Global and Planetary Change 63 (2008) 341–352

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Coral Sr/Ca and Mg/Ca records in Con Dao Island off the Mekong Delta: Assessment of their potential for monitoring ENSO and East Asian monsoon

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ARTICLE INFO

Article history:
Received 10 September 2007
Accepted 6 August 2008
Available online 24 August 2008

Keywords:
Paleoclimate proxy
Coral skeleton
Sea surface temperature
ENSO
East Asian monsoon
South China Sea

ABSTRACT

The climate of the South China Sea (SCS) is dominated by the East Asian monsoon (EAM) and can be related to the El Niño-Southern Oscillation (ENSO) owing to the interaction between ENSO and the EAM. An annually-banded coral (*Porites* sp.) collected from Con Dao Island in the southern SCS was measured for Sr/Ca and Mg/Ca ratios at near-monthly resolution through the annual bands of AD 1948–1999. This island is only ~90 km from the Mekong Delta coast and thus significantly influenced by riverine discharge, suggesting relatively severe environmental stress on corals. The Sr/Ca time series shows a clear annual cyclicity chiefly modulated by sea-surface temperature (SST), whereas the Mg/Ca time series exhibits an indistinct annual cyclicity, indicating that the previously-proposed coral Mg/Ca thermometry is greatly disturbed. An instrumental SST record in Con Dao Island (since 1980) has been compared with the Sr/Ca time series to calibrate a Sr/Ca thermometer. The Sr/Ca vs. SST comparison shows that the Sr/Ca thermometer is sometimes disturbed by some factor and that almost all of the disturbances occur around the annual-maximum SST in the warm/wet season. The Sr/Ca data around the annual-minimum SST in the cool/dry season is almost free from the disturbance and thus useful as a SST proxy. The disturbances of the Sr/Ca and Mg/Ca thermometers may be ascribed to the Mekong River discharge and its accompanying phenomena (i.e., large freshwater input, suspended-sediment loads, intense phytoplankton blooms, etc.), which are likely to disturb coral physiological processes. Applying the Sr/Ca thermometer to the whole Sr/Ca time series provides a SST reconstruction from 1948 through 1999. Reconstructed annual-minimum SSTs show a clear quasi-biennial oscillation significantly correlated with ENSO, indicating that the annual-minimum SST in the southern SCS tends to be higher (lower) in El Niño (La Niña) phases. This is compatible with previous observations that the East Asian winter monsoon is weakened (strengthened) in El Niño (La Niña) phases. The reconstructed SST record suggests a warming of 1.0 °C for the latter half of the 20th century. The Sr/Ca and Mg/Ca time series exhibit similar decadal-to-bidecadal variations, which do not seem to be primarily due to SST variability but rather due to some other factor possibly related to disturbance or fluctuation of coral physiological processes. Although both of our Sr/Ca and Mg/Ca data are affected, to a greater or lesser extent, by some non-temperature factor, a part of the Sr/Ca data provides a useful SST proxy and suggests that coral-based SST reconstruction in the southern SCS may be an effective means for monitoring the EAM and ENSO.

1. Introduction

The Western Pacific Warm Pool (WPWP) with mean annual sea-surface temperature (SST)≥29 °C is the warmest open-ocean area on Earth (Fig. 1A) (Locarnini et al., 2006). The WPWP supplies a large quantity of heat and moisture to the atmosphere, resulting in active convection and rainfall in and around the area. The position and intensity of the WPWP convection fluctuate from year to year, between two well-known phases: El Niño and La Niña, with a transition phase between the two. In the El Niño phase, the WPWP convection migrates eastward along the equator to the central Pacific. In the La Niña phase, the WPWP convection is intensified in the western equatorial Pacific. The two phases occur almost irregularly with the duration of each phase varying from 1 to 5 years. This interannual ocean-atmosphere variability, which has a direct impact on the climate of the tropical Pacific, is called the El Niño-Southern Oscillation (ENSO), and its climate system is called the ENSO system. Since the WPWP convection

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doi:10.1016/j.gloplacha.2008.08.002

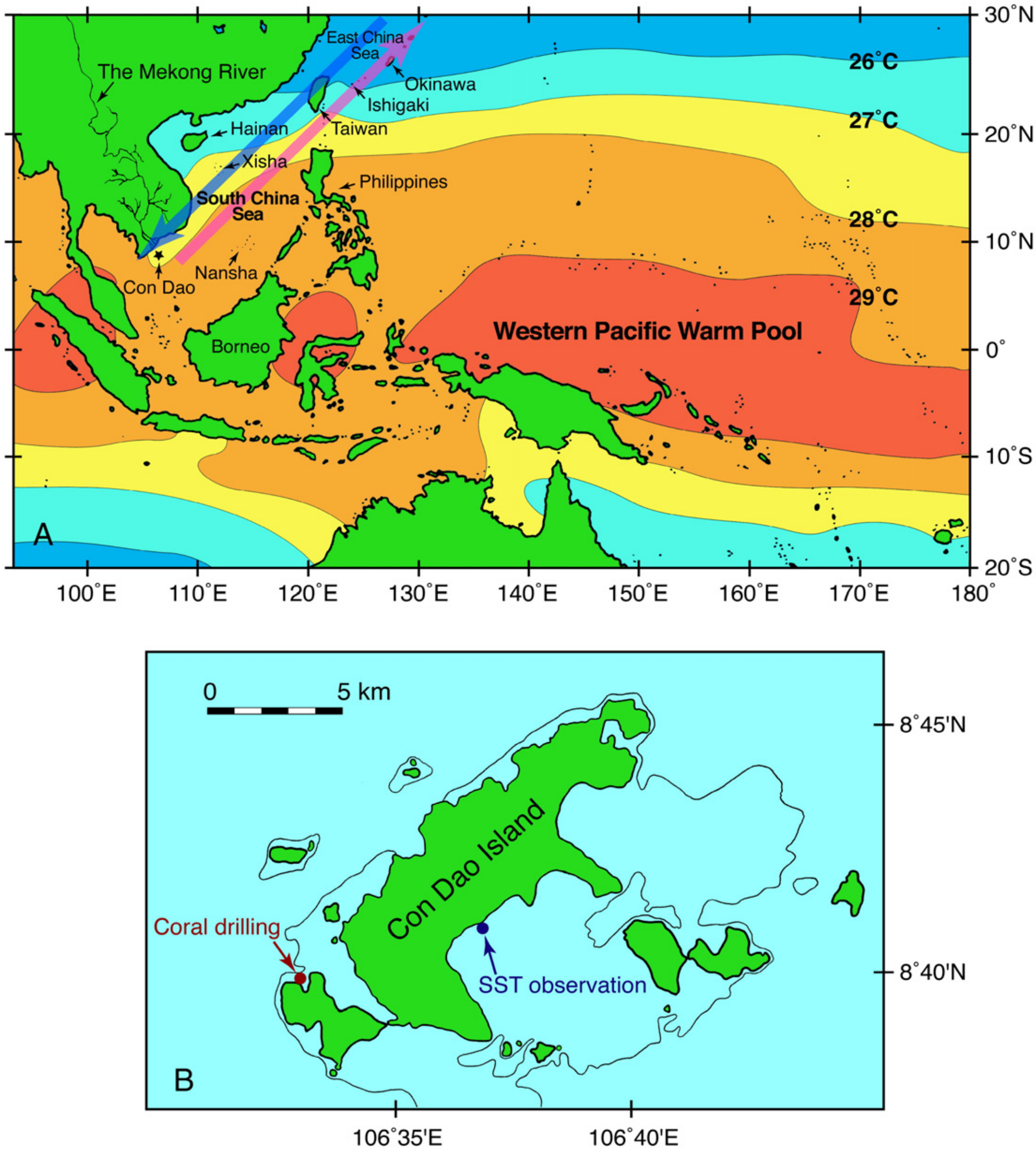

Fig. 1. (A) Location of the South China Sea (SCS) and the average extent of the Western Pacific Warm Pool (WPWP: mean annual sea-surface temperature ≥29 °C) (Locarnini et al., 2006). The climate of the SCS is dominated by the East Asian monsoon: southwesterly winds (warm and wet) in boreal summer and northeasterly winds (cool and dry) in boreal winter. Con Dao Island (the location of this study), Nansha Islands (Spratly Islands), Xisha Islands (Paracel Islands), and Hainan Island are located in the SCS. Taiwan Island, Ishigaki Island, and Okinawa Island are located to the north of the SCS, or on the south edge of the East China Sea (ECS). Con Dao Island is ~90 km from the mouth of the Mekong River. (B) Map of Con Dao Island showing the locations of coral drilling and SST observation. The isobaths indicate a water depth of 20 m.

is strongly linked to the global atmospheric circulations, the ENSO system is coupled with other climate systems such as the monsoons in Asia, Australia, and Africa (e.g., Ropelewski and Halpert, 1987, 1989, 1996; Lau and Sheu, 1988; Kiladis and Diaz, 1989; Yasunari, 1990; Webster and Yang, 1992; Hastenrath et al., 1993; Zhang et al., 1996; Tomita and Yasunari, 1996; Webster et al., 1998; Wang et al., 2000). The ENSO-Asian monsoon system is one of the most prominent of such coupled climate systems. The Pacific Decadal Oscillation (PDO) is another well-known ocean-atmosphere variability in the Pacific, with two phases each persisting for 20–30 years (Mantua et al., 1997; Minobe, 1997, 1999, 2000; Zhang et al., 1997; Minobe and Mantua, 1999; Mantua and Hare, 2002). In 1976, the North Pacific and the eastern-central equatorial Pacific underwent remarkable climate shifts documented by a phase shift of PDO, changes in the ENSO cycle, and other various observations (Douglas et al., 1982; Nitta and Yamada, 1989; Trenberth, 1990; Trenberth and Hurrell, 1994; Graham, 1994; Miller et al., 1994; Deser et al., 1996; Trenberth and Hoar, 1996; Rajagopalan et al., 1997; Guilderson and Schrag, 1998; Wang and An, 2001; Giese et al., 2002). Since the 1976 climate shift, the El Niño phase has occurred more frequently, intensely, and persistently with a SST increase of 0.5–0.8 °C in the eastern-central equatorial Pacific (e.g., Trenberth, 1990; Zhang et al., 1997; McPhaden and Zhang, 2002).

One of the largest difficulties for a clearer understanding of the global climate system is the shortage of long-term meteorological observations especially in tropical regions. In the tropics, most meteorological observations span only the past 30–40 years and only a handful of observations extend into the 19th century. Massive coral skeletons have great potential to extend the limited tropical meteorological observations temporally and spatially, because they grow in the tropical/subtropical shallow waters (<20–30 m in depth) for up to hundreds of years and usually form annual growth bands in their skeletons. High-resolution geochemical analyses of the skeletons