# WORKSHOP IN CHARLOTTESVILLE FOCUSES ON RECONSTRUCTING THE CLIMATE OF THE LATE HOLOCENE

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The late Holocene is the most appropriate period in which to gauge the natural variability of modern future climate, as the basic boundary conditions have not changed significantly over this interval (the la few millennia). Because widespread instrumental data sources are not available before the mid-19tl century, a description of past climate depends on paleoclimatic data sources and the use of climate models. We envisioned that a meeting of researchers with distinct approaches to the study of past cli would significantly advance our understanding of Late Holocene climate history. To this end, a paleoclimate researchers and climate modelers came together to discuss and compare such approaches in a recent workshop ("Reconstructing Late Holocene Climate") held in Charlottesville, Virginia. The workshop was sponsored by the U.S. government (NSF and NOAA-sponsored Earth Systems His program), IGBP/PAGES, the National Research Program of the Netherlands, the Swiss National C Research Program, the German Federal Research Ministry and the German GKSS Research Center.

Three distinct approaches to reconstructing recent climate history have emerged. These include (1 calibration of proxy climate indicators against modern instrumental records to estimate past clim variability (e.g., Mann et al, 1998; Urban et al. 2000; Luterbacher et al. 1999), (2) forward modeling of the forced component of climate change, using estimates of past climate forcings to drive climat integrations (e.g. Rind et al. 1999; Crowley, 2000), and (3) the assimilation of paleoclimate data directl into climate model integrations, using statistical models to upscale the proxy data to large-scale patterns of atmospheric circulation, in a conceptually similar way to the assimilation of meteorological information into numerical weather forecasting models (Weber and von Storch 1999; von Storch et a 2000). In addition, climate models are also being used to model proxy indicators themselves process-based forward proxy models (Weber and von Storch 1999).

The three above approaches to reconstructing past climate history have complementary strength weaknesses. The first method assumes that relationships between proxy indicators and climate remai stable over time, and offers the advantage that the unique trajectory taken by the observed climate estimated. The second approach estimates only the forced component of past climate variability, and it may be compromised by uncertainties in past radiative forcing, as well as by imperfect representati modeled physical processes. The third approach represents a hybrid of the first two; it prescribes dynamical evolution of the system from climate physics but is "nudged" toward the observed climate by the proxy data. This method is more resistant to biases specific to purely empirical or model-bas approaches but it is relatively untested.

An important workshop theme involved the resolution of discrepancies in large-scale tempe reconstructions. Several multicentury reconstructions of Northern Hemisphere temperature based or diverse and widespread proxy data (tree rings, corals, ice cores, sediments, and documentary informati were compared. Although these multiproxy reconstructions yield similar conclusions regarding the course of hemispheric temperature change during the past 1000 years, those emphasizing higher-latitude *summer* data exhibit a more distinct "Little Ice Age" (LIA) during the 16th-19th centuries.

The ability of multiproxy reconstructions to capture long-term temperature variability was discussed detail. Borehole temperature reconstructions (Huang et al, 2000), which capture low-frequency variab only, portray a colder past few centuries than multiproxy estimates, but considerable uncertainty remains in the interpretation of the borehole data owing to possible non-temperature influences. A nev Decomposition' method for obtaining enhanced low-frequency variability from dendroclima reconstructions seems promising (Briffa et al. 2001), but further work is necessary to eliminate p differences in the impacts of ecological stresses on trees of different ages. The need for an ac reconstruction of the low-frequency component of variability is critical, because larger past tempe changes imply a greater climate sensitivity to radiative forcings both past and future.

Additional biases may be introduced to paleoclimate reconstructions by spatial domain and calibrat interval statistics. Existing multiproxy temperature reconstructions are heavily weighted towards t Northern Hemisphere extratropics, though tropical information from corals and high-elevation ice core have been used where available (e.g. Mann et al, 1998). Since half of the surface area of the hemisph resides in the tropics and sub-tropics, this sampling bias remains a source of uncertainty. Differe multiproxy temperature reconstructions were shown to converge when differences in the target seasonality and spatial domain were taken into account. Possible biases introduced by stationar assumptions were also addressed. Results from forced and control coupled model integrations demonstrate that calibration of paleoclimate indicators against a non-stationary 20th century is unl introduce significant bias in reconstructions of past climate patterns if the full covariance information used, over a century or longer calibration period.

Considerable focus was also placed on reconstructing regional patterns of climate variability, such as the El Nino Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the Antarctic Oscillat (AAO), and regional hydrologic change. A frequency-domain analysis of a Pacific SST reconstruction that combines tree ring and coral data suggests that these sources provide information on differe timescales. Results from multiple coral records imply unusual behavior of the tropical Indo-Pacific mid-late 19th century, with enhanced decadal variability and attenuated interannual variabili ENSO-sensitive regions. Extratropical decadal Pacific climate variability was argued not to be distinc from tropical Pacific variability; thus efforts to reconstruct a distinct "Pacific Decadal Oscillation" ind from proxy data may be misplaced.

Although discrepancies are evident between independent NAO reconstructions in the recent literature, new NAO reconstruction that verifies well against the longest instrumental records was shown to b possible if a combined 19th/20th century calibration period is used. Emerging evidence was discussed that the NAO, rather than hemispheric or global changes, may be primarily responsible for the distinct LIA and Medieval Warm Period in Europe and the North Atlantic (e.g. Keigwin and Pickart, 1999). Patterns in long instrumental records appear to support this interpretation during the past few centuries. As in t tropical Pacific, Eurasian climate records also suggest unusual behavior in the 19th century; a coordinated look at this interval was proposed.

Extreme variations in regional hydrologic balance were demonstrated from many sites, including Eas Africa (e.g. Verschuren et al. 1998) and the US Great Plains, where drought fluctuations correspond w solar variability on century time scales. In many parts of the world, major population centers have influenced by significant changes in hydrologic balance over the late Holocene, particularly in the intervals around 4200 and 8200 years BP. In the past few centuries, droughts in the US tend to occur with a few characteristic spatial patterns, which may be associated with specific forcings such as La Niña.

A variety of modeling experiments offered complementary information about recent climate variability. An energy balance model (EBM) forced by estimated changes in radiative forcing (solar radiation, volcanic activity, greenhouse gas concentrations and aerosols) was used to estimate the temperatur response over the past millennium. A similar GCM experiment simulated the last 500 years. The simulations explain most decade-century scale variations in reconstructed Northern Hemispher temperature over the past millennium. In the EBM, however, discrepancies are observed during the century; the modeled hemispheric temperature increases while proxy and instrumental records show slight cooling. A high prescribed EBM sensitivity to radiative forcing is more consistent with the large pa cooling shown by borehole data; a moderate sensitivity agrees more closely with multiproxy he temperature reconstructions. The GCM results support a higher temperature sensitivity.

Process-based models of glaciers and sea level were used to generate synthetic records of the low-frequency proxies on the basis of intermediate-complexity model and GCM simulations, usin unforced runs as well as orbital and solar-forced runs. Simulated synthetic data were used to validat model's response in fields that are not well constrained by existing proxy data, such as the hydrologic cycle, and to analyze mechanisms underlying reconstructed low-frequency variations. Such process-based models make it possible to perform model-data intercomparisons on the level of the proxy itself rather than using reconstructed climatic variables. However, they require a detailed understanding o meteorological processes as well as the complicated (physical, biological or chemical) processe determining the proxy itself. A promising, though quite preliminary, new model of tree-ring growth wa also presented.

A relatively untested, but promising, approach to paleoclimate reconstruction, termed DATUN Assimilation Through Upscaling and Nudging), was discussed at length. The aim of this method is to obtain a physically-based best guess of large-scale atmospheric states during the last millenium with annual temporal resolution. In the first step, statistical upscaling models are formulated to reconstruc modes of continental and hemispheric-scale climate variability that are strongly linked to variability i proxy data. Promising results were demonstrated for the AAO and the NAO, estimated from tree ring data. In the second step, the large-scale variability in the coupled atmosphere-ocean GCM is "nudg towards states which are both close to these reconstructions and consistent with model physics. Preliminary results were described based on the nudging of the Arctic Oscillation (closely related to NAO). The DATUN concept is appealing, but there was a strong argument for an intercomparison o results using a range of models, with differing sensitivities and physical parameterizations, before a r robust evaluation of this approach can be made.

The key result of the workshop was an informed, open discussion of the strengths and weaknesses o various approaches to paleoclimate reconstruction and modeling. Several recommendations emerged:

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An expanded network of paleoclimate data is needed to reduce uncertainties in empirical reconstructions of climate change. More data in low-latitude regions, much of the Southern Hemisphere, and Af particularly needed, as are better regional records, particularly of ENSO and hydrologic varial internationally coordinated effort is required to update many important proxy networks.

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It is important to explore in greater detail the assumption of temporal stability in the relationships between climate and proxy data during the late 20th century.

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Improving climate reconstructions of the late Holocene will require the use of lower-resolution proxies such as lake and ocean sediments, speleothems, and sclerosponges that provide sufficient resolution resolve decade-century scale variability.

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Understanding the sensitivity of large-scale temperature to radiative forcing requires that we resol apparent discrepancies among temperature reconstructions from different data sources. It is also important to better constrain the histories of radiative forcings prior to about AD 1600.

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It is important to continue to develop and validate forward proxy models, using process-orien (experimental and theoretical) approaches. Such models can potentially exploit a wealth of biolog chemical, and physical information contained in proxy records.

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There should be an emphasis on developing projects that involve international, multidisciplinary Participants supported the idea of an international feasibility study involving a paleoclimate prox reanalysis for the 20th century. The study would focus on issues in forward modeling, data assimilati proxy calibration, and the identification of significant gaps in information. Such a study could pr framework for prioritizing the collection of new proxy data.

*The Workshop on Reconstructing Late Holocene Climate was held in Charlottesville Virginia, April 17-20, 2001.*

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