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:	EC-EARTH: developing a European Earth System model based on ECMWF modelling systems
Computer Project Account:	SPNLTUNE
Principal Investigator(s):	Dr. Ralf Döscher
Affiliation:	Rossby Centre, SMHI
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Dr. Souhail Bousetta and Dr. Glenn Carver
Start date of the project:	2015
Expected end date:	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)	25000000	6516046	25000000	25000000
Data storage capacity	(Gbytes)	70000	?	70000	?

Summary of project objectives
(10 lines max)

The integration, testing and tuning of components in EC-Earth 3 are representing a major effort in the development of the model in the framework of this project. During the third phase of the project, main objectives were to tune different versions and configurations of the model and to finalize features and forcing necessary for CMIP6.

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

We did not experience major technical problems with the computing environment.

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 development

Significant work has been performed since the beginning of this special project for developing EC-Earth v3 (based on IFS cy36r4 and NEMO 3.6), with aim to reach a well-tuned Earth-System-Model, suitable for performing CMIP6 simulations and addressing a wide range of scientific questions. Almost 200 issues have been opened and addressed on the EC-Earth development portal, accompanied by the necessary numerical experiments, since the beginning of this SP in 2015. A tight schedule of model releases has been followed in the past months including EC-Earth 3.2.1 in December 2016 (used for AMIP tuning) and EC-Earth 3.2.2 in March 2017 (used to test and tune the coupled model). Resources provided by this SP have been essential to achieve this goal, with a final, greatly improved, release of EC-Earth v3 suitable for CMIP6 and other projects planned for this summer.

In particular owing to the need to keep to this deadline, in the past few months it has been necessary to perform a large set of AMIP and coupled numerical simulations with the model using the project resources. The simulations which have been performed include long coupled model runs both at standard (T255L91/ORCA1), high (T511L91/ORCA025) and low (T159L62ORCA1L75) resolutions, over decades and hundreds of model years respectively. In particularly AMIP tuning of the standard and high-resolution versions of the model and long coupled runs at standard resolution (needed to investigate and fix energy conservation issues between the atmosphere and the ocean) had a consistent impact on the use of resources. Still, the use of the resources of this SP has allowed to reach solutions for all these issues.

The bulk of the tuning work was dedicated to testing of parameter combinations with central tuning targets in the radiative and heat flux balances at the TOA and between the ocean and the atmosphere. Also, global mean temperatures and precipitation and evaporation has been considered. As a result, we have well-balanced atmosphere standalone configurations, which currently serve as the base for further coupled tuning, which involves solving issues of ocean circulation, ocean temperature and sea ice cover.

Another important component of the SP usage was the implementation and testing of CMIP6 forcing functions into the different components and configurations of the ESM. Below we show selected exampled of specific tuning and testing work.

Albedo of the Greenland ice sheet

The importance of albedo parameterization for the surface mass balance of the Greenland ice sheet in EC-Earth has been tested by Helsen et al. (2016). The albedo of the surface of ice sheets changes is a function of time, due to the effects of deposition of new snow, ageing of dry snow, bare ice exposure, melting and runoff. Currently, the calculation of the albedo of ice sheets is highly parameterized within the Earth System Model EC-Earth, by using a constant value for areas with thick perennial snow cover. This is an important reason why the surface mass balance (SMB) of the Greenland ice sheet (GrIS) is poorly resolved in the model. The purpose of this study was to improve the SMB forcing of the GrIS, by evaluating different parameter settings within a snow albedo scheme. The resulting SMB is downscaled from the lower resolution global climate model topography to the higher resolution ice sheet topography of the GrIS, such that the influence of these different SMB climatologies on the long-term evolution of the GrIS is tested by ice sheet model simulations (Fig. 1). This results in an optimised albedo parameterization that can be used in future EC-Earth simulations with an interactive ice sheet component.

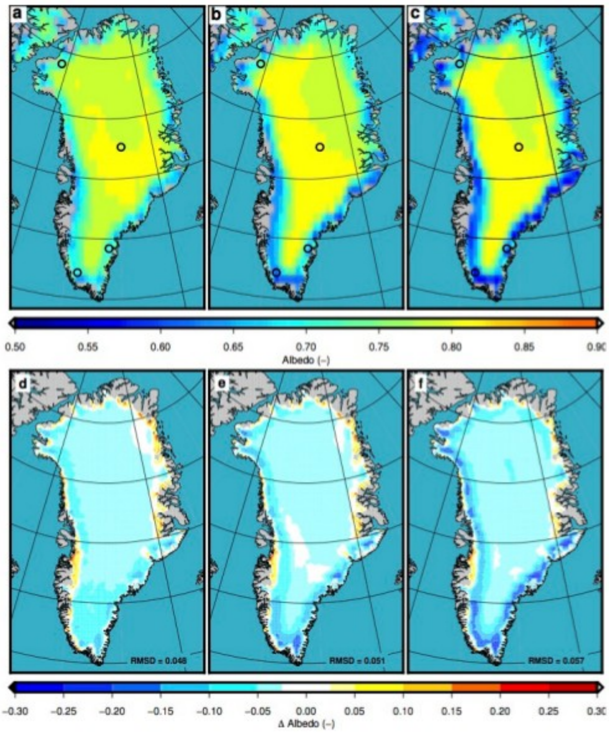


Figure 1. Average JJA albedo (1990-2012) from EC-Earth for the "Sto" scheme (a), "Cph" scheme (b) and the "Utr-8" scheme (c). Difference with JJA albedo from RACMO2 (Van Angelen et al., 2014) is shown in (d-f). Albedo is only shown for the ice sheet surface type, i.e. grey land area is outside the ice sheet domain in EC-Earth.

Implementing of primary biological aerosol particles (PBAP)

Treatments of emissions of primary biological aerosol particles (PBAP) were implemented in the global Earth System model EC-Earth. These emission schemes were improved to account for the strong peaks of PBAP concentrations in connection to precipitation events, which has been measured recently. The model is now able to treat the emission of bacteria, spores (Fig. 2) and pollen in dependency of precipitation, 10m wind speed, relative humidity, season, vegetation type, vegetation cover, and leaf area index. Sensitivity studies on the degree of detail of the PBAP emission parameterization were conducted. The resulting concentration fields of the three PBAP were compared between the different sensitivity setups and, more generally, to the rare available measurements. The model is applied for a set of sensitivity studies concerning the degree of detail of the enhanced PBAP emission parameterizations. The global simulations were conducted for one year (2006) with a 3°x2° horizontal resolution.

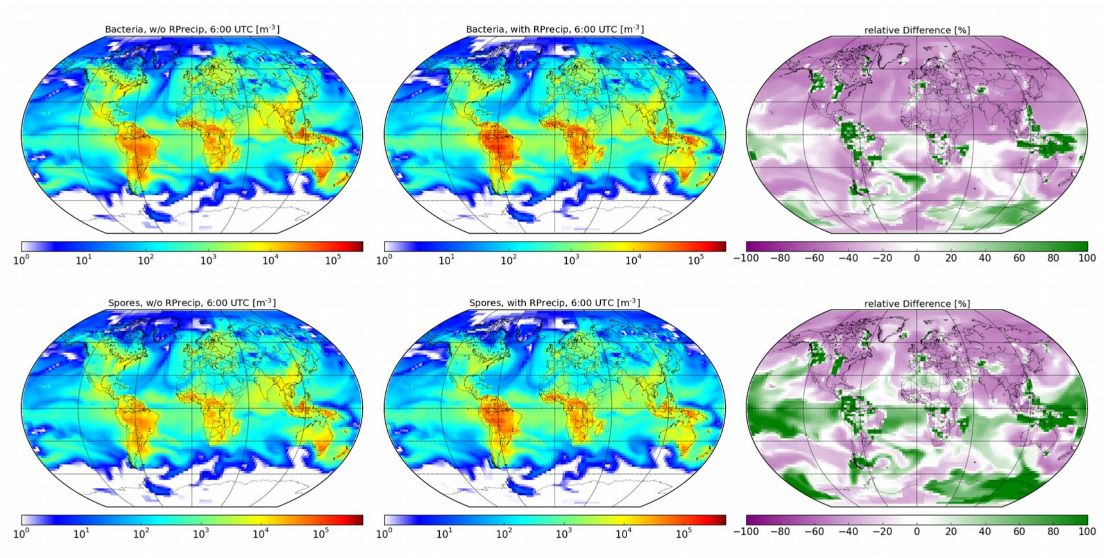
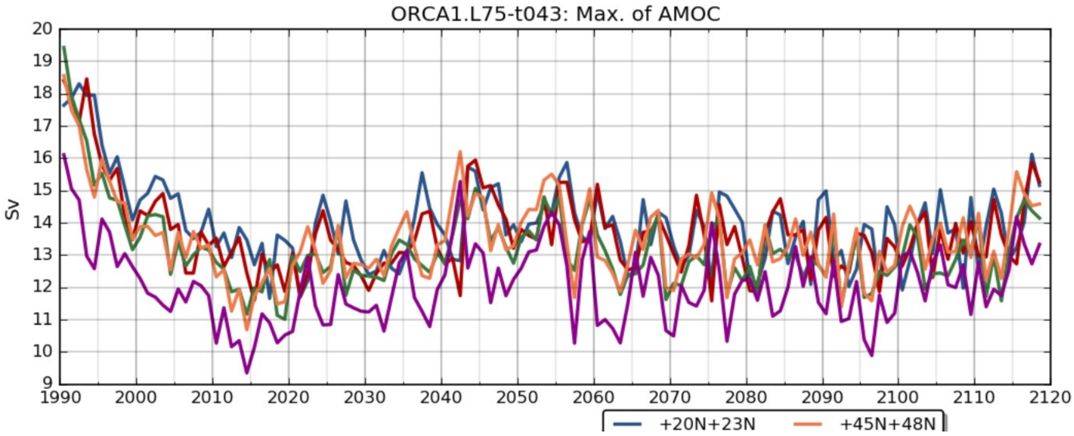


Figure 2. Modelled bacteria (upper) and spores (lower) number concentration without (left) and with emission additionally triggered by precipitation (middle), and relative difference between both.

Tuning of the Atlantic Meridional Overturning Circulation (AMOC)

The Atlantic Meridional Overturning Circulation (AMOC) after implementation of the latest NEMO versions in EC-Earth 3.2 appeared to be much too weak at a level of about 9 Sv, while 17 Sv are the observational target for recent climate conditions. The problem was found in both low resolution (T159L62ORCA1L75) and standard resolution (T255L91ORCAL75) configurations, while the high resolution configuration (T511L91/ORCA025) shows a higher AMOC.



Intensive testing was carried out to find solutions for the problem of a too weak AMOC. This included mixing parameterization, runoff and ice calving descriptions, sea ice parameterizations and dynamic parameterizations with repect to coastal currents. Solutions appear to be related to ocean mixing underneath the top mixed layer. Recent configurations do now show an AMOC of 13-15 Sv (Fig. 3), which is subject to further improvement.

Other testing and tuning activities

Further simulations under the SPNLTUNE account have been carried out to

- implementing and testing CMIP6 stratospheric ozone and aerosols: the EC-Earth code has been modified to read the CMIP6 data sets and remap them to the IFS grid. Testing these implementation required running the model for few years with the old and new forcings and to compare the results. Additional small runs tested the robustness of the code with different setup (random start date, various run length, etc).

- prepare ERA-20C 1950 initial conditions: data sets were retrieved through MARS requests, modified to account for EC-Earth land characteristics (e.g. orography). Spin up runs of 20 years were needed to stabilize the soil moisture. This was done at standard and high resolutions.

- configure the AMIP-reader for fixed year application

- test and merge atmospheric nudging functionality

- test and merge aerosol forcing for GCM configurations (MACv2-SP)

- testing and syncronizing trunk and tuning branches

- implementing and testing a new description of Secondary Organic Aerosol (SOA) formation from monoterpenes and isoprene.

- A new particle formation was improved by a scheme taking into account both monoterpenes and sulfuric acid.

- testing and tuning of the low-resolution of the new EC-EARTH versions, i.e. v3.2.1/3.2.2 in the T159L62ORCA1L75 configuration. Tuning was started based on parameters obtained from previous AMIP tunings at standard resolution T255L91ORCAL75, and continued by coupled simulation tuning at low resolution. Central tuning targets were the radiative balances at TOA and at the interface between ocean and atmosphere for recent climate. Tuning details of the experiments and the corresponding namelists are summarised on the EC-Earth portal.

List of publications/reports from the project with complete references

We list selected publications related to different phases of the project.

Helsen, M., Van de Wal, R., Reerink, T., Bintanja, R., Sloth Madsen, M., Yang, S., Li, Q., and Zhang, Q.: Influence of albedo parameterization on surface mass balance in the perspective of Greenland ice sheet modelling in EC-Earth, The Cryosphere Discuss., https://doi.org/10.5194/tc-2016-281, in review, 2016.

Schrödner, R., V. Phillips, E. Swietlick (2017), Biogenic aerosol particles in the Earth system model EC-Earth, in Air Pollution Modeling and its Application XXV, 2 - 7 October 2016, edited by C. Mensink and G. Kallos, Springer International Publishing.

Pausata, Francesco SR, Gabriele Messori, and Qiong Zhang. "Impacts of dust reduction on the northward expansion of the African monsoon during the Green Sahara period." Earth and Planetary Science Letters 434 (2016): 298-307. doi:10.1016/j.epsl.2015.11.049

Muschitiello, F., Q. Zhang, H. S. Sundqvist, F. J. Davies, and H. Renssen, 2015: Arctic climate response to the termination of the African Humid Period. Quaternary Science Reviews, 125, 91-97, doi:10.1016/j.quascirev.2015.08.012.

Davini P.,von Hardenberg J., Filippi, L., Provenzale A. (2014). Impact of Greenland orography on the Atlantic Meridional Overturning Circulation. *Geophysical Research Letters.* Article in Press.

Palazzi, E., von Hardenberg, J., Terzago, S., Provenzale, A. (2014). Precipitation in the Karakoram-Himalaya: a CMIP5 view. *Climate Dynamics*, 25 p. Article in Press. doi: 10.1007/s00382-014-2341-z

Van Noije, T.P.C., Le Sager, P., Segers, A.J., van Velthoven, P.F.J., Krol, M.C., Hazeleger, W., Williams, A.G., and Chambers, C.D., 2014. Simulation of tropospheric chemistry and aerosols with the climate model EC-Earth, Geosci. Model Dev., 7, 2435-2475, doi:10.5194/gmd-7-2435-2014.

Weiss, M., Miller, P., van den Hurk, B., van Noije, T., Stefanescu, S., Haarsma, R., van Ulft, L.H., Hazeleger, W., Le Sager, P., Smith B., and Schurgers, G., 2014. Contribution of dynamic vegetation phenology to decadal climate predictability, J. Climate, doi:10.1175/JCLI-D-13-00684.1.

Summary of plans for the continuation of the project

(10 lines max)

The EC-Earth consortium will apply for a new SP.