Inversion results and implications

The global sea level variations implied by the freshwater forcing histories for the three different mixing formulations are nearly identical; each showing a drop of ~15 m during the prolonged ~3 kyr warm phase starting around 38 ka BP or model year 1000. The subsequent sequence of warm-cold phases (between 35-30 ka BP) is associated with ~5 m variations in sea level. The timing and amplitude of these sea level variations are not inconsistent with two independent reconstructions, given their uncertainties (Thompson and Goldstein, in press; Waelbroeck et al., 2002). Although the relatively large uncertainties preclude a solid conclusion, the comparison illustrates the level of accuracy that is necessary for a more stringent test of the freshwater hypothesis from the sea level record. Furthermore, these results highlight the potential importance of ice sheet growth in maintaining a negative high latitude freshwater balance for the phases of sustained warmth, with the length of the warm phases being directly related to the amplitude of the sea level fall.

The striking similarities among the three mixing formulations may be surprising considering the very different steady state response of each model to freshwater forcing (Fig. 1a). We find that the processes governing the model’s transient response to freshwater forcing to be usually very similar and only begin to diverge after a few hundred years. In all cases, the imposition of a high latitude freshening reduces meridional density gradients and, hence, the strength of the meridional circulation with changes in vertical mixing lagging. A more thorough examination of the causes of this similarity is being investigated.

Conclusion

This stochastic inverse model exercise suggests that the freshwater forcing hypothesis of abrupt climate change is consistent with the most direct estimates of past sea level, assuming that (i) our interpretation of the Greenland record in terms of temperature changes in the high northern latitudes is correct, and (ii) the highly simplified model we have used captures the relevant physics. This consistency does not depend on the formulation of vertical mixing in the model. Whether more complete models are sensitive to the formulation of vertical mixing in their transient response to high latitude freshening warrants further investigation.

References

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Late Holocene hydrological variability in ombrotrophic peatlands of eastern North America

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Introduction

Ombrotrophic peatlands, particularly “raised bogs”, comprise a rich but underutilized source of Holocene paleoenvironmental records for North America. These peatlands, which are scattered from the Atlantic to the Pacific coasts at latitudes between 42° and 65°N, are dominated by Sphagnum moss and a few vascular plants, have elevated surfaces, and receive all surface moisture directly from the atmosphere. Water tables of these bogs are perched above the groundwater table, and most water loss is through evapotranspiration. Accordingly, ombrotrophic bogs are hydrologically sensitive to precipitation and temperature variations across a range of temporal scales, from seasonal to millennial.

Sedimentary records from ombrotrophic peats can span 1000-10,000 years, with temporal resolution ranging from sub-centennial to sub-decadal depending on accumulation rates. A variety of paleoenvironmental proxies, including testate-amoeboae, peat humification, pollen, plant macrofossils, charcoal, stable isotopes (H, C, O), and biomolecular markers, are preserved in these peats. We are conducting a study of all of these proxies in late Holocene peats from raised bogs along a transect spanning the Great Lakes/St. Lawrence corridor, from Minnesota to Maine. We are coupling these paleoclimate reconstructions with extensive modern calibration studies and investigations of historical climate variability. These studies are leading to detailed multivariate climatic reconstructions and development and testing of hypotheses regarding the underlying climate dynamics.

Peatland records of drought synchrony in the Central United States

Peat records from sites 1000 km apart in north-central Minnesota (Hole Bog) and southeastern Michigan (Minden Bog) span the past
Figure 1. Paleohydrological records from ombrotrophic peatlands 1000 km apart in southeastern Michigan and north-central Minnesota show spatial coherence over the past 2000 years. High-frequency patterns between 600-1000 years ago show good correspondence with tree-ring records from the Great Plains and Rocky Mountains to the West. The blue trace represents the Michigan record and the red trace the Michigan record, both expressed in terms of depth to water table based on multivariate analysis of testate amoeba assemblages (see Booth & Jackson, 2003 for details). Modified from Booth et al. (2006).

Emerging proxies: Molecular biomarkers and compound-specific stable isotopes

We are currently developing and applying other proxies from ombrotrophic peatlands of mid-continental and eastern North America. One new approach is the use of molecular biomarkers. For example, Sphagnum differs from vascular plants and terrestrial mosses in the frequency distribution of n-alkane chain-lengths (Nichols et al., in press); because water retention is less critical for Sphagnum, cuticle waxes tend to be constructed of shorter (and presumably more economical) alkane chains. Ecological and paleoecological studies (based on plant macrofossils) indicate that Sphagnum moss tends to be especially productive during extended wet periods, while droughts favor expansion of erics, sedges, and other vascular plants. Stratigraphic records of n-alkane distributions from Minden Bog generally correspond to patterns inferred from testate amoebae and humification (Fig. 2). However, humification and n-alkane spectra show an apparent dry anomaly ca. 1300 yr BP that is unrecorded by the testate amoebae. This underscores the need for multiple proxies that record different kinds of hydrological responses to different aspects of climate variation.

Another promising avenue is the identification and extraction of organic compounds specific to Sphagnum. Preliminary results indicate that 2-heptacosanone can be extracted from at least seven different species of Sphagnum but not from any vascular plants or other mosses found in peatlands. Such Sphagnum-specific biomarkers can be used not only as an index for quantifying Sphagnum productivity but also for compound-specific analysis of δD and δ13C, which can provide further information on moisture balance and temperature.

Sphagnum macrofossils are well preserved in all but the most humified peats. Analysis of compound-specific and taxon-specific δ18O (from cellulose in Sphagnum)
Science Highlights: U.S. ESH Program

Pollen assemblages have traditionally been the primary paleoclimatological tool for continental regions at timespans longer than the past few centuries. Development of independent paleoclimate records from testate amoebae, stable isotopes, and biomarkers preserved in peatlands and other archives now allows us to use pollen data to assess vegetational responses to climate change and variability. The Minden record, for instance, demonstrates that a regional shift from beech to white pine dominance 800-1000 years ago, and an accompanying increase in fire incidence was driven by the onset of drier conditions (Booth and Jackson, 2003). This vegetational transition had been controversial, ascribed variously to decreasing temperatures or activities of indigenous peoples. We are currently developing high-resolution pollen records for selected time intervals to assess regional vegetational responses to transient climate events, and to gauge the limits of pollen sensitivity to climate change.

Outlook

Our ultimate goal is to develop a multiproxy, synoptic-scale network of paleohydrological and paleoecological records from ombrotrophic peatlands. Eventually, this network could stretch from coast to coast, and from ca. 45°-60°N in North America. With such a network, Holocene climate variability can be assessed at timescales ranging from multi-decadal to millennial. Spatiotemporal patterns of variability within the network, and between bog records and other archives (tree-ring, lake-level, aeolian, glacial) should provide a basis for assessing mechanisms governing climate change and variability. Bog-based records of climate change can also be utilized to identify climate drivers of forest and fire dynamics, inferred from pollen, macrofossil and charcoal data. European scientists are currently developing a network of bog records across Eurasia. Thus, the potential exists for a circumbroreal paleoclimate network for the entire Northern Hemisphere, based on multiple proxies from peatland archives. Such a network could generate significant advances in understanding the patterns and mechanisms of Holocene climate evolution.

References