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Key Points:

- Coral $\Delta\delta^{18}O$ records indicate more saline mid-Holocene surface waters in the South China Sea
- Increased salinity may be caused by strengthened Asian Monsoon and/or northward shift of the ITCZ
- Coral $\Delta\delta^{18}O$ is a better tool for reconstructing sea surface salinity than coral $\delta^{18}O$ in the South China Sea

Supporting Information:

- Supporting Information S1
- Data Set S1

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Saltier sea surface water conditions recorded by multiple mid-Holocene corals in the northern South China Sea

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Abstract The typical features of the mid-Holocene can be used to better understand present-day climate conditions and the potential trends of future climate change. The surface conditions, including sea surface temperature (SST) and sea surface salinity (SSS), of the South China Sea (SCS) are largely controlled by the East Asian monsoon system. Surface water conditions reconstructed from coral proxies can be used to study the evolution of the East Asian monsoon during the mid-Holocene. However, there are some discrepancies among existing coral-based studies regarding whether the mid-Holocene sea surface water was much saltier than the present day surface waters. Based on paired Sr/Ca and $\delta^{18}O$ of modern and three fossil corals, this paper reconstructs the patterns of seasonal variation in SSS during the mid-Holocene in the northern SCS. The $\Delta\delta^{18}O$ records (a proxy for SSS) derived from the three fossil corals were all heavier than that from the modern coral, which suggests the presence of more saline surface waters during the mid-Holocene in the northern SCS. These results are consistent with previous studies based on records reconstructed from coral and foraminifera, as well as from numerical simulations. Reduced rainfall caused by the strengthened Asian Monsoon and/or the northward shift of the intertropical convergence zone during the mid-Holocene would explain the increased salinity of the surface waters of the northern SCS. The findings presented here clarify the discrepancies among previous studies and confirm the existence of saltier surface waters in the northern SCS during the mid-Holocene.

1. Introduction

The East Asian monsoon is a major element within the global climatic system, and the monsoon-dominated hydrological conditions are important to natural ecosystems and human activity across East Asia [*An*, 2000]. As the largest marginal sea in the northwest Pacific Ocean, the surface water conditions, including sea surface temperature (SST) and sea surface salinity (SSS), in the South China Sea (SCS) are controlled largely by the East Asian monsoon system [*Ding*, 1994]. Therefore, SST and SSS records reconstructed using different proxies are, in turn, important elements in the study of the changing nature and variability of the East Asian monsoon [*Tian et al.*, 2004; *Wang et al.*, 2005a; *Steinke et al.*, 2010].

Regarding the reconstruction of SST and SSS, massive corals undoubtedly provide the most reliable archives as they incorporate isotope and elemental tracers reflecting the climatic and environmental conditions in the ambient seawater during skeleton precipitation [*Felis and Pätzold*, 2003]. In addition, they contain clear annual bands and have high growth rates, thereby providing a detailed record of seasonal variations of these two variables in the seawater that surrounded them [*Gagan et al.*, 2000; *Lough*, 2010]. The ratios of Sr/Ca in coral skeletons have long been used to reconstruct changes in SST [*Smith et al.*, 1979; *Beck et al.*, 1992; *McCulloch et al.*, 1999], and $\delta^{18}O$ values in coral reflect SST and $\delta^{18}O$ in ambient seawater [*Swart and Coleman*, 1980; *Dunbar and Wellington*, 1981]. Residual $\delta^{18}O$ (i.e., $\Delta\delta^{18}O$), which is calculated by subtracting the contribution of temperature from coral $\delta^{18}O$, can be used as a tracer of seawater $\delta^{18}O$ ($\delta^{18}O_{sw}$) and therefore salinity [*McCulloch et al.*, 1994; *Gagan et al.*, 1998, 2000; *Corrège*, 2006]. Early mid-Holocene surface water conditions saltier than today have been reconstructed from paired coral Sr/Ca and $\delta^{18}O$ series in Vanuatu of the southwest Pacific [*Duprey et al.*, 2012].

In the SCS, the mid-Holocene SST and SSS have received much recent attention in the context of the study of the East Asian monsoon and its climatic impacts [*Shen et al.*, 2005; *Sun et al.*, 2005; *Wei et al.*, 2007;

Yokoyama et al., 2011]. During the mid-Holocene (roughly from 7000 to 5000 year BP), the East Asian summer monsoon was stronger than at present [*Wang et al.*, 2005b], the climate was warmer over the tropical western Pacific [*Gagan et al.*, 1998], and the sea level rose to the present level [*Yokoyama et al.*, 2011]. These typical features give new insights into the mid-Holocene climatic variability and provide new benchmarks against which testing the reliability of the climate models, therefore can be used to better understand both present-day climate conditions and potential future climate trends. Our previous studies [*Wei et al.*, 2007; *Deng et al.*, 2009], based on high-resolution paired coral Sr/Ca and δ^{18}O records, suggest that SSTs were warmer than the present and that there was a higher SSS at around 6494 $\pm$ 24 year BP in the mid-Holocene in the northern SCS. Two other studies, based only on high-resolution coral δ^{18}O records, also showed higher SSS levels caused by the reduced mid-Holocene rainfall amounts between approximately 4400 and 6600 year BP in the same region [*Sun et al.*, 2005; *Yokoyama et al.*, 2011]. However, another study, which attempted to quantitatively reconstruct past rainfall using coral Sr/Ca and δ^{18}O data, suggested that annual rainfall around 6730 year BP was 20% higher than modern-day levels in the northern SCS [*Shen et al.*, 2005]. If this was the case, SSS levels during the mid-Holocene would have been lower than at present; however, the western Pacific Ocean SSS record reconstructed from foraminiferal Mg/Ca and δ^{18}O records follows a declining trend from the mid-Holocene to the present [*Stott et al.*, 2004]. The southwest Pacific SSS records for the period 6700–6500 year BP obtained from coral Sr/Ca and δ^{18}O data also follow this declining trend [*Duprey et al.*, 2012].

These differences among existing reconstructions of mid-Holocene sea surface water conditions may be related to the following two aspects. The first is that some studies reconstructed SSS records using only coral δ^{18}O. It is known that δ^{18}O values in coral reflect both SST and δ^{18}O in ambient seawater [*Dunbar and Wellington*, 1981; *Swart and Coleman*, 1980], and the contribution from temperature should be deducted before using coral δ^{18}O to explore changes in seawater salinity. The second factor is that these studies were based on single coral cores. Replication is the best way to identify nonclimatic artifacts in individual coral records and to isolate the source of these discrepancies, and so obtain accurate and reliable paleoclimatic records [*Jones et al.*, 2009]. To better constrain the nature of monsoon evolution and freshening processes in the northern SCS, some researchers have suggested that further work, including multiple proxies such as Sr/Ca and δ^{18}O series obtained from multiple fossil corals, is required [*Yokoyama et al.*, 2011]. Here we use coupled Sr/Ca and δ^{18}O series from three fossil corals that grew between approximately 6100 and 6500 year BP to reconstruct the sea surface conditions during the mid-Holocene in the northern SCS and to clarify the discrepancies among existing studies.

2. Materials and Methods

The three mid-Holocene corals growing more than 30 years, SYL-1-3 (ca. 6342 year BP), SYL-4 (ca. 6217 year BP), and SYO-15 (ca. 6494 year BP), were drilled from three *Porites lutea* colonies on the fringing reef at Dadonghai, which is near Sanya, southern Hainan (Figure 1). In addition, a modern coral (sample SYA) was drilled from a *Porites lutea* colony living about 2 m below the low tide level on the fringing reef in Sanya Bay (Figure 1). The Sr/Ca data obtained from these three fossil corals were used by *Wei et al.* [2007] to reconstruct the SST records during the mid-Holocene in the northern SCS. In addition, the Sr/Ca and δ^{18}O data from the fossil coral SYO-15, and also from the modern coral SYA, have been used to study variations in the timing of the rainy season during the mid-Holocene [*Deng et al.*, 2009; *Deng and Wei*, 2015] and also to study the environmental factors controlling coral skeletal δ^{13}C in the northern SCS [*Deng et al.*, 2013]. However, the δ^{18}O data from the fossil cores SYL-1-3 and SYL-4 are reported for the first time in this study. The detailed analytical methods used can be found in *Deng et al.* [2009]. The regional climate and environmental conditions including SST and SSS of the study also refer to *Deng et al.* [2009]. The mean monthly SSS data are the averaged monthly values for the period 1960–1995 in Sanya [*Zhong*, 1997]. The mean monthly SST data are based on the observational records for the period 1961–1999 from the Yulin Naval Base in Sanya.

Seawater δ^{18}O ($\delta^{18}O_{sw}$) levels can be obtained from coral $\Delta\delta^{18}$O data and were calculated here using the Australian National University (ANU) method; i.e., $\Delta\delta^{18}O = d\delta^{18}O/dT \times [T_{\delta 18O} - T_{Sr/Ca}]$ [*Gagan et al.*, 1998; *McCulloch et al.*, 1994], where $d\delta^{18}O/dT$ is the temperature-dependent oxygen isotope fractionation, and $T_{\delta 18O}$ and $T_{Sr/Ca}$ are the apparent SSTs calculated from δ^{18}O and Sr/Ca ratios using the δ^{18}O-SST and Sr/Ca-

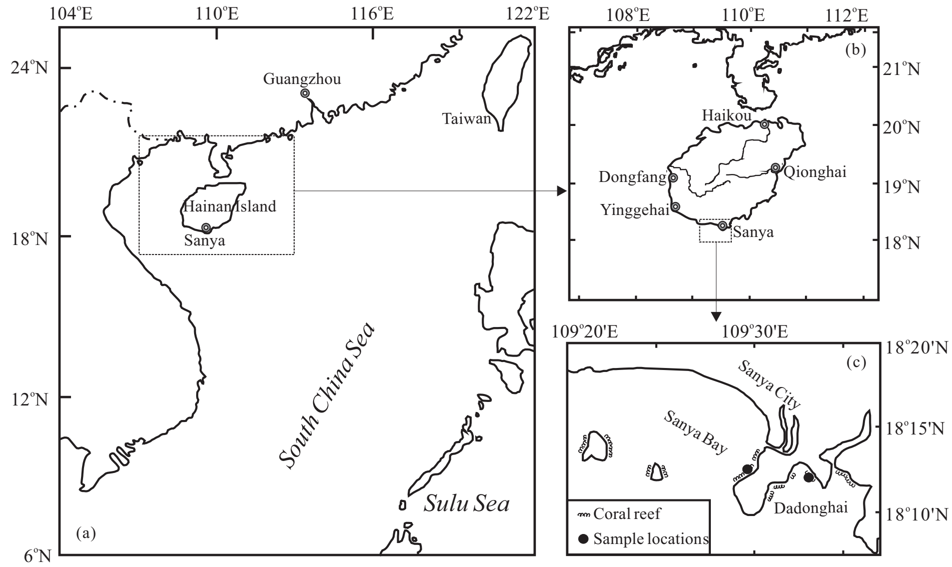

Figure 1. Location map of study site in the SCS showing: (a) the northern SCS, (b) Hainan Island, and (c) the Sanya coral reef and sampling locations of the corals analyzed in this study. The modern coral was collected in Sanya Bay, and the mid-Holocene corals from Dadonghai.

SST equations reported by *Deng et al*. [2009], respectively. The error for the $\Delta\delta^{18}O$ is estimated using the method suggested by *Cahyarini et al*. [2008]. For details of the calculation see *Deng et al*. [2009].

The growth chronologies of the corals were constructed using Sr/Ca ratios that track changes in ambient water temperature, by assuming that each Sr/Ca cycle represents 1 year, and by cross-validating this approach with visual observations from the X-radiographs, as the pairs of high-density and low-density bands represent annual growth [*Dodge and Vaisnys*, 1975; *Knutson et al*., 1972]. The X-radiographs of the corals SYA and SYO-15 refer to *Deng et al*. [2009], and those of corals SYL-1-3 and SYL-4 are presented in the supporting information Figures S1 and S2, respectively. Maxima in the Sr/Ca ratios were assigned to the beginning of each year, which is generally the coldest period in this region. Other ages between the two neighboring Sr/Ca maxima were obtained by linear interpolation assuming a linear growth rate of corals. In the case of the modern coral, the age assignment began at the top of the core with the tissue layer, whose age was known from the date of collection (16 January 1991) of the core. For the fossil coral, the age assignment was based on seasonal cycles preserved within the Sr/Ca ratios and the U-series ages. The detailed chronological information was reported in *Wei et al*. [2007]. Calendar ages were assigned to the $\Delta\delta^{18}O$ data over the lifespan of the corals according to the age models outlined above based on the Sr/Ca cycles.

To extract the seasonal climatic variations recorded by the corals, the monthly means of the time series were calculated by converting the series to monthly resolution, and then averaging the data for each month across the whole series, i.e., we calculated the average for all of the January values, all of the February values, and so on [*Deng et al*., 2009; *Duprey et al*., 2012]. Monthly resolution was obtained by linear interpolation for annual cycles with $<$12 data points, and by nearest neighbor smoothing for annual cycles with $>$12 data points.

3. Results

Annual periodicities were evident in both the modern and mid-Holocene coral $\delta^{18}O$ and $\Delta\delta^{18}O$ records (Figure 2). Coral $\delta^{18}O$ values varied from -6.08‰ to -4.55‰, -6.28‰ to -3.25‰, -6.36‰ to -3.97‰, and -6.50‰ to -3.82‰ for samples SYA, SYL-4, SYL-1-3, and SYO-15, respectively, and with amplitudes of 1.53‰, 3.03‰, 2.39‰, and 2.68‰, respectively (Table 1). The average $\delta^{18}O$ values of these corals were -5.56‰ ($1\sigma = 0.32$), -5.15‰ ($1\sigma = 0.46$), -5.29‰ ($1\sigma = 0.47$), and -5.43‰ ($1\sigma = 0.51$), respectively (Table 1). Coral $\Delta\delta^{18}O$ values varied from -0.56‰ to -0.44‰, -0.43‰ to 1.93‰, -0.61‰ to 1.24‰, and -0.46‰ to 1.43‰ for the SYA, SYL-4, SYL-1-3, and SYO15 samples, respectively, with amplitudes of 1.00‰,

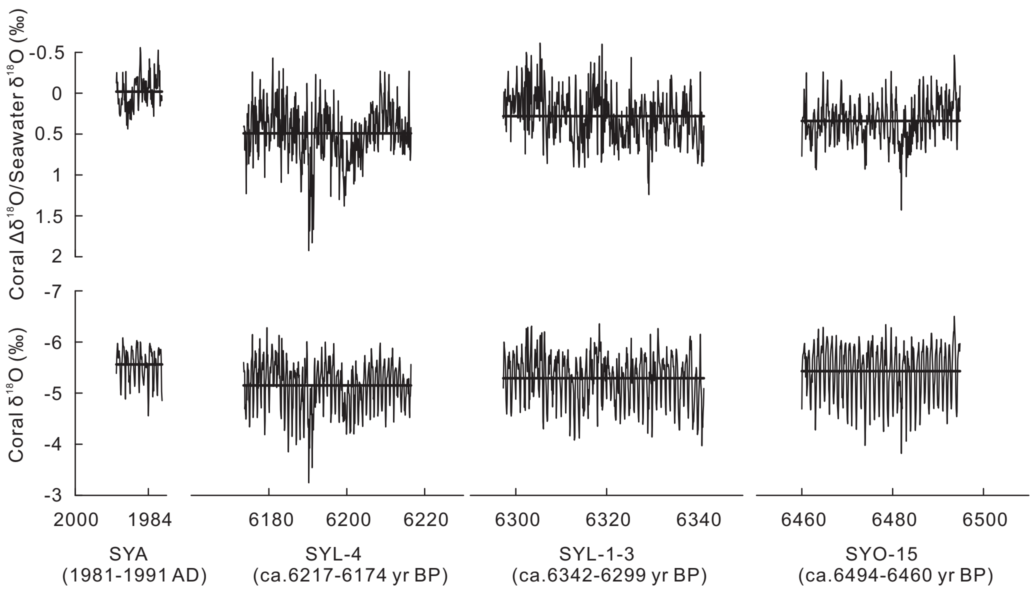

Figure 2. Temporal variations in $\delta^{18}O$ and $\Delta\delta^{18}O$ of the modern coral and three mid-Holocene fossil corals. The black horizontal lines indicate the average for each series.

2.36‰, 1.85‰, and 1.89‰, respectively (Table 1). The average $\Delta\delta^{18}O$ values of these corals were −0.02‰ ($1\sigma = 0.20$), 0.49‰ ($1\sigma = 0.34$), 0.28‰ ($1\sigma = 0.30$), and 0.34‰ ($1\sigma = 0.25$), respectively (Table 1).

The mean monthly coral $\delta^{18}O$ and $\Delta\delta^{18}O$ series are presented in Figure 3. The mean monthly coral $\delta^{18}O$ variations range from −5.86‰ to −4.94‰, −5.51‰ to −4.60‰, −5.65‰ to −4.64‰, and −5.92‰ to −4.62‰ for the SYA, SYL-4, SYL-1-3, and SYO15 samples, respectively, with amplitudes of 0.92‰, 0.91‰, 1.01‰, and 1.30‰, respectively (Table 2). The mean monthly coral $\Delta\delta^{18}O$ variations range from −0.17‰ to 0.12‰, 0.32‰ to 0.65‰, 0.15‰ to 0.46‰, and 0.15‰ to 0.52‰ for the SYA, SYL-4, SYL-1-3, and SYO15 samples, respectively, and with amplitudes of 0.29‰, 0.33‰, 0.31‰, and 0.37‰, respectively (Table 2).

4. Discussion

4.1. $\Delta\delta^{18}O$ Values as a Proxy for SSS

As discussed in section 1, previous studies have used coral $\delta^{18}O$, rather than coral $\Delta\delta^{18}O$ data, to directly reconstruct SSS levels for the SCS [*Sun et al.*, 2005; *Yokoyama et al.*, 2011]. However, coral $\delta^{18}O$ does not record seawater $\delta^{18}O$ alone, but also includes the contribution from temperature [*Swart and Coleman*, 1980; *Dunbar and Wellington*, 1981]. Therefore, the issue of the reliability of coral $\delta^{18}O$ and $\Delta\delta^{18}O$ as a proxy for SSS should be addressed before they are used in this context. The modern coral $\Delta\delta^{18}O$ and $\delta^{18}O$ series show different seasonal variation patterns, and the former is much closer to the variation trends seen in the instrumental SSS record (Figure 4). Correlation between the mean monthly modern coral $\delta^{18}O$ and the instrumental SSS is poor and insignificant ($r = 0.33$, $n = 12$, $p = 0.15$; Figure 4a). However, the correlation

Table 1. $\delta^{18}O$ and $\Delta\delta^{18}O$ Data From the Modern Coral and the Three Mid-Holocene Fossil Corals[a]

	Mean Values[b]		Variation Ranges[c]		Amplitudes[d]	
Coral Name (Age)	$\delta^{18}O$	$\Delta\delta^{18}O$	$\delta^{18}O$	$\Delta\delta^{18}O$	$\delta^{18}O$	$\Delta\delta^{18}O$
SYA (1981–1990)	−5.56 (0.32)	−0.02 (0.20)	−6.08 to −4.55	−0.56 to 0.44	1.53	1.00
SYL-4 (ca. 6217–6174 year BP)	−5.15 (0.46)	0.49 (0.34)	−6.28 to −3.25	−0.43 to 1.93	3.03	2.36
SYL-1-3 (ca. 6342–6299 year BP)	−5.29 (0.47)	0.28 (0.30)	−6.36 to −3.97	−0.61 to 1.24	2.39	1.85
SYO-15 (ca. 6494–6460 year BP)	−5.43 (0.51)	0.34 (0.25)	−6.50 to −3.82	−0.46 to 1.43	2.68	1.89

[a]Isotope values are reported in ‰ VPDB.
[b]Mean values are expressed with 1σ uncertainties in brackets.
[c]Variation ranges are the variation from the minimums to the maximums.
[d]Amplitudes were calculated as the difference between the maximums and minimums.

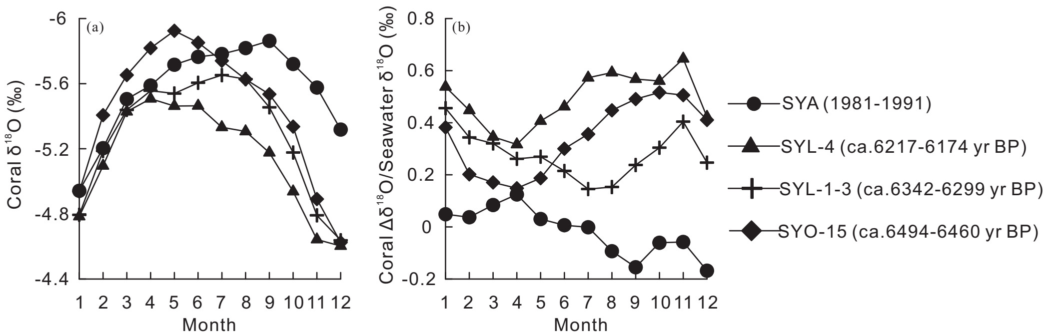

Figure 3. Mean monthly values of (a) δ^{18}O and (b) $\Delta\delta^{18}$O (seawater δ^{18}O) for the modern coral and three mid-Holocene fossil corals. The solid lines with symbols (circles, triangles, crosses, and diamonds) represent corals SYA, SYL-4 (ca. 6217–6174 year BP), SYL-1-3 (ca. 6342–6299 year BP), and SYO-15 (ca. 6494–6460 year BP), respectively.

improves after subtracting the effect of temperature, and the mean monthly modern coral $\Delta\delta^{18}$O and instrumental SSS are more closely correlated ($r = 0.74$, $n = 12$, $p = 0.003$; Figure 4b). These differing correlation levels may suggest that coral $\Delta\delta^{18}$O is a more reliable proxy than δ^{18}O for long-term variations in SSS in the northern SCS. According to the error estimation method suggested by *Cahyarini et al*. [2008], the error for the $\Delta\delta^{18}$O results is about 0.07‰ in this study [*Deng et al*., 2009]. Thus, the annual variation amplitudes (0.29–0.37‰) of the mean monthly coral $\Delta\delta^{18}$O, both for modern and fossil corals, are significantly larger than their estimated errors. Another issue should be noted is that the SSS reconstruction based on the ANU method should be done in the place where SST and SSS do not co-vary, because their co-variation will bias the estimate of the regression slope of coral δ^{18}O-SST and contribute to inevitable errors to $\Delta\delta^{18}$O [*Cahyarini et al*., 2008]. Regarding the situation in Sanya, the monthly SST and SSS records do not co-vary and have poor correlation ($r = -0.17$, $n = 12$, $p = 0.298$; Figure 5). On the other hand, the $\Delta\delta^{18}$O data extracted from the coral Sr/Ca and δ^{18}O are based on the same transfer equations and the coral Sr/Ca and δ^{18}O are normalized to the same reference standards. These facts indicate that the variation of the coral $\Delta\delta^{18}$O calculated by the ANU method can be used to compare SSS levels during different periods in this region, but the reliability of the coral δ^{18}O as an SSS proxy should be challenged.

4.2. SSS During the Mid-Holocene

The three fossil corals have heavier $\Delta\delta^{18}$O values than the modern coral (Figures 2 and 3; Tables 1 and 2), which means that the sea surface δ^{18}O during the mid-Holocene was heavier and the SSS was higher than at present. The $\Delta\delta^{18}$O of the mean values of the fossil corals are heavier by about 0.51‰, 0.30‰, and 0.36‰ than that of modern coral for SYL-4, SYL-1-3, and SYO-15, respectively, and yielded a heavier average $\Delta\delta^{18}$O of 0.39‰. However, this heavier average value is less than the 0.60‰ that was calculated from a mid-Holocene coral δ^{18}O in the northern SCS by *Yokoyama et al*. [2011]. The average of the three fossil coral $\Delta\delta^{18}$O values (0.37‰, $1\sigma = 0.11$) obtained here is in good agreement with the value (0.36–0.39‰) of the mid-Holocene seawater δ^{18}O series reconstructed from coupled foraminifera Mg/Ca and δ^{18}O from the western Pacific by *Stott et al*. [2004] (Figure 6). This further supports that the mid-Holocene sea surface water was saltier than modern-day water of the northern SCS.

Table 2. Mean Monthly δ^{18}O and $\Delta\delta^{18}$O of the Modern Coral and the Three Mid-Holocene Fossil Corals[a]

	Variation Ranges[b]		Amplitudes[c]	
Coral Name (Age)	δ^{18}O	$\Delta\delta^{18}$O	δ^{18}O	$\Delta\delta^{18}$O
SYA (1981–1990)	−5.86 to −4.94	−0.17 to 0.12	0.92	0.29
SYL-4 (ca. 6217–6174 year BP)	−5.51 to −4.60	0.32 to 0.65	0.91	0.33
SYL-1-3 (ca. 6342–6299 year BP)	−5.65 to −4.64	0.15 to 0.46	1.01	0.31
SYO-15 (ca. 6494–6460 year BP)	−5.92 to −4.62	0.15 to 0.52	1.30	0.37

[a]Isotope values are reported in ‰ VPDB.
[b]Variation ranges are the variation from the minimums to the maximums.
[c]Amplitudes were calculated as the difference between the maximums and minimums.

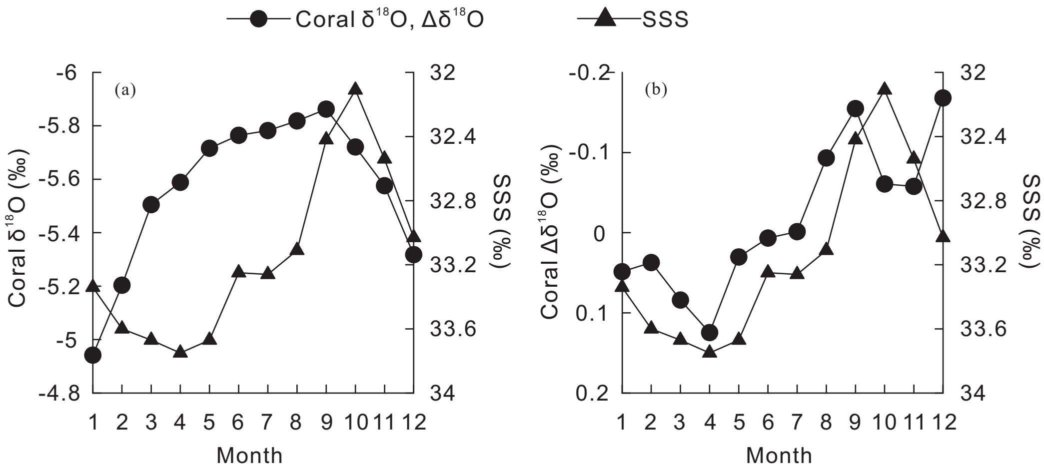

Figure 4. Mean monthly instrumental SSS (line with solid triangles) compared with (a) mean monthly coral δ^{18}O (line with solid circles) and (b) $\Delta\delta^{18}$O (line with solid circles). The mean monthly SSS data are the averaged monthly values for the period 1960–1995 in Sanya [*Zhong*, 1997].

The mean monthly $\Delta\delta^{18}$O of the three fossil corals have different seasonal variation patterns, although they are all heavier than that of the modern coral (Figure 3b). For example, for the modern coral, the minimum $\Delta\delta^{18}$O values occur between September and December, but the maximum $\Delta\delta^{18}$O values occur in April. The corals SYL-4 and SYO-15 have similar variation trends with the $\Delta\delta^{18}$O minimum occurring in April and the maximum in November (SYL-4) or October (SYO-15). As for coral SYL-1-3, its $\Delta\delta^{18}$O minimums occur in approximately July or August, and $\Delta\delta^{18}$O maximums occur between November and the following February. These differing distribution patterns may have been caused by changes in the timing of the rainy season during the mid-Holocene in the northern SCS. The peak rainy season occurred at different times during the mid-Holocene and so led to different freshening periods for the surface seawater. Our previous studies demonstrated that the timing of the rainy season changed during the mid-late Holocene over the northern SCS and even over the western Pacific Ocean [*Deng et al.*, 2009, 2014; *Deng and Wei*, 2015]. In contrast to the variations in coral $\Delta\delta^{18}$O, the mean monthly δ^{18}O series of the three fossil corals have similar variation patterns and are similar to the series from the modern coral (Figure 3a). The different patterns of variation shown by the mean monthly coral δ^{18}O and $\Delta\delta^{18}$O series may indicate that coral δ^{18}O contains more information regarding SST but is not a good proxy for SSS, and that coral $\Delta\delta^{18}$O is a much better proxy to use to reconstruct SSS.

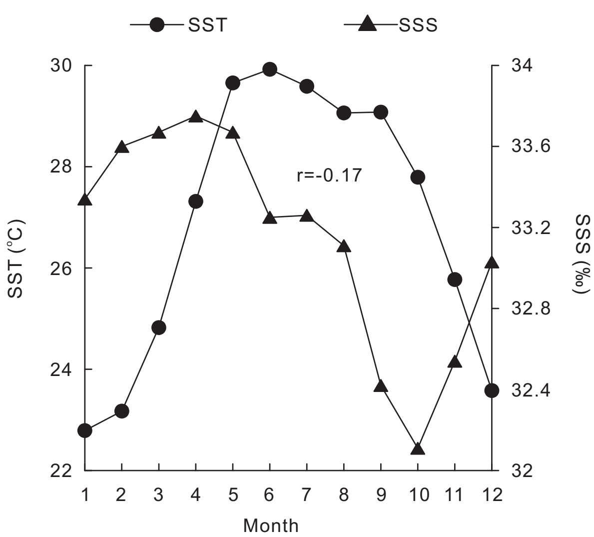

Figure 5. Mean monthly instrumental SSS (line with solid triangles) and SST (line with solid circles) in Sanya. The mean monthly SSS data are the averaged monthly values for the period 1960–1995 in Sanya [*Zhong*, 1997]. The mean monthly SST data are based on the observational records for the period 1961–1999 from the Yulin Naval Base in Sanya.

4.3. Possible Mechanisms Associated With More Saline Surface Waters

The East Asian summer monsoon was strong during the mid-Holocene [*Wang et al.*, 2005b], and this strengthened monsoon would have led to a more northerly position of the intertropical convergence zone (ITCZ) [*Yancheva et al.*, 2007]. The shift in the mean latitudinal position of the summer ITCZ may have led to a change in the position of the rainfall belts] [*Fleitmann et al.*, 2003, 2007]. A previous study based on coupled coral records and an atmosphere-ocean general circulation model (GCM) model suggested that a northward shift of the ITCZ could have led to increased

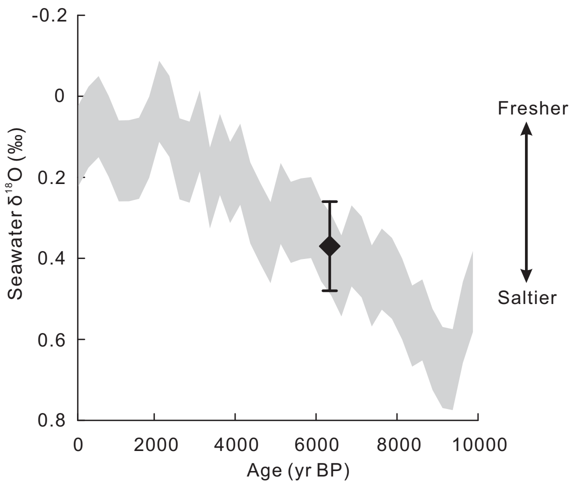

Figure 6. The average seawater δ^{18}O reconstructed from the three mid-Holocene corals is in good agreement with the series reconstructed by *Stott et al.* [2004]. The gray area is the 1σ uncertainty envelope and represents the long-term evolution trend of seawater δ^{18}O reconstructed from coupled foraminifera Mg/Ca and δ^{18}O during the Holocene in the western Pacific by *Stott et al.* [2004]. The diamond with error bar ($1\sigma = 0.11$) indicates the result from this study.

continental rainfall over inland Asia, but less rainfall over the SCS, during the mid-Holocene [*Yokoyama et al.*, 2011]. Other results of coupled simulations also indicate the northward shift of the ITCZ and enhanced rainfall in the northern part of the ITCZ in the mid-Holocene around 6000 ky BP [*Braconnot et al.*, 2007]. Therefore, during the mid-Holocene, it is likely that the strengthening of the Asian Monsoon and/or a northward shift of the ITCZ would have caused a reduction in rainfall amounts that then led to more saline surface waters in the northern SCS.

5. Conclusions

Based on geochemical records consisting of coupled Sr/Ca and δ^{18}O preserved in a modern coral and three fossil corals, we reconstructed the seasonal patterns of SSS variation during the mid-Holocene in the northern SCS. The $\Delta\delta^{18}$O (a proxy of SSS) values from the three fossil corals were all heavier than those from the modern coral, which suggests saltier surface waters in the northern SCS during the mid-Holocene. These results are consistent with a previous study [*Yokoyama et al.*, 2011], as well as with the western Pacific Ocean SSS record reconstructed from foraminifer Mg/Ca and δ^{18}O [*Stott et al.*, 2004]. A reduction in rainfall caused by the strengthened Asian Monsoon and/or the northward shift of the ITCZ during the mid-Holocene would have generated these saltier surface waters in the northern SCS. Our results clarify the discrepancies among existing studies and confirm the existence of saltier surface water conditions during the mid-Holocene in the northern SCS.

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