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 (July 2016-June 2017)
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	20,035,873	25,000,000	16,065,000
Data storage capacity	(Gbytes)	50000	/	50000	/

Summary of project objectives
(10 lines max)

In this special project we plan to 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. Hindcast simulations will allow us to evaluate if there is sensible improvement in the model climate due to stochastic parameterizations. Future scenarios will allow us to answer another question: what is the expected impact of stochastic parameterizations on future scenarios, under a different anthropogenic forcing? 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 2016-June 2017.

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

AMIP Model tuning at standard resolution with updated CMIP6 forcing fields

The past year has seen a rapid development effort, in which different model versions had to be tuned. In particular, version 3.2.1 of the model has been tuned to take into account the availability of updated CMIP6 forcings, including updated CMIP6 GHG concentrations, solar forcing and the MacSPv2 simplified aerosol forcing. Using the sensitivities to a set of atmospheric tuning parameters (mainly convective and cloud-related parameters), it has been possible to prepare several new improved tuning parameter sets by “simulating” their impact in terms of radiative fluxes, even before performing actual runs. A series of short test runs (20 years each) with each new estimated parameter set has allowed to rapidly converge onto an improved tuned version of the model, which shows, for transient present-day runs, realistic surface energy fluxes and cloud forcing.
The already known sensitivities have been integrated with an additional tuning parameter (RCLDIFF – mixing coefficient for turbulence), which has a significant impact on cloud cover. To this end, sensitivities have been determined using a series of short (6 years) AMIP runs. Tuning runs have been performed and repeated in order to allow the release of EC-Earth model versions 3.2.1 (December 2016) and an improved namelist has been developed for EC-Earth 3.2.2 (March 2017).

Tuning of the stochastic physics version with SPPT

A series of tuning runs have been performed in collaboration with Oxford University aimed at tuning the model when the SPPT stochastic physics scheme is active. Tuning was necessary since SPPT leads to significantly reduced net surface energy fluxes (a contribution of the order of -0.8 W/m2), a problem which is being investigated separately. Use of the same climate sensitivities measured for the standard low-resolution model allowed to estimate rapidly an improved set of atmospheric tuning parameters, confirmed by a series of short AMIP simulations over a few decades of years. The tuning runs, providing a recommended IFS namelist for model runs with stochastic physics, have been performed both for EC-Earth 3.2.1 and EC-Earth 3.2.2.

High-resolution AMIP tuning (T511L91)

Model energy fluxes and cloud cover are resolution dependent, so that the high-resolution model version requires a separate tuning, also in AMIP runs. Using the same parameter sensitivities measured at low resolution, and through a series of short runs (5/6 years each), we were able to develop a new set of atmospheric tuning parameters for the T511L91 model version. The runs were performed for anthropogenic forcing conditions in the year 1950 (of interest for the HighResMIP protocol).

Energy and mass conservation in stochastic physics

A fix for the SPPT scheme developed last year (see the 2016 report for details) has been included in the EC-Earth trunk in release 3.2.1, after careful testing. The fix guarantees that the global average of the tendencies (i.e. winds, temperature and more importantly specific humidity) before and after the SPPT perturbation is conserved. In particular, runs in the historical period showed that the inclusion of the scheme does address the imbalance of precipitation minus evaporation, which is now the same as for EC-Earth without stochastic physics. Further it was found that the inclusion of the scheme did not meaningfully alter the overall energy balance. Computing difference between the TOA energy balance and surface energy balance provides the same averages for deterministic runs and for runs using the SPPT fix.

Energy conservation issues

The coupled model (3.2.1) was found to not be energy conserving. More specifically, we found a strong mismatch between the net surface heat flux computed from IFS and the heat the ocean was actually receiving, as revealed both by the integrated change in ocean heat content and by the output diagnostic files written by NEMO. In particular, at standard resolution, NEMO was found to be receiving 1.04 W/m2 (as an average over the ocean only) more than what actually sent by IFS (as recorded in its diagnostic output files). High-resolution runs showed an even worse mismatch of about + 3W/m2. A detailed investigation of this issue required several coupled runs over periods of 20 years. In particular it was possible to break down this imbalance into individual contributions due to different effects. +1.6 W/mw were found to be associated with the non-solar flux (STR+SLHF+SSHF). Investigation revealed in particular a problem associated with the longwave flux sent by IFS to NEMO (the sum of the tile-specific fluxes did not correspond to the total grid-cell average assumed by IFS). Consultation with ECMWF (E. Dutra) has permitted to identify the problem, which had been corrected in very recent cycle of IFS. Backporting from cy41r2 the relevant fix has allowed to resolve this particular problem.
The particular choice of conservation options used for OASIS (multiplicative conservation, GLBPOS, vs. additive conservation- GLOBAL) was responsible for an additional small difference of +0.09 W/m2 for the solar component of the radiative flux. In the end GLBPOS was adopted as an option for all radiative fluxes.
Finally, also through discussion with the NEMO developers, it was verified that, in addition to geothermal heating (a source of about 0.065 W/m2), since NEMO takes into account the heat content associated with the temperatures of rainfall, evaporation and runoff, and since IFS does not take into account of these effects, a sink of energy in the oceans results, equivalent to -0.23 W/m2 (for T255L91/ORCA1L75). It was decided to simply acknowledge the existence of this issue in the coupled system, in keeping with the strategy adopted also by other CMIP modeling groups. (Details are documented in EC-Earth issue #189).

Freshwater conservation issues

The coupled ocean-atmosphere system (3.2.0) was found (mid 2016) to present a very unrealistic freshwater deficit (about 0.06 m per year). Investigation of the issue allowed to identify a series of problems in the NEMO coupling interface related to river runoff and sublimation. Additionally, it was found that there was a problem in the sublimation over ice calculated by IFS and sent to NEMO Fixing these issues allowed to recover an excellent mass-conservation in the coupled system. A remaining imbalance associated with a global average Evaporation – Precipitation imbalance in the atmosphere (about -0.016 mm/day) has been fixed adjusting the river runoff flux to compensate (details are documented in EC-Earth issue #252).

Scientific results

In parallel to technical model development, analysis of recent model runs has allowed to develop scientific studies on a wide range of topics. In particular, 2017 saw finally the publication of the paper *Davini et al 2017a*, in which, analysing a large set of high-resolution simulations, made possible also thanks to model development resources provided by ECMWF, we found an improvement in the simulation of Euro-Atlantic atmospheric blocking following resolution increase. The same paper also showed that including stochastic parameterisation in the low-resolution runs helps to improve some aspects of the tropical climate – specifically the Madden–Julian Oscillation and tropical rainfall variability.

These findings have been further explored more in detail in two follow-up papers. In *Davini et al. 2017b* we find that increasing resolution leads to a negligible bias in blocking frequency over Europe when resolution reaches or exceeds 40km. A combined effect by the more resolved orography and by a change in tropical precipitation is identified as the source of an upper tropospheric planetary wave. At the same time, a weakening of the meridional temperature gradient reduces the upper level baroclinicity and the zonal mean winds. Following these changes, in the high-resolution configurations the Atlantic eddy-driven jet stream is weakened and less penetrating over Europe. This favours the breaking of synoptic Rossby waves over the Atlantic ridge and thus increases the simulated European blocking frequency. However, the Atlantic jet stream is too weak and the blocking duration is still underestimated, suggesting that the optimal blocking frequencies are achieved through a compensation of errors.

In *Watson et al. 2017*, the impact on the statistics of tropical rainfall of the stochastically perturbed parameterization tendency scheme (SPPT) and of the stochastic kinetic energy backscatter scheme (SKEBS) are evaluated. The schemes generally improve the statistics of simulated tropical rainfall variability, particularly by increasing the frequency of heavy rainfall events, reducing its persistence and increasing the high-frequency component of its variability

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. (2017a) Climate SPHINX: evaluating the impact of resolution and stochastic physics parameterisations in climate simulations, *Geosci. Model Dev.,* 10, 1383–1402, https://doi.org/10.5194/gmd-10-1383-2017
- Watson, P. A. G., Berner, J., Corti, S., Davini, P., von Hardenburg, J., Sanchez, C., Weisheimer, A., & Palmer, T. N. (2017). The impact of stochastic physics on tropical rainfall variability in global climate models on daily to weekly timescales. *Journal of Geophysical Research: Atmospheres*. https://doi.org/10.1002/2016JD026386
- P. Davini, S. Corti, F. D'Andrea, G. Rivière, J. von Hardenberg (2017b) Improved winter European atmospheric blocking frequencies in high-resolution global climate simulations. *JAMES*, 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 coupled version of the model (currently release 3.2.2), including recent adjustments to the NEMO namelists (made necessary to guarantee in particular representation of Atlantic meridional transport). Also the addition of still missing forcings (stratospheric aerosols and variable land vegetation) will require a final retuning of the model. The tuning periods considered will include anthropogenic forcing for present day, 1950 (for HighResMIP) and preindustrial (1850). Both standard and high resolution, with and without stochastic physics, will be considered. The tuning strategy will aim at achieving realistic equilibrium temperatures in long forced fixed-year runs and realistic temperatures and radiative fluxes in transient present-day runs.
Long coupled transient integrations at low and high resolution will be performed following the CMIP6 and HighResMIP protocols, with and without stochastic physics.