GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 17, 1891, doi:10.1029/2003GL017959, 2003

High resolution tropical climate record for the last 6,000 years

Kathy Tedesco[1] and Robert Thunell

Department of Geological Sciences, University of South Carolina, Columbia, South Carolina, USA

Received 13 June 2003; accepted 6 August 2003; published 6 September 2003.

[1] Planktonic foraminiferal oxygen isotope records from the Cariaco Basin, offshore Venezuela were used to construct high-resolution tropical Atlantic climate records for the mid to late Holocene. Our results indicate that major increases in δ^{18}O due both to increases in salinity and decreases in sea surface temperature occurred at least six times over the last 6,000 years (~6,000–5,000, 4,500–4,200, 3,800–3,200, 3,000–2,800, 2,200–2,000, and 1200–800 cal yrs. B.P.). The initial δ^{18}O increase centered at 5,500 years ago is coincident with the development of arid conditions in the Caribbean region and the end of the "African humid period" indicating a global drying of the northern tropics at this time. Synchronous with the aridification of the Caribbean region are the onset of wetter conditions in the South American Altiplano and the reoccupation of this region by humans. This combination of contrasting climate conditions is attributed to a southward displacement of the Inter-Tropical Convergence Zone (ITCZ) that would have resulted in decreased precipitation and increased trade wind intensity in the Caribbean region and increased rainfall over the Altiplano. *INDEX TERMS:* 4267 Oceanography: General: Paleoceanography; 4231 Oceanography: General: Equatorial oceanography; 4870 Oceanography: Biological and Chemical: Stable isotopes; 4802 Oceanography: Biological and Chemical: Anoxic environments. **Citation:** Tedesco, K., and R. Thunell, High resolution tropical climate record for the last 6,000 years, *Geophys. Res. Lett.*, *30*(17), 1891, doi:10.1029/2003GL017959, 2003.

1. Introduction

[2] It is well established that the Holocene has not been a period of uniformly warm climate conditions [*Keigwin*, 1996; *Bond et al.*, 1997; *deMenocal et al.*, 2000; *Thompson et al.*, 2002; *Friddell et al.*, 2003]. In high latitudes, the early to middle Holocene appears to have been warmer than the last 5,000 years, while the opposite trend seems to have been true at low latitudes [*Rimbu et al.*, 2003]. Additionally, the entire 10,000 year period has been punctuated by millennial-scale cooling events [*Alley et al.*, 1997; *Bond et al.*, 1999]. In the Caribbean region, the wet conditions that persisted through the mid-Holocene [*Hodell et al.*, 1991; *Higuera-Gundy et al.*, 1999] were replaced by drier conditions during the late Holocene [*Haug et al.*, 2001]. In this paper, we use high-resolution planktonic foraminiferal δ^{18}O records from a Cariaco Basin sediment core to reconstruct the climate history of the Caribbean region for the past 6,000 years. The Cariaco Basin, an anoxic basin located off the northern coast of Venezuela, provides an exceptional archive of both regional and global climate variations [*Hughen et al.*, 1996; *Black et al.*, 1999; *Peterson et al.*, 2000; *Haug et al.*, 2001]. The climatology of the Cariaco region is driven by the seasonal migration of the ITCZ (Figure 1). During boreal winter and spring, the ITCZ is in its most southerly position, rainfall is at a minimum and strong easterly winds cause intense upwelling along the Venezuelan coast. As the ITCZ migrates to the north during boreal summer, the trade winds diminish, upwelling ceases, and precipitation increases. As a result, the varved sediments accumulating in Cariaco Basin provide a record of climate variability of tropical-subtropical regions influenced by the trade winds. It also should be noted that these seasonal changes in ITCZ position have linkages to the South American monsoon [*Hastenrath and Greischar*, 1993; *Zhou and Lau*, 1998]. Specifically, when the ITCZ is in its most southerly position, a strong center of convection develops over the Amazon Basin, drawing in moist air from the Atlantic Ocean and resulting in high precipitation (Figure 1). Thus, when the Cariaco Basin region or northern tropics are dry, the southern tropical region of South America is wet, and vice versa.

2. Samples and Methods

[3] Gravity core CAR7-1 was collected in the Cariaco Basin at 10°40′N, 64°42′W and 366 meters water depth. It was sampled continuously at 0.5 cm intervals for δ^{18}O measurements of two species of planktonic foraminifers, *Globigerinoides ruber* (pink) and *Neogloboqudrina dutertrei*. Analyses were carried out using a VG Optima stable isotope ratio mass spectrometer and the data are reported in delta notation relative to the Vienna Pee Dee Belemnite. The long-term standard reproducibility for δ^{18}O based on replicate measurements is ±0.07‰.

[4] The core chronology is based on radiocarbon ages determined by accelerator mass spectrometry on samples of *Globigerina bulloides* (Table 1). The age calibration program, CALIB rev. 4.3 [*Stuiver and Reimer*, 1993] was used to convert conventional ^{14}C dates to calibrated calendar years (cal) using a 420-year reservoir correction for the Cariaco Basin [*Hughen et al.*, 1998]. The top of the core is dated at 143 cal years B.P., while the base of the core has an age of 6167 cal years B.P. This time scale yields an average sedimentation rate of ~37.5 cm kyr^{-1} and an average sample spacing of ~13 years.

3. Oxygen Isotope Records

[5] *Globigerinoides ruber* is a subtropical-tropical species that lives in the surface mixed layer [*Deuser*, 1987].

---

[1] Present Address: Office of Global Programs, National Oceanic and Atmospheric Administration, Silver Spring, MD 20910, USA.

0094-8276/03/2003GL017959$05.00

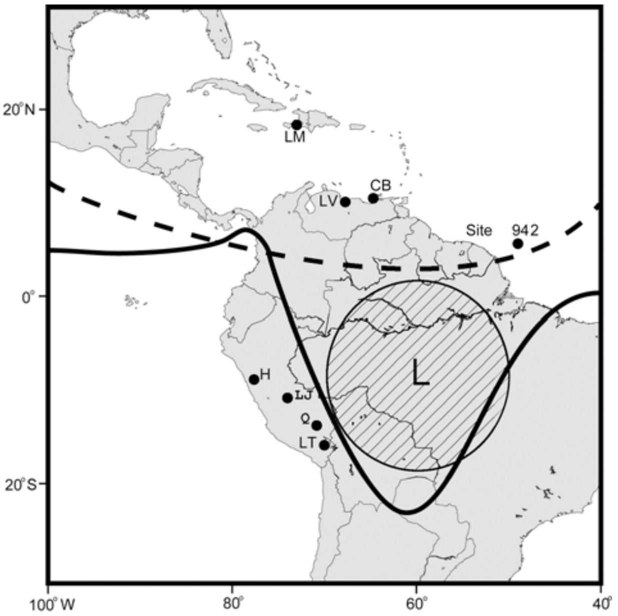

Figure 1. Map showing locations of different climate records referred to in this study and the present day boreal winter (solid line) and boreal summer (dashed line) positions of the ITCZ. Also shown is the low pressure center associated with the South American monsoon that develops over the Amazon Basin during austral summer. CB = Cariaco Basin, H = Huascaran, LJ = Lake Junin, LM = Lake Miragoane, LT = Lake Titicaca, LV = Lake Valencia, Q = Quelccaya.

Data from Cariaco Basin sediment trap samples indicate that the average annual $\delta^{18}O$ of *G. ruber* (pink) is not weighted toward a particular season but rather reflects mean annual surface ocean conditions [*Tedesco*, 2002]. The preferred habitat of *N. dutertrei* is a well-stratified photic zone where it lives within the thermocline close to the chlorophyll maximum [*Fairbanks et al.*, 1982]. The $\delta^{18}O$ values of *N. dutertrei* from Cariaco Basin sediment trap samples range between 0 and −0.75‰ annually (~20–23.5°C), with low values during late summer-fall and high values during spring upwelling [*Tedesco*, 2002]. Although the depth of calcification varies throughout the year, the $\delta^{18}O$ values remain fairly constant indicating that *N. dutertrei* calcifies over a narrow range of temperatures.

[6] The mid to late Holocene Cariaco Basin oxygen isotope records are primarily a function of local temperature and salinity changes, since global changes in the isotopic composition of sea-water due to changes in ice volume were insignificant during the last 6,000 years [*Fairbanks*, 1989; *Schrag et al.*, 1996]. The modern annual salinity range in the Cariaco Basin is less than 1‰ (36.2–37‰; *Muller-Karger et al.*, 2001) and is equivalent to an $\delta^{18}O$ change of less than 0.2‰ based on the present day salinity-$\delta^{18}O$ relationship for this region [*Fairbanks et al.*, 1992]. However, past changes in salinity could have been considerably larger than this [*Haug et al.*, 2001] and thus would have contributed significantly to the measured $\delta^{18}O$ variability. SST range from ~22 to 29°C annually, with a modern mean annual value of 25–26°C. The 7°C annual change is equivalent to a 1.5‰ change in $\delta^{18}O$.

Table 1. AMS Radiocarbon Data for Cariaco Basin Core CB7-1

Sample Depth (cm)	Material	Measured ^{14}C Age (^{14}C yr B.P.)	Calibrated ^{14} C Age (Cal ^{14}C yr B.P.)	Calibrated 1 sigma age range (Cal ^{14}C yr B.P.)
0	*G. bulloides*	550 ± 40	143	248–106
25	*G. bulloides*	1340 ± 40	887	913–823
50	*G. bulloides*	1890 ± 50	1403	1479–1344
75	*G. bulloides*	2430 ± 50	2036	2107–1974
100	*G. bulloides*	2850 ± 40	2624	2690–2495
125	*G. bulloides*	3460 ± 60	3325	3372–3247
150	*G. bulloides*	3980 ± 50	3950	4001–3871
175	*G. bulloides*	4320 ± 60	4410	4498–4349
200	*G. bulloides*	4890 ± 60	5227	5280–5048
226	*G. bulloides*	5760 ± 40	6167	6195–6106

4. Holocene Climate Variability

[7] The $\delta^{18}O$ time series provide evidence of significant variations in surface hydrography of the Cariaco Basin over the last 6,000 years (Figure 2). Both records are marked by

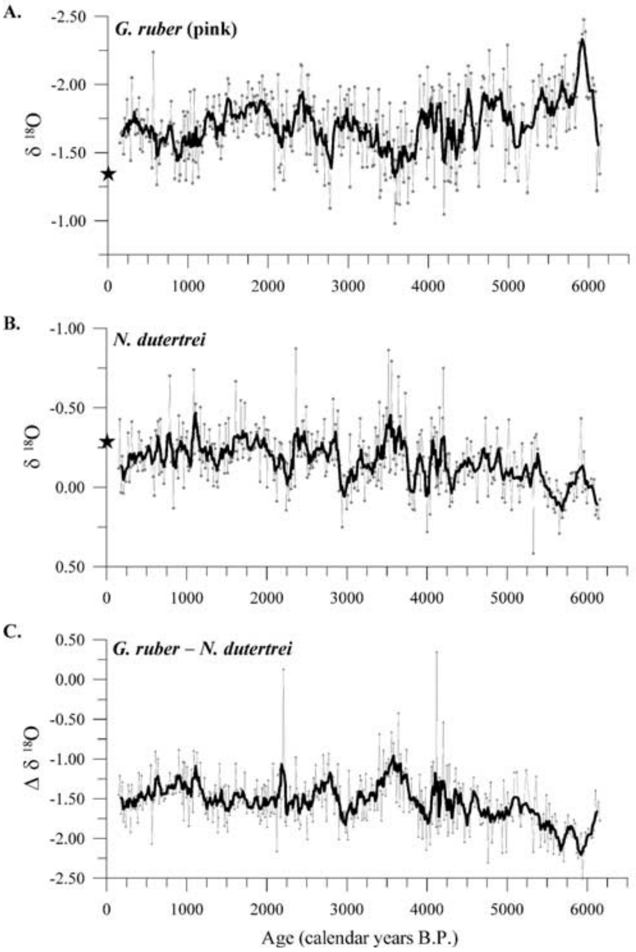

Figure 2. Oxygen isotopic compositions and temperature estimates for (A) *G. ruber* (pink) and (B) *N. dutertrei*. Stars represent modern mean $\delta^{18}O$ values from sediment trap specimens collected between January 1997 and December 1999. (C) Interspecies $\delta^{18}O$ difference, $\Delta\delta^{18}O$, between *N. dutertrei* and *G. ruber*. Bold line represents the 5-point running mean. All records are plotted to time in calendar years.

considerable high frequency (i.e. decadal) variability that is comparable to that previously observed in faunal records for the last millennium from the basin and attributed to the North Atlantic oscillation [*Black et al.*, 1999]. However, the focus of this paper is on the century to millennial scale changes present in the δ^{18}O records. Using the modern relationship between upper ocean conditions in the Cariaco Basin and migration of the ITCZ as an analog for past climate change, we infer that increases in δ^{18}O values in the geologic record represent the combined effect of decreased SST, possibly due to increased upwelling, and higher salinities due to decreased precipitation associated with the southward displacement of the ITCZ. Similarly, past decreases in δ^{18}O are interpreted as a warming and freshening of surface water due to northward migration of the ITCZ, reduced upwelling and increased precipitation.

[8] Our record begins during the mid-Holocene climate optimum with *G. ruber* δ^{18}O values being their lowest and indicating that annual average SST were higher and surface salinities lower than at any other point during this period (Figure 2). This is indicative of an ITCZ in a very northerly position. The ensuing 6,000 years are marked by large, century to millennial-scale changes in δ^{18}O. In particular, large increases in δ^{18}O occurred at ~6,000 to 5,000, 4,500–4,200, 3,800–3,500, 3,000–2,800, 2,500–2,200 and 1200–800 cal yrs. B.P. The high δ^{18}O values recorded during these events are close to the present-day annual mean δ^{18}O for *G. ruber* (−1.35‰) suggesting hydrographic conditions similar to today. δ^{18}O values are highest at about 3,500 cal yrs. B.P., a time when various paleoclimate records from the Caribbean indicate significantly drier conditions in the region [*Higuera-Gundy et al.*, 1999; *Haug et al.*, 2001].

[9] The δ^{18}O record of *N. dutertrei* tends to be inversely related to that of *G. ruber*. The highest salinities and coolest temperatures are recorded from 6,000 to 5,000 cal yrs. B. P., followed by a long term warming and freshening trend (Figure 2). However, most of the *N. dutertrei* δ^{18}O data fall within a narrow range (0.0 to −0.5‰) indicating that conditions within the thermocline region did not deviate significantly from the present day average thermocline conditions. The largest increase in the *N. dutertrei* δ^{18}O record occurred from 3,500–3,000 cal yrs. B.P. and is coincident with the development of more arid conditions in the Caribbean region [*Hodell et al.*, 1991; *Haug et al.*, 2001].

[10] Data for Cariaco Basin sediment trap samples show that the interspecies δ^{18}O difference ($\Delta\delta^{18}$O) between *G. ruber* (pink) and *N. dutertrei* can be used to estimate the mean annual surface to thermocline temperature gradient [*Tedesco*, 2002]. The sediment record of $\Delta\delta^{18}$O illustrates significant decreases at 3,500, 2,800 and 1,000 cal yrs. B.P. (Figure 2). The two events at ~3,500 and 1,000 cal yrs. B.P. are also distinctive due to the presence of the planktononic foraminifer *Globorotalia crassaformis*, a species that is absent from our Cariaco Basin core for most of the mid to late Holocene [*Tedesco*, 2002]. *Globorotalia crassaformis* is a deep dwelling species that is most prolific when the thermocline is shallow [*Ravelo and Andreason*, 1999] and presently is one of the dominant species during upwelling in the Cariaco Basin [*Tedesco and Thunell*, 2003]. We interpret the reduced difference in δ^{18}O between the two species at ~3,500 and 1,000 cal yrs. B.P., and the presence of *G. crassaformis* during these periods to be indicative of a shallow thermocline and intense upwelling. Over the last millennium, there has been a steady increase in $\Delta\delta^{18}$O, signifying a decrease in upwelling intensity.

[11] The shifts we observe in upper ocean hydrography of the Cariaco Basin during the last 6,000 years are synchronous with events identified in other tropical paleoclimate records from both the Caribbean-South American region [*Hodell et al.*, 1991; *Higuera-Gundy et al.*, 1999; *Haug et al.*, 2001] and Africa [*deMenocal et al.*, 2000; *Thompson et al.*, 2002]. Particularly pertinent to our study is the observation that conditions in the Cariaco region have become progressively drier since the mid-Holocene due to a southward migration of the ITCZ [*Haug et al.*, 2001]. Specifically, the large increase in δ^{18}O in our record centered at 5,500 cal yrs coincides with an increase in metal concentrations in Cariaco Basin sediments, indicating the onset of drier conditions [*Haug et al.*, 2001]. At this same time in tropical Africa, there was a shift to cooler temperatures that terminated the “African Humid Period” [*deMenocal et al.*, 2000]. Similarly, the cooler and drier conditions that developed in Cariaco Basin from 3,800 to 3,500 cal yrs. B.P. (Figure 3) are also seen in the Kilimanjaro δ^{18}O record and mark the onset of the “First Dark Age”, the period of most severe drought in tropical Africa during historical times [*Thompson et al.*, 2002]. Oxygen isotope and pollen records from Lake Miragoane, Haiti indicate that the lake filled with water in the early Holocene and remained high until the development of arid conditions ~3,400 cal yrs. B.P. [*Hodell et al.*, 1991; *Higuera-Gundy et al.*, 1999].

[12] In contrast to the Caribbean region, the austral summer is the season of maximum precipitation in the southern tropics of South America, including the Altiplano where ~75% of the annual precipitation falls between December and March [*Thompson et al.*, 2002]. During austral summer, water vapor derived from the tropical Atlantic Ocean is advected across the Amazon Basin to a center of deep convection east of the Altiplano [*Zhou and Lau*, 1998; Figure 1]. Precipitation on the northern Altiplano is highly correlated with water levels in Lake Titicaca [*Baker et al.*, 2001]. An increase in lake level began at about 4,500 cal yrs. B.P. and this increase in precipitation allowed humans to reoccupy the Altiplano after an absence of nearly 5,000 years due to dry conditions [*Nunez et al.*, 2002]. A detailed lake level curve for Lake Titicaca shows that high stands also occurred at 3,500–3,200, 2,800–2,500, 2,200–2,000 and 500–0 cal yrs. B.P. [*Abbott et al.*, 1997]. These periods of increased precipitation in the Altiplano coincide with cooler, drier conditions in the Caribbean, as indicated by our δ^{18}O records.

[13] *Maslin and Burns* [2000] reconstructed Amazon River outflow history for the past 14,000 years in order to calculate a moisture budget for the drainage basin. The inferred discharge history is similar to the climate record of Lake Junin, Peru [*Seltzer et al.*, 2000]. Both records show increasing moisture levels through the Holocene. This increase is coeval with the intensification of the Southern Hemisphere summer insolation at 10°S, which would lead to progressively enhanced convection, and thus greater penetration of Atlantic source air into the Amazon Basin resulting in increased precipitation [*Maslin and Burns*, 2000]. *Seltzer et al.* [2000] suggested that variations in the effective moisture at Lake Junin were due to changes in the mean

position of the ITCZ and intensity of convection in the Amazon Basin.

[14] The synchronous changes observed in the oxygen isotope records from the Cariaco Basin, paleoclimate records from the Caribbean region, and precipitation records from the Altiplano of Bolivia/Peru and the Amazon Basin can best be explained as responses to movements of the ITCZ and its differential impact on precipitation in the northern and southern tropics. As postulated by *Haug et al.* [2001], a southward shift of the ITCZ over the course of the Holocene may have resulted from changes in the seasonality of insolation associated with the 21-kyr precession cycle, with this seasonality increasing in the Southern Hemisphere and decreasing in the Northern Hemisphere during the last 5,000 years. This increased seasonality and southward displacement of the ITCZ combined with an intensification of the South American summer monsoon would have changed the moisture balance of the Caribbean region. A southerly shift in the ITCZ would result in decreased precipitation, increased trade wind intensity and more intense upwelling in the Cariaco Basin at the same time as the Altiplano and Amazon Basin regions were experiencing increased precipitation. In addition, the shift to a negative water balance in the Caribbean region in the mid-Holocene is coeval with the establishment of arid conditions in tropical Africa [*deMenocal et al.*, 2000].

[15] **Acknowledgments.** This research was supported by NSF Grants OCE-0118349 and OCE-0315234.

References

Abbott, M., M. Binford, M. Brenner, and K. Kelts, A 3,500 ^{14}C yr High-resolution record of water-level changes in Lake Titicaca, Bolivia/Peru, *Quat. Res.*, *47*, 169–180, 1997.

Alley, R. B., et al., Holocene climatic instability: A prominent, widespread event 8,300 yr ago, *Geology*, *25*(6), p. 483–486, 1997.

Baker, P. A., et al., The history if the South American Tropical precipitations for the past 25,000 years, *Science*, *291*, 640–643, 2001.

Black, D. E., et al., Eight centuries of North Atlantic ocean atmosphere variability, *Science*, *286*, 1709–1713, 1999.

Bond, G., et al., A pervasive Millennial-Scale Cycle in North Atlantic Holocene and Glacial Climates, *Science*, *278*, 1257–1266, 1997.

Bond, G., et al., The North Atlantic's 1–2 kyr climate rhythm: Relation to Heinrich events, Dansgaard/Oeschger cycles and the Little Ice Age, in *Mechanisms of global climate change at millennial time scales*, edited by P. U. Clark, R. S. Webb, and L. D. Keigwin, *Geophys. Mono.*, *112*, 35–58, 1999.

deMenocal, P., J. Ortiz, T. Guildersen, and M. Sarnthein, Coherent High- and low-latitude climate variability during the Holocene warm period, *Science*, *288*, 2198–2202, 2000.

Deuser, W. G., Seasonal variations in isotopic composition and deep-water fluxes of the tests of perennially abundant planktonic foraminifera of the Sargasso Sea: Results from sediment-trap collections and their paleoceanographic significance, *J. Foram. Res.*, *17*, 14–27, 1987.

Fairbanks, R. G., A 17,000-year glacio-eustatic sea level record: Influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation, *Nature*, *342*, 637–642, 1989.

Fairbanks, R. G., C. Charles, and J. Wright, Origin of meltwater pulses, in *Radiocarbon After Four Decades*, edited by R. E. Taylor, 473–500, 1992.

Fairbanks, R. G., et al., Vertical distribution and isotopic fractionation of living planktonic foraminifera from Panama Basin, *Nature*, *298*, 841–844, 1982.

Friddell, J., R. Thunell, T. Guilderson, and M. Kashgarian, Increased northeast Pacific climate variability during the warm middle Holocene, *Geophys. Res. Lett.*, *30*(11), 1560, doi:10.1029/2003GL017048, 2003.

Hastenrath, S., and L. Greischar, Further work on the prediction of northeast Brazil rainfall anomalies, *J. Clim.*, *6*, 743–758, 1993.

Haug, G. H., et al., Southward penetration of the Intertropical convergence Zone through the Holocene, *Science*, *293*, 1304–1308, 2001.

Higuera-Gundy, A., et al., A 10,300 ^{14}C record of climate and vegetation change in Haiti, *Quat. Res.*, *52*, 159–170, 1999.

Hodell, D. A., et al., Reconstruction of Caribbean climate change over the past 10,500 years, *Nature*, *352*, 790–793, 1991.

Hughen, K. A., et al., Deglacial changes in ocean circulation from an extended radiocarbon calibration, *Nature*, *391*, 65–68, 1998.

Hughen, K. A., J. Overpeck, L. Peterson, and S. Trumbore, Rapid climate changes in the tropical Atlantic region during the last deglaciation, *Nature*, *380*, 51–54, 1996.

Keigwin, L. D., The Little Ice Age and Medieval warm Period in the Sargasso Sea, *Science*, *274*, 1504–1508, 1996.

Maslin, M. A., and S. J. Burns, Reconstruction of the Amazon Basin effective moisture availability over the past 14,000 years, *Science*, *290*, 2285–2287, 2000.

Muller-Karger, F. E., et al., The annual cycle of primary production in the Cariaco Basin: Response to upwelling and implication for vertical export, *J. Geophys. Res.*, *106*, 4527–4542, 2001.

Nunez, L., M. Grosjean, and I. Cartajena, Human occupations and climate change in the Punta de Atacama, Chile, *Science*, *298*, 821–824, 2002.

Peterson, L. C., G. Haug, K. Hughen, and U. Rohl, Rapid change sin the hydrologic cycle of the tropical Atlantic during the last glacial, *Science*, *290*, 1947–1951, 2000.

Ravelo, A. C., and D. Andreasen, Using planktonic foraminifera as monitors of the tropical surface ocean, in *Reconstructing ocean history- a window into the future*, edited by F. Abrantes and A. Mix, Plenum Press, New York, 217–244, 1999.

Rimbu, N., et al., Arctic/North Atlantic Oscillation signature in Holocene sea surface temperature trends as obtained from alkenone data, *Geophys. Res. Lett.*, *30*(6), 1280, doi:10.1029/2002GL016570, 2003.

Schrag, D., G. Hampt, and D. Murray, Pore fluid constraints on temperature and oxygen isotopic compositions of the glacial ocean, *Science*, *272*, 1930–1932, 1996.

Seltzer, G., D. Rodbell, and S. Burns, Isotopic evidence for late Quaternary climate change in tropical South America, *Geology*, *28*, 35–38, 2000.

Stuiver, M., and P. Reimer, Extended ^{14}C database and revised CALIB 3.0 ^{14}C age model calibration program, *Radiocarbon*, *35*, 215–230, 1993.

Tedesco, K., Development of paleoenvironmental proxies and their application to the Holocene climate record of the Cariaco Basin, PhD dissertation, Univ. South Carolina, 200 p., 2002.

Tedesco, K., and R. Thunell, Seasonal and Interannual Variations in Planktonic Foraminiferal Flux and Assemblage Compositions in the Cariaco Basin, Venezuela, *J. Foraminiferal Res.*, in press, 2003.

Thompson, L., et al., Kilimanjao ice core records: Evidence of Holocene climate change in tropical Africa, *Science*, *298*, 589–593, 2002.

Zhou, J., and K. Lau, Does a monsoon climate exist over South America?, *J. Clim.*, *11*, 1020–1040, 1998.

K. Tedesco, Office of Global Programs, National Oceanic and Atmospheric Administration, Silver Spring, MD 20910, USA.

R. Thunell, Department of Geological Sciences, University of South Carolina, Columbia, SC 29208, USA. (thunell@geol.sc.edu)