Century-scale movement of the Atlantic Intertropical Convergence Zone linked to solar variability

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[1] The abundance of the planktic foraminifer *Globigerinoides sacculifer* in Gulf of Mexico (GOM) sediments is a proxy for the influx of Caribbean surface waters (the Loop Current) into the GOM. Penetration of the Loop Current into the GOM is related to the position of the Intertropical Convergence Zone (ITCZ): northward migration of the ITCZ results in increased incursion of the Loop Current into the GOM; southward migration of the ITCZ results in decreased penetration of the Loop Current into the GOM. Abundance variations of *G. sacculifer* in a sediment core from the Pigmy Basin in the GOM show distinct century-scale cyclicity over the last 5,000 years. The periodicity of these abundance variations is similar to the century-scale periodicity observed in proxy records of solar variability, which suggests that the average position of the ITCZ and thus Holocene century-scale variability in the Caribbean-GOM region is linked to solar variability. *INDEX TERMS:* 1620 Global Change: Climate dynamics (3309); 4267 Oceanography: General: Paleoceanography; 1650 Global Change: Solar variability. **Citation:** Poore, R. Z., T. M. Quinn, and S. Verardo (2004), Century-scale movement of the Atlantic Intertropical Convergence Zone linked to solar variability, *Geophys. Res. Lett.*, *31*, L12214, doi:10.1029/2004GL019940.

1. Introduction

[2] The potential for substantial climate change due to human activities has increased research on high-frequency climate variability of the current interglacial interval (the Holocene). Continuous high-resolution records from marine cores in the subpolar, subtropical, and tropical Atlantic [*Bond et al.*, 1997, 2001; *de Menocal et al.*, 2000; *Tedesco and Thunell*, 2003] indicate that the Holocene was punctuated by a series of quasi-periodic cold events. The most recent cold event, the Little Ice Age (LIA), was preceded by a period of warmer climate, the Medieval Warm Period (MWP). In addition, many Holocene records show considerable decadal- to century-scale variability [e.g., *Peterson et al.*, 1991; *Bond et al.*, 2001; *Haug et al.*, 2001; *Poore et al.*, 2003; *Tedesco and Thunell*, 2003].

[3] Although proxy records demonstrate that Holocene climate is highly variable, the details of the decadal- to century-scale variability and regional patterns of change are poorly known. In addition the causes of high-frequency variability are uncertain. Some workers argue that millennial to sub-millennial variability is related to external (solar) forcing [e.g., *Denton and Karlén*, 1973; *Bond et al.*, 2001; *Poore et al.*, 2003], while others argue that high-frequency variability is caused by internal dynamics of the global climate system [e.g., *Cane and Clement*, 1999]. In this report we present a continuous highly resolved (~30-year sampling interval) proxy record of climate variability for the last 5,000 yrs (calibrated years before present) from a sediment core from the Pigmy Basin in the Gulf of Mexico (GOM).

2. Gulf of Mexico

[4] The GOM is a semi-enclosed basin at the northwestern edge of the tropical Atlantic Ocean. Surface-water circulation and prevailing winds in the Caribbean – GOM region show large annual changes linked to seasonal migration of the Intertropical Convergence Zone (ITCZ) (Figure 1). During boreal winter, the ITCZ lies near the equator. Easterly winds from the Atlantic bring rains to the Amazon Basin, and prevailing westerly surface winds from the Pacific bring moisture into the west coast of North America. The primary surface-ocean current in the GOM is the Loop Current, which brings warm waters from the Caribbean Sea through the Yucatan Strait into the GOM before exiting into the North Atlantic Ocean through the Florida Straits. In winter the Loop Current and thus warm Caribbean surface water generally does not penetrate into the western or northern GOM. Warm, tropical waters from the Caribbean are restricted to a narrow band in the southeastern GOM reflecting the flow of the Loop Current from the Yucatan Strait directly to the Florida Strait.

[5] During boreal summer (Figure 1), the ITCZ moves north of the equator in response to increased solar insolation in the Northern Hemisphere. The northward migration of the ITCZ results in southeasterly surface winds from the Caribbean Sea and GOM and southerly winds from the Gulf of California bringing summer moisture to Mexico and the southwestern United States (the American monsoon). Surface flow through the Yucatan Strait is increased and the Loop Current penetrates deep into the GOM [*Müller-Karger et al.*, 1991; *Sheinbaum et al.*, 2002]. Sea surface temperatures are tropical (>28°C) throughout the GOM during the summer months.

3. Materials and Methods

[6] Data used in this study are the relative abundance of a planktic foraminifer (*Globigerinoides sacculifer*) generated from a large box core (MD02 2553) taken from the Pigmy Basin on the continental slope of the northern GOM in the summer of 2002 (Figure 1). Sediment samples at 1 cm intervals were processed for faunal analyses using standard procedures [*Poore et al.*, 2003].

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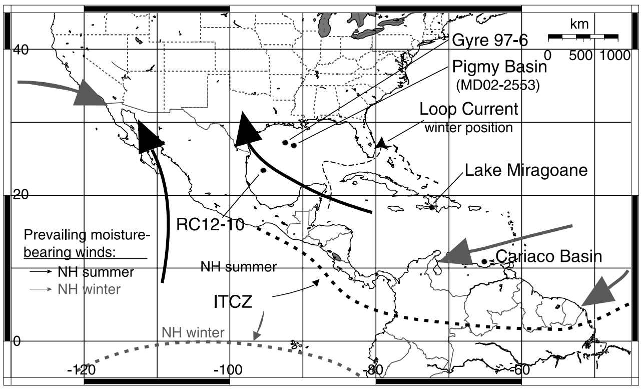

Figure 1. Map showing location of cores and sites of climate records in Caribbean and Gulf of Mexico discussed in text. Generalized path of prevailing moisture bearing winds and position of the Intertropical Convergence Zone (ITCZ) for the Northern Hemisphere winter and summer are shown by bold arrows and dashed lines. Generalized position of Loop Current during winter season is shown by light dashed line. Adapted from *Poore et al.* [2003].

[7] Chronology is provided by 8 AMS radiocarbon dating of samples of mixed planktic foraminifers[1] (Figure 2). Our results are presented in calibrated years. We used a linear fit to the dates to develop an age model. R^2 for the model is .999. Assuming constant accumulation rates the mean sampling interval of our record is 30 years. We used the multitaper method (MTM) of spectral analysis [e.g., *Ghil et al.*, 2002], which is part of the SSA-MTM Toolkit for Spectral Analysis (http://www.atmos.ucla.edu/tcd/ssa), to perform frequency domain analysis and to facilitate the identification of periodic oscillations in our data.

4. Millennial-Scale Variability in the ITCZ

[8] Changes in solar insolation related to changes in orbital forcing caused the average position of the ITCZ to migrate during the Holocene [*Hodell et al.*, 1991; *Haug et al.*, 2001]. In the early Holocene increased summer insolation resulted in warming of the Northern Hemisphere and northward movement of the average position of the ITCZ. As the average position of the ITCZ moved northward in the early Holocene, enhanced southeasterly winds resulted in increased precipitation along the northern coast of Venezuela as monitored by runoff records in the Cariaco Basin [*Haug et al.*, 2001] and in lake-level records at Lake Miragoane in Haiti [*Hodell et al.*, 1991]. After about 5 ka, decreasing summer insolation in the Northern Hemisphere and resulting southward movement of the average position of the ITCZ causes a decline in southeasterly winds. Thus precipitation in Haiti and along the north coast of Venezuela declined [*Hodell et al.*, 1991; *Haug et al.*, 2001]. Changes in surface-water circulation in the GOM parallel the changes in atmospheric circulation inferred from the Lake Miragoane and Cariaco proxy records. The relative abundance of the planktic foraminifer *G. sacculifer* in faunal assemblages in GOM sediments is an indicator for influence of the Loop Current [*Brunner*, 1979; *Poore et al.*, 2003]. Increased penetration of the Loop Current into the GOM at the beginning of the Holocene in response to the northward migration of the ITCZ and the resulting enhancement of the summer circulation pattern is indicated by increased abundance of *G. sacculifer* in faunal assemblages from northern and western GOM sediments [*Poore et al.*, 2003]. After reaching maximum values in the mid-Holocene, the abundance of *G. sacculifer* in faunal assemblages from the northern and western GOM declines towards the present as the average position of the ITCZ migrates back towards the equator.

5. Century-Scale Variability of the ITCZ

[9] Figure 2 shows *G. sacculifer* abundance variation in core MD02- 2553 from the Pigmy Basin. There is an overall

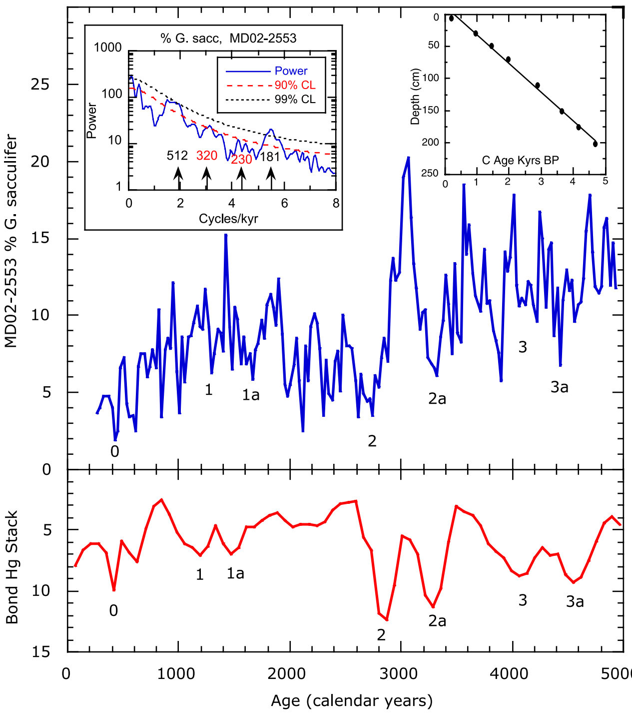

Figure 2. Plot showing abundance variation of *Globigerinoides sacculifer* in foraminifer assemblages from core MD02-2553 and subpolar North Atlantic drift ice proxy record (stack) from *Bond et al.* [2001]. Drift ice proxy record scale is inverted so that North Atlantic cold events match declines in MD02-2553 G. sacculifer relative abundance. North Atlantic and GOM time scales are independent. Events numbered 0 through 3a are North Atlantic cold events identified by *Bond et al.* [2001]. Events 1–3 included two cold pulses and we have designated the older pulse in each with an a to facilitate comparison with the MD02-2553 record. Inset in upper left shows results of spectral analysis of the MD02-2553 record using multitaper method (MTM). Arrows point to peaks that are statistically significant at the 99% (black) and 90% (red) confidence level. Numbers over arrows are in years per cycle. Inset in upper right shows age depth plot for AMS ^{14}C dates from MD02-2553. Dates are in ^{14}C years with a 400 year reservoir correction. Analytical error of ±40 years is too small to show on figure. See text for discussion.

[1] Auxiliary material is available at ftp://ftp.agu.org/apend/gl/2004GL019940.

decline in the abundance of *G. sacculifer* over the last 5 ka. This pattern is consistent with other records from the area and is explained by the equatorward movement of the average position of the ITCZ from the mid-Holocene to the present. Century-scale oscillations are also evident in the *G. sacculifer* record over the last 5 ka.

[10] *Poore et al.* [2003] found century-scale cycles in *G. sacculifer* abundances between 7.4 and 2.8 Ka in cores from the western GOM (RC 12-10) and the northern GOM slope (Gyre 97-6 PC 20), but problems with dissolution and sampling density prevented identification of clear cycles in the last 2.8 ka years of these records. *Poore et al.* [2003] also found that minima in *G. sacculifer* abundances in the GOM records corresponded generally in time to major cold events in the subpolar North Atlantic as identified by drift ice proxy records [*Bond et al.*, 2001].

[11] The North Atlantic "stack" drift ice record of *Bond et al.* [2001] is shown on Figure 2. Major ice-rafting events (0–3) over the last 5 ka in the North Atlantic stack correspond with minima in the MD02-2553 *G. sacculifer* abundance record. Minor age offsets of events between cores are within the range of uncertainties in the independent chronologies of the North Atlantic and GOM records.

[12] We performed spectral analyses of the MD02-2553 *G. sacculifer* time-series using the MTM technique [e.g., *Ghil et al.*, 2002]. The results (inset on Figure 2) show significant (>99% confidence level) concentrations of variance at periods at 180 and 512 years. Spectral peaks with periods at ~320 and 220 years are also evident (90% confidence level). *Poore et al.* [2003, Figure 7] found similar century-scale concentrations of variance in *G. sacculifer* abundance variations in GOM cores RC 12-10 (550, 300, and 212) and Gyre 97-6 PC 20 (300, 230, and 170) between 7.4 and 2.8 ka. Geologic records are imperfect recorders of climate signals and the depositional environments, sampling density and age control of the cores vary. The fact that the cores contain several periods of variance that are nearly identical suggests that they are responding to the same forcing. The new MD02-2553 record demonstrates that mid-Holocene century-scale oscillation identified by *Poore et al.* [2003] continue into the late Holocene and further show that the GOM records are consistent with the subpolar North Atlantic drift ice records over the last 5 ka.

[13] The century-scale concentrations of variance embedded in the GOM records are similar to concentrations of variance found in ^{14}C production records ($\Delta^{14}C$ derived from tree ring studies) [e.g., *Stuiver et al.*, 1991, Figure 22; *Stuiver and Braziunas*, 1993, Figures 9a and 9b]. The century-scale variability in the ^{14}C production record is a proxy for solar variability [e.g., *Eddy*, 1977; *Stuiver et al.*, 1991]. Increased solar activity strengthens the Earth's geomagnetic field and shields the atmosphere from incoming cosmic rays that produce ^{14}C. Decreased solar activity results in a weaker geomagnetic field, which results in an increase in cosmic ray flux that leads to higher ^{14}C production. Potential errors in the ^{14}C production record include delays in the migration of ^{14}C from the top of the atmosphere to the biosphere and changing oceanic mixing rates. However historical observations show a good correspondence between sunspot cycles and the tree-ring derived ^{14}C production record [e.g., *Eddy*, 1977]. Variability in solar output as monitored by ^{14}C production records is complicated. Depending on the technique used and the time-window analyzed, a number of century-scale periodicities are present in the ^{14}C production record including periods near 500, 300, 200, and 150 years [*Stuiver et al.*, 1991; *Stuiver and Braziunas*, 1993; *Poore et al.*, 2003] which closely match the periodicities found in the GOM records.

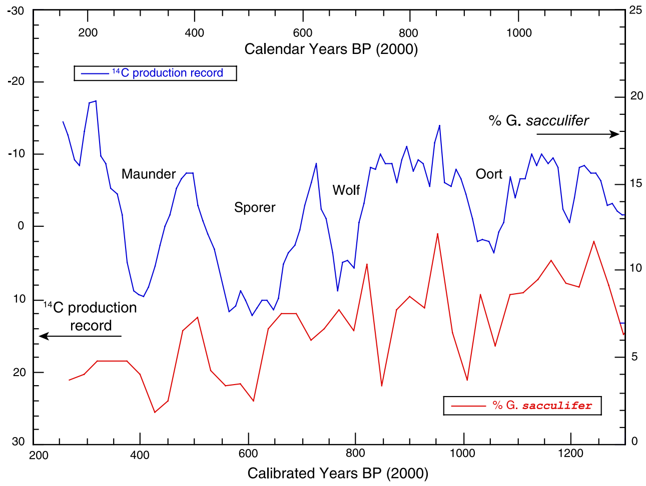

Figure 3. Comparison of ^{14}C production record [*Stuiver et al.*, 1998] and the MD02-2553 *G. sacculifer* abundance record for last 1200 years. Scale of the ^{14}C production record is inverted so that increased solar activity is up on the plot. The MD02-2553 record is uniformly offset 100 years from the ^{14}C production record. The offset is within the error of the MD02-2553 chronology. Note that the Sporer, Wolfe, and Oort Mimima (decreased solar activity) correspond with minima in *G. sacculifer* abundance.

[14] As another test of the link between solar variability and our GOM records we compared the *G. sacculifer* abundance time-series from MD02-2553 with the ^{14}C production record [*Stuiver et al.*, 1998] over the last 1200 years (Figure 3). Inspection of Figure 3 reveals correspondence between the decreases in solar activity represented by the Sporer, Wolf and Oort Minima and reductions in *G. sacculifer* abundance. The correlation shown on Figure 3 is our preferred correlation but other correlations are possible within the uncertainties of the chronology for the MD02-2553 record. More definitive direct correlation with the ^{14}C production record requires reduction of the uncertainties in dating the marine record.

[15] Changes in solar irradiance are small (~0.1%) and it is likely that amplification of changes in solar output are required to force Earth's climate (see discussion in *Lean and Rind* [1999]). Recent modeling studies suggest that solar variability may be amplified by a variety of processes including changes in ozone photochemistry and abundance, changes in upper stratospheric winds and changes in oceanic thermohaline circulation [e.g., *Schindell et al.*, 1999].

6. Conclusions

[16] Movement in the average position of the ITCZ is the most likely process linking changes in solar output with the century-scale variability in the Caribbean- GOM region. Just as insolation variations related to orbital changes cause

the average position of the ITCZ to change over the course of the Holocene [*Hodell et al.*, 1991; *Haug et al.*, 2001; *Poore et al.*, 2003] we infer that variations in solar output on century time-scales results in warming and cooling of the Northern Hemisphere that shifts the average position of the ITCZ.

[17] Historical reconstructions show strong links between solar variation and climate. The LIA has long been associated with intervals of reduced solar output [e.g., *Eddy*, 1977]. The Northern Hemisphere surface temperature record from 1610 to 1800 shows a high correlation (r^2 = .86) with reconstructed solar irradiance [*Lean et al.*, 1995]. The similarity of cycles in Holocene climate records from the GOM and other areas [*Peterson et al.*, 1991; *Bond et al.*, 2001; *Hodell et al.*, 2001] that are essentially identical to century-scale cycles in proxies for solar variability indicates that Holocene climate variability is also linked to solar variability on century time-scales.

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