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: 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	250000000	250000000	5438067
Data storage capacity	(Gbytes)	50000	20	50000	80

Summary of project objectives

The global coupled climate model EC-Earth is built on the knowledge of present day and the physical parametrisations are based on present-day observation. However we don't know if such a model is valid for another unknown climate condition, i.e. either a future scenario or climate in the past. The current project aims to perform various simulations for past climate with the latest version of EC-Earth. We follow the PMIP protocols to perform two time slice simulations: Mid-Holocene (MH, 6000 years BP), Last Glacier Maximum (LGM, 21,000 years BP), Last Interglacial (LIG, 127,000 years BP), Mid-Pliocene (3 ma years ago), as well as a transient simulation for Last Millennium (LM, 850 AD to 1850 AD). The model will be tuned if necessary and the results will be validated against paleo proxy data and other model simulations. The climate sensitivity will be evaluated under different climate forcing. More sensitivity experiments under these climate conditions will be 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. During current year we have been continue investigating the reasonable, by trying the different boundary conditions and run even longer. Recent results show that the system seems transferring to another equilibrium, which is very interesting for a further investigation.

Most of the data are transferred to local super computer at National Computer Centre (NSC) in Sweden for processing and analysis; therefore the storage is a crucial issue for us. Since different research group frequently requests our data, there are frequent read/write and need the space on hard disk. We are searching for possible solution right now.

We did not use too much resource from January to June 2016. This is due to the tunning of the new version of EC-Earth 3.2. Once the tunning process is completed and the model version is frozen for CMIP6 experiments, we may 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. Some of the above listed experiments have been rerun when problems are identified. A few additional experiments have been run upon the suggestions from the reviewers for our submitted paper. Now the results of the green Sahara experiments are used to investigate the different climate response, and formed into five publications/manuscripts. The results also presented in several institutions upon invitation.

The major results from these experiments are:

- Western African monsoon became stronger and extended northward under a green Sahara and reduced dust condition. Monsoon season also lasted longer. However, reduced dust alone would not lead to northward extension of the monsoon (Pausata et al., 2016).
- Arctic became cooling after the Green Sahara changed into Desert. Local albedo change results in decrease of thermal gradient between Arctic and subtropical region, lead to decrease of heat transport both in atmosphere and ocean and consequently lead to cooling over Arctic (Muschitiell et al., 2015).
- Under a green Sahara with reduced dust condition, the amplitude and periodicity of the ENSO is reduced, which is suggested by a few proxy data (Pausata et al., 2016).

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. Regime shift in LGM simulation

As reported in last year, our LGM simulation encountered a 'strange' behaviour when model run after 800 years, the sea ice grows exponentially. During the year we have discussed with many oceanographers, sea ice experts and modelers, try to understand if it is a model technical problem or a naturally variability in the model system. It is difficult to explain the sea ice growth, in particular after around year 600 when the growth rate accelerates in an exponential manner. If the growth was thermodynamic, the growth rate would decrease with time — not increase. The thermodynamic growth of 100–200 m ice is very weak and cannot physically explain what happens. Surface accumulation of snow also could not give an accelerated growth. Most modeling groups that run LGM simulations did not report such problem because they either did not run more than 500 years, or they have the constrain of sea ice growth, such as a CCSM LGM simulation "In the glacial model runs, the potential mean sea-ice thickness of each grid cell is limited to a maximum of 30 m in order to reach equilibrium." As showing in Fig.1, a continuous run does tend to a decrease in sea-ice growth and global mean sea surface temperature increase, which indicating a climate regime shift to another equilibrium state. We will continue the simulation for another few hundreds years and to observe the evaluation of this run.

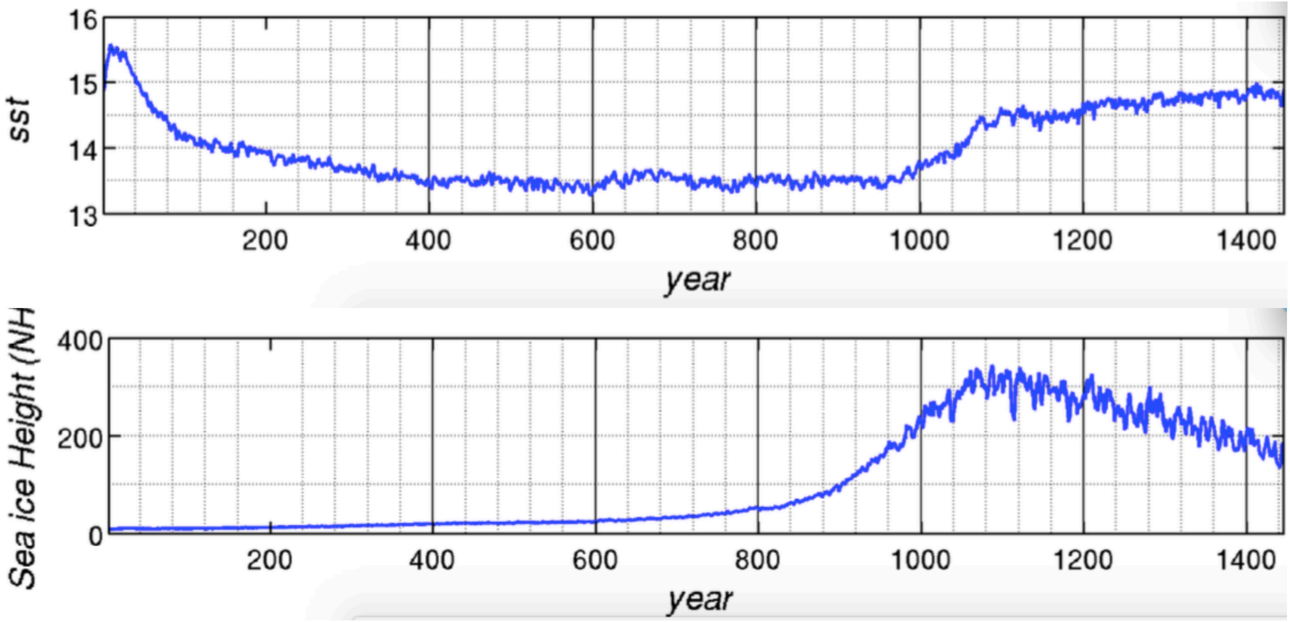

Figure 1. The evolution of global mean sea surface temperature (SST) and sea ice thickness in Northern Hemisphere in LGM run for 1450 years.

3. Testing of different ice-sheet boundary conditions for LGM simulation

In previous PMIP3 LGM protocol, an ice-sheet reconstruction is given for all the modelling groups. In upcoming PMIP4 LGM protocol, the previous ice-sheet reconstruction is no longer recommended but provides two new ice sheet reconstructions by Peltier et al. (2015) and Tarasov et al. (2002, 2012). To compare how sensitive the model to these boundary conditions, we have used all provided ice-sheet and did the test runs under LGM condition. All the runs are started from 300 years of previous run and a comparison in global mean SST shows that the from those new ice sheet reconstructions are about 0.5°C warmer than the previous boundary condition. And the SST from Peltier reconstruction is a bit warmer than those from Tarasov. We are doing comparisons now and will report the evolution to the community.

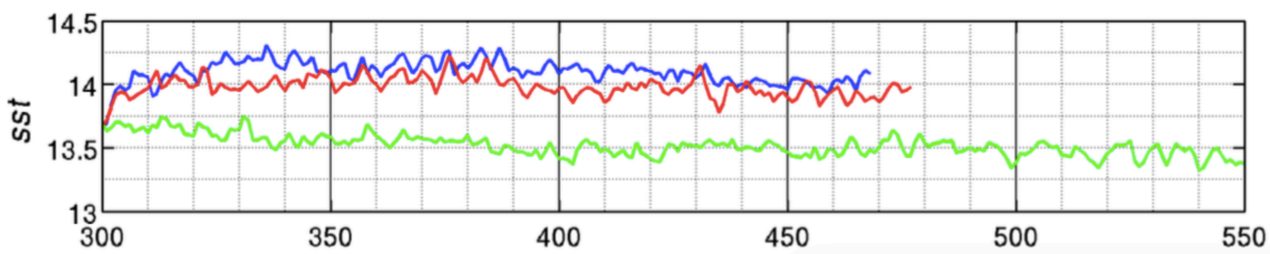

Figure 2. The evolution of global mean SST in LGM runs with three ice-sheet reconstructions, blue: Dick Peltier, red: Lev Tarasov, and green: PMIP3.

4. Mid-Pliocene experiment

We have recently finished a Mid-Pliocene experiment with EC-Earth. The Mid-Pliocene experiment is corresponding to the period about 3.3 -3 million years ago, which is believed to have similar geographical distribution and same level of atmospheric CO_2 concentration about 400-450 ppm. In our setup we have changed the land-sea mask, topography, bathymetry as suggested by the geological reconstructions, and set CO_2 level as 400 ppmv. The simulation is run for 500 years and reaches the equilibrium around 300 years and the last 200 years data are used for analysis. Comparing with the published reconstruction data and other model results, our simulation is much better agreeing with reconstruction (Figure 3), in particularly for a strong Arctic amplification, which is shown in data with high confidence, but was not reproduced by other climate models, according to Dowsett et al. (2012). A warmer Arctic and North Atlantic is clearly linked to the significant reduction of the sea-ice in Arctic, about 90% Arctic sea-ice diminishes in Pliocene, and from July to October the entire Arctic is ice-free, a small area of very thin sea-ice appears in November, with about same situation in June, which indicating about half year of ice-free Arctic (Figure 4).

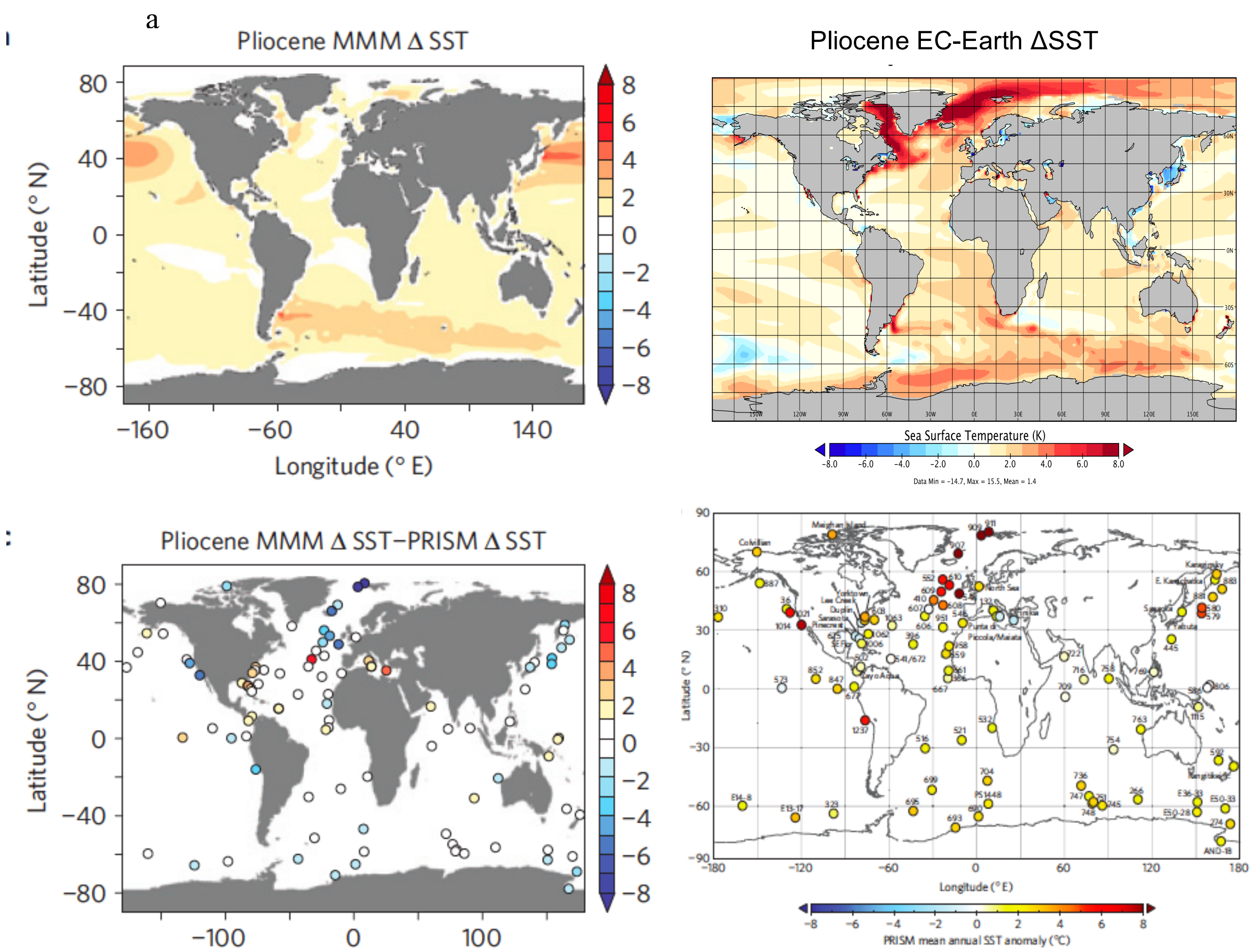

Figure 3. The global SST changes during mid-Pliocene relative to pre-industrial in multi-model simulation ensemble, in EC-Earth simulation, multi-model error and PRISM reconstructions.

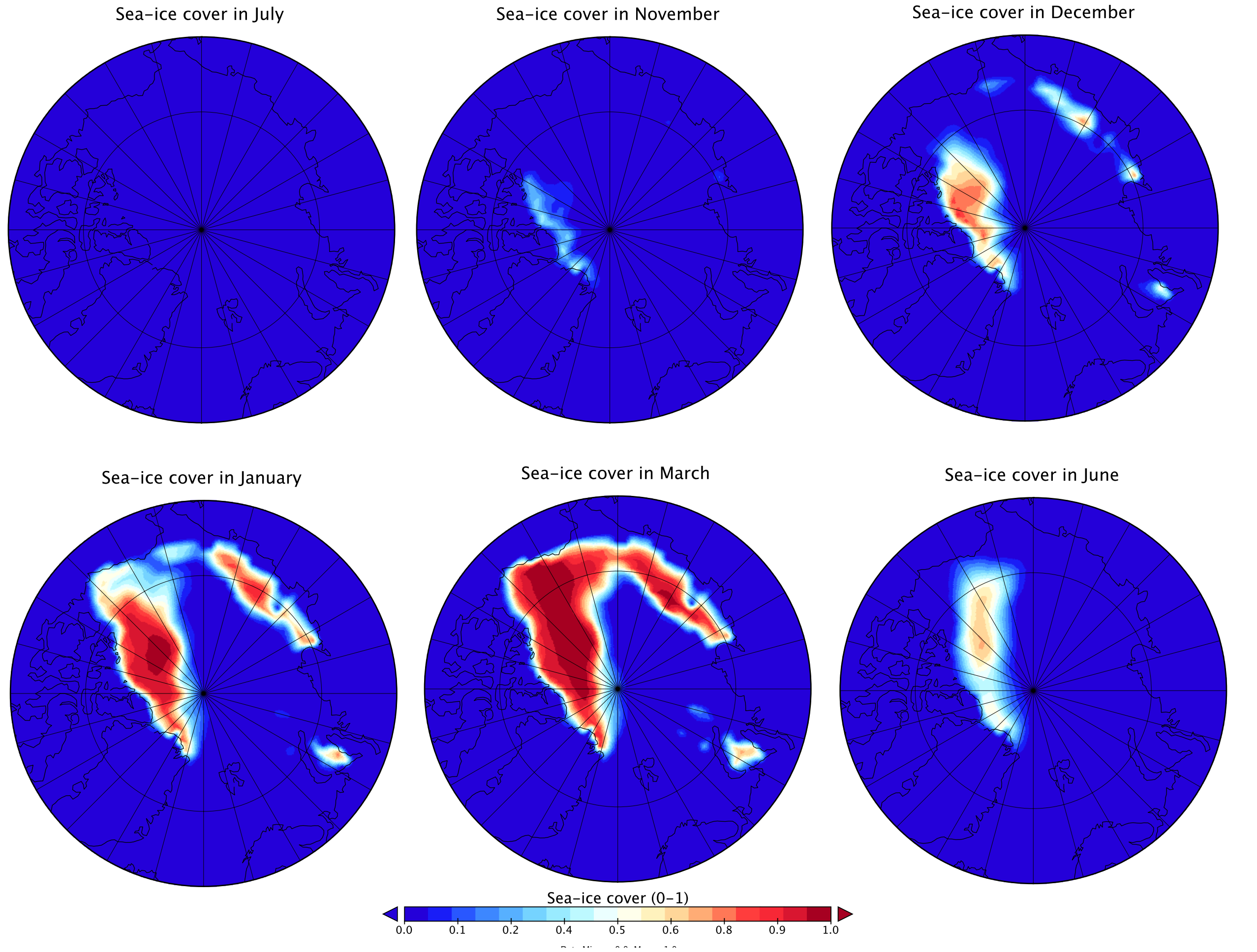

Figure 4. Sea-ice distribution in mid-Pliocene simulation in different months.

These results of mid-Pliocene simulation has been presented in a Pliocene workshop in Leeds in March 2016 and drawn attention, because no other model has reproduced the strong Arctic amplification and ice-free Arctic. It encourages us proceed this research and find out why EC-Earth can successfully reproduce most of the features revealed by the paleco proxy reconstructions.

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June 2016

List of publications/reports from the project with complete references

Published/accepted

Salih, A.A.M., Zhang, Q., Pausata, F.S.R., and Tjernström, M, 2016: Sources of Sahelian-Sudan moisture: insights from a moisture-tracing atmospheric model, *J. Geophys. Res.*, accepted.

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Zhang, P., D. Chen, H.W. Linderholm, Q. Zhang, 2015: How similar are annual and summer temperature variability in central Sweden?, *Advances in Climate Change Research*, 6, 159-170, doi: 10.1016/j.accre.2015.11.001.

Yang, H., Y. Zhao, Z. Liu, Q. Li, F. He and Q. Zhang, 2015: Heat Transport Compensation in Atmosphere and Ocean over the Past 22,000 Years. *Sci. Rep.*, 5, 16661, doi: 10.1038/srep16661.

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.

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Xu, G., X. Liu, G. Wu, T. Chen, W. Wang, Q. Zhang, Y. Zhang, X. Zeng, D. Qin, W. Sun, and X. Zhang, 2015: Tree ring δ18O's indication of a shift to a wetter climate since the 1880s in the western Tianshan Mountains of northwestern China. *J. Geophys. Res. Atmos.*, 120, 6409–6425. doi: 10.1002/2014JD023027.

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Submitted

Pausata S.R.P., Q. Zhang, F. Muschitiello, Z. Lu, L. Chafik, E. M. Niedermeyer, J. C. Stager and Z. Liu, 2016: Greening of the Sahara suppressed ENSO variability during the Mid-Holocene, submitted to *Nature Geoscience*.

Hind A., Q. Zhang and G. Brattström, 2016: Estimating Arctic amplification using ratios, submitted to Scientific Report, under review.

Gaetani M., G. Messori, Q. Zhang, C. Flamant, A. Evan and F.S.R. Pausata, 2016: Understanding the mechanisms behind the West African Monsoon northward extension during Mid-Holocene, submitted to Climate Dynamic

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

We will continue running the LGM long simulation and three ice-sheet simulations to investigate the climate variability. The analysis for the model output from LGM, LIG, mid-Pliocene will be done within several collaborations.

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.

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