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	2018 (July 2017-June 2018)
Project Title:	Impact of atmospheric stochastic physics in high-resolution climate simulations with EC-Earth
Computer Project Account:	SPITVONH
Principal Investigator(s):	Jost von Hardenberg
Affiliation:	Institute of Atmospheric Sciences and Climate, National Research Council (ISAC-CNR), Italy
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Antje Weisheimer
Start date of the project:	1/1/2016
Expected end date:	31/12/2018

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)	25000000	21188608	25000000	1573502
Data storage capacity	(Gbytes)	50000	/	50000	/

Summary of project objectives
(10 lines max)

In this special project we explore the impact of Stochastic Physics (in the atmosphere) in long climate integrations as a function both of model resolution and stochastic parametrizations in coupled and uncoupled configurations. To this day, atmospheric stochastic parameterizations have not been tested extensively for long climate runs. Particular attention will be placed to the tuning of the model using the SPPT atmospheric stochastic parameterization for climatic applications, with the goal of reaching a realistic representation of the main radiative fluxes and conservation of energy and humidity in the atmosphere.

Summary of problems encountered (if any)
(20 lines max)

No specific problem encountered in the period July 2017-June 2018.

Summary of results of the current year (from July of previous year to June of current year)
This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

Model tuning

Both due to inclusion of additional CMIP6 forcing fields and to further developments and fixes in the model, EC-Earth has been subject to rapid development in the past year. We have attempted to maintain at all times a well-tuned version of the model after each change and, where possible, to establish the impact of the changes in terms of global energy fluxes, also in model versions with stochastic physics and at high resolution. The tuning strategy aims at achieving realistic equilibrium temperatures in long forced fixed-year runs and realistic temperatures and radiative fluxes in transient present-day runs, particularly in AMIP experiments. In coupled runs the climate sensitivity estimated from previous long coupled runs is used to estimate equilibrium temperatures based on current net surface fluxes and mean global temperature and to suggest tuning corrections (using so-called Gregory plots). Using partially also resources from this project, additional tuning effort has been dedicated to model changes related to the parameterization of background surface albedo as a function of vegetation cover, the impact of different past, present and future land vegetation covers, sensitivity to different boundary and initial conditions, in particular orography, the implementation of stratospheric aerosol forcing, fixes in atmosphere-ocean coupling and energy conservation issues and the impact of different cloud activation scheme. A more detailed description of these issues is available in the report of the SPNLTUNE special project.

Impact of the Stochastic Physics on ENSO in past and future coupled simulations

We evaluated the impact of stochastic physics in past-to-future (PFC) simulations with IFS at the T255L91 configuration, coupled with NEMO using the ORCA1 grid (a tripolar grid with resolution of 1 longitudinally and refinement to 1/3 at the Equator) with 46 vertical levels. Six ensemble members were run, three with the stochastic parameterisation active and three control members without stochastic parameterisation, from 1850 to 2100 (from 2005 to 2100 the forcing is consistent with the RCP8.5 scenario). The Stochastic Physics schemes used in the Atmospheric component of the EC-Earth Model are the same used in the operational ECMWF Seasonal Forecast System (System 4).

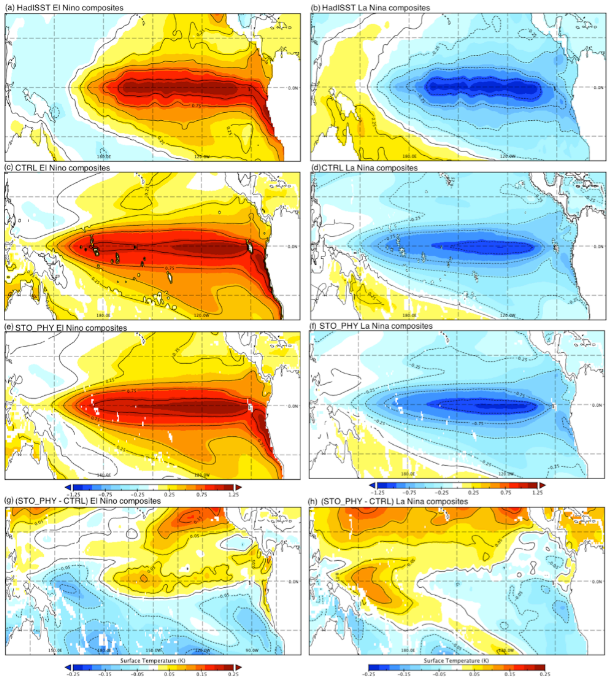

Figure 1: Sea Surface Temperature (SST) composites (1870-2005) of El Niño events in (a) HadISST1 (c) CTRL and (e) STO_PHY runs and composites of La Niña events in (b) HadISST1, (d) CTRL and (f) STO_PHY runs.

The PFC experiment consisted of six ensemble members: three ensemble members use stochastic physics schemes in the atmospheric component of the EC-Earth Model (STO_PHY); three ensemble members were run without including stochastic physics (CTRL). In our analysis we tried to assess the impact of stochastic physics on ENSO simulations and discuss the mechanisms leading to such an impact. Main motivation of our study is the recent result by Christensen et al. 2017, where it is shown that the use of the multiplicative Stochastically Perturbed Parameterization Tendencies (SPPT) scheme in the Community Atmosphere Model (the atmospheric component of CCSM4) improves significantly the ENSO power spectrum by reducing the excessive power at periods of three-four years and increasing the power with periods less than three years.

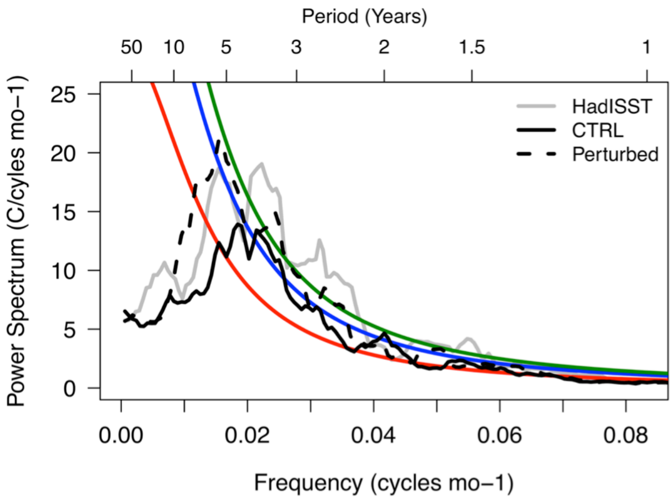

Figure 2: The power spectrum of the Niño 3.4 timeseries in ensemble mean CTRL (solid black), ensemble mean STO_PHY (dashed black) and HadISST1 (grey). The red line is the Markov red noise spectrum (red) and its 95% (blue) and 99% (green) confidence bounds.

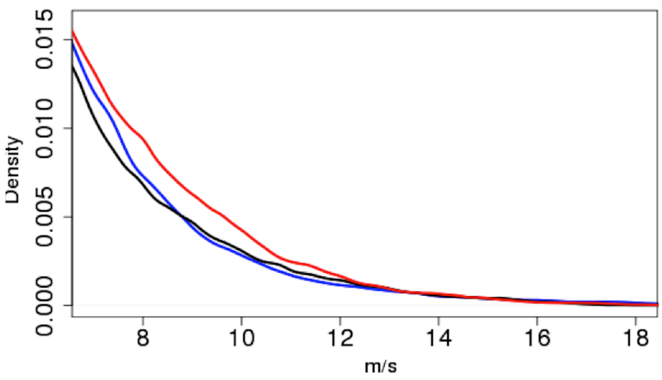

Figure 3: The distribution of U850 (westerly wind) anomalies (m s^{-1}) from the ERA-Interim dataset (black), ensemble mean CTRL (blue), and ensemble mean STO_PHY (red). The data are first smoothed using a 5-day running mean and low frequency variability (over 1 year) is filtered, and the PDFs are constructed using all spatial points between 5N and 5S and between 130E and 260E.

By comparing an ensemble of three members of control historical simulations with three ensemble members that include stochastic physics in the atmosphere, we find that the implementation of stochastic physics in the atmosphere improves the excessively weak representation of ENSO in EC-Earth. Specifically, the amplitude of both El Niño and, to a lesser extent, La Niña increases (Fig 1).

Stochastic physics ameliorates the temporal variability of ENSO at interannual time scales, demonstrated by the emergence of peaks in the power spectrum with periods of 5-7 years and 3-4 years (Fig 2).

The impact of stochastic physics on the amplitude of ENSO in EC-EARTH is opposite to that found on CCSM4 and shown in Christensen et al. 2017. However, in both cases the inclusion of stochastic physics in the atmospheric component of the coupled model seems to lead to an improved representation of ENSO variability and amplitude.

This apparent “paradox” can be explained by analogy with an idealized Delayed Oscillator (DO) model with stochastic noise. In the DO model stochastic perturbations increase the ENSO amplitude when the atmosphere-ocean coupling is weak, while they decrease the ENSO amplitude when the atmosphere-ocean coupling is strong. The “weakness” of the power spectrum in the EC-Earth CTRL

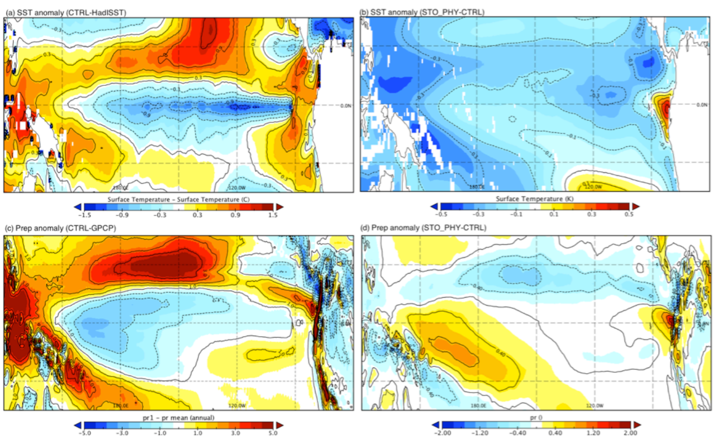

Figure 4: (a) The SST bias (CTRL-HadISST1) in EC-Earth and (b) the SST difference between STO_PHY and CTRL. Unit is □C (c) The precipitation bias (CTRL-GPCP) and (d) the precipitation difference between STO_PHY and CTRL. Unit: mm/day.

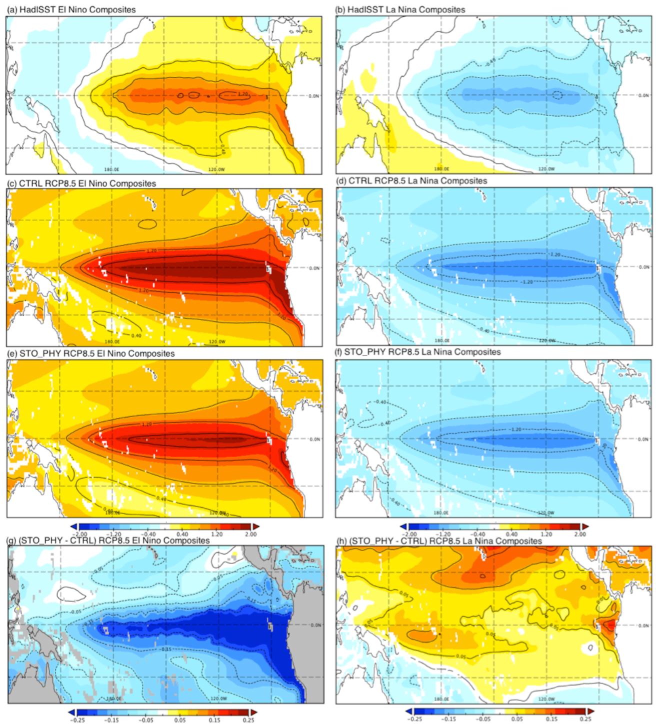

Figure 5: As Figure 1 but for CTRL_RCP8.5 and STO_PHY_RCP8.5 and HadISST1.

suggests that this model might fit in the weak coupling "category". (While the prominent power spectrum in CCSM4 suggests that CCSM4 might fall in the strong coupling “category”). This would imply that a too weak atmosphere and ocean coupling might be responsible for the underestimated ENSO variability in the EC-Earth control runs.
The stochastic physics in the atmosphere increases Westerly Wind Burst (WWB) occurrences (i.e. amplification of noise amplitude) that would trigger more and stronger El Niño events (i.e. increase of ENSO oscillation) in the coupled EC-Earth model (see Fig. 3). Further analysis of the mean state bias of EC-Earth suggests that a cold SST and dry precipitation bias in the central tropical Pacific together with a warm SST and wet precipitation bias in the western tropical Pacific are responsible for the coupled feedback bias (weak coupling) in the tropical Pacific that results in the weak ENSO simulation in EC-Earth (Fig.4).

In order to strengthen the argument that the mean state is one of the possible reasons for the deficiency of ENSO simulation in climate coupled models, the same analysis was performed considering the impacts of stochastic physics on ENSO with future scenario coupled runs. The future scenario runs (CTRL_RCP8.5) are forced following the RCP8.5 scenario thus simulating a global warming world. Therefore, these EC-Earth simulations can be treated as if they were performed using a coupled model with an even larger mean state bias with much warmer SST anomalies compared to historical experiments. In CTRL_RCP8.5 the amplitude of both El Niño (Figure 5c) and La Niña (Figure 5d) is stronger than the CTRL historical experiments. With stochastic physics, the amplitude of El Niño decreases significantly but the amplitude of La Niña decreases less, as shown for historical experiments.

The change of the temporal variability of ENSO is shown in Figure 6 for CTRL_RCP8.5, STO_PHY_RCP8.5 and HadISST1. CTRL_RCP8.5 has sharp and narrow ENSO power spectrum: applying stochastic physics the power spectrum decreases for the time period between 3 to 4 years.

Overall the impact of stochastic physics on ENSO behaviour in the EC-Earth RCP8.5 scenario is the opposite to that seen in historical experiments. Indeed, in the “climate change” simulation the impact

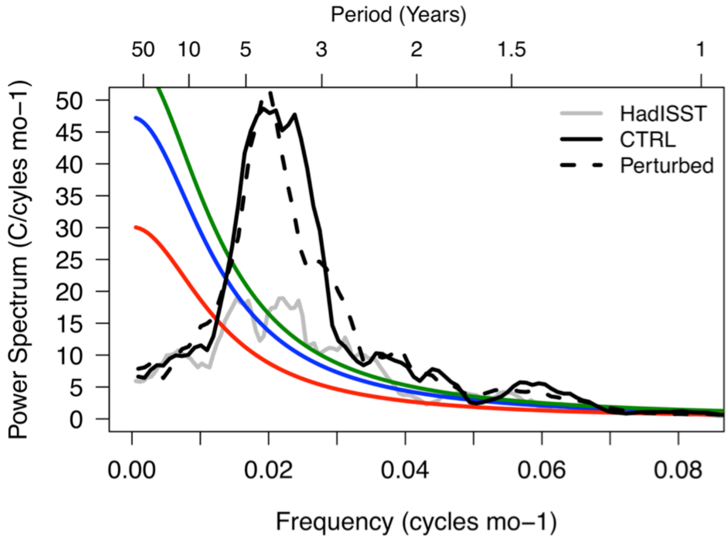

Figure 6: As Figure 2 but for CTRL_RCP8.5 (black solid), STO_PHY_RCP8.5 (black dashed) and HadISST1 (grey solid).

of stochastic physics on ENSO is somehow in agreement with that found by Christensen et al. 2017 (doi:10.1175 /JCLI-D-16-0122.1) in the CCSM model.

The above results suggest that the impact of stochastic physics on ENSO for the EC-Earth model depends on the mean state. When a different external forcing is applied to the EC-Earth model, the mean state changes accordingly and this leads to an almost reverse outcome when stochastic physics is included.

The details of the mechanisms that explain how the stochastic physics affect ENSO are clearly dependent on the biases of the coupled climate models, especially on the coupled feedback in the tropical Pacific. The representation of unresolved sub-grid scale variability through stochastic physics schemes can interact with the resolved scales improving low frequency aspects of the simulated climate.

List of publications/reports from the project with complete references

- Davini, P., von Hardenberg, J., Corti, S., Christensen, H. M., Juricke, S., Subramanian, A., Watson, P. A. G., Weisheimer, A., and Palmer, T. N., 2017: Climate SPHINX: evaluating the impact of resolution and stochastic physics parameterisations in the EC-Earth global climate model, *Geosci. Model Dev.*, **10**, 1383-1402, doi:10.5194/gmd-10-1383-2017.

- Watson, P. A. G., J. Berner, S. Corti, P. Davini, J. von Hardenberg, C. Sanchez, A. Weisheimer, and T. N. Palmer (2017), The impact of stochastic physics on tropical rainfall variability in global climate models on daily to weekly time scales, *J. Geophys. Res. Atmos.*, **122**, 5738–5762, doi:10.1002/2016JD026386.

- Davini, P., Corti, S., D'Andrea, F., Rivière, G., & von Hardenberg, J. (2017). Improved Winter European Atmospheric Blocking Frequencies in High-Resolution Global Climate Simulations. *Journal of Advances in Modeling Earth Systems*, 9, 2615-2634. https://doi.org/10.1002/2017MS001082.

- Yang, C., Christensen, H. M., Corti, S., von Hardenberg, J. and Davini, P., 2018: The impact of stochastic physics on the El Niño Southern Oscillation in the EC-Earth coupled model. *Climate Dynamics*, under review

Summary of plans for the continuation of the project

(10 lines max)

The next months will be dedicated to finalising tuning of the CMIP6 version the model (release 3.2.3 due in these days), mainly in coupled atmosphere-ocean experiments. In particular the goal will be to try and address also specific regional model biases where possible, such as excessive surface temperatures in the Souther Oceans or biases in surface temperatures and forcing by land vegetation in Siberia. Both high-resolution (T511L91) and stochastic physics versions of the model will be included in the tuning effort. We will perform long coupled runs both for present-day and for the pre-industrial period (1850) using CMIP6 forcing and evaluating if additional tuning is needed compared to the AMIP tuned version of the model. In parallel, with dedicated experiments, we will evaluate the impact of Stochastic Physics and the possible need of additional tuning in this case.