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	2016
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
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	20064139
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 second phase of the project, main objectives were to complete the model with features and forcing necessary for CMIP6. Here we focus on effects of aerosol, albedo of ice sheets, orbital forcing, atmospheric nudging and variable land use. The work was done in standard and low resolutions, which are planned for most applications in the upcoming CMIP6 project. Both the physical climate model and Earth system configurations were involved in the development and tuning work.

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

Development and tuning of EC-Earth version 3.2 with coupling to TM5

Activities with TM5 at KNMI have largely been focused on the development and tuning of the EC-Earth version with coupling to the atmospheric composition module TM5. After the EC-Earth version 3.2-beta was released in late 2015, it has been merged with the multi-component branch, which includes the interactive coupling with TM5. With this model configuration, a number of short atmosphere-only simulations have been performed with one-way and two-way coupling to TM5. The analysis has focused on the simulation of tropospheric aerosols.

Three lines of development were followed:

- Analysis of aerosol direct radiative effects
- Development and tuning of atmospheric nudging for tropospheric composition simulations
- Tuning of the dust emission source in free climate simulations

Analysis of aerosol direct radiative effects

The radiative effects due to direct aerosol-radiation interactions was analyzed using atmosphere-only simulations for present-day conditions with prescribed sea-surface temperatures and sea ice conditions. With this setup, three four-year simulations were performed which differed only in their representation of aerosols. In the first simulation, aerosols were simulated interactively using two-way coupling to TM5; in the second simulation, aerosols were prescribed using the CMIP5 mass mixing ratios used in the standard version of EC-Earth 3.2-beta; in the third simulations, the aerosols were removed before entering the radiation scheme. The effect of aerosols on the shortwave radiative fluxes at the top of the atmosphere and at the surface and on the SW absorption in the atmosphere was calculated by comparing the radiative fluxes in the simulations with interactive or prescribed aerosols with those in the reference simulation without aerosol radiative effects. As an example, Figure 1 shows the aerosol effects on the clear-sky flux at the top of the atmosphere (top panels) and on the atmospheric absorption (bottom panels).

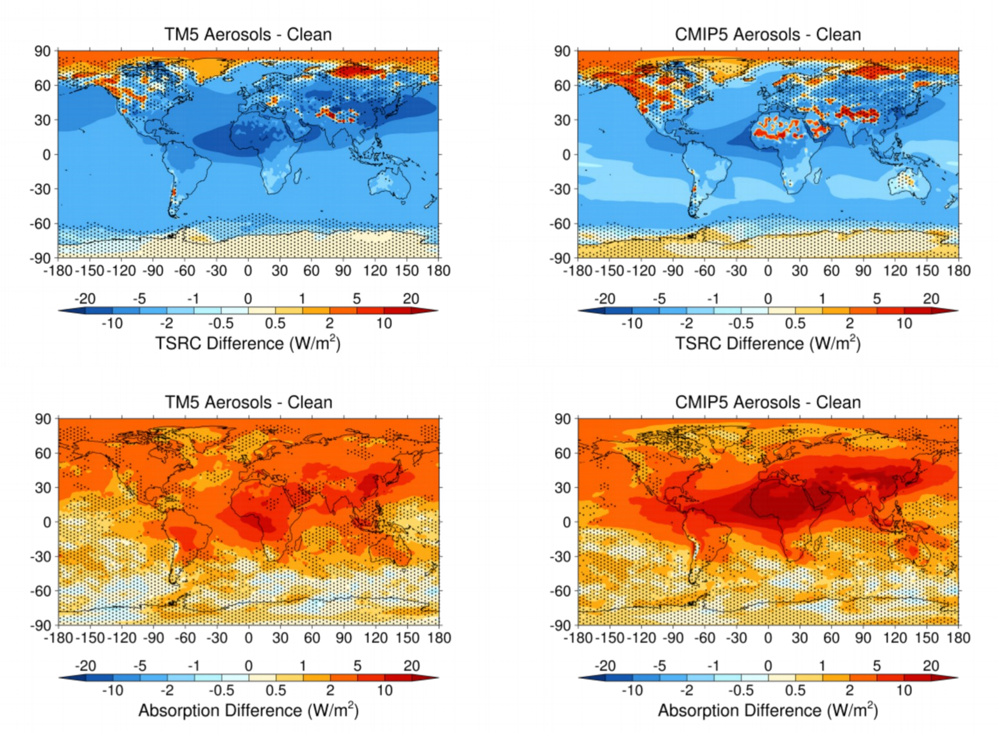

Figure 1. Aerosol direct radiative effects on the clear-sky flux at the top of the atmosphere (top) and on the atmospheric absorption (bottom), for the cases with interactive (left) and prescribed (right) aerosols. The flux perturbations shown are annual means based on the first two simulated years. The stippled areas indicate regions where the aerosol effects are statistically insignificant at the 5% level.

The simulation with interactive aerosols gives qualitatively similar flux perturbation patterns as the simulations with prescribed CMIP5 aerosols. It should be noted that the model has been improved in several aspects after completion of these simulations. For instance, the snowfall contribution was missing in the large-scale and convective precipitation fields that IFS sent to TM5, reducing the wet removal at high latitudes. Also, the calculation of dust emissions in the interactive simulations has been revised (see below).

Development and tuning of atmospheric nudging for tropospheric composition simulation

Code for nudging of atmospheric fields was ported to EC-Earth 3.2-beta, and merged with the multi-component branch, allowing to do atmospheric composition simulations with nudging of IFS towards ERA-Interim fields. A large number of two-year simulations have been performed in atmosphere-only configuration with interactive coupling to TM5, for various combinations of the nudging coefficients applied for the different variables. In this way, we assessed the possibility to reproduce the results from the standalone TM5 model driven by ERA-Interim meteorological fields. Our preliminary conclusion is that the best agreement is obtained using a nudging time scale of around 6 hours for vorticity, divergence, temperature and surface pressure, with nudging of specific humidity and cloud variables switched off. With these settings, the nudged EC-Earth simulation produces quite similar aerosol concentrations and optical depths as the standalone model, although differences remain due to differences in model physics (e.g. the convective parameterization) and resolution between the IFS version used in EC-Earth (T255L91) and ERA-Interim (T159L60). In Figure 2 we compare the simulated aerosol optical depth from the standalone and nudged simulations for boreal summer 2006.

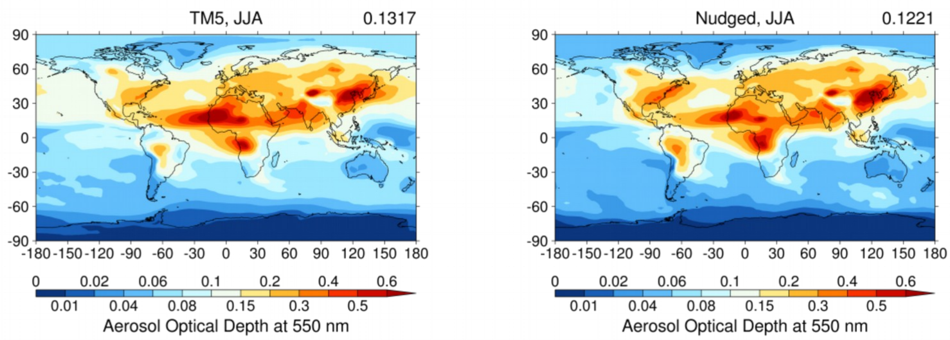

Figure 2. Aerosol optical depth for summer 2006, simulated by the standalone TM5 model driven by ERA-Interim (left) and by the same TM5 configuration as part of EC-Earth with IFS nudged to ERA-Interim (right).

We also tested the effect of reducing the coupling period for the exchange between IFS and TM5 in EC-Earth from six to three hours. The results from these tests indicate that reducing the coupling period below 6 hours does not substantially change the simulation of atmospheric composition variables.

Tuning of the dust emission source in free climate simulations

Additional simulations with EC-Earth 3.2-beta in free climate mode with one-way coupling to TM5 have been carried out. The resulting aerosol concentration and optical depth have been compared against the results obtained with the standalone version of TM5 driven by ERA-Interim. The wind-driven dust source calculated in TM5 turned out to be much higher in EC-Earth. This is a well-known feature of the dust source parameterization in the model, in which dust is assumed to be mobilized only above a certain threshold surface wind speed. To minimize resolution dependencies, a parameter was introduced in the parameterization which acts as a scaling factor for this threshold. A number of sensitivity simulations have been performed, in which the value of this parameter was changed between the default value of 0.6 and 1.0. For the untuned version of EC-Earth 3.2-beta, reasonable emission amounts are obtained using a value around 0.7. Increasing the tuning parameter from 0.6 to 0.7 reduces the global dust source from about 2660 to 1250 Tg/yr, compared to 990 Tg/yr in the standalone simulation. Additional fine tuning of this parameter will be undertaken once a tuned CMIP6 version of EC-Earth will be released.

Albedo Parameterizations as Calibration Tool for a coupled Greenland Ice Sheet model and EC-Earth

The albedo of the surface of ice sheets changes through the year, as a function of deposition of fresh snow, ageing of dry snow, and melt and runoff. Currently, the albedo of ice sheets is highly simplified within the Earth System Model EC-Earth, by taking a constant value for areas with thick perennial snow cover. To improve on this, several adjusted snow albedo schemes are tested here on their performance on the Greenland ice sheet.
The different snow albedo schemes used in the different model groups in Stockholm, Copenhagen and Utrecht groups are compared. Different choices are made for time-decaying or constant albedo for either wet or dry conditions, and different values for maximum and minimum snow albedo are used.
As albedo influences the surface energy balance, and thereby the surface mass balance (SMB), the effect of different albedo schemes on Greenland ice sheet SMB is assessed. As a following step, SMB is downscaled to the Greenland topography on a higher resolution, and the influence of these different climatologies on the long-term evolution of the Greenland ice sheet is tested. This results in an optimal albedo parameterization that can be used in future EC-Earth simulations with interactive ice sheet component.

Testing, tuning and debugging the low resolution version of EC-Earth

Low resolution versions of EC-Earth are the configurations T159L62ORCA1L46 and T159L62ORCA1L75. Stockholm university performed tuning and testing for EC-Earth 3.2 at lower resolution to resolve issues about numerical instabilities. The goal was to identify and correct any bugs in the code, configuration, or initial files that cause instabilities and make sure that the model can be run for at least 50 model years without regular crashes.

Orbital forcing in EC-Earth

Stockholm university carried out implementation of orbital forcing that can be controlled at runtime and testing in EC-Earth 3.2. The orbital forcing in IFS model was fixed at some present-day condition which is sufficient for most experiments. However, paleo runs and very long simulations e.g. last millennium runs, require a variation of the orbital forcing. Implementation and extensive testing has been carried out.

Variable land use in EC-Earth

Variable land-use and vegetation was implemented and tested in EC-Earth 3.1 and 3.2. IFS reads a seasonal cycle albedo based on MODIS observations and it is repeated after every year. For transient simulations we need to adjust this file to reflect the changes in land-use and vegetation over time. This is mainly targeted for ESM simulations and related to LPG-Guess. An albedo look-up table based on the 4 albedo values (UV, VIS, Diff, Direct) is derived based on the previous work by Houldcroft CJ, Grey WMF, Barnsley M, Taylor CM, Los SO and North PRJ 2009, ”New vegetation Albedo parameters and global fields of soil background albedo derived from MODIS for use in a climate model”, J. Hydrometeorol. 10, 183-198.

List of publications/reports from the project with complete references

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

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)

By the end of summer 2016, the CMIP6 version of the coupled climate model EC-Earth will be released in different configurations. The model will include the CMIP6 standard aerosol forcing MAC-SP2 and will be prepared to run with additional forcing for CMIP6-DECK runs after further tuning. Following the EC-Earth tuning concept, atmosphere-only tuning of different resolutions will be followed by coupled tuning. The expected result is a climate model ready for CMIP6, able to simulate recent climate and its variability reasonably well and at the same time resembles observed integrative constraints, such as the surface and TOA energy balances. The central judgement of the new climate model will be based on Reichler and Kim climate model performance index. Initially the tuning and testing effort will continue to focus on the physical model. Later, tuning will be extended to high resolution versions and ESM configurations.