



Full length article

Wet and cold climate conditions recorded by coral geochemical proxies during the beginning of the first millennium CE in the northern South China Sea



Hangfang Xiao^{a,b}, Wenfeng Deng^{a,*}, Xuefei Chen^{a,b}, Gangjian Wei^a, Ti Zeng^c, Jian-xin Zhao^d

^a State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China

^b School of Earth Science, University of Chinese Academy of Sciences, Beijing 100049, China

^c Key Laboratory of Marginal Sea Geology, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China

^d Radiogenic Isotope Laboratory, Centre for Microscopy and Microanalysis, The University of Queensland, Brisbane, Queensland 4072, Australia

ARTICLE INFO

Article history:

Received 26 July 2016

Received in revised form 3 December 2016

Accepted 9 December 2016

Available online 10 December 2016

Keywords:

Eastern Han

Three Kingdoms

Western Jin

Sea surface temperature

Sea surface salinity

South China Sea

ABSTRACT

The past two millennia include some distinct climate intervals, such as the Medieval Warm Period (MWP) and the Little Ice Age (LIA), which were caused by natural forcing factors, as well as the Current Warm Period (CWP) that has been linked to anthropogenic factors. Therefore, this period has been of great interest to climate change researchers. However, most studies are based on terrestrial proxy records, historical documentary data, and simulation results, and the ocean and the tropical record are very limited. The Eastern Han, Three Kingdoms, and Western Jin periods (25–316 CE) cover the beginning first millennium CE in China, and were characterized by a cold climate and frequent wars and regime changes. This study used paired Sr/Ca and $\delta^{18}\text{O}$ series recovered from a fossil coral to reconstruct the sea surface water conditions during the late Eastern Han to Western Jin periods (167–309 CE) at Wenchang, eastern Hainan Island in the northern South China Sea (SCS), to investigate climate change at this time. The long-term sea surface temperature (SST) during the study interval was 25.1 °C, which is about 1.5 °C lower than that of the CWP (26.6 °C). Compared with the average value of 0.40‰ during the CWP, the long-term average seawater $\delta^{18}\text{O}$ (−0.06‰) was more negative. These results indicate that the climate conditions during the study period were cold and wet and comparable with those of the LIA. This colder climate may have been associated with the weaker summer solar irradiance. The wet conditions were caused by the reduced northward shift of the intertropical convergence zone/monsoon rainbelt associated with the retreat of the East Asian summer monsoon. Interannual and interdecadal climate variability may also have contributed to the variations in SST and seawater $\delta^{18}\text{O}$ recorded over the study period.

© 2016 Published by Elsevier Ltd.

1. Introduction

Global warming has become the focus of increasing concern within the climate change research community over recent years. To better understand present-day climate conditions and the potential trend of future climate change, it is important to extend the temporal scale of investigation into the last two millennia (Taira, 1980; Fritz et al., 2000; Hu et al., 2001; Booth et al., 2006; Mann, 2007; Anderson et al., 2010; Tierney et al., 2010; Vuille et al., 2012; Consortium, 2013; Wurtzel et al., 2013; Denniston et al., 2015; Donnelly et al., 2015; H. Yan et al., 2015b). The importance of the last two millennia is that they include some distinct climate intervals. For example, climate anomalies such as the Med-

ieval Warm Period (MWP, 900–1300 CE; Lamb, 1965; Crowley and Lowery, 2000; Bradley et al., 2003) and the Little Ice Age (LIA, 1550–1850 CE; Robock, 1979; Bradley and Jones, 1993; Matthews and Briffa, 2005) are believed to have been caused by natural forcing (e.g., solar variability and volcanic emissions). However, the Current Warm Period (CWP, 1850–present CE; Wu et al., 2012; Fleury et al., 2015) is a climate anomaly that has been linked with anthropogenic factors (e.g., industrialization and land-use changes).

In China, the problem of climate change over the past two millennia has been of longstanding interest to the paleoclimatic community (e.g., Gong and Hameed, 1991; Shi et al., 1999; Zheng et al., 2001; Yang et al., 2002, 2016; Ge et al., 2003, 2004, 2011; Holmes et al., 2009; Tan et al., 2011; Hao et al., 2012, 2016; Q. Ge et al., 2013; Q.S. Ge et al., 2013; H. Yan et al., 2015a; Q. Yan et al., 2015a, 2015b). However, almost all of these studies were based

* Corresponding author.

E-mail addresses: wfdeng@gig.ac.cn, wfdeng@gmail.com (W. Deng).

on terrestrial proxy records, historical documentary data, and simulation results. High-resolution ocean and tropical records are very limited; therefore, the full characteristics of the seasonal to annual climate over the past two millennia remain unclear.

The ocean plays an integral part in influencing the climate system and is intrinsically linked to the atmosphere through heat storage, global heat transportation, evaporation, freezing and thawing in polar regions, and gas storage and exchange (including CO₂; Herr and Galland, 2009). Therefore, climate change records from the ocean will undoubtedly improve our knowledge of the evolution of climate change over various periods. Massive coral is one of the most reliable proxies for climatic and environmental change in the ocean, as it contains clear annual bands and has high growth rates, thereby recording high-resolution climate information from the surrounding seawater in which it lived (Gagan et al., 2000; Lough, 2010). The Sr/Ca ratios preserved in coral skeletons have long been used to reconstruct changes in sea surface temperature (SST; Smith et al., 1979; Beck et al., 1992), and δ¹⁸O values in coral reflect SST and δ¹⁸O in the ambient seawater (Swart and Coleman, 1980; Dunbar and Wellington, 1981). Residual δ¹⁸O (i.e., Δδ¹⁸O), which is calculated by subtracting the contribution of temperature from coral δ¹⁸O, can be used as a tracer for seawater δ¹⁸O (δ¹⁸O_{sw}) and therefore salinity or rainfall (McCulloch et al., 1994; Gagan et al., 1998, 2000; Corrège, 2006; Deng et al., 2009, 2014b; Deng and Wei, 2015).

As the largest marginal sea of the western Pacific, the climate in the South China Sea (SCS) is controlled by both the East Asian monsoon and the El Niño-Southern Oscillation (ENSO) over seasonal and interannual timescales, respectively (Yan et al., 2011a). Therefore, climate records from the SCS are important for the study of climate change over periods of significant change such as the MWP and LIA. In recent years, there have been a number of successful studies of past climate change based on coral records from the mid-Holocene to the CWP in the SCS (e.g., Sun et al., 2005; Yu et al., 2005; Wei et al., 2007; Liu et al., 2008, 2013; Deng et al., 2009, 2013, 2014b; Chiang et al., 2010; Yu, 2012; Chen et al., 2013; Deng and Wei, 2015; Yang et al., 2015). However, climate records that cover the past two millennia remain limited. In China, the Eastern Han, Three Kingdoms, and Western Jin periods (25–316 CE) mark the beginning of this period and were characterized by a cold climate and frequent wars and regime changes (Chu, 1973; Ge, 2011). Here, we use the paired Sr/Ca and δ¹⁸O records from a fossil coral spanning the late Eastern Han through Western Jin dynasties to reconstruct the sea surface water conditions, including SST and hydrological characteristics, for eastern Hainan Island in the northern SCS. The differences between these periods and the CWP are compared to provide a new insight into climate change at the beginning of the first millennium CE, and a new benchmark for testing the reliability of climate models.

2. Materials and methods

A fossil coral (14FJ12) was collected from a *Porites lutea* colony on the fringing reefs at Fengjiawan, Wenchang, 2 km off the east coast of Hainan Island in the northern SCS (19°23′43.14″N, 110°45′11.16″E; Fig. 1). A modern coral (11LW4), for the comparative study, was collected in April 2011 at Longwan, Qionghai, which is also 2 km off the east coast of Hainan Island in the northern SCS (19°17′11.94″N, 110°39′21.06″E; Fig. 1). The two sampling sites are approximately 16 km apart. This modern coral has been used previously to study decadal variations in the northern SCS (Deng et al., 2013; Chen et al., 2015; Wei et al., 2015).

The fossil coral was dated by U-Th methods on a Nu Plasma multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS) at the Radiogenic Isotope Laboratory, The University

of Queensland. Details of the analysis method were described by Zhou et al. (2011).

The coral cores were first sectioned into slices of 1 cm thick and 5–7 cm wide. Then, X-ray photographs were taken to reveal the regular and well-defined annual density bands, which were used to establish the coral chronology. Next, the coral slices were soaked in 10% H₂O₂ for 24 h to remove organic matter, followed by ultrasonic cleaning in deionized water for 30 min to remove surface contaminants (Wei et al., 2007). Samples were collected at annual intervals along the main growth axis using a digitally controlled milling machine. X-ray diffraction (XRD) analyses of the samples showed that the coral skeleton was 100% aragonite. Scanning electron microscopy (SEM) imaging revealed that there was no secondary aragonite present in the coral skeleton.

Coral skeletal δ¹⁸O and δ¹³C analyses were performed using a GV Isoprime II stable isotope ratio mass spectrometer (IRMS) coupled with a MultiPrep carbonate device that used 102% H₃PO₄ at 90 °C to extract CO₂ from the coral samples, following the procedures described by Deng et al. (2009); the IRMS was located at the State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou, China. Isotope data were normalized to the Vienna Pee Dee Belemnite (V-PDB) using the NBS-19 standard (δ¹⁸O = −2.20‰, δ¹³C = 1.95‰). Multiple measurements on this standard yielded a reproducibility of 0.03‰ for δ¹³C and 0.06‰ for δ¹⁸O. Replicate measurements were made on approximately 15% of the samples and their reproducibilities were comparable to that of the standard.

Analyses of Sr/Ca ratios were conducted on a Varian Vista Pro inductively coupled plasma atomic emission spectrometer (ICP-AES), in the same laboratory as that used for the stable isotope measurements. The standard reference material for calibration is the JcP-1 *Porites* sp. standard prepared by the Geological Survey of Japan (Okai et al., 2002). All Sr/Ca data were normalized to JcP-1 with Sr/Ca = 8.838 mmol mol^{−1} (Hathorne et al., 2013). Replicate analyses of an in-house *Porites* sp. coral standard solution BH-7 showed excellent reproducibility, with an external precision of 0.16%. Replicate measurements were made on approximately 15% of the samples and their reproducibilities were comparable to that of the in-house standard. See Wei et al. (2007) for a more detailed description of the Sr/Ca methodology.

Coral Δδ¹⁸O, a proxy for δ¹⁸O_{sw}, was calculated by subtracting the sea surface temperature (SST) contribution from the coral δ¹⁸O values (Gagan et al., 1998), according to Δδ¹⁸O = dδ¹⁸O/dT × [T_{δ18O} − T_{Sr/Ca}], where dδ¹⁸O/dT is the slope of the empirical δ¹⁸O–SST function reported by Song et al. (2006), and T_{δ18O} and T_{Sr/Ca} are the apparent SSTs calculated from δ¹⁸O values and Sr/Ca ratios, respectively. We used the Sr/Ca–SST relationship reported by Gagan et al. (2012). This equation has been corrected for the apparent attenuation effect from the skeletal mass accumulation of coral. It is identical to the calibration using the annually resolved Sr/Ca ratios and instrumental SST records from the Great Barrier Reef (Deng et al., 2014a), thus it is suitable for calculating SST from annually resolved Sr/Ca ratios.

3. Results

The coral 14FJ12 was dated to 1712 ± 8 year BP, and this age was converted into its Common Era year giving a growing span of ca. 167–309 CE. This interval covers the late Eastern Han (167–220 CE), Three Kingdoms (220–265 CE), and Western Jin (265–316 CE) periods.

The variations of annual SST and seawater δ¹⁸O (δ¹⁸O_{sw}, coral Δδ¹⁸O) are presented in Fig. 2. The annual SST ranges from 23.5 to 26.3 °C, with a variation amplitude of 2.8 °C and an average of

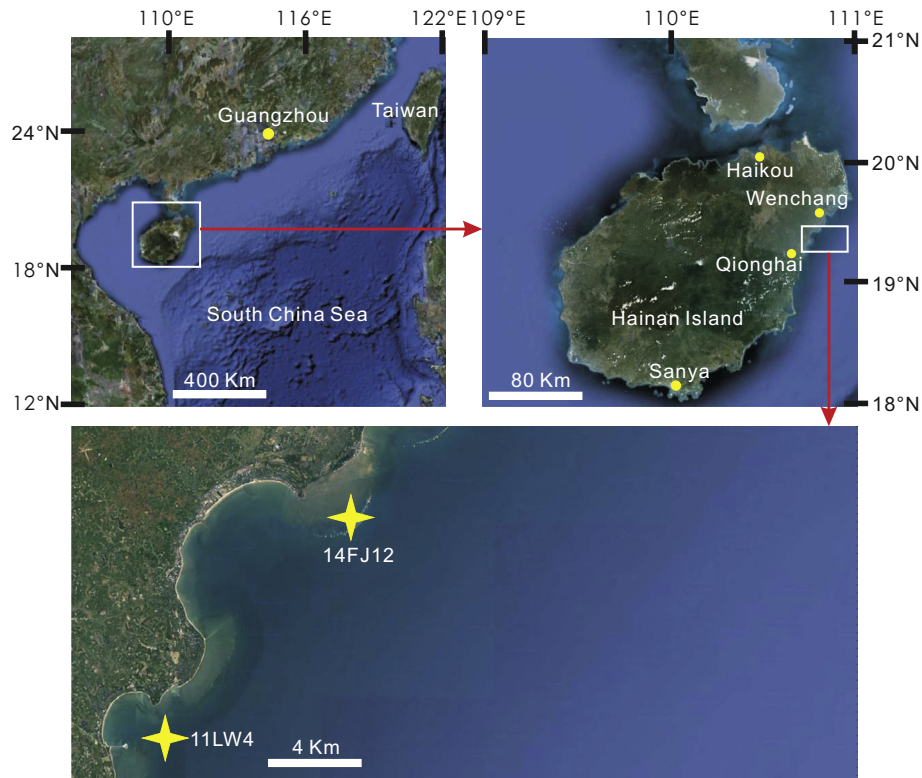


Fig. 1. Satellite image of Hainan Island. Yellow stars indicate sampling locations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

25.1 °C (Fig. 2a). The average annual SST is 25.2 °C, 25.4 °C, and 24.6 °C for the late Eastern Han, Three Kingdoms, and Western Jin periods, respectively (Fig. 2a). The annual $\delta^{18}\text{O}_{\text{sw}}$ values range from -0.63‰ to 0.86‰ , with a variation amplitude of 1.49‰ and an average of -0.06‰ (Fig. 2b). The average annual $\delta^{18}\text{O}_{\text{sw}}$ values are -0.05‰ , -0.02‰ , and -0.13‰ for the late Eastern Han, Three Kingdoms, and Western Jin periods, respectively (Fig. 2b). See the online [supplementary dataset](#) for additional details.

4. Discussion

4.1. The applicability of the coral records

The average of the annual SST records from 1870 to 2011 during the CWP were calculated by averaging the monthly SST, extracted from the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST1.1) dataset (<http://coastwatch.pfeg.noaa.gov/erddap/griddap/erdHadISST.html>; Rayner et al., 2003) on a $1^\circ \times 1^\circ$ grid centered on 19.5°N , 111.5°E (ca. 90 km from the sampling sites) is 26.0°C . Instrumental records indicate that the average of the annual SST from 1960 to 1997 is 25.8°C at Qinglan Harbor Meteorological Observatory, which is approximately 35 km from our sample sites. The average annual SST between 1853 and 2011 reconstructed from the coral Sr/Ca record is 26.6°C . There are no long-term in situ instrumental SST data available that span the growth period of the modern coral (11LW4). Therefore, taking all possible error-inducing factors into account, including site differences, errors in the gridded data, instrumental error, and errors associated with the SST reconstruction, we believe that the SST records derived from coral Sr/Ca are reliable. In addition, all coral Sr/Ca data were normalized to the value of an international coral standard (JcP-1), and then transformed into SST records using the same Sr/Ca–SST thermometer. Another issue should be noted

is the effect of summer upwelling on coral Sr/Ca record. Our study sites are exactly located in the areas affected by the summer upwelling system along the northeast coasts of Hainan Island (Jing et al., 2009; Liu et al., 2013), and the deep ocean water with an unusual Sr/Ca ratio may lead to an artifact in the Sr/Ca–SST calibration (de Villiers et al., 1994). The Sr/Ca–SST equation used here was based on the *Porites* corals from coastal upwelling area and laboratory culturing experiments and has been corrected for the attenuation effect by skeletal mass accumulation (Gagan et al., 2012). Therefore, it is reliable to act as a bridge to compare the SST difference between different time periods. In summary, we are confident that the average long-term reconstructed annual SST records are suitable for comparing and discussing SST trends over the study period.

There are no long-term in situ instrumental $\delta^{18}\text{O}_{\text{sw}}$ data available that span the growth period of the modern coral (11LW4). Gridded data and data from a nearby site are also unavailable. Therefore, it is difficult to discuss the absolute values of reconstructed $\delta^{18}\text{O}_{\text{sw}}$. Fortunately, the $\delta^{18}\text{O}_{\text{sw}}$ data extracted from the coral Sr/Ca and $\delta^{18}\text{O}$ are based on the same transfer equations and are normalized to the same reference standards as Sr/Ca and $\delta^{18}\text{O}$, and this makes it possible to study and compare the relative changes in $\delta^{18}\text{O}_{\text{sw}}$ over the different periods.

4.2. SST records from coral Sr/Ca

The annual SST from the late Eastern Han to Western Jin periods showed large fluctuations, varying between 23.5°C and 26.3°C . The climate during the Three Kingdoms dynasty was relatively warm, but the Western Jin was the coldest of the three periods under consideration here (Fig. 2a). Taking these three periods as a whole, the average value (25.1°C) of long-term SSTs is about 1.5°C lower than that of CWP (26.6°C) obtained from the coral records (Fig. 3a). This

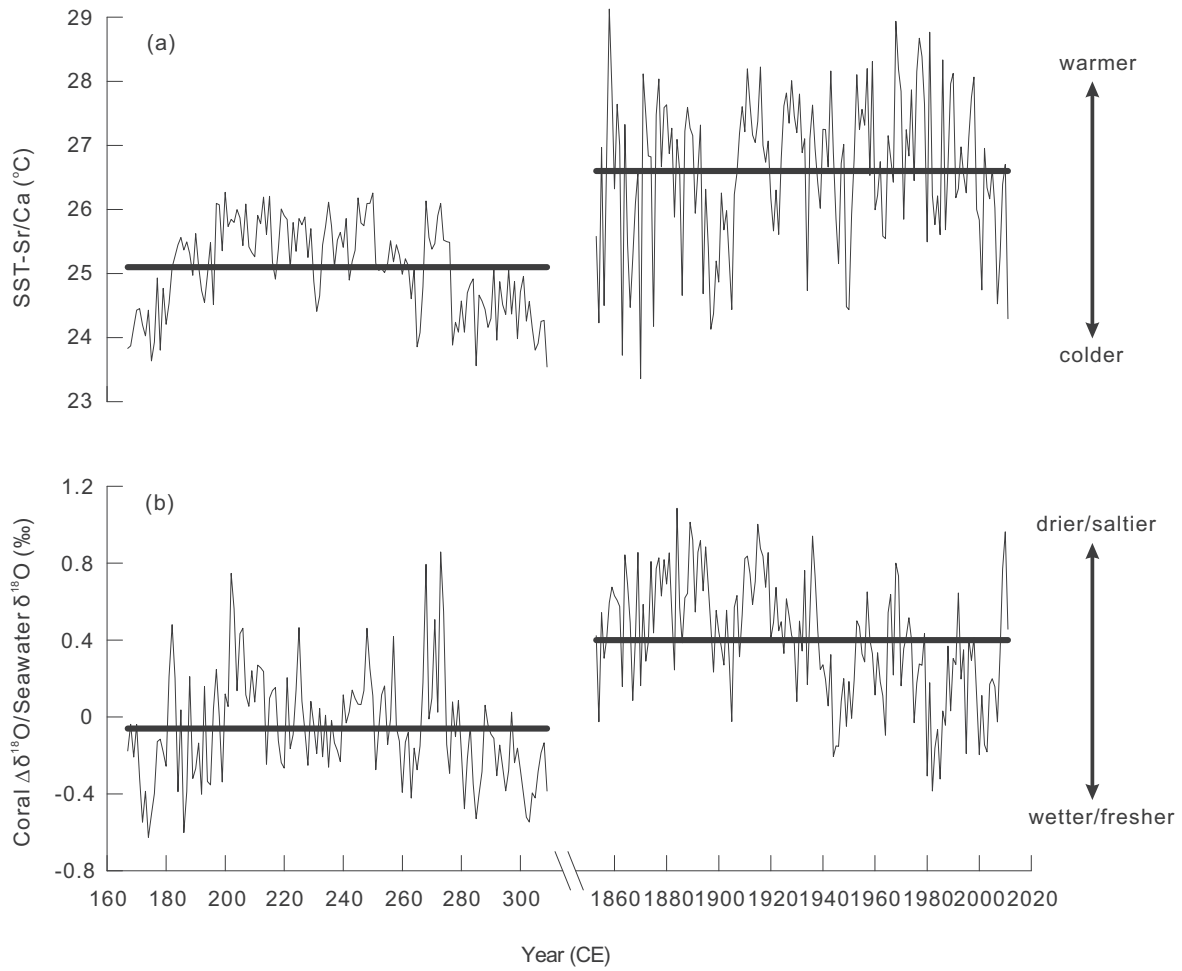


Fig. 3. Comparisons of (a) SST and (b) $\delta^{18}O_{sw}$ between the study interval (late Eastern Han to Western Jin periods) and the CWP. The black horizontal lines indicate the averages of SST and $\delta^{18}O_{sw}$ for the different periods.

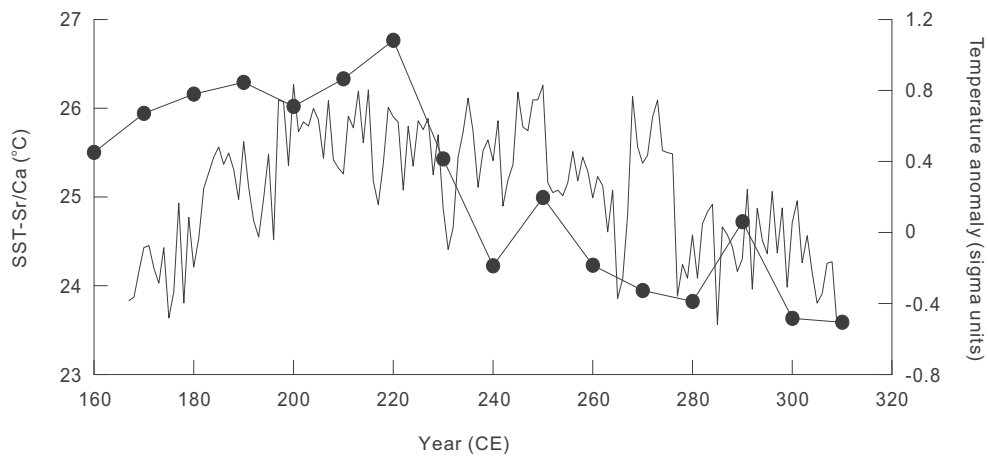


Fig. 4. Comparison of SST (solid line) and a composite temperature anomaly record (line with black dots) established by combining ice cores, tree rings, lake sediments, and historical documents over the late Eastern Han to Western Jin periods.

has a big contribution to the SST, especially in northern SCS (Wu and Chen, 2015; Zhang et al., 2016). The Holocene Asian summer monsoon is linked to the solar changes (Wang et al., 2005) so the co-variations between the annual coral-based SST and the stalagmite $\delta^{18}O$ may reflect that the weaker summer solar irradiance led to the colder SST seen over the century timescale at this time.

As for the ocean–atmosphere interactions, no instrumental or reconstructed records were available for comparison, but there were some signals of interannual (2–7 years) and interdecadal (11 years) variability in the SST record (Fig. 6a). The interannual signals probably record the signature of quasi-biennial and ENSO signals, as the interannual variability in the SCS is remotely influ-

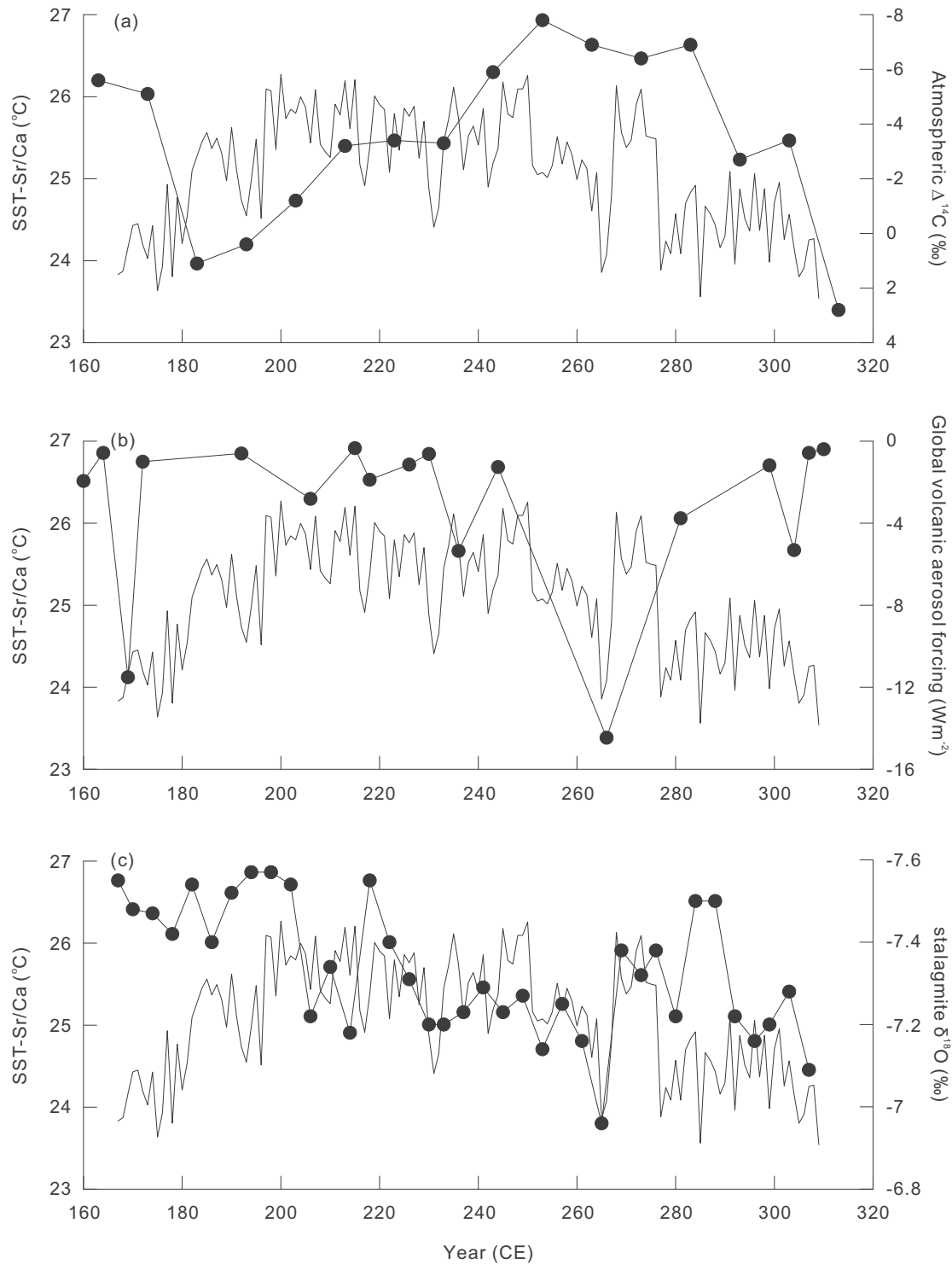


Fig. 5. Comparison of reconstructed SST (solid line) with the (a) residual atmospheric $\Delta^{14}\text{C}$, (b) global volcanic aerosol forcing, and (c) stalagmite $\delta^{18}\text{O}$ records. Lines with black dots indicate the other three variables.

enced by ENSO (Liu et al., 2004, 2011; Wang et al., 2006). As a pattern of interdecadal climate variability in the North Pacific Basin, the Pacific Decadal Oscillation (PDO) has a widespread influence on surface climate, including on temperature and precipitation anomalies in the Pan-Pacific basin (Mantua and Hare, 2002; Gordon and Giulivi, 2004; Yang and Zhu, 2008; Mao et al., 2011). Therefore, these variabilities may suggest that ENSO and the PDO also affected the climate during the late Eastern Han to Western

Jin periods in the northern SCS. The modern coral 11LW4 also recorded ENSO and PDO activity in the northern SCS (Deng et al., 2013).

4.3. $\delta^{18}\text{O}_{\text{sw}}$ records from coral Sr/Ca and $\delta^{18}\text{O}$

The $\delta^{18}\text{O}_{\text{sw}}$ was stable during the three periods studied here, and the average annual $\delta^{18}\text{O}_{\text{sw}}$ during the Western Jin (-0.13‰)

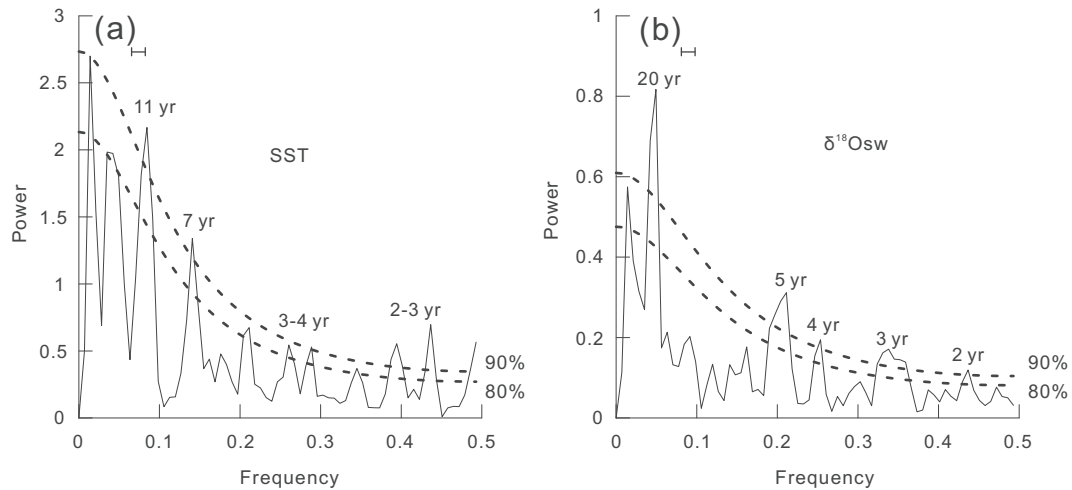


Fig. 6. Power spectra of (a) SST and (b) $\delta^{18}\text{O}_{\text{sw}}$ from coral records calculated using the software PAST (Hammer et al., 2001). The numbers indicate the possible periodicities. The horizontal bars indicate the bandwidths, and the dashed lines indicate the 90% and 80% confidence levels.

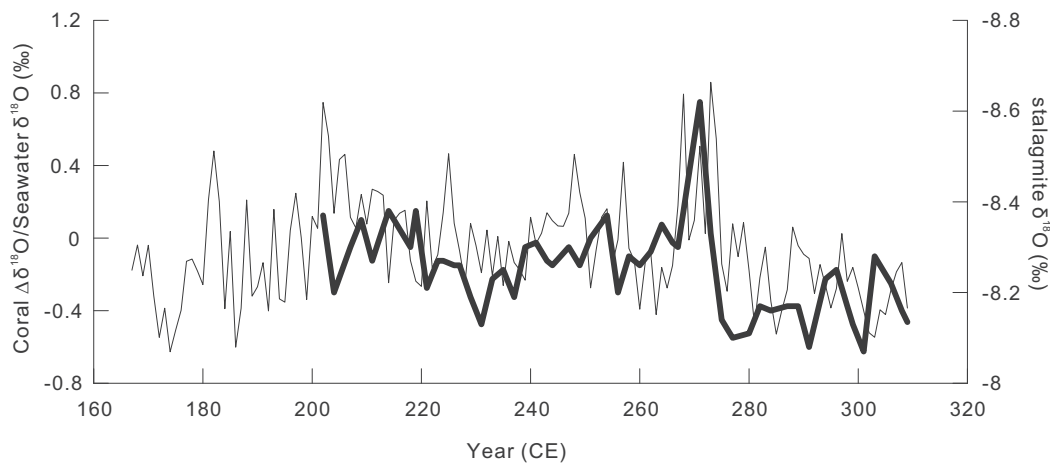


Fig. 7. Comparison between $\delta^{18}\text{O}_{\text{sw}}$ (thin line; reconstructed from the paired coral Sr/Ca and $\delta^{18}\text{O}$) and the stalagmite $\delta^{18}\text{O}$ record from northern China (thick line).

was slightly lower than during the late Eastern Han (-0.05‰) and the Three Kingdoms (-0.02‰ ; Fig. 2b). This difference indicates that the seawater during the Western Jin period was the coldest and freshest of these three periods. Compared with the average long-term $\delta^{18}\text{O}_{\text{sw}}$ in the CWP (0.40‰), the $\delta^{18}\text{O}_{\text{sw}}$ was more negative during the late Eastern Han to Western Jin periods (Fig. 3b). The difference of about 0.40‰ corresponds to a difference of about 2.0 in sea surface salinity as estimated from the relationship between salinity and $\delta^{18}\text{O}_{\text{sw}}$ in the northern SCS (Ye et al., 2014). Therefore, the coral records indicate cold and wet climate conditions during the Late Eastern Han to Western Jin periods. The climate conditions during these three periods were very similar to those during the LIA. Some previous studies have suggested a wet LIA in tropical southern China and the northern SCS (Yan et al., 2011b; Zeng et al., 2012; Wang et al., 2013).

As there are no high-resolution $\delta^{18}\text{O}_{\text{sw}}$ records available from the SCS and adjacent areas for these periods, we compared a stalagmite $\delta^{18}\text{O}$ record from Wanxiang Cave (in Gansu Province, northern China; Zhang et al., 2008) with our coral record. This stalagmite $\delta^{18}\text{O}$ record, together with a record based on lake sediments and ostracod shells in the SCS, has been used to study the intertropical convergence zone (ITCZ) over the western Pacific during the LIA, and the results indicated a dry LIA in northern China, but a wet LIA in the SCS (H. Yan et al., 2015b). Considering the cli-

matic similarity between our study interval and the LIA described above, this stalagmite $\delta^{18}\text{O}$ record was used for our comparative study. The stalagmite $\delta^{18}\text{O}$ record was linearly interpolated to an annual resolution and then compared with the annually resolved coral $\Delta\delta^{18}\text{O}$ record. We found that the coral $\delta^{18}\text{O}_{\text{sw}}$ series and the stalagmite $\delta^{18}\text{O}$ record are anti-correlated ($r = -0.40$, $n = 108$, $p < 0.0001$) and follow a similar variational trend (Fig. 7). Their anti-correlation may suggest that the hydrological conditions in northern China and in the SCS were opposite at the annual timescale during the late Eastern Han to Western Jin periods, which is similar to the situation at these two study sites at the century timescale during the LIA as indicated by H. Yan et al. (2015b). The reduced northward shift of the ITCZ/monsoon rainbelt by the retreat of the East Asian summer monsoon (EASM) may have led to relatively dry conditions in the north, but more rainfall in tropical southern China and the northern SCS. The EASM was relatively weaker during the late Eastern Han to Western Jin periods according to the stalagmite $\delta^{18}\text{O}$ record (Wang et al., 2005). Therefore, the wet conditions at this time seen over the century timescale may also be associated with the contraction of the ITCZ/monsoon zones within the western Pacific accompanied by the retreat of the EASM (H. Yan et al., 2015b). Regarding the opposite hydrological conditions at the annual timescale, further study, especially numerical modeling, is needed to clarify whether or not this is associated

with the retreat of the EASM. There are also interannual (2–5 years) and interdecadal (20 years) variabilities in the $\delta^{18}\text{O}_{\text{sw}}$ (coral $\Delta\delta^{18}\text{O}$) record (Fig. 6b), which may indicate the effect of ENSO and the PDO on hydrological conditions.

5. Conclusions

Based on geochemical records from paired Sr/Ca and $\delta^{18}\text{O}$ preserved in a fossil coral whose growing period covered the late Eastern Han, Three Kingdoms, and Western Jin periods, we reconstructed the sea surface conditions, including temperature and hydrological conditions, during these periods in the northern SCS. Our main conclusions are as follows.

- (1) The annual SSTs from the late Eastern Han to Western Jin periods showed large fluctuations: from 23.5 to 26.3 °C. The average long-term SST during the study period was 25.1 °C, which is about 1.5 °C lower than that during the CWP.
- (2) $\delta^{18}\text{O}_{\text{sw}}$ was stable during the three periods, and the average long-term annual $\delta^{18}\text{O}_{\text{sw}}$ (−0.13‰) was more negative than that over the CWP. This difference suggests wet/fresher hydrological conditions during the late Eastern Han to Western Jin periods.
- (3) The climatic conditions during the late Eastern Han to Western Jin periods were cold and wet in the northern SCS, which is comparable with conditions during the LIA. The cold climate may be associated with the weaker summer solar irradiance. The wet conditions were caused by the reduced northward shift of the ITCZ/monsoon rainbelt associated with the retreat of the EASM. ENSO and the PDO may have also contributed to the interannual and interdecadal variabilities in the SST and $\delta^{18}\text{O}_{\text{sw}}$ records.

Acknowledgments

The authors would like to thank the editor and reviewer for their helpful comments and constructive suggestions. This work was supported by the National Key R&D Project of China (2016YFA0601204, 2013CB956103), the National Natural Sciences Foundation of China (41673115, 41325012) and the State Key Laboratory of Isotope Geochemistry (SKLIG-RC-14-02). This is contribution IS-2319 from GIGCAS. The data for this paper are available as the online supporting dataset and from the corresponding author Deng (wfdeng@gmail.com, wfdeng@gig.ac.cn).

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.jseaes.2016.12.012>.

References

- Anderson, D.M., Baulcomb, C.K., Duvivier, A.K., Gupta, A.K., 2010. Indian summer monsoon during the last two millennia. *J. Quatern. Sci.* 25, 911–917.
- Baede, A.P.M., Ahlonsou, E., Ding, Y., Schimel, D., 2001. The climate system: an overview. In: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P. J., Dai, X., Maskell, K., Johnson, C.A. (Eds.), *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 881.
- Beck, J.W., Edwards, R.L., Ito, E., Taylor, F.W., Recy, J., Rougerie, F., Joannot, P., Henin, C., 1992. Sea-surface temperature from coral skeletal strontium/calcium ratios. *Science* 257, 644–647.
- Booth, R.K., Notaro, M., Jackson, S.T., Kutzbach, J.E., 2006. Widespread drought episodes in the western Great Lakes region during the past 2000 years: geographic extent and potential mechanisms. *Earth Planet. Sci. Lett.* 242, 415–427.
- Bradley, R.S., Hughes, M.K., Diaz, H.F., 2003. Climate in medieval time. *Science* 302, 404–405.
- Bradley, R.S., Jones, P.D., 1993. 'Little Ice Age' summer temperature variations: their nature and relevance to recent global warming trends. *Holocene* 3, 367–376.
- Chen, T., Yu, K., Chen, T., 2013. Sr/Ca-sea surface temperature calibration in the coral *Porites lutea* from subtropical northern South China Sea. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 392, 98–104.
- Chen, X.F., Wei, G.J., Deng, W.F., Liu, Y., Sun, Y.L., Zeng, T., Xie, L.H., 2015. Decadal variations in trace metal concentrations on a coral reef: evidence from a 159 year record of Mn, Cu, and V in a *Porites* coral from the northern South China Sea. *J. Geophys. Res.: Oceans* 120, 405–416. <http://dx.doi.org/10.1002/2014JC010390>.
- Chiang, H.W., Chen, Y.G., Fan, T.Y., Shen, C.C., 2010. Change of the ENSO-related $\delta^{18}\text{O}$ -SST correlation from coral skeletons in northern South China Sea: a possible influence from the Kuroshio Current. *J. Asian Earth Sci.* 39, 684–691.
- Chu, K., 1973. A preliminary study on the climatic fluctuations during the last 5000 years in China. *Sci. Sinica* 16, 226–256.
- Consortium, P.k., 2013. Continental-scale temperature variability during the past two millennia. *Nat. Geosci.* 6, 339–346.
- Corrège, T., 2006. Sea surface temperature and salinity reconstruction from coral geochemical tracers. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 232, 408–428.
- Crowley, T.J., Lowery, T.S., 2000. How warm was the Medieval Warm Period? *AMBIO: J. Hum. Environ.* 29, 51–54.
- Deng, W.F., Wei, G.J., 2015. Decoupling of seasonal temperature and precipitation over the western Pacific during the early mid-Holocene. *Int. J. Climatol.* 35, 794–800.
- Deng, W.F., Wei, G.J., Li, X.H., Yu, K.F., Zhao, J.X., Sun, W.D., Liu, Y., 2009. Paleoprecipitation record from coral Sr/Ca and $\delta^{18}\text{O}$ during the mid Holocene in the northern South China Sea. *Holocene* 19, 811–821.
- Deng, W.F., Wei, G.J., McCulloch, M., Xie, L.H., Liu, Y., Zeng, T., 2014a. Evaluation of annual resolution coral geochemical records as climate proxies in the Great Barrier Reef of Australia. *Coral Reefs* 33, 965–977.
- Deng, W.F., Wei, G.J., Xie, L.H., Ke, T., Wang, Z.B., Zeng, T., Liu, Y., 2013. Variations in the Pacific Decadal Oscillation since 1853 in a coral record from the northern South China Sea. *J. Geophys. Res.: Oceans* 118, 2358–2366. <http://dx.doi.org/10.1002/jgrc.20180>.
- Deng, W.F., Wei, G.J., Yu, K.F., Zhao, J.X., 2014b. Variations in the timing of the rainy season in the northern South China Sea during the middle to late Holocene. *Paleoceanography* 29, 115–125. <http://dx.doi.org/10.1002/2012PA002417>.
- Denniston, R.F., Villarini, G., Gonzales, A.N., Wyrwoll, K.H., Polyak, V.J., Ummenhofer, C.C., Lachniet, M.S., Wanamaker, A.D., Humphreys, W.F., Woods, D., Cugley, J., 2015. Extreme rainfall activity in the Australian tropics reflects changes in the El Niño/Southern Oscillation over the last two millennia. *Proc. Nat. Acad. Sci. USA* 112, 4576–4581.
- Donnelly, J.P., Hawkes, A.D., Lane, P., MacDonald, D., Shuman, B.N., Toomey, M.R., van Hengstum, P.J., Woodruff, J.D., 2015. Climate forcing of unprecedented intense-hurricane activity in the last 2000 years. *Earth's Future* 3, 49–65.
- Dunbar, R.B., Wellington, G.M., 1981. Stable isotopes in a branching coral monitor seasonal temperature variation. *Nature* 293, 453–455.
- Fleury, S., Martinez, P., Crosta, X., Charlier, K., Billy, I., Hanquiez, V., Blanz, T., Schneider, R.R., 2015. Pervasive multidecadal variations in productivity within the Peruvian Upwelling System over the last millennium. *Quatern. Sci. Rev.* 125, 78–90.
- Fritz, S.C., Ito, E., Yu, Z.C., Laird, K.R., Engstrom, D.R., 2000. Hydrologic variation in the northern Great Plains during the last two millennia. *Quatern. Res.* 53, 175–184.
- Gagan, M.K., Ayliffe, L.K., Beck, J.W., Cole, J.E., Druffel, E.R.M., Dunbar, R.B., Schrag, D. P., 2000. New views of tropical paleoclimates from corals. *Quatern. Sci. Rev.* 19, 45–64.
- Gagan, M.K., Ayliffe, L.K., Hopley, D., Cali, J.A., Mortimer, G.E., Chappell, J., McCulloch, M.T., Head, M.J., 1998. Temperature and surface-ocean water balance of the mid-Holocene tropical Western Pacific. *Science* 279, 1014–1018.
- Gagan, M.K., Dunbar, G.B., Suzuki, A., 2012. The effect of skeletal mass accumulation in *Porites* on coral Sr/Ca and $\delta^{18}\text{O}$ paleothermometry. *Paleoceanography* 27, PA1203. <http://dx.doi.org/10.1029/2011PA002215>.
- Ge, Q., Hao, Z., Zheng, J., Shao, X., 2013. Temperature changes over the past 2000 yr in China and comparison with the Northern Hemisphere. *Clim. Past* 9, 1153–1160.
- Ge, Q.S., 2011. *The Climate Change in China during the Past Dynasties*. Science Press, Beijing.
- Ge, Q.S., Zhang, X.Z., Hao, Z.X., Zheng, J.Y., 2011. Rates of temperature change in China during the past 2000 years. *Sci. China Earth Sci.* 54, 1627–1634.
- Ge, Q.S., Zheng, J.Y., Fang, X.Q., Man, Z.M., Zhang, X.Q., Zhang, P.Y., Wang, W.C., 2003. Winter half-year temperature reconstruction for the middle and lower reaches of the Yellow River and Yangtze River, China, during the past 2000 years. *Holocene* 13, 933–940.
- Ge, Q.S., Zheng, J.Y., Hao, Z.X., Liu, H.L., 2013. General characteristics of climate changes during the past 2000 years in China. *Sci. China Earth Sci.* 56, 321–329.
- Ge, Q.S., Zheng, J.Y., Man, Z.M., Fang, X.Q., Zhang, P.Y., 2004. Key points on temperature change of the past 2000 years in China. *Prog. Nat. Sci.* 14, 730–737.
- Gong, G.F., Hameed, S., 1991. The variation of moisture conditions in China during the last 2000 Years. *Int. J. Climatol.* 11, 271–283.
- Gordon, A.L., Giulivi, C.F., 2004. Pacific decadal oscillation and sea level in the Japan/East sea. *Deep Sea Res. Part I* 51, 653–663.

- Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: paleontological statistics software package for education and data analysis. *Palaeontol. Electron.* 4, 1–9.
- Hao, Z.X., Zheng, J.Y., Ge, Q.S., Zhang, X.Z., 2012. Spatial patterns of precipitation anomalies for 30-yr warm periods in China during the past 2000 years. *Acta Meteorol. Sinica* 26, 278–288.
- Hao, Z.X., Zheng, J.Y., Zhang, X.Z., Liu, H.L., Li, M.Q., Ge, Q.S., 2016. Spatial patterns of precipitation anomalies in eastern China during centennial cold and warm periods of the past 2000 years. *Int. J. Climatol.* 36, 467–475.
- Hathorne, E.C., Gagnon, A., Felis, T., Adkins, J., Asami, R., Boer, W., Caillon, N., Case, D., Cobb, K.M., Douville, E., deMenocal, P., Eisenhauer, A., Garbe-Schonberg, D., Geibert, W., Goldstein, S., Hughen, K., Inoue, M., Kawahata, H., Kolling, M., Cornec, F.L., Linsley, B.K., McGregor, H.V., Montagna, P., Nurhati, I.S., Quinn, T.M., Raddatz, J., Rebaubier, H., Robinson, L.F., Sadekov, A., Sherrill, R., Sinclair, D., Tudhope, A.W., Wei, G.J., Wong, H.R., Wu, H.C., You, C.F., 2013. Interlaboratory study for coral Sr/Ca and other element/Ca ratio measurements. *Geochim. Geophys. Geosyst.* 14, 3730–3750. <http://dx.doi.org/10.1002/ggge.20230>.
- Herr, D., Galland, G.R., 2009. The Ocean and Climate Change. Tools and Guidelines for Action. IUCN U.S. Multilateral Office, Gland, Switzerland.
- Holmes, J.A., Cook, E.R., Yang, B., 2009. Climate change over the past 2000 years in Western China. *Quatern. Int.* 194, 91–107.
- Hu, F.S., Ito, E., Brown, T.A., Curry, B.B., Engstrom, D.R., 2001. Pronounced climatic variations in Alaska during the last two millennia. *Proc. Nat. Acad. Sci. USA* 98, 10552–10556.
- Jing, Z.-Y., Qi, Y.-Q., Hua, Z.-L., Zhang, H., 2009. Numerical study on the summer upwelling system in the northern continental shelf of the South China Sea. *Cont. Shelf Res.* 29, 467–478.
- Lamb, H.H., 1965. The early medieval warm epoch and its sequel. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 1, 13–37.
- Liu, Q.Y., Feng, M., Wang, D.X., 2011. ENSO-induced interannual variability in the southeastern South China Sea. *J. Oceanogr.* 67, 127–133.
- Liu, Q.Y., Jiang, X., Xie, S.P., Liu, W.T., 2004. A gap in the Indo-Pacific warm pool over the South China Sea in boreal winter: seasonal development and interannual variability. *J. Geophys. Res.: Oceans* 109, C07012. <http://dx.doi.org/10.1029/2003JC002179>.
- Liu, Y., Peng, Z., Chen, T., Wei, G., Sun, W., Sun, R., He, J., Liu, G., Chou, C.-L., Zartman, R.E., 2008. The decline of winter monsoon velocity in the South China Sea through the 20th century: evidence from the Sr/Ca records in corals. *Glob. Planet. Change* 63, 79–85.
- Liu, Y., Peng, Z.C., Shen, C.C., Zhou, R.J., Song, S.H., Shi, Z.G., Chen, T., Wei, G.J., DeLong, K.L., 2013. Recent 121-year variability of western boundary upwelling in the northern South China Sea. *Geophys. Res. Lett.* 40, 3180–3183. <http://dx.doi.org/10.1002/grl.50381>.
- Lough, J.M., 2010. Climate records from corals. *Wiley Interdiscipl. Rev.: Clim. Change* 1, 318–331.
- Mann, M.E., 2007. Climate over the past two Millennia. *Ann. Rev. Earth Planet. Sci.* 35, 111–136.
- Mantua, N.J., Hare, S.R., 2002. The Pacific decadal oscillation. *J. Oceanogr.* 58, 35–44.
- Mao, J., Chan, J.C.L., Wu, G., 2011. Interannual variations of early summer monsoon rainfall over South China under different PDO backgrounds. *Int. J. Climatol.* 31, 847–862.
- Matthews, J.A., Briffa, K.R., 2005. The ‘Little Ice Age’: re-evaluation of an evolving concept. *Geogr. Ann.: Series A, Phys. Geogr.* 87, 17–36.
- Mcculloch, M.T., Gagan, M.K., Mortimer, G.E., Chivas, A.R., Isdale, P.J., 1994. A high-resolution Sr/Ca and $\delta^{18}\text{O}$ coral record from the Great Barrier Reef, Australia, and the 1982–1983 El-Niño. *Geochim. Cosmochim. Acta* 58, 2747–2754.
- Okai, T., Suzuki, A., Kawahata, H., Terashima, S., Imai, N., 2002. Preparation of a new Geostandards Survey of Japan geochemical reference material: Coral JcP-1. *Geostandards Newslett.* 26, 95–99.
- Rayner, N.A., Parker, D.E., Horton, E.B., Folland, C.K., Alexander, L.V., Rowell, D.P., Kent, E.C., Kaplan, A., 2003. Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *J. Geophys. Res.: Atmos.* 108, 4407. <http://dx.doi.org/10.1029/2002JD002670>.
- Robock, A., 1979. The “Little Ice Age”: northern hemisphere average observations and model calculations. *Science* 206, 1402–1404.
- Shi, Y.F., Yao, T.D., Yang, B., 1999. Decadal climatic variations recorded in Guliya ice core and comparison with the historical documentary data from East China during the last 2000 years. *Sci. China Earth Sci.* 42, 91–100.
- Sigl, M., Winstrup, M., McConnell, J.R., Welten, K.C., Plunkett, G., Ludlow, F., Bunntgen, U., Caffee, M., Chellman, N., Dahl-Jensen, D., Fischer, H., Kipfstuhl, S., Kostick, C., Maselli, O.J., Mekhaldi, F., Mulvaney, R., Muscheler, R., Pasteris, D.R., Pilcher, J.R., Salzer, M., Schupbach, S., Steffensen, J.P., Vinther, B.M., Woodruff, T. E., 2015. Timing and climate forcing of volcanic eruptions for the past 2500 years. *Nature* 523, 543–549.
- Smith, S.V., Buddemeier, R.W., Redalje, R.C., Houck, J.E., 1979. Strontium-calcium thermometry in coral skeletons. *Science* 204, 404–407.
- Song, S.H., Zhou, W.J., Peng, Z.C., Liu, W.G., Cheng, P., Xian, F., 2006. Response to environmental conditions of coral $\delta^{18}\text{O}$ of *Porites lutea* from Shalao, Hainan Island. *Mar. Geol. Quatern. Geol.* 26, 23–28 (in Chinese with English abstract).
- Stuiver, M., Reimer, P.J., Bard, E., Beck, J.W., Burr, G.S., Hughen, K.A., Kromer, B., McCormac, G., Van der Plicht, J., Spurk, M., 1998. INTCAL98 radiocarbon age calibration, 24,000–0 cal BP. *Radiocarbon* 40, 1041–1083.
- Sun, D.H., Gagan, M.K., Cheng, H., Scott-Gagan, H., Dykoski, C.A., Edwards, R.L., Su, R. X., 2005. Seasonal and interannual variability of the Mid-Holocene East Asian monsoon in coral $\delta^{18}\text{O}$ records from the South China Sea. *Earth Planet. Sci. Lett.* 237, 69–84.
- Swart, P.K., Coleman, M.L., 1980. Isotopic data for scleractinian corals explain their paleotemperature uncertainties. *Nature* 283, 557–559.
- Taira, K., 1980. Environmental-changes in eastern Asia during the past 2000 years - Volcanism, tectonism, climate, and Paleo-oceanography. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 32, 89–97.
- Tan, L.C., Cai, Y.J., An, Z.S., Edwards, R.L., Cheng, H., Shen, C.C., Zhang, H.W., 2011. Centennial-to decadal-scale monsoon precipitation variability in the semi-humid region, northern China during the last 1860 years: records from stalagmites in Huangye Cave. *Holocene* 21, 287–296.
- Tierney, J.E., Oppo, D.W., Rosenthal, Y., Russell, J.M., Linsley, B.K., 2010. Coordinated hydrological regimes in the Indo-Pacific region during the past two millennia. *Paleoceanography* 25, PA1102. <http://dx.doi.org/10.1029/2009PA001871>.
- de Villiers, S., Shen, G.T., Nelson, B.K., 1994. The Sr/Ca-temperature relationship in coralline aragonite: influence of variability in $(\text{Sr}/\text{Ca})_{\text{seawater}}$ and skeletal growth parameters. *Geochim. Cosmochim. Acta* 58, 197–208.
- Vuille, M., Burns, S.J., Taylor, B.L., Cruz, F.W., Bird, B.W., Abbott, M.B., Kanner, L.C., Cheng, H., Novello, V.F., 2012. A review of the South American monsoon history as recorded in stable isotopic proxies over the past two millennia. *Clim. Past* 8, 1309–1321.
- Wang, C.Z., Wang, W.Q., Wang, D.X., Wang, Q., 2006. Interannual variability of the South China Sea associated with El Niño. *J. Geophys. Res.* 111, C03023. <http://dx.doi.org/10.1029/2005JC003333>.
- Wang, L.-C., Behling, H., Lee, T.-Q., Li, H.-C., Huh, C.-A., Shiao, L.-J., Chen, S.-H., Wu, J.-T., 2013. Increased precipitation during the Little Ice Age in northern Taiwan inferred from diatoms and geochemistry in a sediment core from a subalpine lake. *J. Paleolimnol.* 49, 619–631.
- Wang, Y.J., Cheng, H., Edwards, R.L., He, Y.Q., Kong, X.G., An, Z.S., Wu, J.Y., Kelly, M.J., Dykoski, C.A., Li, X.D., 2005. The Holocene Asian monsoon: links to solar changes and North Atlantic climate. *Science* 308, 854–857.
- Wei, G.J., Deng, W.F., Yu, K.F., Li, X.H., Sun, W.D., Zhao, J.X., 2007. Sea surface temperature records in the Northern South China Sea from mid-Holocene coral Sr/Ca ratios. *Paleoceanography* 22, PA3206. <http://dx.doi.org/10.1029/2006PA001270>.
- Wei, G.J., Wang, Z.B., Ke, T., Liu, Y., Deng, W.F., Chen, X.F., Xu, J.F., Zeng, T., Xie, L.H., 2015. Decadal variability in seawater pH in the West Pacific: evidence from coral $\delta^{11}\text{B}$ records. *J. Geophys. Res.: Oceans* 120, 7166–7181. <http://dx.doi.org/10.1002/2015JC011066>.
- Wu, R.G., Chen, Z., 2015. Intraseasonal SST variations in the South China Sea during boreal winter and impacts of the East Asian winter monsoon. *J. Geophys. Res.: Atmos.* 120, 5863–5878. <http://dx.doi.org/10.1002/2015JD023368>.
- Wu, W., Tan, W., Zhou, L., Yang, H., Xu, Y., 2012. Sea surface temperature variability in southern Okinawa Trough during last 2700 years. *Geophys. Res. Lett.* 39, L14705. <http://dx.doi.org/10.1029/2012GL052749>.
- Wurtzel, J.B., Black, D.E., Thunell, R.C., Peterson, L.C., Tappa, E.J., Rahman, S., 2013. Mechanisms of southern Caribbean SST variability over the last two millennia. *Geophys. Res. Lett.* 40, 5954–5958. <http://dx.doi.org/10.1002/2013GL058458>.
- Yan, H., Sun, L., Oppo, D.W., Wang, Y., Liu, Z., Xie, Z., Liu, X., Cheng, W., 2011a. South China Sea hydrological changes and Pacific Walker Circulation variations over the last millennium. *Nat. Commun.* 2, 293. <http://dx.doi.org/10.1038/ncomms1297>.
- Yan, H., Sun, L.G., Wang, Y.H., Huang, W., Qiu, S.C., Yang, C.Y., 2011b. A record of the Southern Oscillation Index for the past 2000 years from precipitation proxies. *Nat. Geosci.* 4, 611–614.
- Yan, H., Soon, W., Wang, Y.H., 2015a. A composite sea surface temperature record of the northern South China Sea for the past 2500 years: a unique look into seasonality and seasonal climate changes during warm and cold periods. *Earth-Sci. Rev.* 141, 122–135.
- Yan, H., Wei, W., Soon, W., An, Z.S., Zhou, W.J., Liu, Z.H., Wang, Y.H., Carter, R.M., 2015b. Dynamics of the intertropical convergence zone over the western Pacific during the Little Ice Age. *Nat. Geosci.* 8, 315–320.
- Yan, Q., Korty, R., Zhang, Z.S., 2015a. Tropical cyclone genesis factors in a simulation of the last two millennia: results from the community earth system model. *J. Clim.* 28, 7182–7202.
- Yan, Q., Zhang, Z.S., Wang, H.J., Jiang, D.B., 2015b. Simulated warm periods of climate over China during the last two millennia: the Sui-Tang warm period versus the Song-Yuan warm period. *J. Geophys. Res.: Atmos.* 120, 2229–2241. <http://dx.doi.org/10.1002/2014JD022941>.
- Yang, B., Braeuning, A., Johnson, K.R., Shi, Y.F., 2002. General characteristics of temperature variation in China during the last two millennia. *Geophys. Res. Lett.* 29. <http://dx.doi.org/10.1029/2001GL014485>.
- Yang, G.F., Chen, Z.H., Wu, F.D., Gao, M.L., Yin, Z.G., Guo, B., 2016. Climate variability over the last 2000 years inferred from glycerol dialkyl glycerol tetraethers (GDGTs) in alkaline Nalin Lake of Inner Mongolia, China. *Environ. Earth Sci.* 75, 634. <http://dx.doi.org/10.1007/s12665-016-5363-5>.
- Yang, H.Q., Yu, K.F., Zhao, M.X., Shi, Q., Tao, S.C., Yan, H.Q., Chen, T.R., Liu, G.H., 2015. Impact on the coral reefs at Yongle Atoll, Xisha Islands, South China Sea from a strong typhoon direct sweep: Wutip, September 2013. *J. Asian Earth Sci.* 114, 457–466.
- Yang, X., Zhu, Y., 2008. Interdecadal climate variability in China associated with the Pacific Decadal Oscillation. In: Fu, C., Jiang, Z., Guan, Z., He, J., Xu, Z. (Eds.), *Regional Climate Studies of China*. Springer, Berlin, Heidelberg, pp. 97–117.
- Ye, F., Deng, W., Xie, L., Wei, G., Jia, G., 2014. Surface water $\delta^{18}\text{O}$ in the marginal China seas and its hydrological implications. *Estuar. Coast. Shelf Sci.* 147, 25–31.
- Yu, K.F., 2012. Coral reefs in the South China Sea: their response to and records on past environmental changes. *Sci. China Earth Sci.* 55, 1217–1229.

- Yu, K.F., Zhao, J.X., Wei, G.J., Cheng, X.R., Wang, P.X., 2005. Mid-late Holocene monsoon climate retrieved from seasonal Sr/Ca and $\delta^{18}\text{O}$ records of *Porites lutea* corals at Leizhou Peninsula, northern coast of South China Sea. *Glob. Planet. Change* 47, 301–316.
- Zeng, Y., Chen, J., Zhu, Z., Li, J., Wang, J., Wan, G., 2012. The wet Little Ice Age recorded by sediments in Huguangyan Lake, tropical South China. *Quatern. Int.* 263, 55–62.
- Zhang, P.Z., Cheng, H., Edwards, R.L., Chen, F.H., Wang, Y.J., Yang, X.L., Liu, J., Tan, M., Wang, X.F., Liu, J.H., An, C.L., Dai, Z.B., Zhou, J., Zhang, D.Z., Jia, J.H., Jin, L.Y., Johnson, K.R., 2008. A test of climate, sun, and culture relationships from an 1810-Year Chinese cave record. *Science* 322, 940–942.
- Zheng, J.Y., Zhang, P.Y., Ge, Q.S., Man, Z.M., 2001. Centennial changes of drought/flood spatial pattern in eastern China for the last 2000 years. *Prog. Nat. Sci.* 11, 280–287.
- Zhou, H., Zhao, J., Qing, W., Feng, Y., Tang, J., 2011. Speleothem-derived Asian summer monsoon variations in Central China, 54–46 ka. *J. Quatern. Sci.* 26, 781–790.
- Zhang, H.L., Yu, K.F., Shi, Q., Yan, H.Q., Chen, T.G., 2016. The negative correlation between SST of the northern South China Sea and strength of EASM on inter-annual and inter-decadal time scale. *Trop. Geogr.* 36, 34–40, 47, (in Chinese with English abstract).