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Northern South China Sea SST changes over the last two millennia and possible linkage with solar irradiance

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ABSTRACT

High-resolution surface temperature records over the last two millennia are crucial to understanding the forcing and response mechanism of Earth's climate. Here we report a bidecadal-resolution sea surface temperature (SST) record based on long-chain alkenones in a gravity sediment core retrieved from the northern South China Sea. SST values varied between 26.7 and 27.5 °C, with a total variability ~1 °C over the last 2000 years. The general SST variation pattern matches well with total solar irradiance (TSI) changes. Relatively warm period between 800 and 1400 AD and cool period 1400-1850 AD could be identified, in agreement with the commonly defined periods of Medieval Warm Period and Little Ice Age. Within chronological uncertainty, notable short cooling events at 640-670 AD, 1030-1080 AD, 1260-1280 AD and 1420-1450 AD, coincide with large volcanic eruption events. The general coincidence of SST changes with TSI and volcanic eruption events suggests strong impact of external forcing on sea surface conditions in the studied area. In addition to the direct TSI changes, volcanic eruptions might have induced oceanic and atmospheric circulation adjustments which might be responsible for the short cooling events as revealed in the alkenone-SST record.

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1. Introduction

Earth's surface temperature changes over the last two millennia have been crucial to understanding current global warming issues, and reconstructed at regional, continental, and global scales using proxy data from various archives (Mann, 2007). Many of the high-resolution data have been used to produce a global array of climate as part of the "2k Network" in the IGBP Past Global Changes (PAGES) project (Ljungqvist et al., 2012; Mann, 2007, 2008; Mann and Jones, 2003; Neukom and Gergis, 2012; Neukom et al., 2014; PAGES 2k Consortium, 2013; PAGES Ocean2k Working Group, 2012), as well as in the 4th and 5th IPCC Assessment Report. Now some concepts, such as the Medieval Warm Period (WMP) and Little Ice Age (LIA), are widely accepted as the common climatic features over the last two millennia. However, comparisons among high-resolution temperature records derived from different proxies show distinctly spatial discrepancies, particularly between land and ocean, northern and southern hemispheres (PAGES 2k Consortium, 2013). Indeed, even the most prominent epochs during the last two millennia, the WMP and LIA, do not have specific definitions in terms of their time span, suggesting no global synchronous temperature patterns (Mann, 2007; PAGES 2k Consortium, 2013). Studies on those discrepancies would be helpful to deciphering climatic forcing-response processes, which however requires adequate coverage of high-resolution temperature reconstructions from various environment settings.

The mostly used annually-resolved proxy data are from continental archives, such as tree rings (Anchukaitis et al., 2012; Liu et al., 2009; Wilson et al., 2016) and ice cores (Dahljensen et al., 1998; Kobashi et al., 2011). Marine archives like corals and giant clams could produce annual-resolution paleotemperatures, which are often too short in most cases, and therefore usually concatenated to produce longer temperature records at millennial scale

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(Cobb et al., 2003; Yan et al., 2015). Marine sediments with relatively high sedimentation rates could provide continuous, decadal-resolution temperature reconstructions based on the foraminifera Mg/Ca (Oppo et al., 2009), GDGTs (Wu et al., 2012) and long-chain alkenones (Ruan et al., 2015; Sicre et al., 2008; Zhao et al., 2006).

The unsaturation index of long-chain alkenones ($U^{K'}_{37}$) have been established as an useful proxy to reconstruct sea surface temperature (SST) (Conte et al., 2006; Müller et al., 1998; Sikes et al., 1997; Volkman et al., 1995), and thought to have better indication to the most surface temperature than other proxies (Smith et al., 2013). At longer timescale, $U^{K'}_{37}$-SSTs generally record climate changes driven by earth's orbital cycles (Liu and Herbert, 2004). At millennial to centennial scale, changes in the $U^{K'}_{37}$-SST are usually interpreted to respond to monsoon or oceanic circulation changes (Kong et al., 2014, 2015; Zhao et al., 2014; Zhao et al., 2006). With increasing resolution amount and number of alkenone-derived SST records, distinct differences have found between $U^{K'}_{37}$-SSTs in the coastal and open sea of northern South China Sea (SCS), particularly during the late Holocene (Kong et al., 2014; Wang et al., 1999b). Similar to the northern SCS, the general trend of many $U^{K'}_{37}$-SSTs records have been found to follow the increasing winter insolation through the Holocene in the tropical Pacific and Indian oceans (Leduc et al., 2010).

The impact of solar irradiance and volcanic eruptions on continental temperatures could be clearly identified from annual-to decadal-resolution records, and the two are considered as the main external forcings (Anchukaitis et al., 2012; Gao et al., 2008; Mann, 2007; PAGES 2k Consortium, 2013). In contrast, it is still unclear how SSTs were influenced by different forcing factors, partly due to lacking adequate continuous high-resolution SST records (PAGES Ocean2k Working Group, 2012).

Here, we have analyzed long-chain alkenones in the upper 45 cm of a gravity core NS02G, covering the last 2000 years. Our main objectives are to reconstruct a bidecadal-resolution SST record in the open sea of northern SCS, and assess the regional temperature response and potential forcing mechanisms.

2. Oceanographic settings

The study area is located in the northern South China Sea (SCS), largest marginal sea of the Western Pacific Ocean. The SCS is almost a semi-enclosed, connected to surrounding seas and oceans through 5 narrow straits in the south, Taiwan and Luzon Strait in the north. The Taiwan and Luzon Straits are the important channels for water and thermal exchange with East China Sea and Western Pacific. The current through the Luzon Strait is considered as an intrusion branch of the Kuroshio Current off east coast of Philippines (Hu et al., 2000; Xue et al., 2004).

The annual mean SST of the southern part is higher than 28 °C and included to the Western Pacific Warm Pool (WPWP, SST>28 °C). The northern SCS shows distinct seasonal patterns in the SST field (http://apdrc.soest.hawaii.edu/) under the influence of Asian monsoons and Kuroshio Current intrusion. In summer, SST distribution is nearly homogenous across the northern SCS, while in winter, coastal SST is much lower than the open sea. The temperature isotherms are almost parallel with the southern China coastal line. Generally, the SST distribution in the northern SCS is strongly modulated by the Asian summer and winter monsoons (Su, 2004).

3. Sampling and analytical methods

3.1. Sampling

A 4.6-meter gravity core NS02G (19.8° N, 113.9° E) was retrieved from the offshore continental slope at a water depth of 562 m in the northern SCS (Fig. 1) in April 2012, by Guangzhou Marine Geological Survey Bureau. Monthly SST at the NS02G location ranges from ~22 °C in winter to ~30 °C in summer with an annual mean at ~26.5 °C (http://www.esrl.noaa.gov/psd/data/timeseries/). The whole NS02G core consists of gray clay and is rich in foraminifera.

3.2. Chronology

The chronology of NS02G is based on accelerator mass spectrometry (AMS) ^{14}C ages of 14 planktonic foraminifera specimens. All the foraminifera samples except R01 used for ^{14}C dating are mixtures of *Globigerinoides ruber* and *Globigerinoides sacculifer*. The foraminifera were pretreated under standard procedure, and measured ^{14}C concentration at the Beta Analytic laboratory in Miami, USA. Among the results, 6 AMS ^{14}C ages have been published previously (Kong et al., 2014), other 8 new ages were measured in September, 2017.

Foraminifera species picked from the core top sediment sample R01 (0–3 cm) is *Globigerinoides ruber* (white). Measured ^{14}C concentration of R01 is 108.2 ± 0.4 percent of modern carbon (pMC, 1950 AD as reference). It suggests that the foraminifers were living after the year 1950 AD. Some colored foraminifers with fragile spines were observed in sample R01 under the microscope, suggesting the core top sediment is quite “fresh”. The ^{210}Pb dating results on core NS02G have been reported by Kong et al. (2014). The excess ^{210}Pb concentration of the top 1 cm is 669 Bq/kg, and drops fast to about zero at ~3 cm. This confirms the young ^{14}C age of sample R01, and suggests the surface sediment had not been disturbed. Based on the ^{14}C and ^{210}Pb results, the depth 2 cm in the core was set as 0 cal yr BP, and the age above 2 cm was roughly calculated as after 1950 AD.

The measured ^{14}C ages of all the foraminifera samples (except R01) were calibrated using Marine13 dataset (Reimer et al., 2013) and CALIB 7.04 program with 400 years reservoir ($\Delta R = 0$)

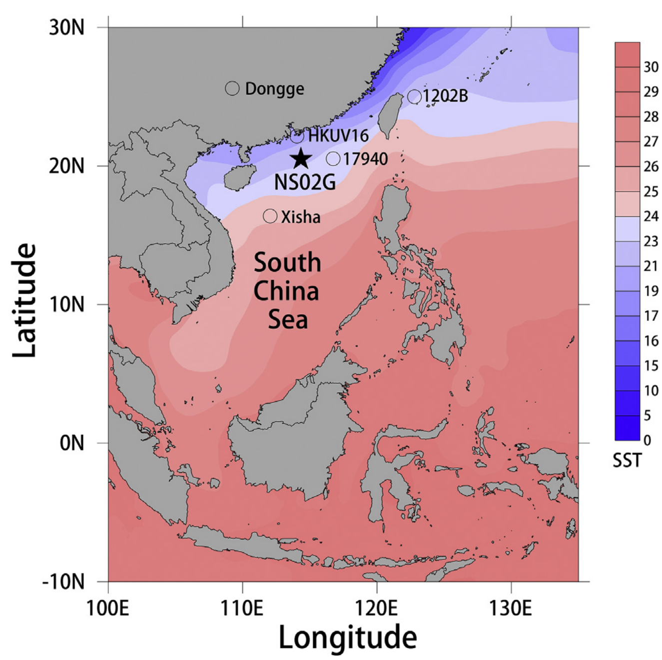

Fig. 1. Map of study area and sampling site NS02G (black star). Black circles denotes studied sites cited in this paper. The color contour is 30-years (1980-2010) averaged January SST (http://apdrc.soest.hawaii.edu/las/v6/constrain?var=962). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

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