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The Influence of ENSO/IOD on SST Signal in Kendari, Southeast Sulawesi Waters: 27-year-records of Sr/Ca from *Porites* corals

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Abstract - Indonesia is an interesting and important location for a climate study, because it is located in the centre of a warm pool and adjacent to Pacific and Indian Oceans. Long records of climate data are required from this region to more understand the climate variability and the response of global warming. Geochemical proxies derived from *Porites* corals are believed to be an excellent climate recorder. Sr/Ca content in *Porites* corals from Kendari, Southeast Sulawesi shows that seasonal variability of SST is resolved by coral Sr/Ca from this region. The monsoon strongly influences reconstructed SST from coral Sr/Ca. Coral SST shows strong power spectrum at the 2.75 year period. Annual to interannual coral SST signal is stronger than the decadal to interdecadal signal. Both ENSO and IOD influence coral SST at two-month and three-month lags respectively.

Keywords: Sr/Ca, *Porites*, coral, ENSO/IOD, Kendari

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INTRODUCTION

Background

Indonesia is an important place for a climate study, because it is located between Indian and Pacific Oceans, what is so called the Indo-Pacific warm pool, which means the sea surface temperature (SSTs) is high and the rainfall is abundant. The consequence is that Indonesia is influenced both by Indian and Pacific Ocean climate events such as the Indian Ocean Dipole (IOD) and the El Nino Southern Oscillation (ENSO). Both climate phenomena have a severe socio-economic impact, as they may cause serious droughts or floods over adjacent land areas. However, the response of the IOD and ENSO to future global warming is uncertain, as the instrumental data record is not sufficient for this purpose (Vecchi, 2008; Cai *et al*., 2013). To better understand the response of the Indo-Pacific to global warming, additional climate data from older time periods (*e.g.* Holocene) with different climatic boundary conditions would extremely be helpful. There is still lack of climate data in Indonesia which is from the older period. Coral geochemical proxies are one of climate archives which can provide such climate data. Sr/Ca content in corals has been demonstrated as a temperature proxy (*e.g.* Cahyarini et *al*., 2009; Linsley *et al*., 2000). Combination of living and fossil corals can provide long time series climate data extending hundreds or even thousands of years ago.

Indonesian archipelago which is rich in coral reef biodiversity can provide information of climate which can be extracted from corals as the main component of coral reef ecosystem. A previous study from Cahyarini *et al.* (2008) showed Sr/Ca records from Jukung Island which indicates clearly seasonal variation on the sea surface temperature (SST). Coral Sr/Ca from inshore island in the Seribu Island complex shows the influence of air temperature rather than SST (Cahyarini and Zinke, 2010). Recently, results from modern Timor *Porites* corals demonstrated that coral Sr/Ca is a good proxy for temperature (Cahyarini *et al*., 2014). In Timor, the 20th century coral-based SST and SSS are influenced by the IOD, while ENSO only influences SST on interannual time scales. On decadal time scales, there is a strong correlation between the IOD and Timor SST and SSS leading about 1.6 - 2 years (Cahyarini *et al.*, 2014). The small changes of SST variation in the Indonesian maritime continent will contribute to Indo-Pacific SST variability (Qu *et al*., 2005). It is important to understand the SST variability in the Indonesian maritime continent. Thus, the development from additional long time series climatic record from many locations inside Indonesian sea is required. In particular, the response of the IOD and ENSO to different climatic boundary conditions will be understood. According to Aldrian and Susanto (2003), based on its rain fall variation, Indonesia is divided into three regions: (1) region strongly influenced by monsoon, (2) region influenced by both ENSO and IOD, and (3) region strongly influenced by ENSO. The studied site is in the eastern part of Sulawesi which seems to be influenced by the Lifamatola exit passage of Indonesian through flow (ITF) (flows between Halmahera and Sulawesi) (Figure 1) and in the region where rain fall is influenced by ENSO/IOD (Aldrian and Susanto, 2003).

In this study, modern *Porites* corals from Kendari, Southeast Sulawesi waters (Figure 1) was analyzed for Sr/Ca. SST variability was reconstructed based on coral Sr/Ca. ENSO/IOD signal was extracted from coral Sr/Ca to understand the SST response of ENSO/IOD in this area.

Studied Site

Porites corals from Bintang Samudra-Kendari waters, Southeast Sulawesi, were studied. The coral site (03.89721 S 123.61118 E) (Figure 1) facing Banda Ocean, is located at the Indonesian through flow (ITF) Lifamatola exit passages (Sprintall *et al*., 2004) (Figure 1). The ITF is mass water transported from the Pacific Ocean to the Indian Ocean through the Indonesian sea. The ITF

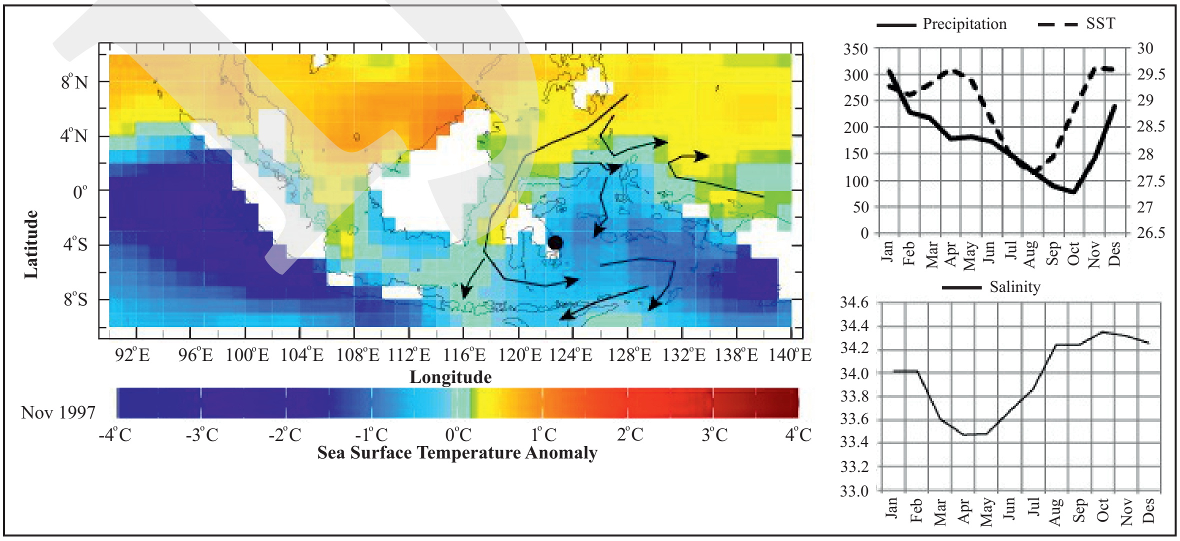

Figure 1. (Left) Coral site (black dot), the Indonesian through flow (dark arrow lines) and map showing the SST anomaly during November 1997 (El Nino year). (Right) Climatology data of precipitation (bold lines), SST (dashed lines) and salinity (thin dark lines) in the studied area.

is important for transferring the climate signals and its anomaly around the world. The transferred water from the surface to upper thermocline North Pacific origin flows through Makassar Strait, while the lower and deeper water masses of South Pacific origin directly flow through Maluku and Halmahera Seas and the overflow at the Lifamatola passage (Sprintall *et al*., 2004). This vertical and horizontal water movements contribute to the Indonesian climate variability. Besides, the other factors are monsoon and ENSO/IOD. The coral site is included in the region which is the largest seasonal amplitude of SST (>4^o). The annual to interannual cycles of SST in this region is less than its seasonal cycle (Qu *et al*., 2005). According to Aldrian and Susanto (2003), the studied site is included in the region A, which means the annual rainfall pattern is dominant in Indonesia. In this region, there is one peak and one through that are influenced by two monsoons, *i.e.* the northwest monsoons which causes wet season over Indonesia maritime continent and southeast monsoons which causes dry season over Indonesia. In the coral site, the warmest SST occurs in April and the coolest SST in August, while high precipitation is in January and the lowest precipitation is in October. The low salinity occurs in April and maximum in October which coincides with low precipitation (Figure 1).

Material and Methods

Porites corals (code BSA) from Kendari waters, Southeast Sulawesi, were drilled in August 2011. The coral coring used a hand drill which is powered by a scuba tank. The drilling bit is 5 cm in diameter and 30 cm long. A 3 m extension rod was used to get longer cores (Cahyarini, 2012; for a detail coral coring method used in this study). Coral core was cut into a 5mm thick slab. X-Radiograph of the coral slab was done to get a clear density band and to select the line transect for subsampling. The coral slab was then rinsed in the ultrasonic bath, and was dried in an oven of 70^{o}C. The cleaned slab was subsampled along the coral growth axis using a manual hand drill with 0.7mm drilling bit to get the powder for Sr/Ca analysis in a monthly resolution. The coral powder was weighted for 0.150 - 0.200 mg and then was dissolved in 2 N HNO_3 to get 30 ppm of $CaCO_3$. The analysis of coral Sr/Ca used ICP OES at Laboratory of Geochemistry at SMART, Singapore.

The first development of chronology used the banding calculation from the coral x-radiograph. The corals show dark/light band under X-ray, which represents low/high coral density (Figure 2). The paired dark/light band of coral skeleton represents one-year growth. Calculating back from the top to bottom cores obtained the age of the coral sample. In this study, the top coral is time when the coral was drilled *i.e* August 2011. The coral banding based-chronology was smoothed using coral Sr/Ca. The anchor point was defined based on maximum/minimum SST which was in April/August, where the SST maximum/minimum coincided with Sr/Ca minimum/maximum. The result of chronology development shows that coral BSA was extented from May 1984 to August 2011 (Figure 3).

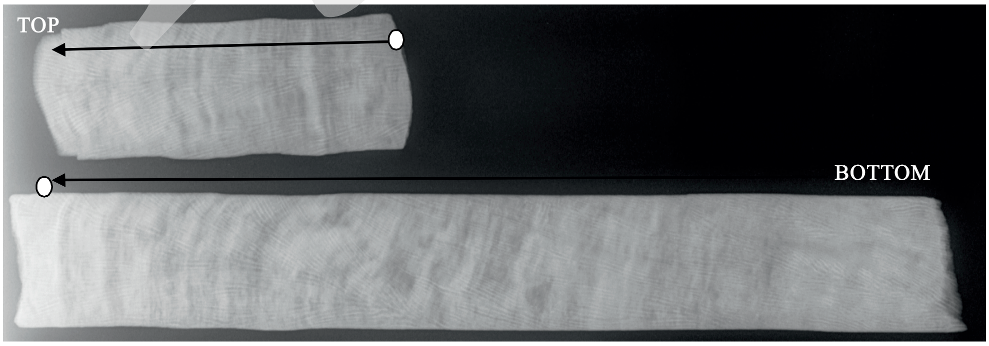

Figure 2. X-radiograph of *Porites* corals (BSA) was used in this study. Dark/light bands show low/high coral density. A paired dark/light band represents one-year growth.

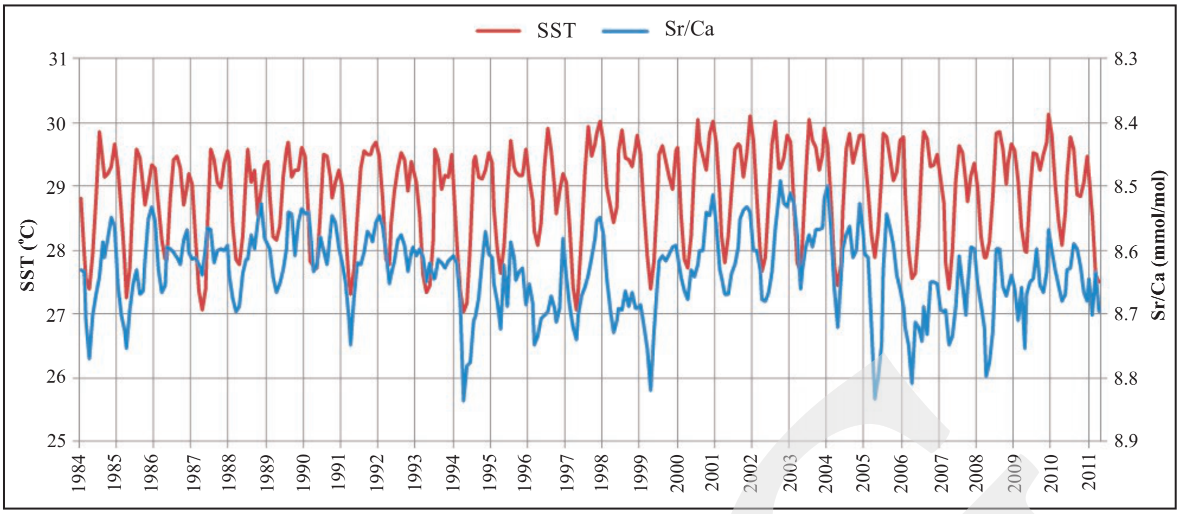

Figure 3. Monthly variation of SST from ERSST version 3b data base (red lines) and coral Sr/Ca from *Porites* coral sample BSA (blue lines).

In this study, sea surface temperature (SST) data from the Extended Reconstructed Sea Surface Temperature (ERSST version 3b) data set (Smith *et al.*, 2008; Xue *et al.*,2003) was used. The ERSST data set is the longest time series available in a monthly resolution, which cover the time period of 1854 to the present, with a spatial resolution of 2°. These data are based on the SST data from Comprehensive Ocean Atmosphere Data set (COADs) and use improved statistical methods that allow a stable reconstruction using sparse data. The Excel software is used to perform simple statistical analysis of time series data, *i.e.* linear regression, standardize, and to perform the graphic of the data. KNMI climate explorer developed by Oldenborg and Burgers (2005) was used to analyze the advance statistic, such as field (spatial) correlation, average annual (seasonal) correlation, filtering, *etc.*

Results and Discussion

The analysis of *Porites* coral Sr/Ca (BSA) from Kendari waters shows the maximum value of 8.8377 mmol/mol and the minimum value of 8.49105 mmol/mol. The mean value of BSA coral Sr/Ca is 8.6411 mmol/mol. BSA *Porites* corals extent from May 1984 to August 2011. Sr/Ca shows clearly seasonal variation in period of 1985 to 2011 (Figure 3).

Coral Sr/Ca shows high correlation coefficient (R=0.538) with SST during the period of 1985 - 2011 in a monthly resolution (Figure 4) with the calibration slope (-0.0453) is in the slope agreement of Sr/Ca vs SST regression, *i.e.* -0.04 to -0.08 mmol/mol/°C (de Vellier *et al.*, 1994; Marshal and McCulloch, 2002; Cahyarini *et al.*, 2009). The calibration equation of coral Sr/Ca vs SST in this study is Sr/Ca= -0.0453 SST + 9.9458 (R= 0.538, N = 281, $p<0.0001$). This calibration equation is used to reconstruct SST (mentioned as coral SST) in this region. The annual mean correlation of coral SST and SST is low (R=0.18), with the calibration slope of 0.316 mmol/mol/°C. From the period of 1984 to 1994, the coral SST shows that it is warmer than the SST, while from 1995 to the present the coral SST is cooler than the SST. However, the variation pattern of coral SST and SST shows a similarity.

Based on the monthly mean data, both SST and coral SST show that April is the warmest temperature in this region, while the lowest temperature is in August. SST and coral SST data show that the high deviation is in March, and the decrease in December (Figure 5).

Spatial correlation of coral SST and SST is done with three-month average over the period

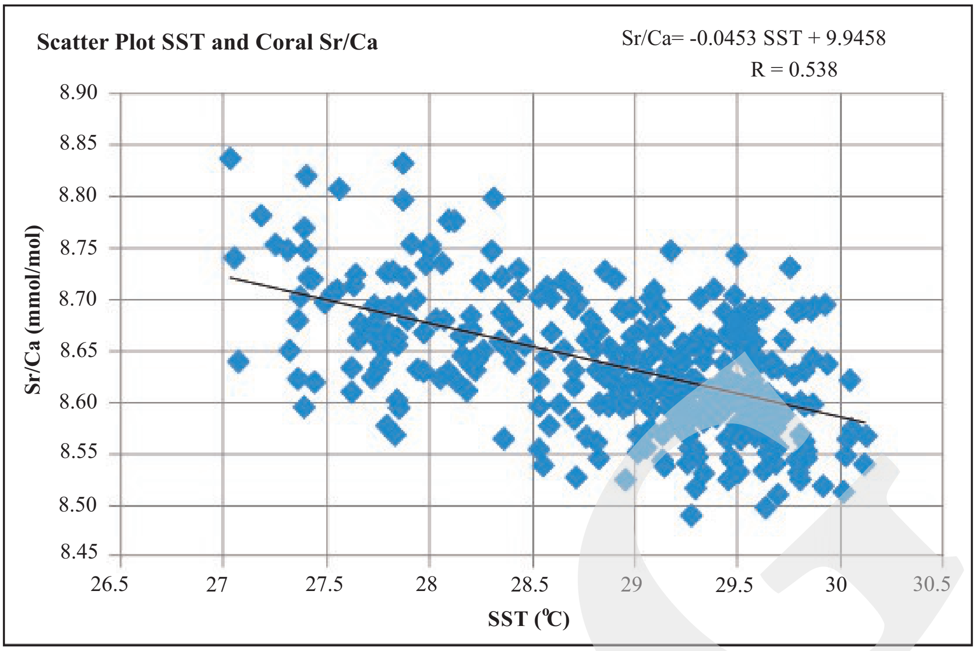

Figure 4. Calibration of monthly variation of Sr/Ca content in *Porites* corals (BSA) and SST from ERSST for the period of May 1984 to August 2011. The dark line is linear regression line.

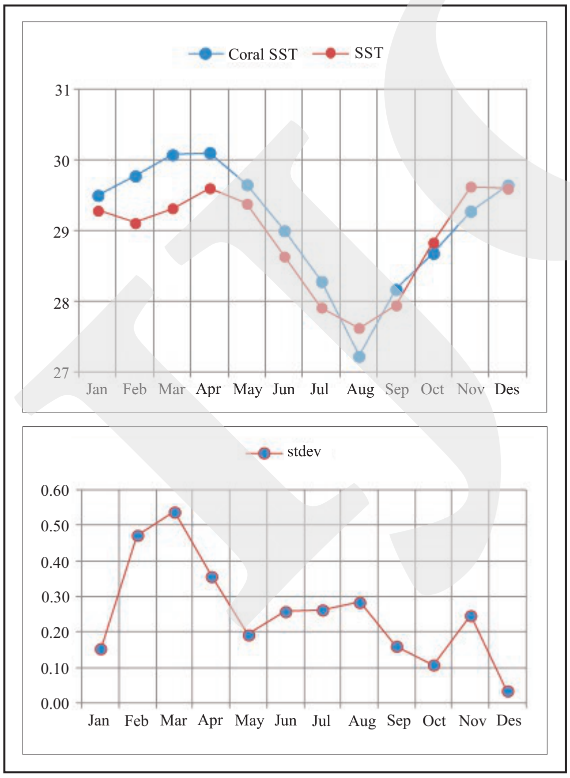

Figure 5. Monthly mean coral SST and SST from ERSST data base (upper) and standard deviation of coral SST (below).

of 1984 to 2011. The spatial correlation between the coral proxy and SST as illustrated in Figure 6 shows a weak correlation during September-October-November (SON) and December-January-February (DJF). The strong correlation occurred on the other seasons. During March-April-May (MAM) the strongest positive correlation is shown between coral SST and eastern Pacific Ocean SST. The strong connection indication in the internal eastern Indonesian seas and the eastern Pacific Ocean is an indication that this area is also affected by the phenomena over the Pacifics. The correlation with the Pacific Ocean decreases in June-July-August (JJA) season, however increasing correlation is shown with the eastern Indian Ocean during JJA. This indicates that during JJA, the phenomena in the Indian Ocean strongly influence the western Indonesian sea. During wet season, DJF and SON, on the other hand, are the least correlated season where there is no clear signal either from the Pacific or the Indian Oceans.

In the annual mean scale, coral SST variability inside Indonesia seas shows a high correlation with eastern Pacific and Indian Oceans. This indicates that a strong connection between annual mean SST variability in the Pacific and Indian Ocean events with internal Indonesian seas occurs. ENSO is one of climate phenomena in the

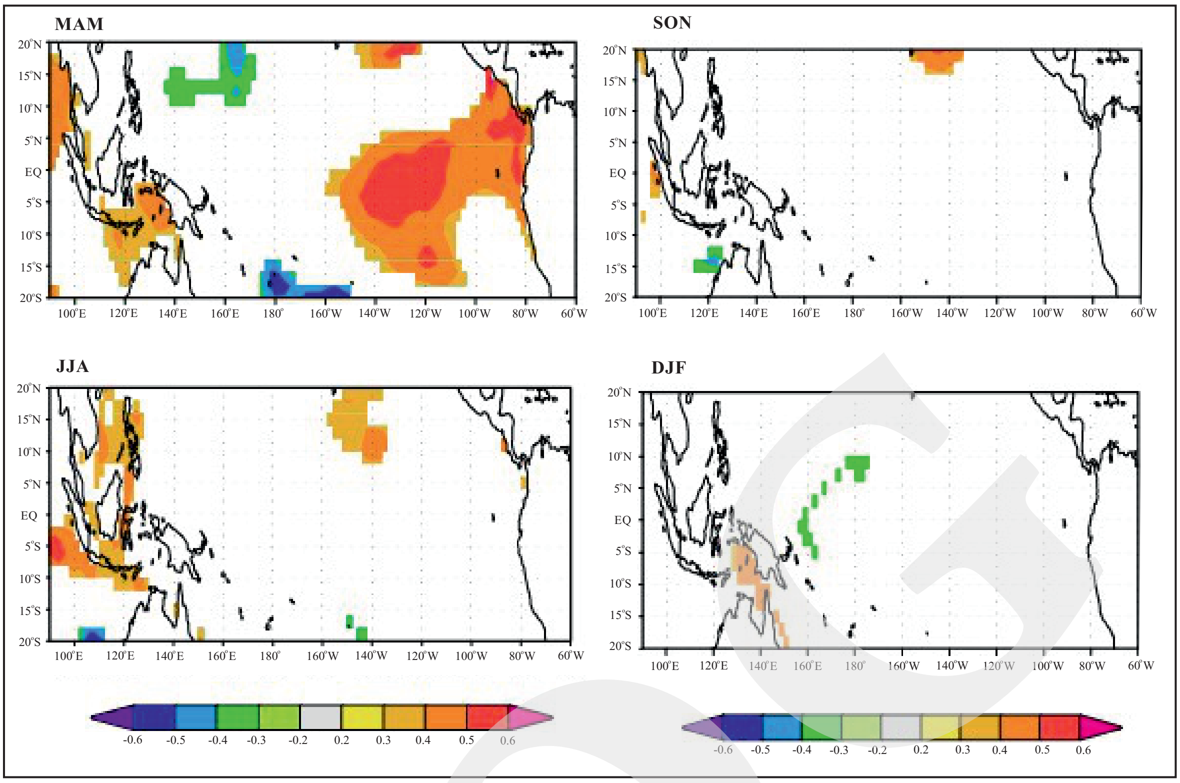

Figure 6. Field correlation between SST and coral SST, p<10%, from the period of 1984 -2011.

Pacific Ocean which is characterized by the SST anomaly gradient in the western and eastern Pacific Oceans, while IOD is a climate phenomenon which is characterized by the SST anomaly gradient in the western and eastern Indian Oceans. The intensity of the IOD is represented by the anomalous SST gradient between the western equatorial Indian Ocean (50°E - 70°E and 10°S - 10°N) and the south eastern equatorial Indian Ocean (90°E - 110°E and 10°S - 0°N). This gradient is named as Dipole Mode Index (DMI). When the DMI is positive then, the phenomenon is referred as the positive IOD and the opposite (Saji *et al.*, 1999). Nino 3.4 index was used to identify the ENSO signal in the coral SST, while Dipole Mode Index (DMI) was used to identify the IOD. Nino 3.4 index is the SST anomaly in the Nino 3.4 region (*i.e.*120°W - 170°W and 5°S - 5°N). In the studied area, ENSO influenced SST variation in two-month lag, while IOD at three-month lag, El Nino/IOD is leading. Figure 7 shows the correlation between coral Sr/Ca and Nino 3.4 (DMI). It shows a high correlation between coral Sr/Ca and ENSO and with DMI as well, during dry seasons.

Both DMI and Nino 3.4 indices are compared to the coral SST variability in this region. It shows that during ENSO/IOD years, the response of this event to coral SST is different from one year to the other. During the strong El Nino year 1997/1998, the positive anomaly of SST in the Nino 3.4 region coincided with the positive anomaly of SST at the coral site (Figure 8). Increasing SST is shown in the late 1997 during El Nino/IOD which was followed by the decreasing SST in the late 1998 during the La Nina. However, in some other El Nino years and IOD as well there is no clear signal of the SST anomaly recorded in BSA coral during the period of 1984 - 2011.

Decadal to interdecadal SST variation is not clearly shown in BSA corals rather than the annual to interannual SST variation. This is shown by the strong power spectrum of coral SST in the annual to interannual period. The most significant peak of power spectrum is at 2.67 years (Figure 9). However, it requires longer time series data to look for the decadal to interdecadal signal.

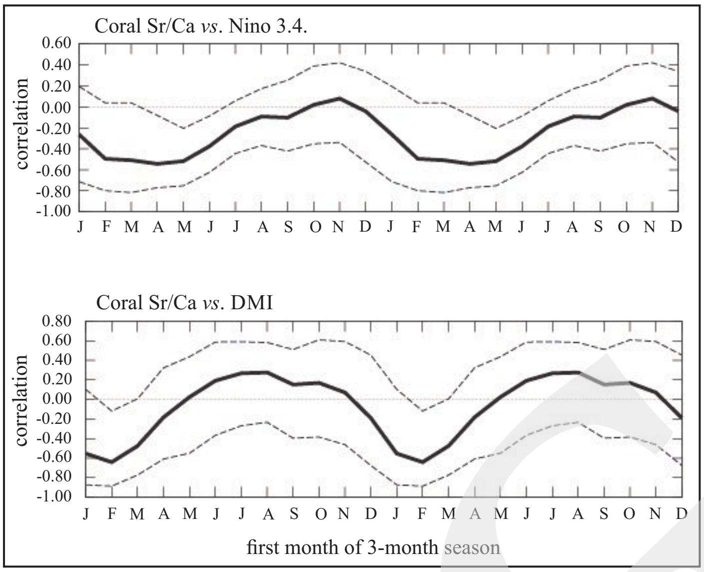

Figure 7. Running correlation between coral Sr/Ca and Nino 3.4 index (upper) and Dipole Mode Index (DMI) (below).

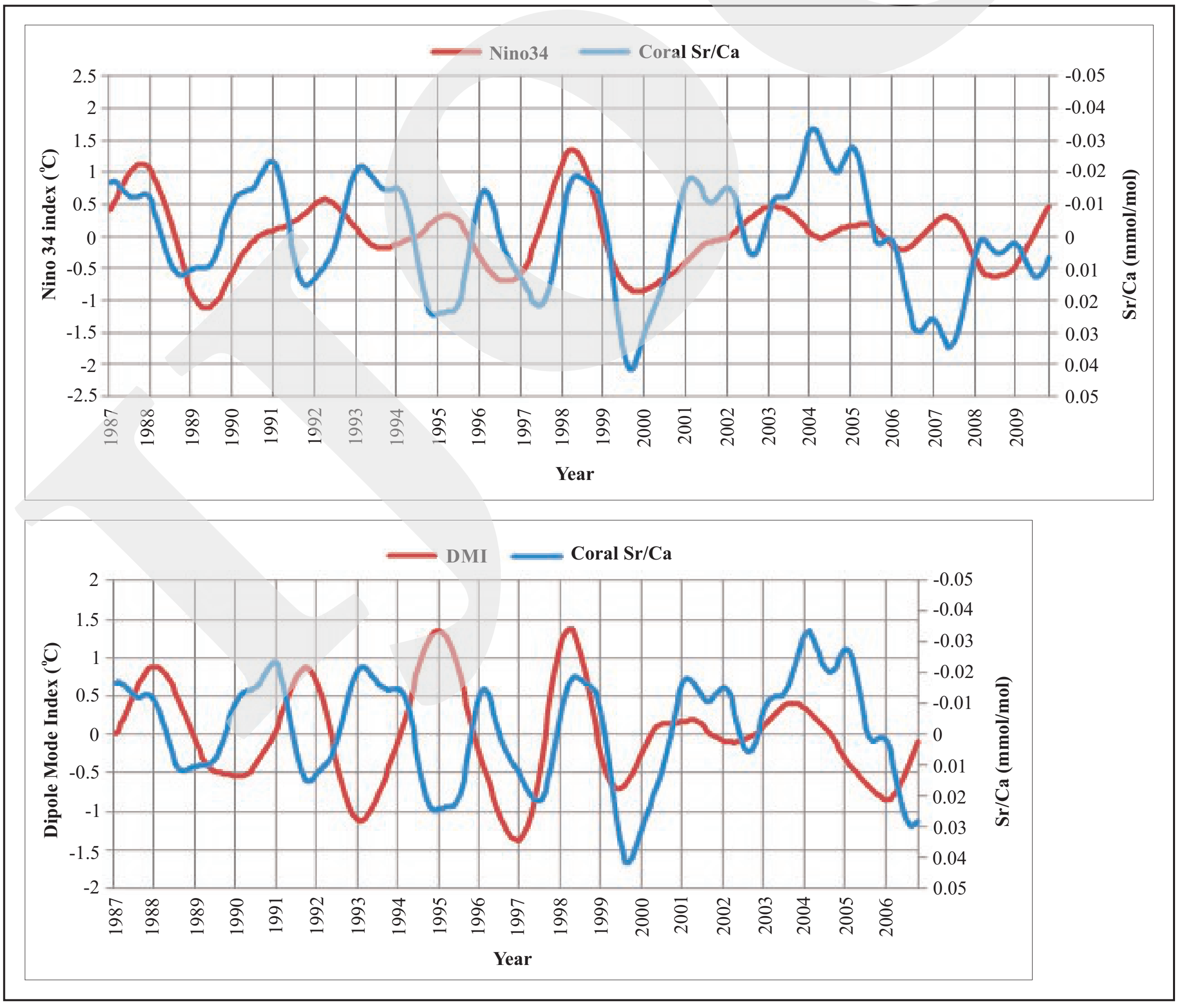

Figure 8. Comparison of coral Sr/Ca and Nino 3.4 index (upper) and DMI (below). The data are 2-7year band pass filtered. The Nino 3.4 index is based on ERSST version 3b, which can be obtained from http://www.ncdc.noaa.gov/sst/. The DMI is based on HadISST provided by Climate Variation Predictability and Applicability Research Program, RIGC/JAMSTEC.

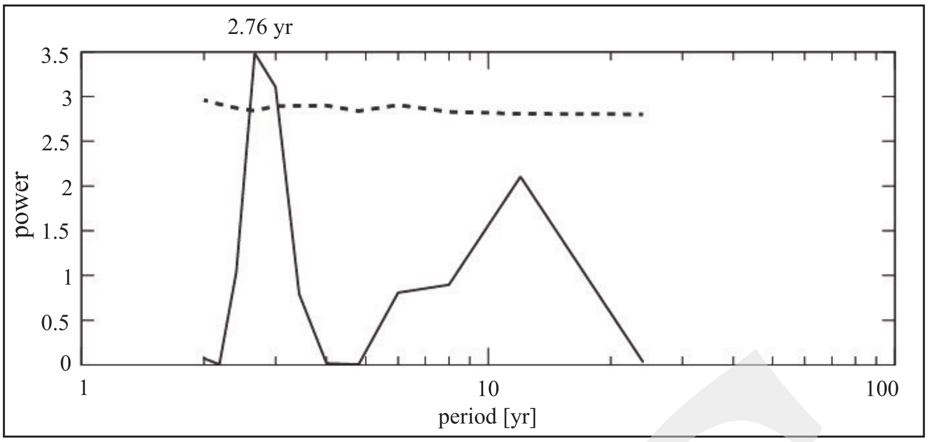

Figure 9. Power spectrum of coral SST. Dashed line is 95% confidential level with the same autocorrelation (-0.223).

CONCLUSIONS

Sr/Ca content in *Porites* corals from Kendari (BSA), southwestern Sulawesi, shows clearly a seasonal variation of SST signal from the period of 1984 - 2011. The most significant peak of coral SST power spectrum is at 2.75 years. This shows that the annual signal is strongly recorded in BSA coral. Decadal to interdecadal variation of SST is not shown in the BSA corals. This could be the data are too short.

Monsoon strongly influences SST in the region which was recorded in BSA coral. During MAM it is indicated that Pacific SST variability strongly influences SST in Kendari waters, while Indian Ocean SST strongly influences during JJA.

Both ENSO and IOD influence SST variability in the studied area, where ENSO and IOD influence at two-month and three-month lag respectively.

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