Exchanges
- Supplementary Contributions -

Holocene climate variability investigated using data-model comparisons

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In climate research there is a continuing need for information about climate variability on longer time-scales than modern meteorological measurements can provide. As a consequence, interest in the climate of the Holocene (approximately the last 11500 years) has increased over the last decade. To obtain an overview of the latest developments in Holocene research, a workshop was held in Louvain-la-Neuve, Belgium in June 2002. The aim was to bring together two communities that traditionally have been rather separated, namely climate modellers and researchers working with proxy data, to discuss the possibilities of improving model–data studies. The workshop was the second in a sequence of meetings sponsored by the European Science Foundation within the framework of the HOLIVAR programme (HOLocene clImate VARiability), which seeks to address the aims of the PAGES/CLIVAR Intersection by promoting the use of high resolution paleoarchives and climate models to improve our understanding of decadal to century climate variability.

The challenge of comparing model output with information provided by proxy data (tree rings, ice cores, documentary records, etc.) was discussed in detail. The comparison is considered a challenge 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 kilometres 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 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, but that appropriate treatment of these residuals could avoid biased comparisons. Examples were given (Collins et al., 2002) of the comparison, at the inter-decadal time scale, of levels of internally-generated variability simulated during a GCM[1] control run with 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, that could be partly accounted for by the inclusion of natural external forcing changes (solar irradiance or volcanic aerosols). Comparisons of proxy-based temperature reconstructions with EBM[2] 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 for the past 1000 years. On longer time scales, both quantitative and qualitative comparisons of proxy data with the climate simulated by GCMs and EMICs[3] were presented, using simulations of time slices, transient simulations of particular events (e.g., Figure 1 and Renssen et al., 2002) and transient simulations of virtually the full Holocene (Crucifix et al., 2002; Brovkin et al., 2002).

The workshop participants agreed on the great potential offered by the *forward-modelling* approach, where appropriate process-based (physical, biological, chemical) or empirical models are driven by climate model output to simulate a proxy value or time series, which is then compared with the actual proxy data. This approach can deal explicitly with non-linear and non-invertible proxy response to multiple climate drivers, and can also aid our understanding of the processes responsible for the proxy behaviour. Insufficient development, tuning and validation of process-based models for different proxy types and locations has restricted the application of the forward-modelling approach to date, but notewor-

[1] GCM: coupled ocean-atmosphere general circulation model
[2] EBM: energy balance model
[3] EMIC: Earth system model of intermediate complexity

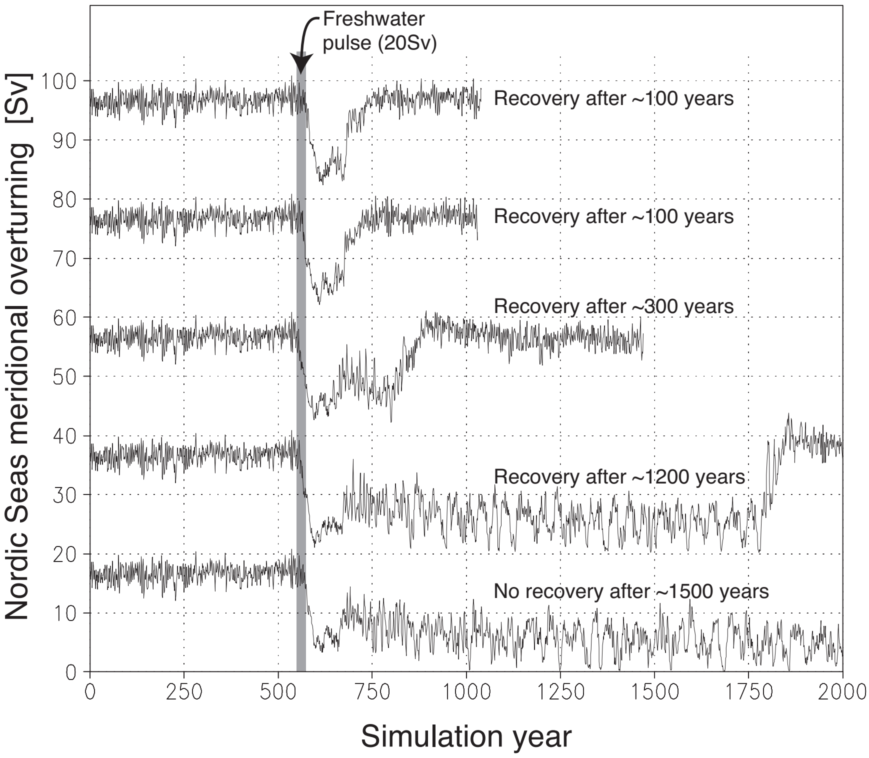

Fig. 1: Simulation of the 8.2 ky BP event (Renssen et al., 2002): response of the thermohaline circulation to freshwater pulses of 20 Sv released during simulation years 550-570 in the Labrador Sea, for 5 ensemble members (each offset by 20 Sv for clarity). Other forcings are representative of 8.5 ky BP.

thy progress was reported at the workshop, including the simulation of tree rings, ice cores, glacier length and local sea level (e.g., Reichert et al., 2001, Weber and Oerlemans, 2003). Forward modelling is now being used to assess some aspects of simulated variability over the past few centuries, as well as throughout the Holocene using EMICs.

While inverse reconstruction and forward modelling with proxy data allow *comparison* with model output, presentations were also made of possible methods for the *combination* of proxy and model data to provide improved estimates of past climate variations. One technique, named DATUN (Data Assimilation Through Upscaling and Nudging, Jones and Widmann, 2002), 'nudges' the climate towards an atmospheric circulation state that has been reconstructed from a set of paleodata, while remaining consistent with the model's physics and the applied external forcings. The assimilation of paleodata is still under development, but preliminary results were presented at the workshop.

A second method was proposed (by Mat Collins), where many realisations of each simulation year are generated (again under appropriate external forcing variations), and the closest analog to the available paleodata for that year is selected, before proceeding to the next year of the simulation.

The assimilation method requires the inverse reconstruction of past atmospheric circulation, while the analog approach could be combined with either inverse or forward-modelling techniques. Both approaches would allow the actual evolution of simulated climate variations to be assessed against independent proxy data, as well as providing reanalysis-type data for past climate (with obvious caveats about reliable time and space scales).

The equilibrium model simulations that provide snapshots of mean climate under specific forcing periods (e.g., the mid-Holocene climate of 6000 y BP) were still considered to be a valuable approach, but many results from other types of simulations were also reported. Transient simulations of the past few centuries, or the past millennium, have been performed using EBMs, EMICs and GCMs driven by estimates of solar, volcanic, greenhouse gas and land-cover forcings. Extension of these studies to the entire Holocene may be achievable, but is hampered by the absence of reliable multi-millennia forcing series and, for GCM simulations, the computer processing requirements of such extended simulations. Current alternatives are to use EMICs (which may also include dynamical representations of other climatic subsystems such as vegetation and ice sheets), or to run a sequence of time slice integrations of a GCM (e.g., 40 years every 1000 years during the Holocene; Paul Valdes, personal communication).

It was proposed that efforts toward simulation of climate, and the development of proxy data syntheses, might be usefully concentrated on specific periods during the Holocene:

- the classical "Little Ice Age",
- the Sub-boreal–Sub-atlantic transition around 850 BC (2750 y BP),
- the termination of the African Humid Period around 6–5 ky BP, and
- the 8.2 ky BP cooling event.

Evidence was presented from proxy data that significant climate change occurred during these periods, and the stronger signal-to-noise ratio for these events should make diagnosis of climate behaviour more feasible in both data and models. It was noted at the workshop (Figure 1) that model studies focusing on these periods should also aim at performing ensemble runs to capture the natural variability in the models (e.g., Renssen et al., 2002) and thereby allow the model to encompass the single realisation represented by reality (as registered in proxy data).

Discussion made it clear that a hierarchy of modelling studies, including GCMs and EMICs, was considered essential, given the uncertain forcings, the need for ensemble simulations, and the complex interactions taking place within and between subsystems of the Earth system. It was proposed that the HOLIVAR programme establish a database of the different model runs covering the Holocene that would be accessible to the scientific community.

Further information

Abstracts of the workshop presentations are available at http://www.cru.uea.ac.uk/~timo/holivar/.

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