Assimilation of palaeoclimate proxy data into GCMs taking into account downscaling techniques and forward models

Supervisor: Martin Widmann (Birmingham)

Abstract Quantifying and understanding natural climate variability on long time scales is key to distinguishing natural and anthropogenic variability during the 20th and 21st century, and to predict the future climate. Climate variability in the pre-instrumental period can be estimated either from climate proxy data, e.g. tree rings, ice cores or stalagmites, or from numerical simulations. Palaeoclimate simulations have been performed so far mainly by prescribing climate forcings such as solar radiation and atmospheric composition. However, as a consequence of internal climate variability, the temporal evolution of the climate states is not completely determined by the forcings. In principle this problem can be addressed by combining empirical information from proxy data with numerical simulations (for an overview see Widmann et al. 2010). This approach is used operationally in meteorology and is known as data assimilation (DA), but adapting it to palaeoclimatic applications is challenging. This project aims at refining a DA approach that has been developed at the University of Birmingham in collaboration with the Max Planck Institute for Meteorology (MPI-Met) in Hamburg. The improved DA method will be used in to obtain improved climate reconstructions for key periods during the last millennium, for instance the medieval warm period or the Maunder Minimum cold period.

Methods The improved DA method uses ensemble simulations with the MPI-ESM General Circulation Models and is based on the selection of ensemble members that are closest to palaeoclimate proxy data to obtain a simulation that is both consistent with the model physics and with the empirical knowledge. This approach has been already successful with Earth System Models of Intermediate Complexity (Goosse et al. 2006). The increase in computing power now allows this for the first time using more complex GCMs. We use a sequential approach in which ensembles for sub-periods are generated after the proxy data for the previous period have been assimilated; a simplified version where the ensemble for the whole analysis period is generated prior to the assimilation step has already been used by Bhend et al. (2012).

The fundamental framework of DA usually contains an 'observation operator', which links the simulated state to the empirical data that are assimilated. In palaeoclimatic applications this step has so far not been explicitly included. Instead local or regional temperature reconstructions have been used and have been directly compared to the simulated grid-cell values (sometimes considering only anomalies, which essentially removes the bias in the simulations and proxy data). This project aims at using recently developed more advanced downscaling methods (e.g. Eden and Widmann 2013) to estimate regional temperature or precipitation from the simulations prior to comparison. It also aims to systematically explore in which regions the climate model can be expected to give a good estimate for temporal variability (Eden et al. 2012), i.e. where the comparison with proxy data is justified. This step is conceptually related to determining what is known as the 'background error' in the standard DA framework, which should be taken into account for defining optimal cost functions for comparison. Finally, the project will also aim at including so-called 'forward models' for proxy data, which link climatic states directly to the proxy data and would be the best choice for an observation operator in DA.

Training The project gives the chance to work on cutting-edge problems in palaeoclimate modelling using supercomputers, state-of-the-art climate models, and advanced statistical downscaling methods. Co-supervision by the MPI-Met will be arranged and the supervisory team will provide training in all aspects of the project such as climate modelling, palaeoclimatology and statistics. It also brings multiple national and international links.

Requirements Applicants should have a background in a related field such as climatology, geosciences, or physics or mathematics. Sound mathematical and statistical skills, as well as programming experience are essential. Working experience with UNIX, FORTRAN, and climate modelling would be beneficial. For further details please contact M. Widmann (m.widmann@bham.ac.uk).

References

J. Bhend, J. Franke, D. Folini, M. Wild, and S. Broennimann, 2012:. An ensemble-based approach to climate reconstructions. *Climate of the Past*, 8(3),963-976.

Eden, J.M., Widmann, M., Grawe, D, and Rast. S., 2012: Reassessing the skill of GCM-simulated precipitation. *J. Climate*, **25**(11), 3970-3984.

Eden, J.M., M. Widmann, 2013: Downscaling of GCM-simulated precipitation using Model Output Statistics. *J. Climate*, in press.

Goosse H., H. Renssen, A. Timmermann, R.S. Bradley and M.E. Mann, 2006: Using paleoclimate proxy- data to select an optimal realisation in an ensemble of simulations of the climate of the past millennium. *Climate Dynamics*, 27, 165-184.

Widmann, M., H. Goosse, G. van der Schrier, R. Schnur and Jan Barkmeijer, 2010: Using data assimilation to study extratropical Northern Hemisphere climate over the last millennium. *Climate of the Past,* 6, 1-18.

Applicants should apply via http://www.birmingham.ac.uk/postgraduate/courses/research/gees/earth-sciences.aspx where they should click on 'Apply now' and choose the option 'PhD in Department of Earth Sciences' and give the PhD title in the 'Funding details' section of the online application.