SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Last Glacial Maximum and Mid-Holocene Climate in EC-Earth
Computer Project Account:	spdkyang
Start Year - End Year :	2013 - 2014
Principal Investigator(s)	Shuting Yang
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The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The goal of this project is to use the EC-EARTH model for simulations for the periods of the Last Glacier Maximum (LGM, about 21ka) and the Mid-Holocene (MH, about 6ka), in order to evaluate the capability of the EC-EARTH in simulating the past climate and to investigate the climate response under different forcing. Applying climate models to the paleoclimate conditions, for which the external forcing are large and relatively well known from the proxy data, can test the performance and liability of state-of-the-art climate model, and thereby assess the ability of these models to simulate radically different climates other than just the present conditions.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

Adaptation of the standard EC-Earth for the paleoclimate condition was technically challenging and overcoming the difficulties took much more time than expected. For the first, the model physics associated with radiation calculations, the surface parameterisation of snow and land ice, etc., need to be modified accordingly. For the second, the initial and forcing files as well as boundary conditions, including land-sea mask, surface topography and the ocean bathymetry, also need to appropriate adopted to the paleo-conditions. The technical complexity to correct and consistent implementation of the above considerations leads to severe delay of the original project deliverable plan. The initial work of the model modification was carried out on the EC-EARTH version for CMIP5 (i.e., version 2.3). However, it turned out that porting the version 2.3 to the new ECMWF HPC was too time consuming. With new development in the EC-EARTH version 3 and the mitigation of the ECMWF HPC, we decided to collaborate with the Department of Physical Geography, Stockholm University (NATGEO) and carry out the long simulations with the adopted version of EC-EARTH v3 for the LGM and MH.

Much of the time during the project was spent for the above model development and testing. The allocated resource was largely used during the test, and not much left for productive simulations which were expensive for the paleo-time scale. We thus were not able to complete the planned simulations, even though we had drop the original plan of MH simulation and focused only on the LGM period.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

It was difficult to estimate the resource needed during the application phase for people who has little experience in using the HPC at ECMWF. A guideline on how to calculate the Billing unit from the CPUs would be very helpful (maybe it already exists?)

Summary of results

(This section should comprise up to 10 pages and can be replaced by a short summary plus an existing scientific report on the project.)

The research carried out in this project was done in close collaboration with the Department of Physical Geography, Stockholm University (NATGEO). We acknowledge the modelling group led by Dr. Qiong Zhang at NATGEO for sharing their results. Much of the simulations reported here were performed under the special project SPSEZHAN.

Model adaptation for paleoclimate simulations

The paleoclimate conditions are significantly different from the present day. In order to apply the climate model EC-EARTH, which is developed for present day climate, for the paleoclimate simulations, one needs to adapt the model physics, boundary and forcing conditions accordingly. The primary work during the project years has been on adaptation and testing of the EC-EARTH for the LGM and MH conditions. The adaptation includes implementations of

(1) the solar insolation change driven by the orbital changes;
(2) appropriate topography and land sea mask;
(3) appropriate ice sheet coverage and the surface physical process accordingly;
(4) appropriate ocean bathymetry;
(5) other prescribed boundary conditions according to the PMIP3 (Paleo-climate Model Intercomparisons Project phase 3) experiment protocol;
(6) last but not least, consistent initial conditions (especially ocean conditions) for LGM.

In collaboration with NATGEO, all five required modifications have successfully implemented and tested in EC-EARTH v3.0. The new calculation for the orbital forcing is adopted from CAM3.0, in which the solar insolation is computed using the method of Berger (1978). The test experiments with the new implemented orbital forcing in the EC-EARTH v3.0 for the pre-industrial (0 ka,1850 AD), MH (6 ka, 6000 BP) and LGM (21 ka, 21000 BP) show that the model calculated insolation is the same as that calculated from climate model CESM and MIP-ESM as well as that provided by PMIP3 data base for the three paleo-periods. Further examination indicates that the magnitude and seasonality of the solar insolation during the MH and LGM is significantly different from that in pre-industrial period. The orbital forcing is thus regarded as the major forcing for the climate in MH and LGM.

In the standard EC-EARTH model, the surface scheme (H-TESSEL) does not distinguish land ice from the soil. All grid-points of land are treated as soil with a mimic of ice-sheets/glaciers as 10 m of accumulated perennial snow. In order to foster the influence of the considerably large glaciers in the cold climate such as LGM, a new surface process for ice sheets is introduced. An explicit land ice mask is applied to ensure the ice characteristics (i.e., thermal conductivity and volumetric hear capacity), and the surface properties (ie., albedo, longwave emissivity, roughness for heat, momentum and moisture, and skin layer conductivity, etc.) are adapted for grid points covered with ice-sheets/glaciers. To better represent the snow melt-albedo feedback, a new albedo parameterization for snow on land ice is introduced with snow aging and snow melt considered. Snow melt is activated with a net positive energy flux at the surface and a skin temperature exceeding the melting temperature threshold but constrained with energy conservation. These improvements with ice-sheet/glacier surface processes improve the model performance as shown in Figure 1. The cold biases in Northern Hemisphere and warm biases in Southern Hemisphere reduced greatly in the improved model, with the annual mean global averaged SSTs increased about 0.25C which is closer to the observation.

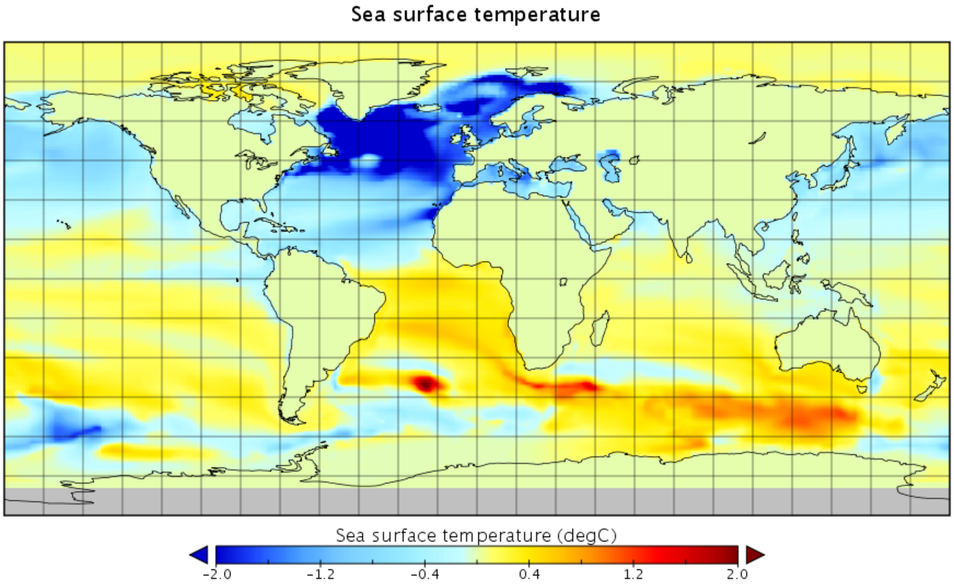

Figure 1. Global mean SST difference between experiments without and with ice-sheet surface processes for pre-industrial condition. (Courtesy: Q. Zhang).

LGM climate simulation

The new EC-EARTH model with the above improvements has been successfully applied for paleoclimate simulations of different time periods. Zhang et al. had performed two multi-century time-slice LGM simulations starting from different ocean initial conditions taken from previous runs by Zhang et al (2013) and interpolated to the present model grid. The two initial states are chosen for conditions resembling either a glacier or a present-day ocean. Figure 2 shows the temporal evolution of SSTs in the two simulations as well as in the pre-industrial (PI) control run. After more than a hundred years of initial spin-up, the SSTs in the two simulations fall to a similar level, although it takes another 2-3 hundred years for the SSTs to reach a quasi-equilibrium state. The global mean SST in the LGM is about 13-14°C that is about 3°C lower than the PI control. The simulated LGM climate is characterized by significantly colder and drier conditions compared to PI climate. The averaged global mean surface air temperature in the last 100 years of the 800-year LGM run is more than 6°C lower than in the PI run, with the excessive cooling over the ice sheets. The annual precipitation is also reduced for most area in comparison with the PI period, with the largest reduction over tropical west Pacific and along the coastal regions, and slightly decrease in the intertropical convergence zone (ITCZ). Regional increase of precipitation is also seen in the south Pacific convergence zone (SPCZ). These changes seem consistent with previous studies (Toracinta et al, 2004). However, unlike in the previous study by Otto-Bliesner et al (2006) in which precipitation over the continental ice sheets are observed to decrease up to 2 mm/day in comparison with PI run, the EC-Earth simulated precipitation change over the ice sheet is marginal.

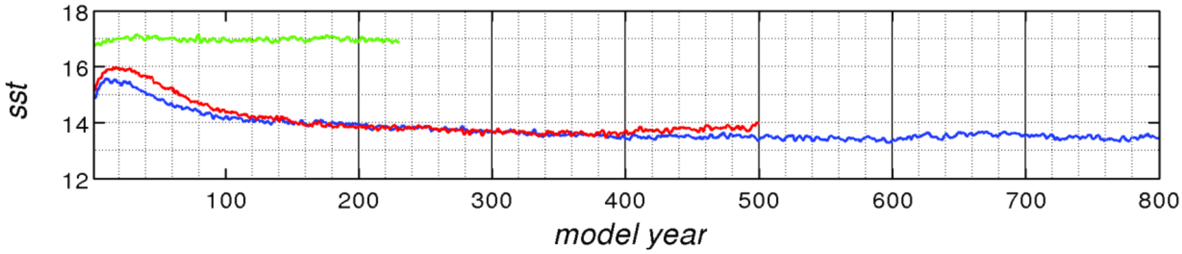

Figure 2. The evolution of global mean sea surface temperature of the two LGM simulations (red and blue lines) and the pre-industrial control run (green line). Unit: °C. (Courtesy: Q. Zhang).

Reference

Berger, A. L.: Long-Term Variations of Daily Insolation and Qua- ternary Climatic Changes, *J. Atmos. Sci*., 35, 2362–2367, 1978.

Otto-Bliesner, B.L., Brady, E.C., Clauzet, G., Tomas, R., Levis, S., and Kothavala, Z.: Last Glacial Maximum and Holocene Climate in CCSM3. *J. Climate*, **19**, 2526–2544, 2006

Toracinta, E.R., Oglesby, R.J., and Bromwich, D.H.: Atmospheric Response to Modified CLIMAP Ocean Boundary Conditions during the Last Glacial Maximum. *J. Climate*, **17**, 504–522, 2004

Zhang, X., Lohmann, G., Knorr, G., and Xu,X.: Different ocean states and transient characteristics in Last Glacial Maximum simulations and implications for deglaciation, *Clim. Past*, **9**, 2319-2333, 2013.

List of publications/reports from the project with complete references

Qiong Zhang, Qiang Li, Maxime Ballarotta, Shuting Yang, Marianne Sloth Madsen, Klause Wyser, 2015: Paleo-simulation setup with EC-Earth, manuscript in preparation.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

More studies of the LGM and MH climate using the modified EC-EARTH v3.0 for paleoclimate simulations are being carried out in the on-going special project SPSEZHAN. The model development will be adapted to the upcoming EC-EARTH version for CMIP6, which will be used to contribute to the CMIP6 endorsed, new PMIP.