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Persistent sea surface temperature and declined sea surface salinity in the northwestern tropical Pacific over the past 7500 years

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ABSTRACT

To understand Holocene climate evolutions in low-latitude region of the western Pacific, paired $\delta^{18}O$ and Mg/Ca records of planktonic foraminifer *Globigerinoides ruber* (250–300 μm, *sensu stricto*, s.s.) from a marine core ORI715-21 (121.5°E, 22.7°N, water depth 760 m) underneath the Kuroshio Current (KC) off eastern Taiwan were analyzed. Over the past 7500 years, the geochemical proxy-inferred sea surface temperature (SST) hovered around 27–28 °C and seawater $\delta^{18}O$ ($\delta^{18}O_W$) slowly decreased 0.2–0.4‰ for two KC sites at 22.7° and 25.3°N. Comparison with a published high-SST and high-salinity equatorial tropical Pacific record, MD98-2181 located at the Mindanao Current (MC) at 6.3°N, reveals an anomalous time interval at 3.5–1.5 kyr ago (before 1950 AD). SST gradient between the MC site and two KC site decrease from 1.5–2.0 °C to only 0–1 °C, and $\delta^{18}O_W$ from 0.1–0.3‰ to 0‰ for this 2-kyr time window. The high SST and low gradient could result from a northward shift of the North Equatorial Current, which implies a weakened KC. The long-term descending $\delta^{18}O_W$ and increasing precipitation in the entire low-latitude western Pacific and the gradually decreasing East Asian summer monsoonal rainfall during middle-to-late Holocene is likely caused by different land and ocean responses to solar insolation and/or enhanced moisture transportation from the Atlantic to Pacific associated with the southward movement of ITCZ.

1. Introduction

The Holocene climate had been once considered to be stable (e.g. Dansgaard et al., 1993). Over the past decade, high-precision archives from ice cores, marine cores, and stalagmites, however, revealed significantly variability in climatic and oceanic conditions from low to high latitudes (e.g., Steig, 1999; Koutavas et al., 2002; Spahni et al., 2005; Wang et al., 2005; Lin et al., 2006; Fleitmann et al., 2007; Linsley et al., 2010). Recently, Holocene atmosphere and ocean circulation scenarios in the tropical Pacific Ocean have been widely reconstructed (e.g., Huang et al., 1997; Lea et al., 2000, 2005; Kienast et al., 2001; Koutavas et al., 2002; Visser et al., 2003; Stott et al., 2004; Wang et al., 2005; Liew et al., 2006; Cai et al., 2010; Linsley et al., 2010). Characterized with high-temperature, high-salinity and low-nutrient seawater, the Kuroshio Current (KC), one of important Western Boundary Currents (WBCs), originating from the North Equatorial Current (NEC) in the western tropical Pacific Ocean, delivers a great amount of heat and energy northward (e.g., Barkley, 1970; Qu, 2003). When the easterly NEC flows nearby the Philippine Islands between 12°N and 15°N, it bifurcates into two currents, the northward KC and the southward Mindanao Current (MC) (Fig. 1) (Qiu and Lukas, 1996; Qu and Lukas, 2003; Kim et al., 2004). As an important WBC in the northwestern Pacific, KC transports huge amount (~15 SV, 1 SV = 10^6 m^3/s) of warm-saline water to the North Pacific subtropical gyre. In the low latitudes, the KC flows through the eastern coasts of Luzon and Taiwan islands, and then enters the southern Okinawa Trough (OT) (Liang et al., 2003).

Modern observations show that there are meridional variations of the bifurcation points of NEC (Qiu and Lukas, 1996; Qu and Lukas, 2003; Kim et al., 2004; Qiu and Chen, 2010; Zhang et al., 2012). During the boreal winter (summer), the bifurcation point moves north- (south-) ward. Inter-annual movements of the bifurcation points have been proved that show a strong link with El Niño/Southern Oscillation (ENSO) variability. During La Niña years, the bifurcation point tends to shift southward, and vice versa in El Niño years (Qiu and Chen, 2010). The inter-annual bifurcation position changes also affect the transports in KC (Kim et al., 2004). The variation of paleo-KC during the last deglaciation has been addressed (e.g., Kao et al., 2006; Chen et al., 2010). Marine sedimentary chemistry implies possible intensity changes of the KC during the Holocene (Kao et al., 2005; Lin et al., 2006); however, robust Holocene thermal and hydrological evidence are required to describe its evolution.

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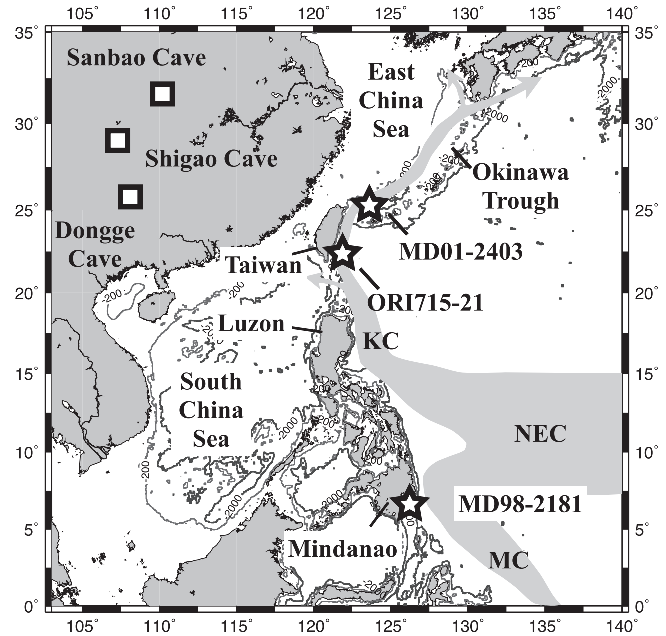

Fig. 1. Oceanographic map with deep-sea sedimentary cores (stars) MD01-2403 (Lin et al., 2006), ORI715-21 (this study) and MD98-2181 (Stott et al., 2004), and Chinese caves (squares), including Sanbao (Dong et al., 2010), Shigao (Jiang et al., 2012), and Dongge (Wang et al., 2005). KC, NEC, and MC denote Kuroshio Current, North Equatorial Current, and Mindanao Current, respectively.

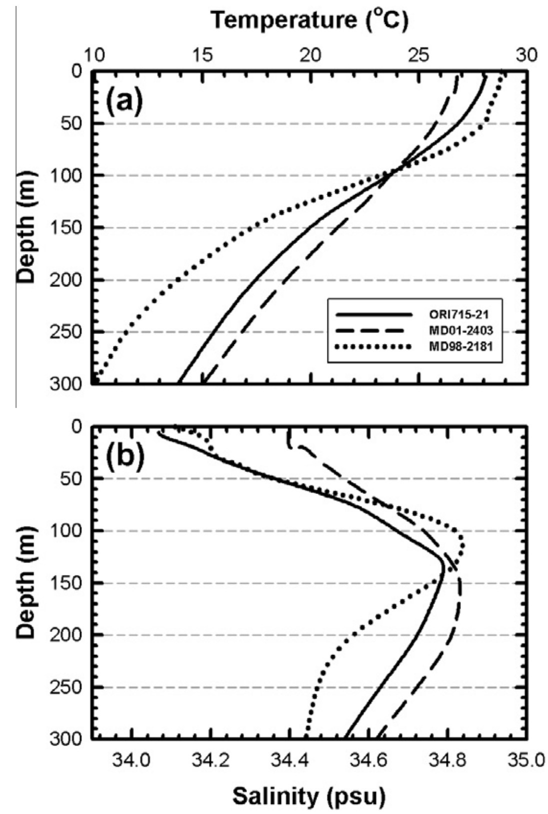

Fig. 2. Regional vertical water-column profiles of (a) temperature and (b) salinity at ORI715-21 (22.5°–23.0°N × 121.0°–121.5°E, solid lines), MD01-2403 (25.0°–25.5°N × 123.0°–123.5°E, dashed lines), and MD98-2181 (6.5°N, 126.5°E, dotted lines). Data were from Ocean Data Bank, ODB, in Taiwan, (http://www.odb.ntu.edu.tw), and WOA Atlas 2009 (Locarnini et al., 2010).

To understand the nature of the Kuroshio evolution during the Holocene, we established records of sea surface temperature (SST), surface seawater $\delta^{18}O$ ($\delta^{18}O_W$), and sea surface salinity (SSS) over the past 7.5 thousand years (ka, before AD 1950) from Core ORI715-21, collected underneath the main KC pathway, off eastern Taiwan in the northwestern Pacific Ocean. Comparison of the planktonic foraminifera-inferred thermal and hydrological conditions of latitudinal distributed sites in the western Pacific Ocean allows us to understand the (1) thermal and hydrological pacing of the middle-to-late Holocene KC variation, (2) the terrestrial and oceanic precipitation changes associated with the Intertropical Convergence Zone (ITCZ) migration by the influence of solar radiation and basin scale moisture transportation changes in the western Pacific, and (3) the possible connection between KC and ENSO evolution.

2. Materials and methods

2.1. Core description

The Core ORI715-21 (22.7°N, 121.5°E, water depth 760 m), a gravity core with 193 cm in length, was collected from the slope underneath the main stream of the KC off eastern Taiwan (Fig. 1). The water depth is much shallower than the carbonate lysocline depth of ~3000 m in the South China Sea (Thunell et al., 1992). No any dissolution feature is observable on the fossil foraminiferal tests through the timespan. This core is abundant with aragonitic pteropod shells. These lines of evidence assure that the foraminiferal tests were well-preserved. The contemporary local annual average (1985–2005) SST and SSS are 27.3 °C and 34.1 psu, respectively (Fig. 2) (Ocean Data Bank, ODB, in Taiwan, http://www.odb.ntu.edu.tw). The velocity of the KC is ~100 cm/s (ODB, http://www.odb.ntu.edu.tw) and the width of KC is ~100 km (Liang et al., 2003) in this area. The working halves of the core were cut into slices of 2-cm in thickness, and foraminiferal samples were collected from each of the slice by standard procedures of washing and sieving.

The age model of ORI715-21 was established by first-round AMS ^{14}C dates in Lin et al. (2006) and five new dates, measured at the Rafter Radiocarbon Laboratory, Institute of Geological and Nuclear Sciences, New Zealand (Table 1). The calendar ages were calculated using CALIB 6.0 program (Stuiver et al., 2010) and a corrected ^{14}C reservoir age of 400 years for global oceans was adopted (Bard et al., 1998). The sedimentation rate of the Core ORI715-21 was 34.5–35.5 cm/kyr during 6.2–7.5 ka gradually decreased to 17.1 cm/kyr at 2.2 ka, and then increased to 20.3–48.6 cm/kyr at 2.2–0 ka. A high sedimentation rate peak (111.1 cm/kyr) is observed at 6.2–6.1 ka. There is no significant turbidite observed in this core. The average sedimentation rate of this core is 25.0 cm/kyr over the past 7.5 ka.

2.2. Stable oxygen isotope measurement

To minimize vital effects, 7–10 tests of a well-defined morphotype of *Globigerinoides ruber* (white, *sensu stricto*, *s.s.*, hereafter abbreviated as *G. ruber*) (Wang, 2000; Löwemark et al., 2005; Steinke et al., 2005) within a limited size range (250–300 μm) were picked for oxygen isotope analyses. For foraminiferal calcite $\delta^{18}O$ ($\delta^{18}O_C$) measurement, our cleaning steps are as follows: (1) Tests of *G. ruber* were slightly crushed, immersed in $CH_3OH_{(aq)}$ and ultrasonicated three times, then cleaned with deionized (DI) water. (2) The tests were treated with 18% $NaOCl_{(aq)}$ overnight to decompose organic material, then cleaned with DI water six times. (3) The cleaned foraminiferal tests were dried in an oven at 50 °C for 48 h.