RECONSTRUCTION OF SEAWATER $\delta^{18}O$ SIGNAL FROM CORAL $\delta^{18}O$: A RECORD FROM BALI CORAL, INDONESIA

By:

Sri Yudawati Cahyarini[1]

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ABSTRACT

Sea surface salinity (SSS) and precipitation are important climate (paleoclimate) parameters. To obtain long time series data of SSS/precipitation one use coral proxy. In this study, seawater $\delta^{18}O$ is extracted from $\delta^{18}O$ content in Bali coral using centering method. The result shows more convincing that $\delta^{18}O_{bali}$ is influenced by both seawater $\delta^{18}O$ and sea surface temperature (SST). In the interannual/decadal scale the variation $\delta^{18}O_{bali}$ clearly shows the variation of seawater $\delta^{18}O$, it is supposed that highly variation of precipitation contribute to the seawater $\delta^{18}O$ variation which mirrored by coral $\delta^{18}O_{bali}$.

Keywords: coral $\delta^{18}O$, seawater $\delta^{18}O$, precipitation, sea surface salinity, sea surface temperature

SARI

Salinitas permukaan laut (SSS) dan curah hujan merupakan parameter penting untuk studi iklim maupun paleoiklim (iklim masa lampau). Untuk mendapatkan data dalam urut-urutan waktu (timeseries) yang panjang dari SSS dan curah hujan diperlukan data proksi geokimia dalam koral. Dalam studi ini kandungan $\delta^{18}O$ dalam air laut dapat di rekonstruksi dari kandungan $\delta^{18}O$ dalam koral dengan menggunakan metode centering. Hasilnya menunjukkan bahwa $\delta^{18}O$ dalam koral dipengaruhi oleh kandungan $\delta^{18}O$ dalam air laut dan SST. Dalam resolusi tahunan dan puluhan tahunan variasi $\delta^{18}O_{bali}$ dalam koral menunjukkan dengan jelas variasi $\delta^{18}O$ dalam air laut, hal ini diduga bahwa dalam resolusi tahunan dan puluhan tahunan variasi curah hujan sangat tinggi yang berkontribusi pada tingginya variasi $\delta^{18}O_{bali}$ dalam air laut sehingga dapat terekam oleh koral.

Kata kunci: $\delta^{18}O$ koral, $\delta^{18}O$ air laut, curah hujan, salinitas permukaan laut, suhu permukaan laut.

1. Research Centre for Geotechnology, Indonesian Institute of Sciences,
   Jl. Sangkuriang Bandung-40135, email: yudawati@yahoo.com; yuda@geotek.lipi.go.id

INTRODUCTION

Sea surface salinity (SSS) and precipitation are important parameters for climate (paleo) studies. Reconstructing past SSS variation is necessary to obtain the long time series SSS/precipitation data which further use for more accurate climate prediction model. Coral geochemical proxy is a promising tool for reconstruction of past climate parameters since they provide continues information from present until back hundreds years in monthly even weekly resolution. Several studies developed method of reconstruction of seawater $\delta^{18}O$ based on coral proxy (e.g Gagan et al., 1998;1994; Ren et al., 2002; Cahyarini et al., 2008). Assuming that seawater $\delta^{18}O$ is linearly correlated with SSS (Schmidt, 1999; Juillet-Leclerc and Schmidt, 2001), thus reconstructing seawater $\delta^{18}O$ will be used further to reconstruct past SSS (precipitation). $\delta^{18}O$ in coral is influenced by both seawater $\delta^{18}O$ and sea surface temperature (SST) (Weber and Woodhead, 1972; Gagan et al., 1998; Pfeiffer et al., 2004; Cahyarini et al., 2008). Using paired proxy in coral e.g Sr/Ca and $\delta^{18}O$, where Sr/Ca is temperature proxy only thus one can reconstruct seawater $\delta^{18}O$. Several studies has used both Sr/Ca and $\delta^{18}O$ in coral to reconstruct seawater $\delta^{18}O$ (e.g Kilbourne et al.,2004; Ourbak et al., 2006; Cahyarini et al., 2008) which shows that paired Sr/Ca and $\delta^{18}O$ is promising tool for seawater $\delta^{18}O$ reconstruction.

In this study will be reconstructed seawater $\delta^{18}O$ from Bali corals. The coral $\delta^{18}O$ from Bali has been published by Charles et al (2003). They mention that the variation of sea surface temperature and precipitation, however it is not clear yet shown in their analysis the incorporation seawater $\delta^{18}O$ signal in the coral $\delta^{18}O$ from Bali corals. In this study will also be shown that the variation of coral $\delta^{18}O$ clearly influenced by seawater $\delta^{18}O$ (precipitation/SSS).

METHODS

Coral $\delta^{18}O$ which is recorded from *Porites* coral from Bali waters (8.15S, 115.30E) (Figure 1) is used in this study. The data extent from 1782-1989. This proxy data is obtained from Charles et al. (2003) (hereafter referred to as $\delta^{18}O_{bali}$). $\delta^{18}O_{bali}$ is analyzed using statistical time series data analysis provided by the KNMI explorer (Oldenborg and Burgers., 2005). Simple linear regression is used to get the correlation between two time series. In this study to know whether the climate parameters such as sea surface temperature (SST), precipitation influence the $\delta^{18}O_{bali}$. The simple linear regression is applied to the $\delta^{18}O_{bali}$ and SST to know the correlation between both timeseries. Besides based on the regression slope of $\delta^{18}O_{bali}$ and SST, one can indicate whether the $\delta^{18}O_{bali}$ is influenced by the precipitation (SSS) or not. Lower slope of $\delta^{18}O_{bali}$ and SST than the published estimated slope i.e -0.18 to -0.22 permil/^{o}C (Gagan et al.,1994;1998; Cahyarini et al., 2008) indicate that precipitation signal incorporated in the aragonite $\delta^{18}O$ besides SST. The low pass band filtered is applied to both proxy and historical data to get low frequency signal variation.

Using centering method (Cahyarini et al., 2008), $\delta^{18}O$ seawater is reconstructed based on coral $\delta^{18}O$ and sea surface temperature (SST). In this study SST, SSS and precipitation data are used for calibration. SST data is obtained from ERSST which available from 1884 to present. SSS is obtained from Simple Ocean Data Assimilation (SODA)

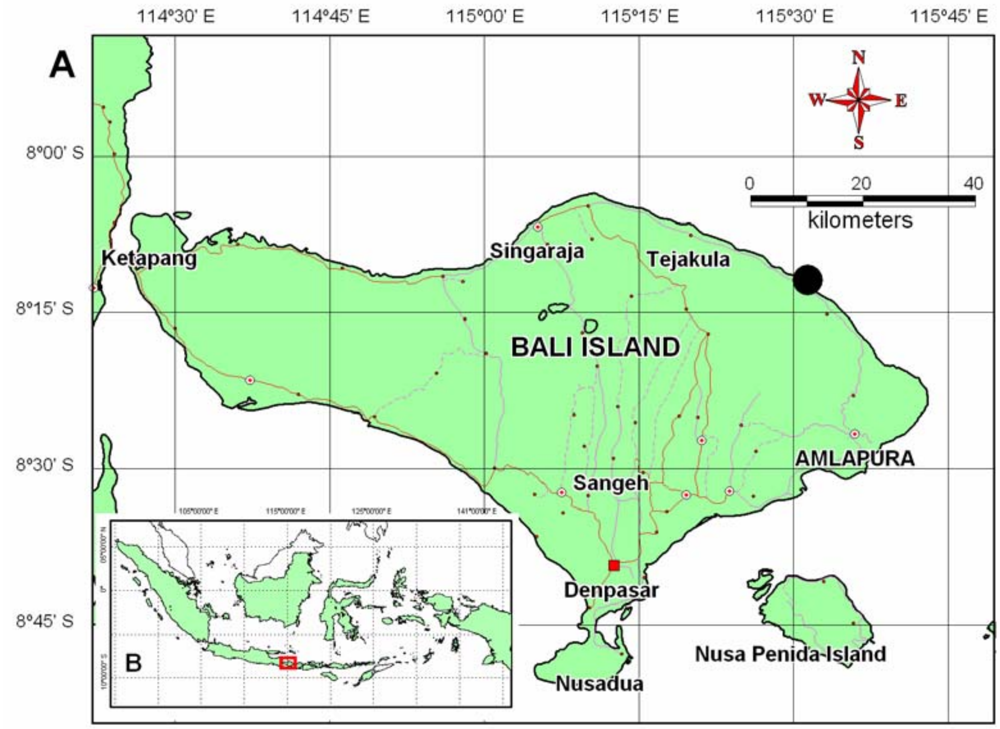

Figure 1. (A) Bali island map and coral site (black dot), (B) Indonesia map and location of Bali (box).

dataset (Carton et al, 2000). The availability of SODA SSS data is from 1958 to 2004. Precipitation measured close to the coral site i.e. Bondalem station is obtained from KNMI database, which available from period of 1952 to 1974. All timeseries are available in monthly resolution.

RESULTS AND DISCUSSIONS

Coral $\delta^{18}O$ is commonly used as a proxy data in the climate study. Incorporation of $\delta^{18}O$ in the aragonite carbonate is influenced by sea surface temperature (SST) and $\delta^{18}O$ seawater. Since Sr/Ca in coral is influenced by temperature only which is prominent proxy for temperature, thus coral $\delta^{18}O$ together with other proxy such as Sr/Ca in coral is used to reconstruct seawater $\delta^{18}O$ (Ren et al., 2002; Cahyarini et al., 2008) which is further to reconstruct SSS. Ideally, for reconstructing $\delta^{18}O$ seawater one should split the powder sample for both $\delta^{18}O$ and Sr/Ca analysis. In this study, there is not yet available Sr/Ca data from the Bali coral core. The available data is coral $\delta^{18}O$ only. Assuming that the SST data from the reanalysis model represents the actual SST variation back to hundreds years, therefore this SST data is used to reconstuct seawater $\delta^{18}O$ together with coral $\delta^{18}O$. In this study centering method (Cahyarini et al., 2008) is used to reconstruct $\delta^{18}O$ seawater. $\delta^{18}O$ content in coral is substracted by coral

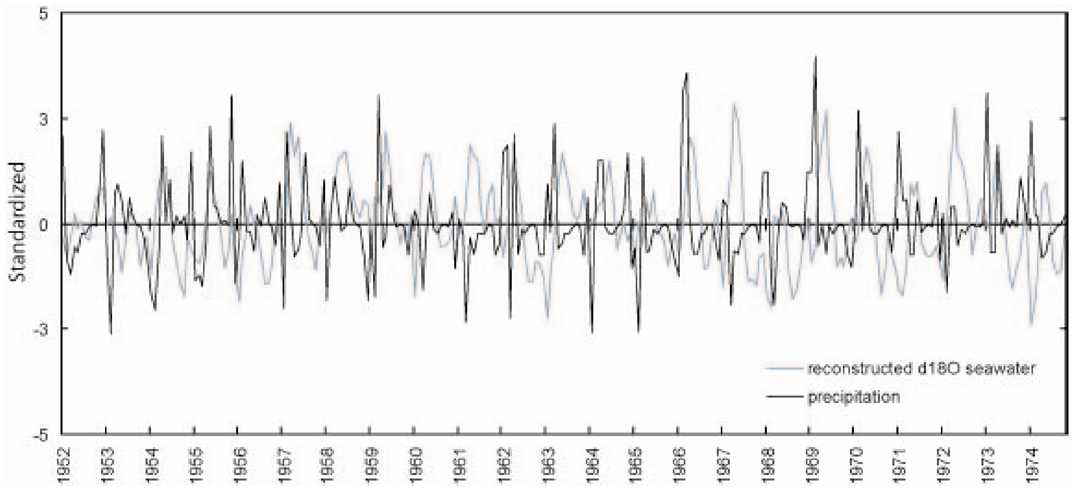

Figure 2 Standardized monthly variation of reconstructed seawater $\delta^{18}O$ for period from 1952 to 1975 compared to precipitation at Bondalam (see text for discussion)

$\delta^{18}O$ changes with respect to sea surface temperature (hereafter referred to as $\delta^{18}Osst$) to get coral $\delta^{18}O$ changes with respect to $\delta^{18}O$ seawater (see equation 1 from Cahyarini et al., 2008).

$$\delta^{18}O_{coral_i} - \overline{\delta^{18}O_{coral}} = \delta^{18}O_{sst_i} - \overline{\delta^{18}O_{sst}} + \delta^{18}O_{sw_i} - \overline{\delta^{18}O_{sw}}$$

i = 1,2,…n

where $\delta^{18}O_{coral}$ is the measured coral $\delta^{18}O$, and $\overline{\delta^{18}O_{coral}}$ is the mean value of measured coral $\delta^{18}O$. $\delta^{18}O_{sw}$ is the variations of coral $\delta^{18}O$ with respect to seawater $\delta^{18}O$, $\overline{\delta^{18}O_{sw}}$ is the mean value of $\delta^{18}O_{sw}$, $\delta^{18}O_{sst}$ is the variations of coral $\delta^{18}O$ with respect to SST, and $\overline{\delta^{18}O_{sst}}$ is the mean value of $\delta^{18}O_{sst}$.

Coral $\delta^{18}O$ from Bali coral (8.15 S, 115.30 E) is used to reconstruct $\delta^{18}O$ of Bali waters. The SST from ERSST position of coral site i.e. 8.15 S, 115.30 E is used to get the variation of the coral $\delta^{18}O$ changes with respect to τηε sea surface temperature (SST). Figure 2 shows standardized monthly variation of reconstructed seawater $\delta^{18}O$ for period from 1952 to 1975 which is compared to the precipitation data from the closest location with the coral site i.e Bondalem. The seasonal variation of reconstructed seawater $\delta^{18}O$ vary in phase with local precipitation, though in some years it vary out of phase e.g in year of 1961, 1967, 1972, 1974. It is inferred due to during those years both SST and precipitation vary out of phase. Thus, both SST and

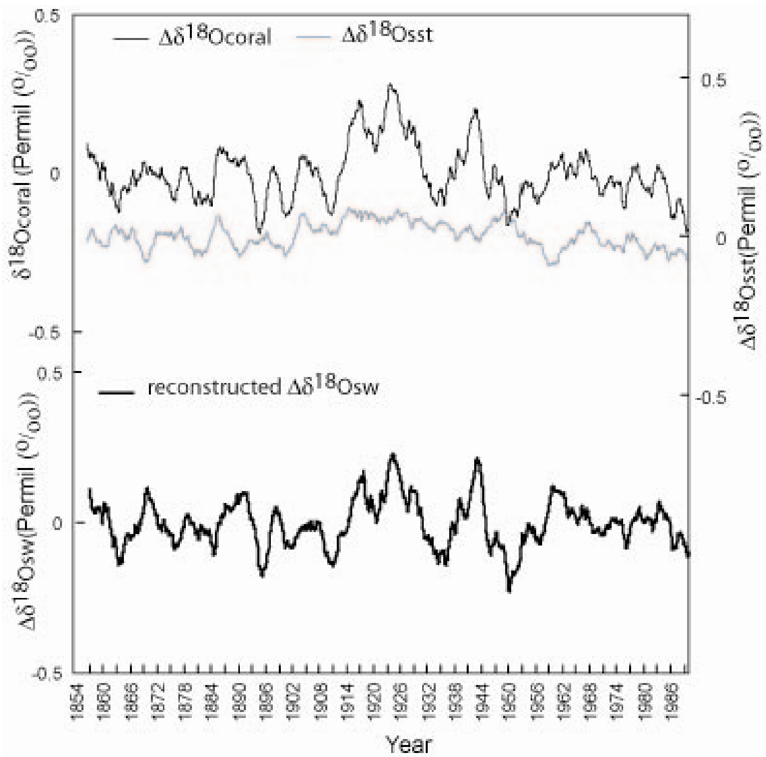

Figure 3. The top panel is centered of coral δ^{18}O (black line) and centered coral δ^{18}O changes with respect to SST (grey line). The bottom panel is reconstructed seawater δ^{18}O data from Bali coral. All timeseries is in 3 years running average.

precipitation damped the signal of seawater δ^{18}O in the coral δ^{18}O, which is resulted in high error propagation of reconstructed δ^{18}O seawater in those years i.e. 1961, 1967, 1972, 1974 .

Charles et al (2003) shows significant power spectrum in $\delta^{18}O_{bali}$ in the interannual period. In this study, to obtain interannual variation 3 years running averaged is applied into the monthly resolution of reconstructed seawater δ^{18}O data from Bali coral (Figure 3). It shows that in interannual time scale the magnitude of reconstructed δ^{18}O seawater vary from 0.2‰ to 0.4‰. Maximum δ^{18}O seawater variation is in the period of 1914-1932 and of 1935-1950, whether it coincides with higher precipitation at coral site during those periods or not needs to be observed. Unfortunately the measured precipitation data from the closest location to the coral site do not cover the periods of the reconstructed δ^{18}O seawater anomaly in this area to convince seawater δ^{18}O anomaly in the 1914-1932 and of 1935-1950 which is recorded by the proxy.

To observed low frequency variation i.e decadal-interdecadal scale, $\delta^{18}O_{bali}$ is filtered using low pass filtered with 120 months frequency band. The 120 months band is applied since the data is in monthly resolution, thus using 120 months band it is expected to get the decadal variation (10 yearly variation). The precipitation, SSS and SST data are also applied the same filtered to compare with the proxy. Period of 1958 to 1989 is selected to all timeseris to obtained the same length of data. The result is shown in Figure 4. All time series including $\delta^{18}O_{bali}$

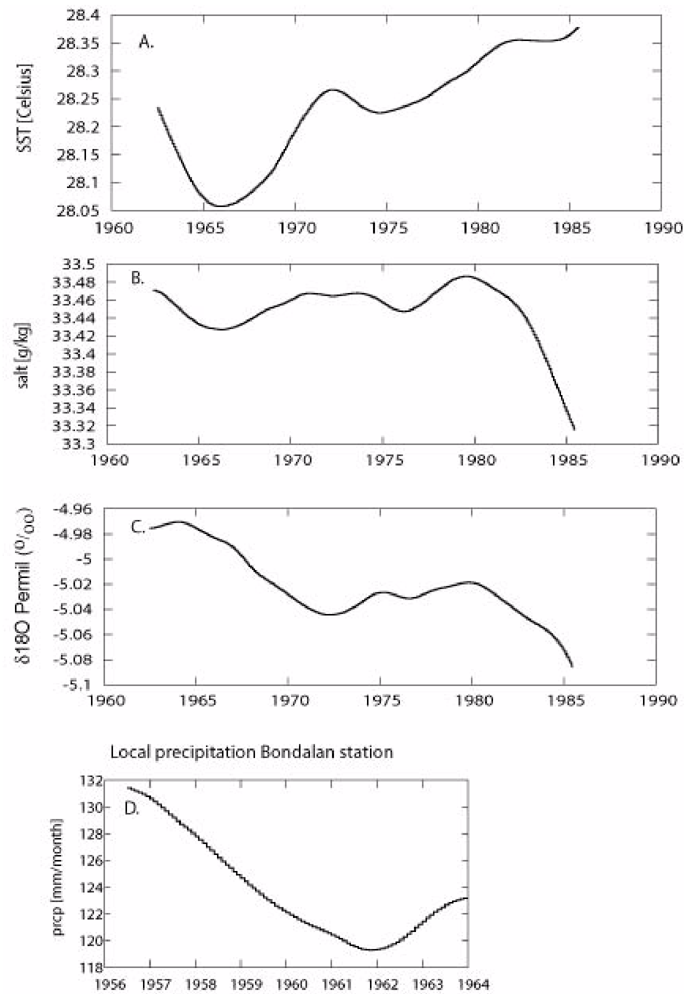

Figure 4 (A) Sea surface temperature, (B) SSS,(C) d18Obali , (D) Precipitation at Bondalem. All timeseries data is filtered for 120 months low pass filter.

shows decreasing till the end of 1965. Clearly warming is shown by SST starting after year of 1965. Both $\delta^{18}O_{bali}$ and SSS decrease abruptly after 1980 which is not shown by SST. It is convinced that in the low frequency time scale $\delta^{18}O_{bali}$ record SSS. Measured precipitation at Bondalem shows decreasing in the period of 1954-1965 similarly shown by $\delta^{18}O_{bali}$ and SSS. This result supports Charles et al.(2003) which mention that $\delta^{18}O_{bali}$ is influenced by both temperature and SSS. However this is not surprising if the SSS strongly recorded in $\delta^{18}O_{bali}$ since it is located at the exit passage of the Indonesian Through Flow (ITF) where the variation of SSS in this region is high in the interannual time scale (Sprintall et al., 2003).

CONCLUSIONS

$\delta^{18}O_{bali}$ influenced by both seawater $\delta^{18}O$ and sea surface temperature. Seawater $\delta^{18}O$ signal is clearly shown in the low frequency signal variation such as interannual and decadal-interdecadal time scale. However, further study should be established to obtain the more accurate calibration of reconstructed seawater $\delta^{18}O$ with precipitation (SSS) data. This can be done through long term monitoring program to obtained the long record of precipitation (SSS)

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REFERENCES

Cahyarini, S.Y., Pfeiffer, M., Timm, O., Dullo, W-C., and Schönberg, D.G., 2008.

Reconstructing seawater $\delta^{18}O$ from paired coral $\delta^{18}O$ and Sr/Ca ratios: Methods, error analysis and problems, with examples from Tahiti (French Polynesia) and Timor (Indonesia). *Geochimica et Cosmochimica Acta*, 72 (12): 2841-2853.

Carton, J. A.,. Chepurin, G., and Cao, X., 2000. A Simple Ocean Data Assimilation Analysis of the Global Upper Ocean 1950-1995. Part 1 Methodology, *Journal of Physical Oceanography,* 30: 294-309.

Charles C.D., Cobb, K., Moore, M. D., and Fairbanks, R.G., 2003. Monsoon-tropical ocean interaction in a network of coral records spanning the 20th century, *Marine Geology*, 201: 207-222.

Gagan, M. K., Chivas, A. R., and Isdale, P. J., 1994. High resolution isotopic records from corals using ocean temperature and mass spawning chronometers, *Earth and Planetary Science Letters*, 121: 549-558.

Gagan, M. K., Ayliffe, L. K. , Hopley, D. , Cali, J. A. , Mortimer, G. E. , Chappel, J., McCulloch, M. T. ,and Head M. J. ,1998. Temperature and surface ocean water balance of mid-Holocene tropical western pacific, *Science*, 279: 1014-1018

Juillet-Leclerc, A. and Schmidt G., 2001. A calibration of the oxygen isotope paleothermometer of coral aragonite from *Porites*, *Geophysical Research Letters*, 28 (21): 4135-4138.

Kilbourne, K. H., Quinn, T. M., Taylor, F. W., Delcroix, T., and Gouriou Y., 2004. El Niño-Southern Oscillation-related SSS variations recorded in the skeletal geochemistry of a *Porites* coral from Espiritu Santo, Vanuatu, *Paleoceanography*, 19, PA4002, doi: 10.1029/2004PA001033.

Oldenborgh, G.J. and Burgers, G., 2005. Searching for decadal variatios in ENSO precipitation teleconnections, *Geophysical Research Letters*, 32, 15, L15701, doi:10.1029/ 2005GL023110.

Pfeiffer, M., Dullo, W. Chr., and Eisenhauer, A., 2004. Variability of the Intertropical Convergence Zone recorded in coral isotopic records from the central Indian Ocean (Chagos Archipelago), *Quaternary Research*, 61: 245 - 255, doi 10.1016/ j. yqres. 2004. 02. 009.

Ren, L., Linsley, B. K., Wellington, G. M., Schrag, D. P., and O. Hoegh-Guldberg, 2002. Deconvolving the $\delta^{18}O$ seawater component from subseasonal coral δ18O and Sr/Ca at Rarotonga in the southwestern subtropical Pacific for the period 1726 to 1997, *Geochimica et Cosmochimica Acta*, 67: 1609-1621.

Schmidt, G. A., 1999. Error analysis of paleo SSS calculations, *Paleoceanography*, 14 (3): 422-429.