Project 9 (WP2): Grand Challenge on clouds and climate sensitivity

Project lead: Sandrine Bony
Post-doctoral researcher: Kenji Izumi
Project Start/End: September 2014 – August 2015

Position offer:

Climate system's response to past vs future conditions: comparing the strengths of radiative forcings and feedbacks for the last glacial maximum and future climates

In the framework of the « Clouds, Circulation and Climate Sensitivity » WCRP "Grand Challenge", The excellence laboratory L-IPSL of the Institut Pierre-Simon Laplace offers a one-year post-doctoral position to analyse the radiative feedbacks operating in the PMIP3/CMIP5 LGM and future climate simulations.

Context

Man is currently disturbing the climate system by modifying the atmospheric composition (e.g. in greenhouse gases and aerosols) and the characteristics of the continental surface. These *forcings* translate into perturbations of the energetic and hydrological cycles in the atmosphere, which are then amplified or dampened through multiple *feedbacks*. Quantifying these feedbacks requires both climate models and observations of climatic changes. One of the largest uncertainties in future climate prediction arises from the difficulties to quantify the feedbacks from clouds, which are crucial in both the energy and hydrological cycles.

Compared to the recent climate changes which have been closely monitored e.g. with satellite observations, climates for periods before the satellite era are not as precisely described, but some past periods are challenging for climate modellers because they are characterised by climate changes much larger than the ones which have been recently observed. The perturbations to the climate system in these cases results from modification of the Earth's orbital parameters, but also consist, like in the scenarios for future climate change, in modifications of the atmospheric composition and of the Earth Surface, e.g. via natural changes in vegetation and changes in ice-sheet extent and height. In the last decades, much effort has been devoted to deciphering new climate archives and compiling them into databases for key periods of the past, as well as attempting to the understanding of these reconstructed climate changes using climate models of different complexities. One such effort is the Palaeoclimate Modelling Intercomparison Project (PMIP), which is currently in its third phase (http://pmip3.lsce.ipsl.fr). The Mid-Holocene (~6000 years ago) and the Last Glacial Maximum (LGM, ~21000 years ago) have been the focus of PMIP since its start. The main forcings needed to model the LGM climate is the presence of huge ice-sheets at mid- to high latitudes over the northern North America and Fennoscandinavia and the decreased concentration in greenhouse gases. The LGM surface climate and oceanic conditions are particularly well documented from multiple climatic archives which have been assembled in data sets such as the MARGO (2009) data set of reconstructions of sea surface temperature or the Bartlein et al (2011) data set of continental climate reconstructions. Finally, for the first time, the LGM climate has been modelled in the CMIP5 exercise with the exact same models as those used to compute future climate changes. There are currently 11 models for which data from the LGM, pre-industrial and future simulations are available in the CMIP5 data base. We therefore have the unique opportunity to analyse, with multiple model output and in a common framework, past and future climate forcings and feedbacks. This is one of the goals set up in the « Clouds, Circulation and Climate Sensitivity » WCRP "Grand Challenge", to which this post-doc will contribute.

Description of work

The successful candidate is expected to analyse the radiative forcings/feedbacks in the LGM vs. future climate simulations available from the CMIP5 archive. A particular focus will be on the cloud radiative forcing, for which analyses tools have been long developed at Laboratoire de Météorologie Dynamique. The candidate will also have the possibility to analyse additional sensitivity simulations run to better understand the impact of each forcing on the LGM climate: land-surface changes vs. atmospheric composition changes. The proposed research has two goals:
- to improve our understanding of the feedbacks (in particular from the clouds) operating in the climate system in LGM simulations, with the same methods as developed to quantify climate feedbacks in present and future climate scenarios;
- to examine whether the available LGM climatic reconstructions such as the MARGO or Bartlein et al, or any upcoming data synthesis, can help discriminate between different values or characteristics of these feedbacks, among the variety of results from the available CMIP5 climate models.

Supervision team: The position is funded by LABEX L-IPSL and IPSL will be the employer.

The successful candidate will work with experts in palaeoclimate modelling at LSCE, in close collaboration with experts in the quantification of radiative forcing and cloud feedbacks at LMD. The main supervisors will be Sandrine Bony at LMD and Masa Kageyama at LSCE.

Duration and salary: The post-doctorate will be recruited for 12 months with a net monthly salary around 2000 euros, commensurate with experience. This includes social services and health insurance.

Contact for applications: Applications should include a vita, a statement of research interests and the names of at least two references including e-mail addresses and telephone numbers. Applications should be submitted by e-mail to Masa Kageyama, LSCE (Masa.Kageyama@lsce.ipsl.fr) and Sandrine Bony, LMD (Sandrine.Bony@lmd.jussieu.fr).

Results

Our activities were related to the Grand Challenge on "Clouds, Circulation and Climate Sensitivity" (Bony et al. 2015), which is one of the six Grand Science Challenges defined by the World Climate Research Programme. The main objective of this Grand Challenge is to improve our understanding on how clouds, atmospheric circulation and climate interact in their response to different climate forcings, corresponding to past and future climate changes. Therefore, we focused on the changes in the atmospheric circulation and precipitation over the tropics across different climate states using CMIP5 models and paleodata. Using paleodata and paleo-simulations, we understand the mechanism of climate variations/changes and evaluate climate model performance outside the range of recent observed climate variability.

Previous climate simulations for historical as well as twenty-first-century projections already showed distinctive large-scale climate responses such as land-ocean contrast, high-latitude amplification, changes in seasonality, and scaling of precipitation with temperature. Using the CMIP5 archive, Izumi et al. (2015a) and Harrison et al. (2015) showed that these large-scale climate responses are generally consistent and linear across different climate states, including paleo-simulations (mid-Holocene and Last Glacial Maximum) and idealized CO_2-induced warmer climates (1%CO_2 and abrupt4xCO_2). Moreover, paleodata are found to support these relationships. Therefore, these large-scale climate changes are real climate responses, and not climate model artifacts. On the other hand, there are large mismatches in the regional responses of precipitation and improvements are required to produce reliable regional projections.

It is well understood that changes in global average precipitation in response to greenhouse-induced warming/cooling are associated with changes in global mean temperature and the water vapor content of the atmosphere. However, regional precipitation changes are also closely influenced by the atmospheric circulation. Therefore, the first part of this project was to identify relationships, in a multi-model context, between changes in tropical precipitation and large-scale tropical atmosphere circulation in CMIP5 simulations of past (mid-Holocene and Last Glacial Maximum) and future climates (1%CO_2 and abrupt4xCO_2). Both hemispheric temperature gradient and atmosphere heat transport at the equator are key factors for the seasonal and interannual tropical rainbelt migrations; tropical rainbelt migrates by about 1.9 degree latitude per 1°C in the temperature gradient toward the warmer hemisphere and around -2.5 degree latitude per 1 PW in atmospheric heat transport at the equator (toward the Northern Hemisphere) across all climate states. Moreover, there are some robust relationships across the different climate states: 1) The area of ascending branch of tropical overturning circulation increases as the ascending branch weakens, and the area of the descending branch decreases as the descending branch weakens. 2) The overturning circulation weakens as the surface temperature increases, and vice versa. 3) The Hadley cell narrows when the overturning circulation weakens, and the shift in the southern edge of the cell is larger than that of the northern edge. 4) Tropopause height increases as surface temperature increases, and vice versa. (Izumi et al. 2015b, c)

A second objective was to investigate how much the atmospheric cloud radiative effect (ACRE, defined as the difference TOA and surface CRE estimates) impacts the tropical atmospheric circulation in the mid-Holocene climate, and changes in the position and strength of tropical rainbelts and the Western African monsoon in particular. For this purpose, we ran the LMDZ AGCM along the design of COOKIE (the Clouds On-Off Klima Intercomparison Experiment) that consists in perturbed simulations in which the model ACRE is turned off in the radiative computation (cloud-off). Preliminary results (Izumi et al. 2015d) indicate that zonal average precipitation decreases at the precipitation maximum position and increases over the most of the tropical latitudes. That is: in the off-cloud climate simulation, the tropical circulation is weaker and the rain band is wider. Moreover, in the mid-Holocene climate, making clouds transparent to radiation moves the summer tropical rainbelt over the West Africa further north. This could suggest ways of improving climate models in their long-standing failure of simulating the green Sahara.

Publications:

Bony, S., B. Stevens, D. M. W. Frierson, C. Jakob, M. Kageyama, R. Pincus, T. G. Shepherd, S. C. Sherwood,A. P. Siebesma, A. H. Sobel, M. Watanabe, and M. J. Webb, 2015: Clouds, Circulation and Climate Sensitivity. *Nature Geoscience*, 8, 261–268, doi:10.1038/ngeo23

Harrison, S.P., P.J. Bartlein, K. Izumi, G. Li, J. Annan, J. Hargreaves, P. Braconnot, M. Kageyama, 2015. Evaluation of CMIP5 palaeo-simulations to improve climate projections. *Nature Clim. Change*, 5, 735-743.doi: 10.1038/NCLIMATE2649

Izumi, K., P.J., Bartlein, and S.P., Harrison, Paleoclimate diagnostics: consistent large-scale temperature responses in warm and cold climates, *EGU General Assembly*, Apr. 2015a, Vienna, Austria. (Oral, invited)

Izumi, K., M. Kageyama, S. Bony, and P. Braconnot, Robust relationship in past and future simulation – atmospheric circulation and hydrological cycle over the tropics, *EGU General Assembly*, Apr. 2015b, Vienna, Austria. (Poster)

Izumi, K., M. Kageyama, S. Bony, and P. Braconnot, Robust relationship in past and future simulation – atmospheric circulation and hydrological cycle over the tropics, *XIX INQUA Congress*, July. 2015c, Nagoya, Japan. (Oral)

Izumi, K., M. Kageyama, S. Bony, and P. Braconnot, Influence of cloud radiative effects on tropical circulation and hydrological cycle in the Mid-Holocene, *Water and Energy Cycles in the tropics*, Nov. 2015d, Paris, France. (Oral)