Millennial-Scale Variability of Western Equatorial Atlantic Ocean Thermocline Depth: Evidence From the Early Pliocene

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ABSTRACT

We use high-resolution oxygen isotope data from planktonic foraminifera in the Western Equatorial Atlantic (Ocean Drilling Program Leg 154, Site 925) to investigate millennial-scale climate variability during an interval of relative climate warmth, the early Pliocene. For this purpose, we have chosen a 100 kyr long time interval from 4.1 Ma to 4.2 Ma and sub-sampled it to obtain an average time step of 700 yr. We reconstruct changes in mixed layer depth using the difference in oxygen isotope values ($\delta^{18}O$) between Globigerinoides sacculifer, a mixed-layer dweller, and Neogloboquadrina dutertrei, a thermocline dweller. Time series analysis of the $\delta^{18}O$ records indicates that temporal changes in mixed layer depth occur at sub-Milankovitch periods of between 10-5 kyr. Similar variability during this interval of time has been observed in lacustrine sediments from the Mediterranean region (Steenbrink et al., 2003). Our results suggest that millennial-scale variability may be a pervasive climate signal during this interval of relative global warmth. As mixed layer depth in the western tropical Atlantic is a function of trade wind strength, we believe that millennial-scale variability in mixed layer depth during the early Pliocene is also tied to changes in wind patterns. We speculate that the millennial-scale changes in mixed layer depth at Site 925 reflect millenial-scale variability in trade wind strength and direction perhaps linked to the interaction between low-latitude insolation and the North African monsoon.

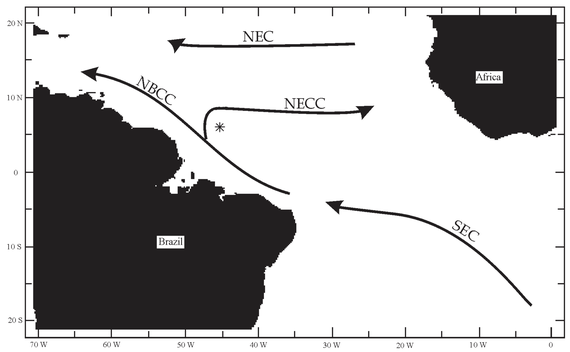

Figure 1 ODP Site 925 Location (asterisk) on Ceara Rise (4°12'N, 43°29'W) with surface water currents and seasonal location of the Intertropical Convergence Zone (ITCZ). Abbreviations: SEC, South Equatorial Current; NBCC, North Brazil Coastal Current; NECC, North Equatorial Counter Current; NEC, North Equatorial Current (created from International Research Institute for Climate Prediction/Lamont Doherty Earth Observatory Climate Data Library).

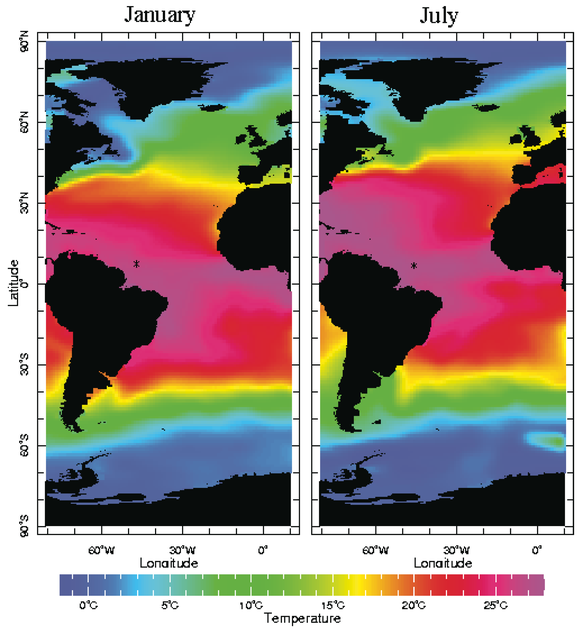

Figure 2 Average ocean surface temperature maps during January, the month when the ITCZ is most southerly, and July, the month when the ITCZ is most northerly. Site location shown by *. (Created from International Research Institute for Climate Prediction/Lamont Doherty Earth Observatory Climate Data Library.)

BACKGROUND

The tropical oceans are an important region to study because they are the relative barometer for the world's climate. Past ocean temperature gradients in the Western Equatorial Atlantic Ocean present information about changes in climate and sea surface hydrography in this region. By reconstructing relative sea surface temperatures of the mixed layer and changes in the depth of the thermocline, models of past climate can be developed and interpreted. The Early Pliocene was a period of warmth, greater than that of today's warmth. By examining this period, it is possible to get apicture of what factors affect warm climates and in turn paint a better picture of how our world might respond to the predicted warming trend in our future. Oxygen isotope data from planktonic foraminifera records the changes in climate during the period. Two species of foraminifera, inhabiting different regions of the ocean depth profile, *Globigerinoides sacculifer* and *Neogloboquadrina dutertrei*, allow the special production of a record that details the changes in ocean temperature gradients. Spectral analysis of this data allows the creation of a model of climatic change during the Early Pliocene.

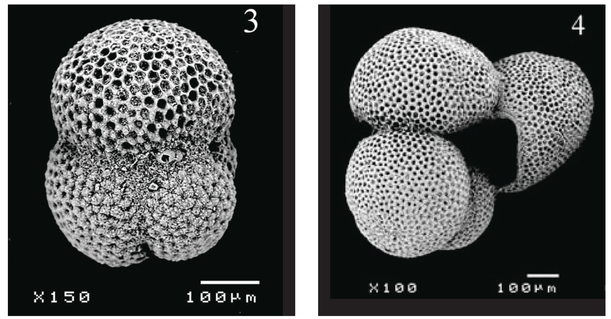

Figure 3
(Left) High-resolution image of foraminifera *Neogloboquadrina dutertrei*.
(Right) High-resolution image of foraminifera *Globigerinoides sacculifer.*

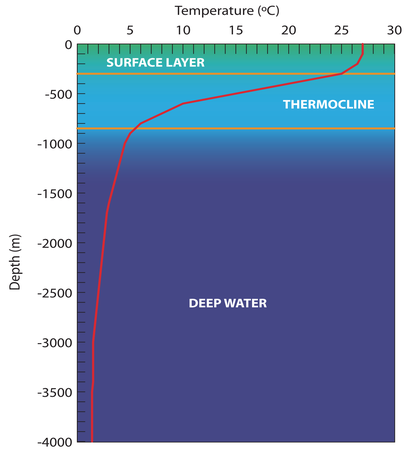

Figure 4 Ocean water temperature profile

CONCLUSION

Our spectral analysis of the high-resolution oxygen isotope ratio data from the planktonic foraminifera, *Globigerinoides sacculifer* and *Neogloboquadrina dutertrei*, yielded time series records with periodicities of 10-kyr, 8-kyr, and 5-kyr. This periodicity is interpreted to reflect long-term changes in the thermocline depth of the Western Equatorial Atlantic during the Early Pliocene. The 10-kyr periodicity is interpreted to be a harmonic of the 23-kyr precession cycle, thus variations in thermocline depth at this periodicity are a function of orbital forcing of solar insolation. The 8-kyr periodicity of variability in thermocline depth is caused by some source internal to the ocean-climate system. The 5-kyr period of variability in thermocline depth may be a harmonic of the 23-kyr cycle. Regional ocean currents that feed the Gulf Stream provide a mechanism for the increased heat transport northward of the expanded heat storage that is a characteristic of a deep thermocline. This has implications for greater heating at the poles. This millennial-scale periodicity is a possible cause for the complete melting of polar ice caps during the Early Pliocene period of relative warmth.

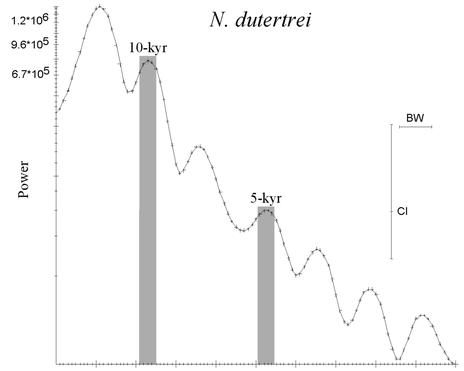

Figure 5 Low-resolution (1.3 kyr time step) spectral analysis data for *Neogloboquadrina dutertrei* δ18O. Gray shaded bars show important cycles (in thousands of years) of ocean temperature gradient variability.

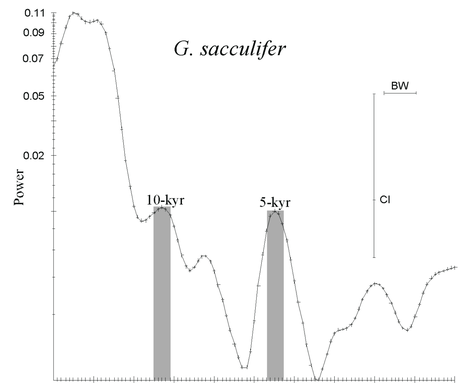

Figure 6 Low-resolution (1.3 kyr time step) spectral analysis data of *Globigerinoides sacculifer* δ18O. Gray shaded bars show important cycles (in thousands of years) of ocean temperature gradient variability.

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