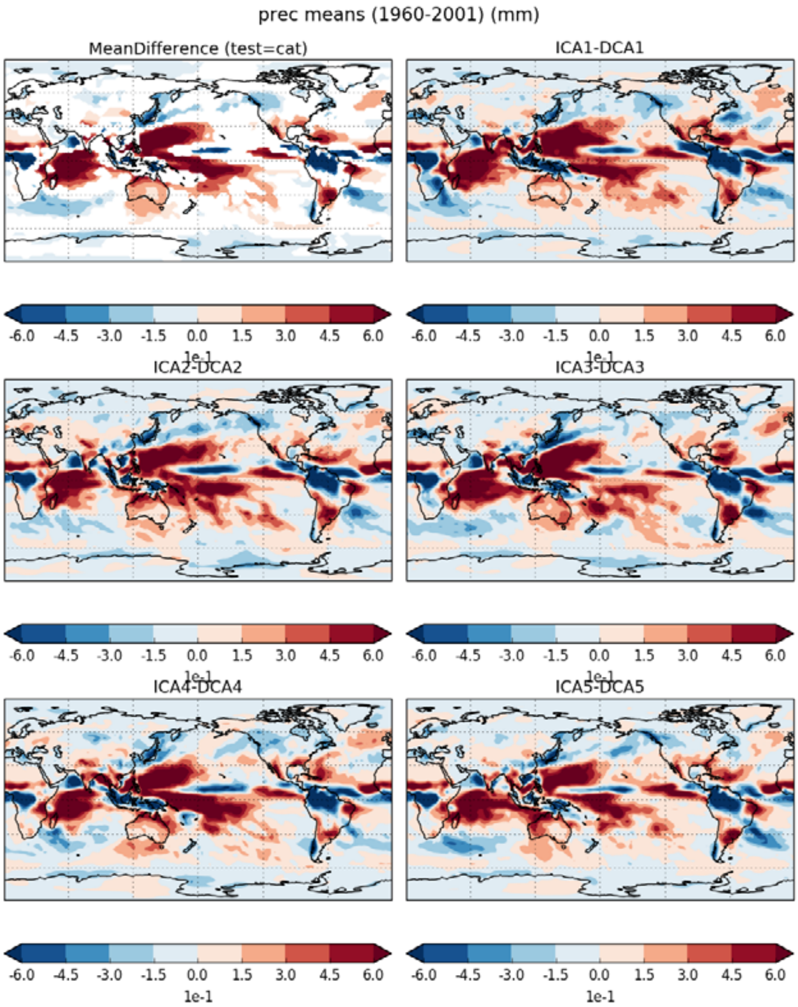

Figure 1: Precip differences between ISPPT simulations ICA1, ICA2, ICA3, ICA4 and ICA5 and deterministic simulations DCA1, DCA2, DCA3, DCA4 and DCA5. Start-dates in each case is, in order, 1960, 1965, 1970, 1975, 1980 (January 1^{st} each year). Top left "Mean difference" is the mean of all these differences, where only statistically significant (with respect to a T-test) changes have been kept.

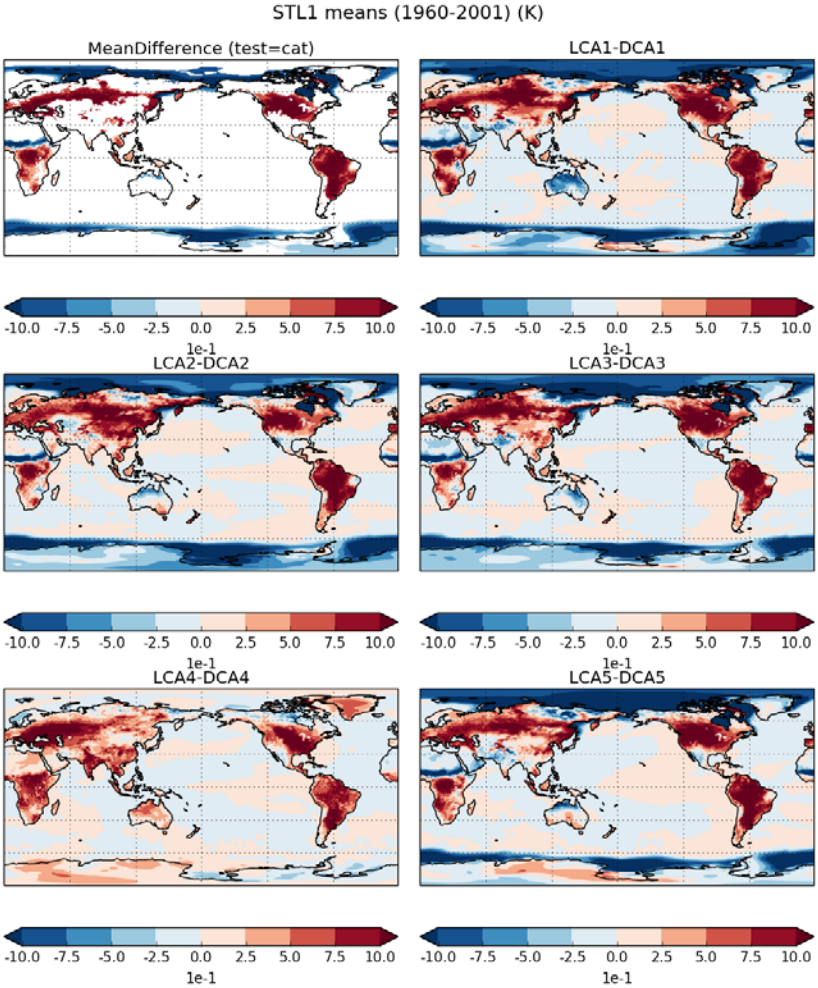

Figure 2: Soil temperature (level 1) differences between Land-scheme simulations LCA1, LCA2, LCA3, LCA4 and LCA5 and deterministic simulations DCA1, DCA2, DCA3, DCA4 and DCA5. Start-dates in each case is, in order, 1960, 1965, 1970, 1975, 1980 (January 1st each year). Top left "Mean difference" is the mean of all these differences, where only statistically significant (with respect to a T-test) changes have been kept.

Extensive analysis of the impacts are being carried out and will be compiled into an implementation paper for these schemes. Preliminary analysis suggests that the main impact of ISPPT on the global energy budget is via an increase in cloud liquid water, increasing the amount of reflected shortwave radiation, and via increased evaporation due partially to increased wind-speeds: this extra evaporation leads to increased total column water and ultimately more precipitation. For the Land-scheme, the main impact comes from a large increase in run-off, which leads to a drying out of the soil and consequently an increase in temperature at the surface.

Secondary Experiments: water conservation

A long-standing problem with SPPT, inherited in ISPPT as well, is the fact that the perturbations do not conserve mass. In particular, this leads to a significant imbalance in precipitation and evaporation, that is currently artificially rectified with the 'mass fixer' described above. Work has been undertaken to attempt to alleviate this problem more satisfactorily by adding perturbations to the surface consistent with those in the atmosphere.

As seen in Figure 3, the control ensemble member for the No SPPT experiment shows a total column water value that lies amongst ensemble members' spread, while for the SPPT experiment the control member has a higher total column water compared to any of the ensemble members. This indicates that the SPPT scheme is perturbing the IFS model in such a way that the ensemble members become consistently drier than the control member. When we add surface perturbations along with SPPT, as seen in Figure 1(c), we see that the surface flux perturbations helps alleviate the non-conservation problem to some extent. We are currently working on extending this work further to create a consistent stochastic parameterization scheme for the atmosphere and the surface fluxes with many different start dates. Some of the units from spgbtpsp account were used for these experiments and development of this scheme.

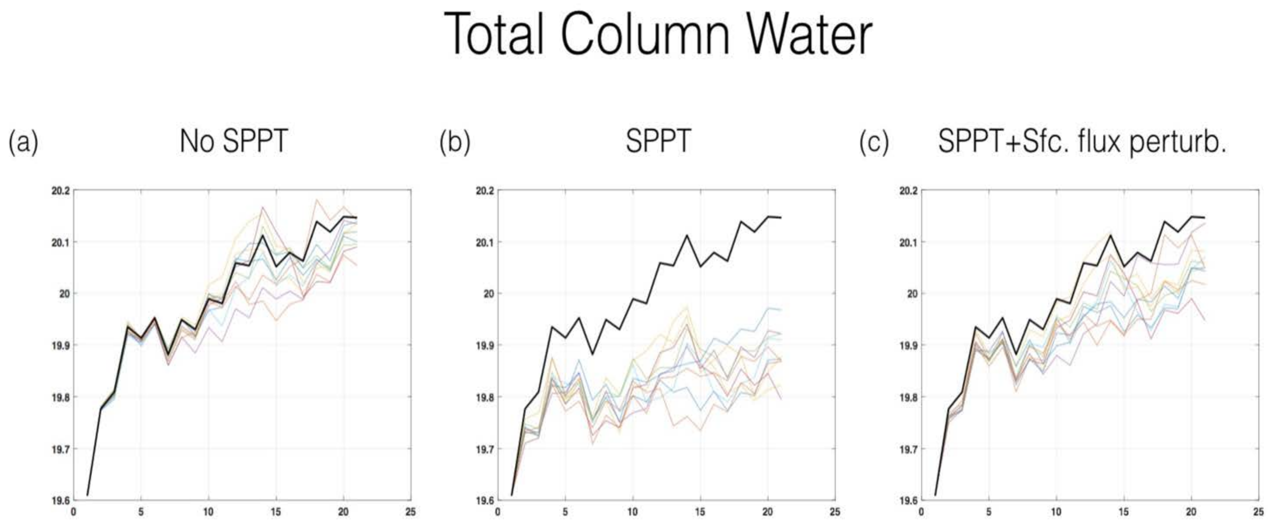

Figure 3: (a) shows the total column water vapor for the control (unperturbed) ensemble member (black line) and other ensemble members for the ensemble run with no SPPT active. (b) Shows the total column water vapor for the control (unperturbed) ensemble member (black line) and other ensemble members for the ensemble run with SPPT active. (c) Shows the total column water vapour for the control (unperturbed) ensemble member (black line) and other ensemble members for the ensemble run with SPPT and surface flux perturbations active.

Tertiary experiments: ocean scheme

We have also implemented new stochastic perturbation schemes for the NEMO ocean model in the framework of EC-Earth. These schemes are extensions of the previously tested schemes which are: perturbations to 1) the Gent-McWilliams eddy parametrization, 2) the turbulent kinetic energy vertical mixing scheme and 3) the enhanced diffusion vertical mixing scheme for unstable stratification (see Juricke et al 2017). The new schemes include stochastic perturbations to surface and bottom boundary stresses, horizontal diffusivity and viscosity, a stochastic albedo parametrization for sea ice melt conditions and a perturbation to the ice strength parametrization as part of the sea ice. We started testing these schemes in NEMO standalone simulations at 1° and did some preliminary tests at 0.25° horizontal resolution. The future plan is to include these schemes in the coupled EC-Earth setup and investigate their impact on the simulated climate. Potentially, some or all of these schemes will be added to the setup with the three already tested ocean schemes listed above. The extended setup will then be used for the PRIMAVERA simulations.

We also investigated the impact of the three stochastic schemes mentioned above on seasonal predictions in a set of 10-month ensemble forecasts. The results are currently being prepared for journal submission. They show that including the stochastic schemes as an estimate of model uncertainty improves seasonal ocean forecasts. Reliability is increased from month 3 onwards and skill scores of sea surface temperature and also 2m air temperature are considerably improved from month 8 onwards. These are promising results that will be revisited once the new schemes have been sufficiently tested.

List of publications/reports from the project with complete references

Juricke, S., T. N. Palmer, and L. Zanna, 2017: Stochastic subgrid-scale ocean mixing: Impacts on low-frequency variability. Journal of Climate, 30 (13), 4997{5019, doi:10.1175/JCLI-D-16-0539.1.

Juricke, S., T. N. Palmer, and L. Zanna, 2017: Stochastic subgrid-scale ocean mixing: Impacts on low-frequency variability. Journal of Climate, 30 (13), 4997{5019, doi:10.1175/JCLI-D-16-0539.1.

MacLeod, D. A., Cloke, H. L., Pappenberger, F. and Weisheimer, A. (2016), Improved seasonal prediction of the hot summer of 2003 over Europe through better representation of uncertainty in the land surface. Q.J.R. Meteorol. Soc., 142: 79–90. doi:10.1002/qj.2631

Christensen, H.M., Lock, S.-J., Morox, I.M., and Palmer, T.N. Introducing Independent Patterns into the Stochastically Perturbed Parametrisation Tendencies (SPPT) scheme. Q.J.R. Meteorol. Soc., in press. doi: 10.1002/qj.3075

Summary of plans for the continuation of the project

We intend to begin testing of the schemes in coupled mode as soon as a tuned version is available. In the meantime, we will carry out further tuning exercises to alleviate the negative energy flux bias introduced by ISPPT to achieve realistic net TOA fluxes, which we consider particularly important for coupled simulations.

Analysis will then be carried out on any potential benefits from these schemes, both in improving raw mean states, spread, as well as dynamics in the form of regime behaviour.

Analysis of the atmosphere only experiments conducted will be analysed further and a paper with this analysis, together with an extensive description of each scheme and its implementation, will be prepared and published.