Climate Modeling

ESF/HOLIVAR Meeting. Louvain-la-Neuve, Belgium, 12-15 June 2002

How could insolation changes, with their modest change in annual mean forcing, cause the drying of the northern subtropical areas—including the full desertification of the Sahara—and the global cooling experienced at high northern latitudes? This question motivated the pioneering general circulation model experiments by Kutzbach and Mitchell in the eighties. They pointed out the importance of the seasonal contrast of insolation in governing the ocean-land temperature gradient. Yet, twenty years later, quantitative understanding of the climate of 6,000 years ago remains a priority and also a prerequisite for confidence in future climate predictions. Modelers have understood the need for considering feedback from the biosphere, the ocean mixed layer and sea-ice, and hence the importance of including these components in state-of-the-art models. While general circulation models have been used to better understand the mean climate features of the Holocene, many new high temporal resolution data have become available, bringing new challenges to climate scientists and modelers. Time series with decadal and annual resolution have shown the need for long transient simulations to reach a better understanding of the mechanisms involved in climate variability and abrupt climate change during the Holocene. Some of the first of these were carried out with models (of intermediate complexity) largely based on a zonally averaged structure with a secondary treatment of the longitudinal resolution. Experiments with CLIMBER-2 (Claussen et al., 1999) suggested that the desertification of Sahara was abrupt because decreasing summer insolation crossed a threshold in Charney's positive monsoon-vegetation feedback. In parallel, Crucifix et al. studied the vegetation-temperature feedback operating at high latitudes, but concluded that this feedback was not strong enough to cause abrupt climate change, at least during the Holocene.

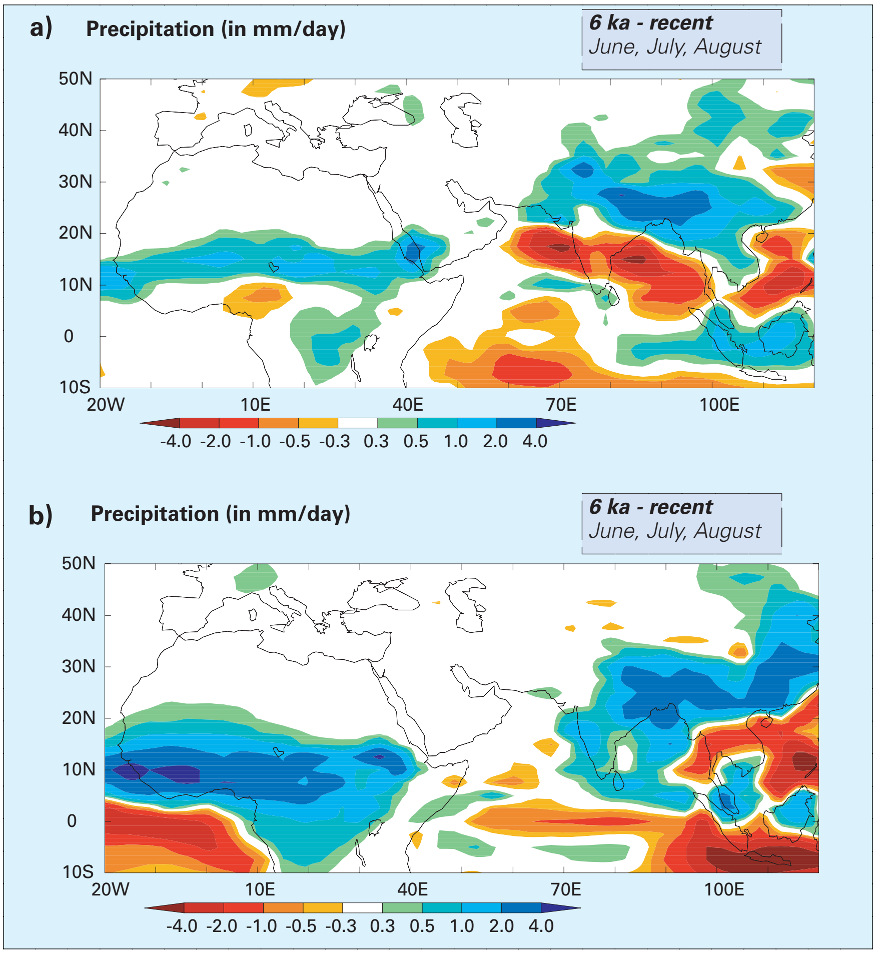

*Figure 1: The figure shows the modelled changes in June-July-August mean precipitation for the changes between the mid-Holocene (6000 years ago) and the present day for an example of (**a**) a PMIP I simulation in which the orbital parameters were changed but the sea surface temperature and vegetation cover were held constant at present day, and (**b**) a PMIP II style simulation in which changes in vegetation and oceanic circulation were modelled. The mo soons are considerably enhanced when these effects are included. The robustness of these results, and the changes in other regions and interannual variability will be examined in the PMIP II project. The results shown are using version 3 of the Hadley Centre model and all simulations should be considered provisional.*

Along with these recently published results, 9,000-year-long time-series computed with 3-D models were presented for the first time. At the cost of increased computing time, the latter models better capture both atmosphere and ocean dynamics, including their natural variability. This sometimes yielded unexpected results. The ECBILT-CLIO model (UCL, Louvain-la-Neuve), for example, exhibits extreme precipitation variability at the century time-scale in the Sahara prior to 5,000 years ago. For the model, insolation is then at such a level that the vegetation-monsoon positive feedback is strongly excited by the internal variability. Even if this result seems unrealistic, it points out the additional complexity brought by the third dimension, and may be an example of the difficulties that will appear when performing similar experiments with state-of-the-art models.

Currently, state-of-the-art models can only be run for specific time slices (although this is rapidly changing and in the next few years we will start to see the first 9000-year simulations with low resolution versions of state-of-the art general circulation models). Coupled atmosphere-ocean-vegetation models can be run for simulations up to a millennium in length, and the annual, decadal, and century scale variability can be examined. For instance, changes in ENSO variability during the mid-Holocene can be examined. Such studies are important to help us understand the controls on climate variability, and to determine whether the current models can successfully reproduce the observed changes. Coupled atmosphere-ocean-vegetation modelling and natural variability will be the major foci of the second phase of the Palaeoclimate Model Intercomparison Project (PMIPII). As well as focusing on the mid-Holocene, the new project will also perform simulations for the early Holocene (see EOS, 1 October 2002, and http://www-lsee.eea.fr.pmip

At such time-scales, it is also crucial to account for solar forcing (i.e., variations in solar activity) and volcanic eruptions. The ECBILT-MOM model, developed at the KNMI, has been used to examine the phase relationships between solar forcing and the extent of glaciers in the Alps. Studies of the last millennium have also highlighted the importance of a good knowledge of the natural variability in forcing mechanisms (e.g. Collins et al., 2002). Model simulations must include this variability if we are to faithfully test the models. Currently, our knowledge of this forcing is generally rather poor.

The increasing importance of gathering more data and modelling expertise on the global carbon cycle during the Holocene was also stressed. Until recently, most attempts to understand the cause for the CO_2 increase during the Holocene were based on conceptual models. With biogeochemical cycles being implemented in models, a more detailed model-data comparison will be possible. Brovkin et al. (2002) recently illustrated the power of such tools by analyzing the consequences of Holocene climate change and change in ocean alkalinity on the terrestrial and oceanic carbon stocks during the Holocene. They also simulated atmospheric $\delta^{13}C$ concentration to compare it with data and test their hypotheses about alkalinity and lysocline depth—even if in this particular case, $\delta^{13}C$ data fail to provide sufficient constraint. The alternative approach is to use the model to generate synthetic records. In other words, attempting to reconstruct the raw data seems to be a promising way to better understand how climate worked in the past.

The meeting suggested many future research directions. It also highlighted the importance of studying both past millennium and longer time-scale variability. All of the approaches are valuable for improving our understanding of climate variability and for evaluating climate models. For this latter problem, it is also essential that we build a new database of the natural variability of climate forcing (especially solar and volcanic), as well as building and maintaining databases of high quality climate proxies for the whole of the Holocene period. The increasing ability of the models and improvements in high-resolution data will ensure that the next few years will be an exciting time.

References

Brovkin, V., Hofmann, M., Bendtsen, J. and Ganopolski, A., 2002: Ocean biology could control atmospheric d13C during glacial-interglacial cycle. Geochemistry Geophysics Geosystems 3: art.no. -1027

Claussen, M., Kubatzki, C., Brovkin, V., Ganopolski, V., Hoelzmann, P. and Pachur, H.J., 1999: Simulation of an abrupt change in Saharan vegetation in the mid-Holocene. Geophysical Research Letters 26: 3037-2040

Collins, M., Osborn, T.J., Tett, S.F.B., Briffa, K.R. and Schweingruber, F.H., 2002: A comparison of the variability of a climate model with paleotemperature estimates from a network of tree-ring densities. Journal of Climate 15: 1497-1515

Michel Crucifix[1] and Paul Valdes[2]

[1]Hadley Centre for Climate Prediction and Research, UK;
michel crucific@metoffice.com
[2]University of Reading, UK;
p.j.valdes@reading.ac.uk

Investigating Holocene Climate Variability: Data-Model Comparisons

ESF/HOLIVAR Meeting. Louvain-la-Neuve, Belgium, 12-15 June 2002

Comparing model output with information provided by proxy data was discussed in detail. The comparison is challenging because the characteristics of model output and paleodata are very different and many sources of uncertainty exist. Climate is represented at different spatial scales: local in proxy records, several hundred kilometers or more in models. Further, the registered variability in proxies is only partly caused by climatic variations, so that it is necessary to isolate the climatic signal using statistical methods and to represent the non-climatic residuals (perhaps by a suitable stochastic model). Finally, the responses of the proxies to the local or large-scale climate may be non-invertible. A number of model-proxy comparison methods were presented at the workshop to address some of these difficulties.

The traditional *inverse* approach is to reconstruct some aspect of climate from proxy data (often including an aggregation to larger spatial scales more suited for comparison with model output) and then compare the reconstruction to simulated climate data. It was demonstrated during the workshop how the non-climatic residuals influence variance, trends and spatial patterns and that appropriate treatment of these residuals can avoid biased comparisons. Examples were given (Collins et al., 2002) of the comparison, at the inter-decadal time-scale, between levels of internally generated variability simulated during a GCM (coupled ocean-atmosphere general circulation model) control run, and the temperature variability reconstructed from tree-ring density across the Northern Hemisphere. The results were sensitive to the processing of the tree-ring data but indicated an underestimation of the variability by the model. This could be partly accounted for by the influence of natural external forcing changes (solar irradiance or volcanic aerosols). Comparisons of proxy-based temperature reconstructions with EBM (energy balance model) simulations of the response to natural and anthropogenic forcings (updated from Crowley, 2000) were presented, with the reconstructions used to identify the climate sensitivity that provides the best fit between model and data