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: Simulations with climate model EC-Earth

Computer Project Account: SPSEZHAN

Principal Investigator(s): Qiong Zhang

Affiliation: Department of Physical Geography,
Stockholm University

Name of ECMWF scientist(s) collaborating to the project
(if applicable) ……………………………………………………………….……

Start date of the project: 2015-01-01

Expected end date: 2017-12-31

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)	250000000	15593531	250000000	2773479
Data storage capacity	(Gbytes)	50000	50	50000	70

Summary of project objectives

The project aims to perform various simulations for past climate with the latest version of EC-Earth. We have done different simulations for the past climate, including five key period suggested by PMIP (Paleoclimate Inter-comparison Project) and several project oriented sensitivity experiments (e.g. Green Sahara during mid-Holocene). The climate sensitivity has been evaluated under different climate forcing. Sensitivity experiments under these climate conditions have been performed to understand the mechanisms of past climate variability.

Summary of problems encountered (if any)

In last years report we have described the problems we encountered with LGM simulation. We have observed very large sea-ice thickness after 800 years simulation that can be 200 meters. We have not identified any reason that responsible for the thick sea-ice and speculate it may be due to the one-category of sea-ice in LIM3. The new sea-ice model version with multi-category sea-ice is expected to improve/solve the problem.

From last year to now we are continuing to tune the low-resolution (T159) of the new version of EC-Earth 3.2, therefore we have not used too much of the allocated resource. Once the tunning process is completed and the model version is frozen for CMIP6 experiments, we may launch the production simulations and use the resources intensively. We will be careful on the usage and try not to affect other users.

Summary of results of the current year (from July of previous year to June of current year)

Part of our planned simulations is run on National Computer Centre (NSC) in Sweden in parallel, and we perform most of the model data analysis on NSC supercomputer. The computer resources both from NSC and ECMWF therefore support the results summarised below.

1. **Green Sahara experiments for mid-Holocene**

Paleo-proxy data suggest that one of the most dramatic changes in rainfall over Africa occurred around 15000 years ago, when increased summer precipitations led to an expansion of the North African lakes and wetlands and an extension of grassland and shrubland into areas that are now desert, giving origin to the so-called "Green Sahara", or African Humid Period. However model simulations have shown limited skill in reproducing the wide range of monsoon amplification responses when forced with Mid-Holocene insolation forcing only. These discrepancies must lie in a shortcoming common to all models such as the improper dust emissions and land surface cover.

With EC-Earth 3.1, we have designed several sensitivity experiments to investigate how potential change in Saharan dust emissions and land surface properties may have altered the climate system in the past. The experiments are listed in table 1.

Table 1. The forcings setup for Green Sahara experiments. The changes in vegetation and dust are applied to the northern African domain 11-33°N, 15°W-35°E.

Experiment	Exp-name	Orbital year	GHG-CH4	Sahara vegetation	Sahara dust
PI control	B400	1850	760	As CMIP5 PI	As CMIP5 PI
6k control	B6KA	- 6000	650	As CMIP5 PI	As CMIP5 PI
6k green dust	G501	- 6000	650	Sahara as shrub	Reduced dust
6k desert dust	P501	- 6000	650	As CMIP5 PI	Reduced dust
PI green	C100	1850	760	Sahara as shrub	As CMIP5 PI
PI green dust	C600	1850	760	Sahara as shrub	Reduced dust

PI desert dust	C700	1850	760	As CMIP5 PI	Reduced dust

The local and remote climate responses based on these experiments have been investigated within the collaboration in Bolin centre where involving PhD student and postdoc fellows, and the corresponding manuscripts have been published/submitted. The model design and simulations have been reported in last year sp_progress. Following the review comments on our submitted paper, we have re-run several experiments by using a new dust map that based on satellite data. A few additional experiments have been run upon the suggestions from the reviewers. Three more high-impact articles have been published based on these simulations and more analyses are ongoing by sharing the data within the international project. 6-hourly data from these simulations are provided to regional modelling as boundary conditions. The results also presented in several institutions upon invitation.

The major results from these experiments are:

- We further investigated the mechanisms behind the northward extension of the West African Monsoon during the Mid-Holocene. The results show a substantial modification of the monsoonal circulation, characterized by an intensification of large-scale deep convection through the entire Sahara, and a weakening and northward shift (~6.5°) of the African easterly jet. The greening of the Sahara also leads to a substantial reduction in African easterly wave activity and the associated precipitation. The reorganization of the regional atmospheric circulation is driven by the vegetation effect on radiative forcing and associated heat fluxes, with the reduction in dust concentration to enhance this response.
- We show that accounting for a vegetated and less dusty Sahara during the mid-Holocene relative to preindustrial climate can reduce ENSO variability by 25%, more than twice the decrease obtained using orbital forcing alone. We identify changes in tropical Atlantic mean state and variability caused by the momentous strength- ening of the West Africa Monsoon (WAM) as critical factors in amplifying ENSO's response to insolation forcing through changes in the Walker circulation. Our results thus suggest that potential changes in the WAM due to anthropogenic warming may influence ENSO variability in the future as well.
- We also show that the greening of the Sahara and reduced dust loadings lead to more favorable conditions for tropical cyclone development compared with the orbital forcing alone. In particular, the strengthening of the West African Monsoon induced by the Sahara greening triggers a change in atmospheric circulation that affects the entire tropics. Furthermore, whereas previous studies suggest lower TC activity despite stronger summer insolation and warmer sea surface temperature in the Northern Hemi- sphere, accounting for the Sahara greening and reduced dust concentrations leads instead to an increase of TC activity in both hemispheres, particularly over the Caribbean basin and East Coast of North America. Our study highlights the importance of regional changes in land cover and dust concentrations in affecting the potential intensity and genesis of past TCs and suggests that both factors may have appreciable influence on TC activity in a future warmer climate. Through the publications and presentations of these scientific results, we have seen that more interests are drawn to these Green Sahara experiments and more investigations can be established within collaboration.

2. Mid-Pliocene experiment

Another focus during this year is the simulation for mid-Pliocene. We have identified some problems in previous finished Mid-Pliocene experiment with EC-Earth 3.1, where we found some weird character in AMOC, which may be caused by the incorrect modification of topography. We have to carefully setup the experiment with correct topography and ocean bathymetric and re-run the simulation. Our second Pliocene experiment shows the similar results as in first simulation but has more sea-ice in Arctic and no ice-free summer is exhibited. We have focused on investing the Arctic amplification in this simulation. A quantification of process contribution using the Climate Feedback and Response Analysis Method (CFRAM) shows that the largest contributor to Arctic amplification is sea-ice albedo feedback and cloud feedback plays a secondary role, whereas the latent and sensible heat fluxes largely offset Arctic amplification through a negative feedback (Fig 1). Significant sea-ice melting is found during summer months from June to October. The large area of open-water facilitates oceanic dynamical process to store large amount of heat content in the ocean. The stored energy is discharged in winter to sea surface, heats the overlying atmosphere through turbulent heat fluxes, and thus maintains the more pronounced Arctic amplification in winter in spite of no incoming solar radiation during polar night.

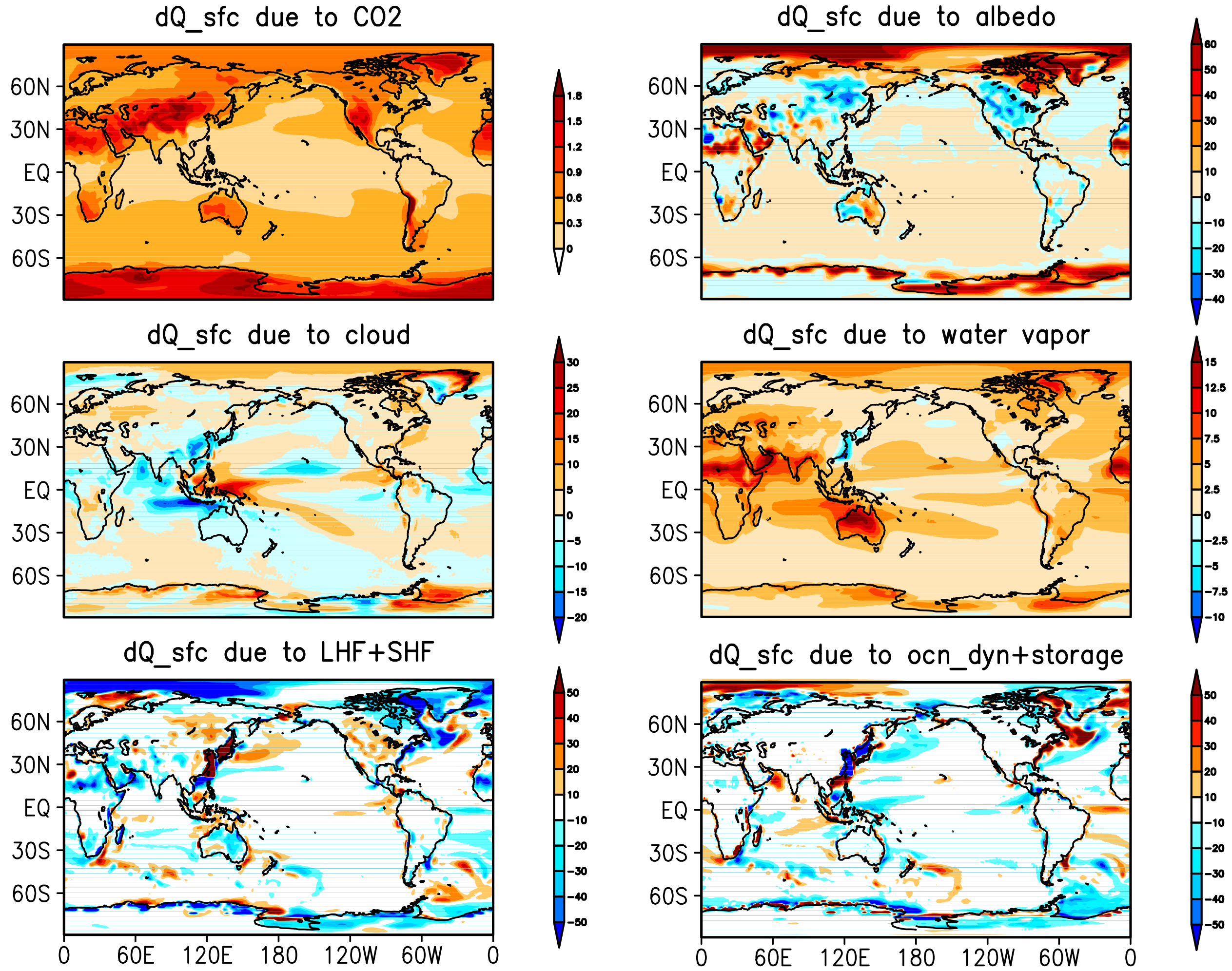

Figure 1. Partial surface temperature changes attributable to radiative processes CO2 forcing, albedo feedback, cloud feedback, water vapor feedback, surface tube turbulence feedback, and ocean dynamic feedback.

We also found that the spatial variation of sea surface temperate (SST) plays a vital role in regulating climate change. Most of previous studies on formation of SST pattern have focused on low and middle latitudes, which involving strong air-sea interaction. However, in high latitudes such as Arctic Ocean, air-sea-ice interaction has to be considered due to the present of sea-ice. The geological data indicate substantial warming over north Atlantic during the Pliocene. However, most climate models underestimate this character in their Pliocene simulations. Our EC-Earth simulation does show pronounced warming SST over North Atlantic in particular over Greenland Sea and Baffin Bay, which is comparable with geological reconstructions. We identify this anomalous warming pattern is the synthesis of SST change in different season. The strongest warming is exhibited in winter in surface air temperature (SAT) over the Arctic Ocean around North Pole, while the change in SST is not evident here due to lack of ocean-atmosphere coupling because of the isolating effect of sea-ice. In summer the warming in SAT is prominent over Greenland Sea and Baffin Bay because of strong ice-albedo positive feedback in ice-melting season, and thus lead to the SST warming through the atmospheric forcing to ocean.

More sensitivity experiments in Pliocene climate conditions are running at the moment to explore the mechanisms that responsible for a warming climate with high concentration of CO2 level, which has implications for our current global warming.

List of publications/reports from the project with complete references

Published/accepted

Gaetani, M., G. Messori, **Q. Zhang**, C. Flamant, and F.S. Pausata, 2017: Understanding the mechanisms behind the northward extension of the West African Monsoon during the Mid-Holocene. J. Climate, https://doi.org/10.1175/JCLI-D-16-0299.1

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Kageyama, M., Braconnot, P., Harrison, S. P., Haywood, A. M., Jungclaus, J., Otto-Bliesner, B. L., Peterschmitt, J.-Y., Abe-Ouchi, A., Albani, S., Bartlein, P. J., Brierley, C., Crucifix, M., Dolan, A., Fernandez-Donado, L., Fischer, H., Hopcroft, P. O., Ivanovic, R. F., Lambert, F., Lunt, D. J., Mahowald, N. M., Peltier, W. R., Phipps, S. J., Roche, D. M., Schmidt, G. A., Tarasov, L., Valdes, P. J., **Zhang, Q.**, and Zhou, T., 2016: PMIP4-CMIP6: the contribution of the Paleoclimate Modelling Intercomparison Project to CMIP6, Geosci. Model Dev. Discuss., doi:10.5194/gmd-2016-106.

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Wang T., **Q. Zhang**, L. Chafik, S. Lossow, C. Risi and D. Murtagh, 2017: Dynamical and chemical stratospheric processes revealsed by stable water isotope measurements from Odin/SMR, revised version in English proof edit, Tellus B, in reivew.

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Helsen M., R. Van de Wal, T. Reerink, R. Bintanja, M. S. Madsen, S. Yang, Q. Li, and Q. Zhang, 2016: Influence of albedo parameterization on surface mass balance in the perspective of Green- land ice sheet modelling in EC-Earth, *The Cryosphere discussions*. DOI: 10.5194/tc-2016-281.

Summary of plans for the continuation of the project (10 lines max)

August 2017

New CMIP6 version of EC-Earth is in final tunning right now. We have committed the PMIP simulations with low resolution of EC-Earth 3.2. Though the most of the PMIP simulations will be run on NSC computer, some scientific question orientated experiments will be run on ECMWF resource, following our project goal. Such simulations are including a mid-Holocene transient run with a dynamical vegetation component to investigate the mechanism of abrupt change for “going into” and “gong out” of green Sahara period.

We plan to complement the stable water isotope tracer into OpenIFS and once the coding work finish we will do various testing run.

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