Holocene variability in Benguela upwelling: Implications for tropical atmospheric circulation

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Persistent millennial-scale climate variability has been seen throughout the Holocene period in drift ice indices in the North Atlantic (Bond et al. 1997; Bond et al. 2001) and sea surface temperature records in the subtropical North Atlantic (deMenocal et al. 2000). So far, however, no Southern Hemisphere records have been discovered that show this variability. Understanding the mechanisms driving this series of cooling events, the most recent of which was the Little Ice Age, is critical for distinguishing human impacts on the climate system from natural climate change. Here, we investigate Holocene variations in Southern Hemisphere subtropical sea-surface temperatures using Mg/Ca, stable isotopic, and faunal census analyses of planktonic foraminifera from Ocean Drilling Program (ODP) Site 1084B off the coast of Namibia (23.5S, 13.0E, 1992m water depth). Site 1084B was selected because of its high deglacial and Holocene sedimentation rates (11-27 cm/kyr) and its location within the Benguela coastal upwelling system. Historical SST variations in this region reflect variations in the intensity and zonality of the southern subtropical trade winds, as well as the northward advection of cooler waters by the southern subtropical gyre.

The relationship between Mg/Ca and growth temperatures of planktonic foraminifera has been defined by culture experiments (Lea et al. 1999) and refined by core-top calibrations (Dekens et al. 2002). Mg/Ca measurements were made at 1-cm intervals in ODP Site 1084B sediments by ICP-OES on ~75 individuals of G. bulloides, a species associated with winter upwelling in this region. The age model was constrained by 13 AMS radiocarbon dates extending to 17,000 calendar years ago. The coretop Mg/Ca value indicates calcification in 13.5°C waters, consistent (within analytical error) with observed winter SSTs for this location.

Most strikingly, the ODP Site 1084B Mg/Ca paleotemperature measurements confirm the synchronized timing of Northern Hemisphere and subtropical Southern Hemisphere deglacial climate changes. The Younger Dryas cool period 13-11.5 kyr ago and an abrupt ~2.5°C warming 11.5 kyr ago into the Holocene are clearly apparent in the 1084B Mg/Ca record, indicating that subtropical Southern Hemisphere deglacial climate variations were in-phase with the Northern Hemisphere. This is consistent with some Southern Hemisphere studies showing Younger Dryas cooling, including several subtropical records (Kim et al. 2002, Kirst et al. 1999, Little et al. 1997) and one midlatitude record (Moreno et al. 2001). High-latitude records show the "Antarctic Cold Reversal" in the Southern Hemisphere significantly leading climate changes in Northern Hemisphere regions (Blunier et al. 1998, Charles et al. 1996), which suggests asynchronous timing of major deglacial climate events in the two hemispheres.

Within the Holocene, ODP Site 1084B Mg/Ca paleotemperatures suggest a series of millennial-scale cooling events which appear to be coincident with cooling events in the subpolar and subtropical North Atlantic. The resolution of the record, however, is only high enough to confirm a few of the early Holocene events between 8.5 and 5.5 kyrs ago as real climate shifts rather than analytical noise. The first of these, known as the "8200 year cold event," is one of the only significant Holocene climate changes recorded in Greenland ice core paleoclimate proxies (Dansgaard et al. 1993), and shows up in many other paleoclimate records throughout the Northern hemisphere (Bond et al. 1997, deMenocal et al. 2000, McDermott et al. 2001, Baldini et al. 2002). These cooling events, however, are conspicuously absent from the only other high-resolution Holocene paleotemperature record from the subtropical South Atlantic, an alkenone unsaturation index sequence from a non-upwelling site in the eastern Angola Basin (Kim et al. 2002). This suggests that the 8200 year cold event in ODP 1084B is driven primarily by atmospheric forcing, although it does not rule out changes in oceanic circulation as the ultimate cause (Barber et al. 1999). High-resolution alkenone paleotemperatures in the Norwegian Sea, however, appear to show warming during this period (Calvo et al. 2002), contradicting arguments that the 8200 year cold event was caused by changes in ocean circulation (Baldini et al. 2002, Barber et al. 1999).

Shifts in the ODP 1084B faunal abundance data during the Younger Dryas and the 8200 yr cold event suggest that different mechanisms may have caused these two cooling events. An increase in *N. pachyderma* (left-coiling, dominant in the core of the upwelling area) and decrease in *G. bulloides* (dominant at the edges of the core upwelling area) during the 8200 yr cold event are consistent with a westward expansion of the core upwelling zone. This could be due to higher intensity or zonality of the subtropical Southern Hemisphere trade winds. There is little change in the ratio of *N. pachyderma* (L) to *G. bulloides* during the Younger Dryas, however, indicating no significant increases in wind-driven upwelling during this period. There is, however, an increase of more southerly species relative to more northerly species during the Younger Dryas. The meaning of this shift is less well-constrained by modern ecological studies.

In summary, multi-proxy studies of the paleoclimate record in ODP 1084B over the last 17,000 years confirm the presence of the Younger Dryas in the subtropical Southern Hemisphere, implying that climate change in at least this part of the Southern Hemisphere matched that of the Northern Hemisphere. The ODP 1084B paleoclimate record also suggests that the 8200 yr cold event was caused by a different underlying mechanism than the Younger Dryas, and that this mechanism was primarily due to changes in trade wind strength.