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MIS 7 interglacial sea-surface temperature and salinity reconstructions from a southwestern subtropical Pacific coral

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ABSTRACT

We generated a 5.5-yr snapshot of biweekly-to-monthly resolved time series of carbon and oxygen isotope composition ($\delta^{13}C$ and $\delta^{18}O$) and Sr/Ca and Mg/Ca from annually banded aragonite skeleton of a ~197 ka pristine *Porites* coral collected at Niue Island (19°00′S, 169°50′W) in the southwestern subtropical Pacific Ocean. This report is the first of a high-resolution coral-based paleoclimate archive during the Marine Isotope Stage (MIS) 7 interglacial. Statistical results suggest that annual averages of sea-surface temperature (SST) and salinity (SSS) at ~197 ka were not significantly different from and ~1.2 higher than at present, respectively. Monthly mean variations showed increased SSS at ~197 ka that was higher (1.4–1.9 relative to today) in the austral summer than in the austral winter. Monthly SST and SSS anomalies at ~197 ka indicated smaller amplitudes by ~0.3°C (11%) and ~0.3 (24%) relative to the present, possibly suggesting less influence of interannual climate variability around Niue. Our results, taken together with other climate proxy records, imply seasonal and interannual modulation of thermal and hydrological conditions, different from today, in the southwestern subtropical Pacific Ocean associated with the Western Pacific Warm Pool and the South Pacific Convergence Zone variability during the MIS 7 interglacial.

Introduction

Ocean–atmosphere interactions in the western tropical/subtropical Pacific strongly influence global climate change. The warm water pool in the western Pacific, designated as the Western Pacific Warm Pool (WPWP), is the region with the highest sea-surface temperature (SST) at > 28°C and the largest latent heat release. Moreover, it has deep atmospheric convection, serving as a major source in the hydrological cycle on the Earth. Areas of the Intertropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ), zones of atmospheric convergence of the trade winds, high cloudiness, and enhanced precipitation (e.g., Trenberth, 1976; Vincent, 1994), are strongly associated with the WPWP. Therefore, it is necessary to develop climate proxy records in the pre-instrumental period from the tropical/subtropical Pacific region to extend our knowledge of climate and ocean variability during the Quaternary, and to constrain climatic parameters for numerical simulations with a high degree of reliability.

Numerous Quaternary paleoclimate records have been extracted from various climate proxies such as deep sea sediments (e.g., Imbrie et al., 1984; Lea et al., 2000; Shackleton, 2000), ice sheets (e.g., Dansgaard et al., 1993; Petit et al., 1999), trees (e.g., Briffa, 2000), speleothems (e.g., McDermott, 2004), and corals (e.g., Gagan et al., 2000, 2004). Continuous long cores from sediments and ice sheets play a leading role in Quaternary paleoclimate reconstructions, although the slow rates of sedimentation frequently preclude them from reconstructions on seasonal and interannual time scales. However, fossil coral archives provide high-resolution windows of generally short duration with which to investigate past atmospheric and oceanic conditions at the tropical/subtropical sea surface.

Massive *Porites* corals, living in tropical/subtropical shallow waters, have annually banded aragonite skeletons and grow at a high rate (commonly up to ~25 mm/yr). They contain informative geochemical tracers within their skeletons, which can provide chronological control and enable high-resolution (daily to annual) sampling. The ages of fossil corals are determined accurately by radiocarbon and uranium-series

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dating methods. Oxygen isotope composition ($\delta^{18}O$) and Sr/Ca are the most conventionally used geochemical tracers in coral skeletons. In general, coral $\delta^{18}O$ reflects seawater temperature and oxygen isotope composition ($\delta^{18}O_{sw}$) (e.g., Epstein et al., 1953; Weber and Woodhead, 1972; McConnaughey, 1989; Tudhope et al., 1995; Gagan et al., 2000; Asami et al., 2004); the latter is also related to salinity associated with evaporation–precipitation balance, upwelling of deeper water, and/or river water input (e.g., Craig and Gordon, 1965; Fairbanks et al., 1997). Coral Sr/Ca is controlled mainly by seawater temperature (e.g., Kinsman and Holland, 1969; Smith et al., 1979; Beck et al., 1992), yielding negative correlations between the two variables (e.g., Shen et al., 1996; Alibert and McCulloch, 1997; Corrège, 2006). In some cases, assuming that coral Sr/Ca change is only related to SST change and that coral $\delta^{18}O$ change is only related to both SST and $\delta^{18}O_{sw}$ changes, coupled determinations of $\delta^{18}O$ and Sr/Ca records from the same coral sample can generate separated datasets of SST and $\delta^{18}O_{sw}$ (e.g., McCulloch et al., 1994; Gagan et al., 1998; Quinn and Sampson, 2002). High-resolution geochemical records from well-preserved fossil coral skeletons can thereby provide important insights into the history of seasonal and interannual variations in thermal and hydrologic balance at the sea surface through time.

Several fossil coral records have been published on corals from the Holocene (e.g., Gagan et al., 1998; Corrège et al., 2000; Woodroffe et al., 2003; McGregor and Gagan, 2004; Morimoto et al., 2007; DeLong et al., 2010) and last deglaciation (e.g., McCulloch et al., 1996; Beck et al., 1997; Cohen and Hart, 2004; Corrège et al., 2004; Asami et al., 2009; Hathorne et al., 2011; Felis et al., 2012), but only a few records have been published from corals older than the last glacial maximum (Tudhope et al., 2001; Felis et al., 2004; Kilbourne et al., 2004a; Ayling et al., 2006; Watanabe et al., 2011). Herein, we present a 5.5-yr long, biweekly-to-monthly resolved time series of variations in stable isotope and elemental ratios from a fossil Niue coral (~197 ka) to reconstruct SST, sea-surface salinity (SSS), and their seasonality at this site for a time window during Marine Isotope Stage (MIS) 7 interglacial. Based on our results, together with other climate proxy records, we discuss climate conditions associated with the WPWP and SPCZ variability in the southwestern Pacific during this period. Although it is known from deep-sea and ice-core archives that the MIS 7 interglacial was slightly colder on average than today, seasonal and interannual variations in tropical/subtropical Pacific SST and SSS at that time remain unknown. Here we report for the first time on MIS 7 interglacial coral records that provide a comparison of climate states between the present and other interglacial periods.

Study area

Geological setting

Niue Island (19°00′S, 169°50′W; 259 km^2), 275–300 km east of the Tonga Trench in the Southwest Pacific (Fig. 1a), is an uplifted atoll with a central former lagoon surrounded by a raised reef core, which has been emergent since the early Pleistocene (Dubois et al., 1975). The carbonate cap ranges in thickness from ~400 to ~700 m and overlies a lower–middle Miocene volcanic edifice (Hill, 1983; Barrie, 1992). Modern topography of the island (Fig. 1b) is characterized by modern fringing reefs, a narrow Pleistocene complex of fringing reefs, and an older atoll platform (Schofield, 1959; Paulay and Spencer, 1992). The depositional age of the upper 320 m of the platform ranges from late-Miocene to late-Pliocene, based on magnetostratigraphy (Lu et al., 1996), strontium isotope chronostratigraphy (e.g., Aharon et al., 1993), and biostratigraphy (Wheeler and Aharon, 1991). The periphery of the island is marked by steep and rough coasts. The interior of the island is a former lagoon floor at elevations of 30–40 m above mean sea level, surrounded by the former reef core with maximum elevations of 55–65 m along the reef crest (e.g., Forbes, 1996; Wheeler and Aharon, 1997).

Modern climatic setting

At present, Niue Island has a subtropical climate with atmospheric temperature ranging approximately from 22.7°C in July and/or August to 27.1°C in February, with an annual average of 24.9°C (Alofi Weather Station, 1980–1989, http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.GCPS/). The annual average SST during 1982–1995 was 26.7 ± 0.3°C (1σ). The annual SST cycle has a mean maximum of ~28.3°C mostly in February or March and a mean minimum of ~25.2°C mostly in August (Fig. 2a). The amplitude of seasonal variations in SST varies from ~1.9 to ~4.3°C with a mean of 3.4 ± 0.7°C (1σ). The monthly SSS shows no regular annual cycle, but it has an annual mean of 35.6 ± 0.2 (1σ) ranging from ~35.3 to ~36.1 for 1982–1995 (Fig. 2b). The maximum and minimum monthly SSS are 35.5–36.3 and 34.9–35.8, respectively, resulting in seasonal amplitudes of SSS ranging from ~0.1 to ~0.9. Monthly solar radiation for 1984–1990 shows regular annual cycles with an annual mean of 229 ± 6 W/m^2 (1σ) (Fig. 2c). The annual total precipitation averages 1674 ± 373 mm/yr (1σ) ranging from ~1144 to ~2248 mm/yr for 1988–1994. The monthly precipitation likely also shows regular annual cycles, but its monthly maximum varies

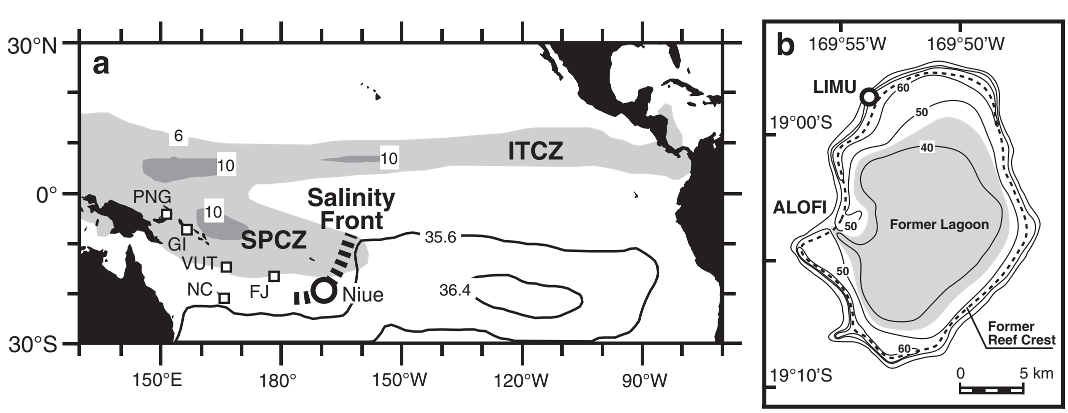

Figure 1. (a) Map of the tropical/subtropical Pacific Ocean showing the location of Niue Island (open circle) and other coral sites (squares) discussed in the text: Papua New Guinea (PNG), Gizo Island, Solomons (GI), Vanuatu (VUT), Fiji (FJ), and New Caledonia (NC). Dark and light gray colors show areas with annual average precipitation of >10 and >6 mm/day, respectively, for 1979–1992 (Xie and Arkin, 1997). Annual average salinity of >36.4 and >35.6 for 1979–1992 (Conkright et al., 2002) is shown as contours. The salinity front, the South Pacific Convergence Zone (SPCZ), and the Intertropical Convergence Zone (ITCZ) are labeled. (b) Topography map of Niue Island, redrawn from Forbes (1996), showing the sampling site Limu (open circle). The areas of lagoon (gray) and reef crest (dotted line) of the former coral atoll are marked.