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	2018
Project Title:	Simulating the green Sahara with EC-Earth 3.2
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:	2018-01-01
Expected end date:	2018-12-31

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)	250.000.000	4.946.772	10.000.000	647.682
Data storage capacity	(Gbytes)	50000	7000	50000	18000

Summary of project objectives

(10 lines max)

The project aims to use the new CMIP6 version of EC-Earth 3.2 to run a transient simulation for mid-Holocene. Due to the final version of the model has not been ready until now, we first have done several experiments using the offline dynamical vegetation model. This is a sensitivity test on response of vegetation to climate. The results show that the mid-Holocene precipitation anomalies dominate the vegetation extent while temperature anomalies adjust the vegetation composition. These sensitivity experiments confirm that dynamical vegetation model LPJ-GUESS has the potential to simulate realistic vegetation during past African humid periods when coupled to EC-Earth.

Summary of problems encountered (if any)

(20 lines max)

EC-Earth produced rainfall during green Sahara period is not enough to develop the Saharan vegetation as showed in paleo-proxy data. This may due to the lack of vegetation-climate feedback, and we expect the fully coupled system may produce more rainfall over Sahara region.

We are the only group using the low-resolution (T159 for atmosphere and land model) version of EC-Earth, therefore we have to tune the low-resolution model ourselves, which cost extra time. A model bug is recently discovered in the current Fountoukis & Nenes cloud activation scheme for the Aerosol Cloud Interaction (ACI). The EC-Earth technique group decided to change back to Abdul-Razzak & Ghan scheme. Which means the model will be re-tunned. These issues will certainly affect efficiency in using the HPC recourses.

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

1. Simulating the Green Sahara using the dynamic vegetation model LPJ-GUESS

To qualitatively evaluate such hypotheses of the orbital-climatic causation of the green Sahara regime, we performed simulations with a dynamic vegetation model, LPJ-GUESS, driven by climate forcings from mid-Holocene time-slice simulations with a coupled model EC-Earth, in which the vegetation is either prescribed to be modern desert or artificially vegetated with reduced dust load. LPJ-GUESS simulates a vegetated Sahara covered by both herbaceous and woody vegetation types consistent with proxy reconstructions only in the latter scenario. This northward expansion of vegetation is associated with a substantially intensified West African monsoon. Sensitivity experiments further suggest that the increased precipitation is the main driver of the change, and the temperature anomalies adjust the plant functional types by fire disturbance. These offline LPJ-GUESS simulations provide constraints on the simulated mid-Holocene vegetation in coupled earth system model studies with EC-Earth in the CMIP6-PMIP4 framework.

We take the climate forcing from the previous EC-Earth Green Sahara simulations to drive the LPJ-GUESS (Fig 1), considering a standard mid-Holocene run and a imposed green Sahara run. The spatial distribution of vegetation simulated with forcing from each of the GCM experiments was compared using 20-year averaged vegetation maps after model equilibrium. Only a slight northward expansion of vegetation was simulated by LPJ-GUESS in the MH forcing experiment (MH) compared to the PI forcing simulation (PI). The high vegetation, mainly consisting of evergreen broadleaf trees, migrated northward by ~5-degree latitude (Fig. 2c). The slightly short grasses emerge to the north of the tree line (Fig. 2c). In the MH_gsrd forcing simulation (MH_gsrd), the vegetation is extended considerably further northward, with tall grasses as far north as 30N (Fig. 2d) along with scattered woody vegetation (Fig. 2d). The MH_gsrd vegetation is qualitatively consistent with recent vegetation/hydrological reconstructions, in which the wooded grassland and grassland is reported as reaching as far north as 22-23oN and 26-27oN, respectively (Fig. 2b) during the mid-Holocene.

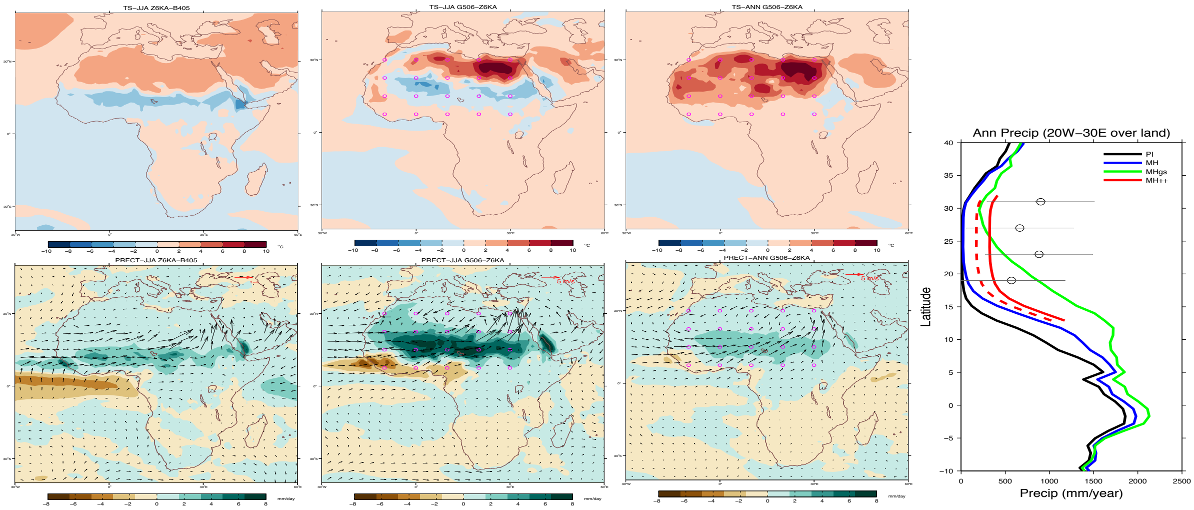

Figure 1. Climate forcing (surface air temperature, total precipitation and 925hPa wind) anomalies from EC-Earth for MH minus PI (a,b) and MH_gsrd minus MH (c-f). (g) Zonal mean (20W-30E over land) annual precipitation. Purple circles in (c-f) depict the 4X5 individual grid cells in the following analyses.

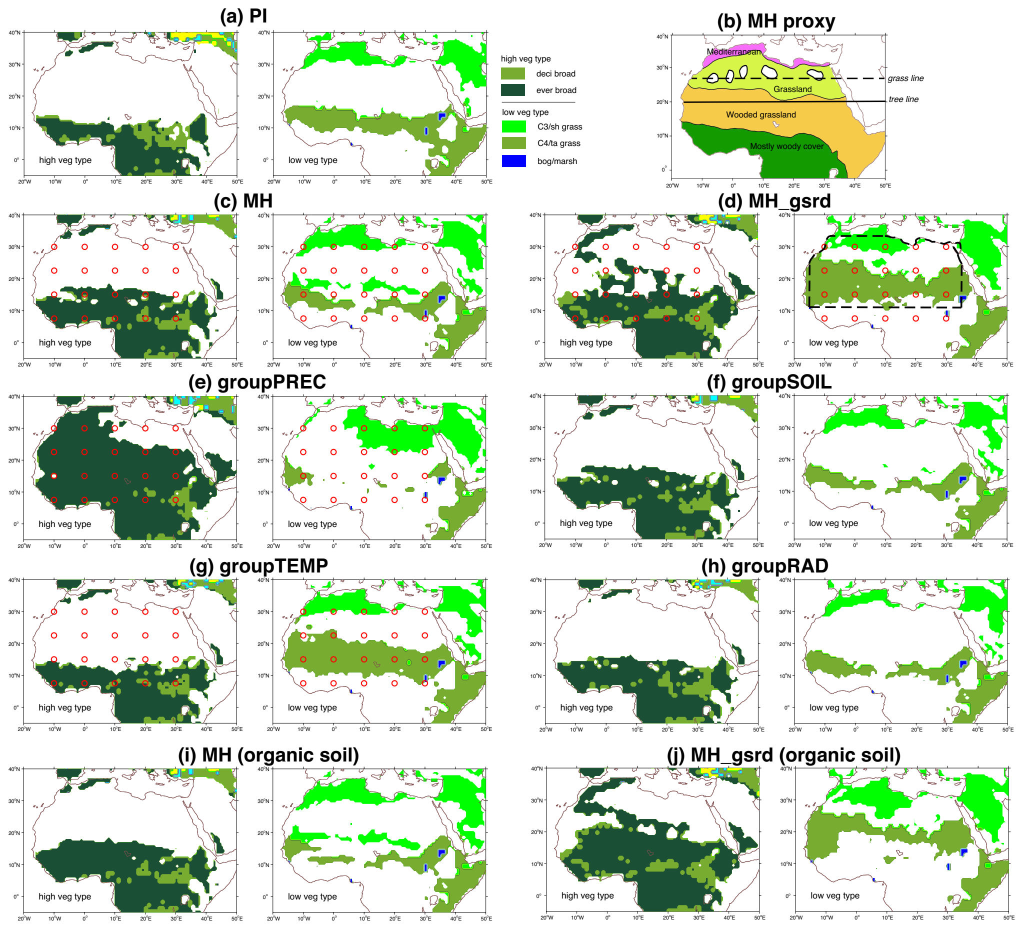

Figure 2. Simulated (a, c-j) vegetation types, in each panel high vegetation is on the left and low vegetation is on the right. Bare soil is set where vegetation cover is less than 20%. Red circles in (c,d) depict the 4X5 individual grid cells in the following analyses. (b) Reconstructed vegetation types from Larrasonana et al. (2013), and black solid line and dashed line show reconstructed tree line and grass line (Hely et al., 2014).

The driving mechanisms of the simulated vegetation patterns were investigated by additional simulations. These simulations focus on the effect of individual forcing changes (from MH to MH_gsrd) in precipitation, air temperature, soil properties and surface radiation, respectively. In groupPREC, the vegetation response is the greatest—almost cover the whole of North Africa (Fig. 2e). It is characterized by the large area of high vegetation, mostly temperate broadleaved evergreen trees, and to the northeast are denser C3 grasses. In contrast, in groupTEMP the extension of the high vegetation is more limited, while the low vegetation as represented by C4 grasses is found further north, comparable to that seen in MH_gsrd. Both high and low vegetation in groupSOIL and groupRAD are quite similar to those in MH (Fig. 2c,g,h), which implies their minor direct impacts on the simulated 'Green Sahara'.

The above modeling results using LPJ-GUESS provide a basis for improved understanding of the 'Green Sahara' biosphere response to climate forcings in the CMIP6-PMIP4 framework. LPJ-GUESS, forced by atmospheric fields generated by an idealized EC-Earth MH_gsrd simulation, is able to reproduce the mid-Holocene vegetation cover in Sahara region in reasonable agreement with reconstructions. Changes to the vegetation extent can be mainly attributed to precipitation anomalies, and changes to the vegetation composition can be mainly attributed to the temperature anomalies in combination with fire interactions. The radiation and soil temperature/moisture forcing have limited impacts on vegetation.

Our modeling results agree reasonably well with proxy reconstructions and other DGVM simulations. The potential model bias in soil texture is quantified, and has a moderate influence on vegetation composition, with organic soils favoring high vegetation in the wetter MH conditions. They provide upper and lower limits on the simulated mid-Holocene vegetation in future coupled ESM studies.

This work represents a step towards carrying out fully-interactive multi-millennial simulations using the coupled Earth system model (ESM) framework EC-Earth-LPJ-GUESS. Mid-Holocene simulations with this framework will aim to capture the vegetation-climate feedbacks believed to be associated with the observed transitions into and out of the Green Sahara period. These vegetation feedbacks will be examined in the future using fully-coupled ESM simulations of the paleoclimate transition in North Africa.

2. Multi-decadal rainfall variability in Western Africa during last millennium

We have analysed multi-decadal rainfall variability over West Africa using our last millennium simulation with EC-Earth. Our model results show an overall drying trend during last millennium, characterized with wet condition during the Medieval Warm Period and dry condition during Little Ice Age (fig 3), especially in the Sahel region. These features are mostly due to the external forcing such as the changes in solar radiation and volcanic eruptions. By removing the linear trend caused by external forcing, we found that high decadal variability in rainfall over the Coast of Guinea, which is modulated by the tropical Atlantic SST. While the rainfall variability over the Sahel region exhibits strong multidecadal variability, which is closely connected to Atlantic multidecadal variability. (Zhang et al., manuscript in preparing)

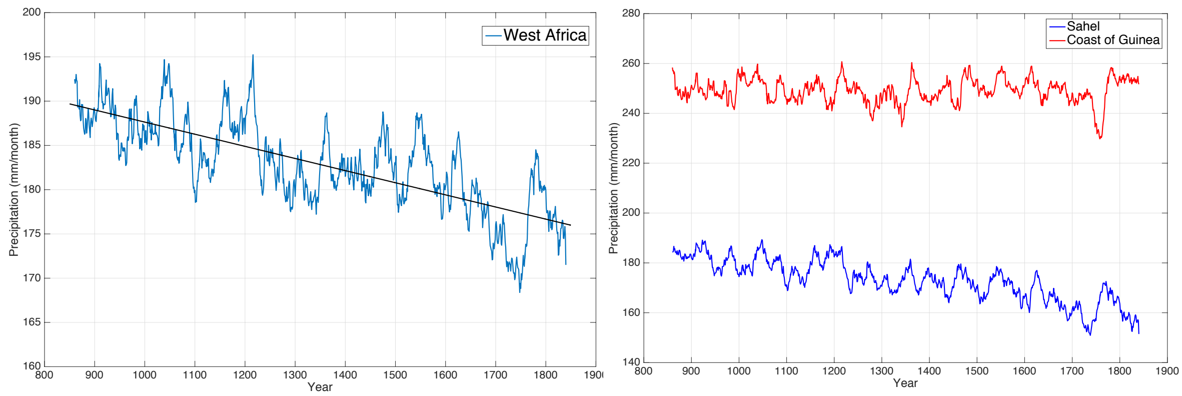

Figure 3. The evolution of summer rainfall (unit: mm/month) during last millennium over (a) western Africa and (b) Sahel (blue) and Coast of Guinea (red).

List of publications/reports from the project with complete references

1. **Zhang Q**., J.C. Hargreaves, P. Braconnot and M. Kageyama, 2017: PMIP4 contribution to CMIP6, PAGES magezine, 25, 160, https://doi.org/10.22498/pages.25.3.160.
2. An, W., S. Hou, **Q. Zhang**, W. Zhang, S. Wu, H. Xu, H. Pang, Y. Wang, and Y. Liu, 2017: Enhanced recent local moisture recycling on the northwestern Tibetan Plateau deduced from ice core deuterium excess records. Journal of Geophysical Research: Atmospheres, 122. https://doi.org/10.1002/2017JD027235.
3. Kageyama, M., Albani, S., Braconnot, P., Harrison, S. P., Hopcroft, P. O., Ivanovic, R. F., Lambert, F., Marti, O., Peltier, W. R., Peterschmitt, J.-Y., Roche, D. M., Tarasov, L., Zhang, X., Brady, E. C., Haywood, A. M., LeGrande, A. N., Lunt, D. J., Mahowald, N. M., Mikolajewicz, U., Nisancioglu, K. H., Otto-Bliesner, B. L., Renssen, H., Tomas, R. A., **Zhang, Q**., Abe-Ouchi, A., Bartlein, P. J., Cao, J., Li, Q., Lohmann, G., Ohgaito, R., Shi, X., Volodin, E., Yoshida, K., Zhang, X., and Zheng, W.: The PMIP4 contribution to CMIP6 – Part 4: Scientific objectives and experimental design of the PMIP4-CMIP6 Last Glacial Maximum experiments and PMIP4 sensitivity experiments, Geosci. Model Dev., 10, 4035-4055, https://doi.org/10.5194/gmd-10-4035-2017, 2017.
4. Jungclaus, J. H., Bard, E., Baroni, M., Braconnot, P., Cao, J., Chini, L. P., Egorova, T., Evans, M., González-Rouco, J. F., Goosse, H., Hurtt, G. C., Joos, F., Kaplan, J. O., Khodri, M., Klein Goldewijk, K., Krivova, N., LeGrande, A. N., Lorenz, S. J., Luterbacher, J., Man, W., Maycock, A. C., Meinshausen, M., Moberg, A., Muscheler, R., Nehrbass-Ahles, C., Otto-Bliesner, B. I., Phipps, S. J., Pongratz, J., Rozanov, E., Schmidt, G. A., Schmidt, H., Schmutz, W., Schurer, A., Shapiro, A. I., Sigl, M., Smerdon, J. E., Solanki, S. K., Timmreck, C., Toohey, M., Usoskin, I. G., Wagner, S., Wu, C.-J., Yeo, K. L., Zanchettin, D., **Zhang, Q**., and Zorita, E.: The PMIP4 contribution to CMIP6 – Part 3: The last millennium, scientific objective, and experimental design for the PMIP4 *past1000* simulations, Geosci. Model Dev., 10, 4005-4033, https://doi.org/10.5194/gmd-10-4005-2017, 2017.
5. Otto-Bliesner, B. L., Braconnot, P., Harrison, S. P., Lunt, D. J., Abe-Ouchi, A., Albani, S., Bartlein, P. J., Capron, E., Carlson, A. E., Dutton, A., Fischer, H., Goelzer, H., Govin, A., Haywood, A., Joos, F., LeGrande, A. N., Lipscomb, W. H., Lohmann, G., Mahowald, N., Nehrbass-Ahles, C., Pausata, F. S. R., Peterschmitt, J.-Y., Phipps, S. J., Renssen, H., and **Zhang, Q**.: The PMIP4 contribution to CMIP6 – Part 2: Two interglacials, scientific objective and experimental design for Holocene and Last Interglacial simulations, Geosci. Model Dev., 10, 3979-4003, https://doi.org/10.5194/gmd-10-3979-2017, 2017.
6. Helsen, M. M., W. van de Wal, R. S. W., Reerink, T. J., Bintanja, R., Madsen, M. S., Yang, S., Li, Q., and **Zhang, Q**., 2017: On the importance of the albedo parameterization for the mass balance of the Greenland ice sheet in EC-Earth, The Cryosphere, 11, 1949-1965, https://doi.org/10.5194/tc-11-1949-2017.
7. Pausata, F. S., **Q. Zhang**, F. Mischitiello, Z. Lu, L. Chafik, E. M. Niedermeyer, J. C. Stager, K. M. Cobb, and Z. Liu, 2017: Greening of the Sahara suppressed ENSO activity during the mid-Holocene. *Nature Communications*, **8**.
8. 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
9. Pausata, F. S. R., K. A. Emanuel, M. Chiacchio, G. T. Diro, **Q. Zhang**, L. Sushama, J. C. Stager, and J. P. Donnelly. 2017. Tropical cyclone activity enhanced by Sahara greening and reduced dust emissions during the African Humid Period. Proceedings of the National Academy of Sciences.

Summary of plans for the continuation of the project

(10 lines max)

We will continue the planed work on Green Sahara by using fully coupled EC-Earth-LPJ-GUESS. Given some issues on model development, we expect the next half year in 2018 will be devoted to model tunning and testing. We continue to apply a new SP project in order to perform the mid-Holocene transient simulation.

Within the collaboration in EC-Earth community, we work closely with experts on dust in University of Helsinki and plan to have the interactive dust in our model as well. This will need the offline test first then couple to the ESM, the procedure will be similar to those for LPJ-GUESS.