A new record of climate variability in the Gulf of Mexico for the last millennium

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Greenland ice core records were among the first to reveal evidence of dramatic climate swings during the last glacial (Taylor et al., 1993). By comparison, Holocene climate as recorded in Greenland ice appears to have been relatively stable. However, as new paleoclimate records have emerged from other locations, it has become increasingly apparent that variations in Holocene climate were larger than previously believed. In marine sediments from the subpolar North Atlantic, for example, a series of cool sea-surface temperature (SST) events has been identified that each persisted for a few centuries and recurred roughly every 1–2 k.y. (Bond et al., 1997). The most recent of these cool SST events corresponds to the Little Ice Age (~ A.D. 1300–1850), a period well documented in historical records from northern Europe and other localities around the world.

In order to better understand the origins of the Little Ice Age, and more generally the origins of Holocene climate change, it is important to document the magnitude and geographic pattern of climate variability over this period, both on land and in the ocean. Relatively few sea floor locations yield sediments that have accumulated rapidly enough to preserve reliable climate information on such short time scales. In this issue of *Geology* (p. 423–426), Richey and co-authors present new data from one such location, Pigmy Basin in the northern Gulf of Mexico. Here, sedimentation rates in excess of 40 cm/k.y. have allowed these authors to produce a decadal-resolved record of climate variability spanning the past 1.4 k.y. Using paired measurements of the Mg/Ca and oxygen isotopic composition ($\delta^{18}O$) of a surface-dwelling planktic foraminifer, Richey et al. have been able to distinguish between SST and salinity changes that occurred in the region. Surprisingly, they find that SST varied by as much as 3 °C over the past 1.4 k.y., a range that is ~75% of the entire glacial to interglacial amplitude of reconstructed SST change in the Gulf of Mexico. Estimated SST during the coldest intervals of the Little Ice Age were 2.0–2.5 °C cooler than present, while SST prior to 1 ka in the Gulf were as warm as, or even up to ~1 °C warmer than, present.

In the Pigmy Basin sediments, an abrupt increase both in foraminiferal $\delta^{18}O$ and in the relative abundance of the planktic foraminifer *Globigerinoides sacculifer* occurred ~0.6 ka. This increase matches in time a distinct shift to higher sea-salt-sodium (ssNa) and terrestrial dust concentrations in the Greenland Ice Sheet Project (GISP2) ice core that marks the start of the Little Ice Age (O'Brien et al., 1995; Meeker and Mayewski, 2002). The abrupt rise in ssNa at the onset of the Little Ice Age, as well as similar increases earlier in the Holocene, has been interpreted to indicate the transport effects of intensified winter storms that resulted from cooling and a deepening of the Icelandic Low. Taken together, the Pigmy Basin data and the GISP2 glaciochemical time series indicate a tight linkage between atmospheric circulation in the high-latitude North Atlantic and surface hydrography in the Gulf of Mexico over at least the last millennium.

What is the nature of this linkage? The new Pigmy Basin data combined with other Atlantic records are beginning to reveal patterns that may eventually help explain not only the Little Ice Age but the rapid and much-larger-amplitude climate shifts of glacial time. At present, the favored paradigm for explaining abrupt climate change centers on past variability of the large-scale meridional overturning circulation (MOC) of the North Atlantic, and its effect on oceanic heat transport into the region (e.g., Alley et al., 1999; Rahmstorf, 2002). Given the similarity in recurrence interval, it has been suggested that the Little Ice Age and earlier Holocene climate oscillations represent a dampened expression of the well-known millennial-scale Dansgaard-Oeschger events of the last glacial, and hence may reflect MOC variability as well. Indeed, at least one Holocene reduction in the Atlantic MOC can be inferred based on $^{231}Pa/^{230}Th$ ratios in deep North Atlantic sediments (McManus et al., 2004), and this event near 5 ka is correspondingly modest when compared to deep circulation changes reconstructed for full glacial conditions. More recently, Lund et al. (2006) have estimated that the volume of water transported by the Gulf Stream through the Florida Straits was reduced by 10% during the Little Ice Age, an observation consistent with reduced oceanic overturning, and implicating diminished poleward heat transport as a potential cause of high-latitude cooling at this time.

Previous work has shown that the hydrologic cycle in the tropics is highly sensitive to abrupt climate change, and that geographically coherent variations in the past distribution of moisture (precipitation-evaporation) can best be explained by shifts in the latitudinal position of the Intertropical Convergence Zone (ITCZ). Modeling studies that have examined the effects of a weakened Atlantic MOC (e.g., Vellinga and Wood, 2002; Zhang and Delworth, 2005) predict a southward shift of the ITCZ in the Atlantic basin and consequent drying of Central America and northern South America, for which abundant proxy evidence exists for the Little Ice Age and the cold stadial periods of the last glacial (see review in Peterson and Haug, 2006). A southward shift of the ITCZ results in a precipitation deficit in the Caribbean and western tropical North Atlantic, and should lead to higher sea-surface salinities. In the new Pigmy Basin record of Richey et al., the abrupt $\delta^{18}O$ increase at the onset of the Little Ice Age is not marked by a coincident change in foraminiferal Mg/Ca, implicating a general rise in Gulf of Mexico salinity rather than a drop in SST as the dominant cause of the shift. In the downstream Straits of Florida, Lund et al. (2006) have also inferred anomalously high Gulf Stream salinities during the Little Ice Age, while Schmidt et al. (2006) have recently presented similar evidence for elevated salinity levels in the Caribbean during the cold stadial intervals of the glacial.

Salinity is undoubtedly a key variable in regulating the strength of the Atlantic MOC through the delicate density balance achieved between cold freshwater input from the north (meltwater during the glacial), and warm salty subtropical waters transported from the south by the Gulf Stream and associated currents. The growing set of observations in support of a build-up of salt in the surface waters of the subtropical North Atlantic during cold periods such as the Little Ice Age and the more extreme stadials of the last glacial suggests that salinity variations originating here as a result of ITCZ and atmospheric changes may play a role in modulating the MOC. Much additional work must be done to work out the details, but with new data sets like that from Pigmy Basin, the big picture is starting to come into focus.

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