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Literature review of sea level variation in the Java Sea

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Abstract

Sea level variation in the Java Sea and its impact on the coastal cities in the northern part of the Java Island are reviewed. Influenced by the recent ENSO (El Niño Southern Oscillation) events from 1993 to 1999, the sea level rise rate of the Java Sea was higher than the global sea level rise rate. During the end of 1997 to 1998 of ENSO years, the sea level of the Java Sea recorded from tide gauges was the highest. The impact of Indonesian througflow within the Makassar Strait surface current on sea level characteristics of the Java Sea is also reviewed.

Keywords: ENSO, Makassar Strait, Indonesian throughflow, Java Sea

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1. Introduction

The northern coast of the Java Island, which has been already vulnerable to the disasters like flooding and inundation due to the northwest monsoon has been threatened by the phenomena of the sea level rise. The northern part of Jakarta is built in the low land area which is widely spread from the coastal line to several kilometers, and used for the industrial and urban areas. The low land of Jakarta city is frequently flooded during the peak of northwest monsoon from December to February not only by the tidal effects but also by the river water from the highland at the south (Nur et. al., 2001). As far as the elevation is concerned Semarang City has different characteristic from Jakarta City. Land elevation of the central area of Semarang City is lower than the mean sea level. And as the consequences the wet land is created by seawater penetration in the central area of Semarang. The sea level rise is the critical phenomenon for the Semarang City. It is predicted that more than quarter of the city will be inundated if the sea level rises around 1 meter (Arbiyakto, 2002). Surabaya City is the second biggest city in Indonesia next to Jakarta. The coastal areas of Surabaya are located in the north and east. Some coastal areas near the port of Surabaya are used for the industrial and residential areas. Nowadays there is a trend to convert the cultivated fish field to the housing areas because the demand of housing in Surabaya was rising. New housing areas will be inundated if the sea level rise around 1 meter (Wuryanti, 2002, Research Institute for Human Settlements Final Reports, 2001).

2. El Niño Southern Oscillation and sea level change

El Niño Southern Oscillation (ENSO) is the most prominent interannual climate variability in the world climate. It is well known that ENSO is associated with devastating droughts over the western tropical Pacific, torrential floods around the eastern tropical Pacific, and unusual weather pattern over the world (Nkendirim, 2000).

Interannual variation of sea level along the northern coast of Java Island and Indonesian seas is dominant factor of the long term trends. During the past decades the ENSO from 1997 to 1998 was the biggest, and made severe drought in Indonesia and the flooding in Bangladesh during the southeast monsoon in 1997 (Kumar *et al.,* 1999). ENSO-induced sea level changes also is the most important component in the Java Sea (Sofian and Kozai, 2004).

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A large scale weakening of the trade winds and warming of the surface layers in the eastern and central equatorial Pacific Ocean characterizes El Niño. El Niño events occur irregularly at intervals of 2 to 7 years, although the average is about once every 3 to 4 years (McPhaden, 1993). And during the strong 1997 to 1998 ENSO years particularly during the northwest monsoon, Indonesia had severe drought (Kumar *et al.*, 1999).

The Southern Oscillation (SO) is a planetary scale phenomenon involving a negative correlation between surface pressure over Indonesia and surface pressure over the southeastern Pacific. It is related to fluctuations in the intensity and position of the Walker circulation, an east-west cell with its upward branch near Indonesia and downward branch over the tropical eastern Pacific. According to the definition of CDC (Climate Diagnostics Center) NOAA, the Southern Oscillation Index (SOI) is defined as the normalized difference in surface pressure between Tahiti, French Polynesia and Darwin, Australia. This is a measure of the strength of the trade winds, which have a component of flow from regions of high to low pressure. High SOI (large pressure difference) is associated with stronger trade winds and La Niña conditions, and low SOI (smaller pressure difference) is associated with weaker trade winds and El Niño conditions. SOI ranging from +1 standard deviation to –1 standard deviation is defined as normal years. Higher negative value indicates a warm event (ENSO) and higher positive value indicates a cold event (La Niña) (Nkendirim, 2000).

Centre of the ENSO problem is the evolution of near-equatorial sea surface temperature (Harrison, 1990). In western Pacific warm pool is migrated eastward with the collapse of the trade winds (McPhaden, 1999). Based on the higher correlation between SST and sea level and between SOI and sea level Nerem and Mitchum (2001) developed simulated long term series of global mean sea level variations. A large increase in global mean SST was observed since 1982, and the largest changing occurred during the ENSO event from 1997 to 1998 that was changed about 0.35°C (Nerem, 1999, Nerem and Mitchum., 2001). Singh (2001) calculated the correlation between SOI and sea level for predicting the sea level one month in advance during the southeast monsoon. Also Singh (2001) found time lag correlation between SOI and the sea level. Singh (2001) also investigated cause effect relationship between sea surface temperature trend and sea level trend during the southeast monsoon in the Bay of Bengal, Bangladesh. The impact of ENSO on the sea level of Java Sea which was represented by the high correlation between SOI and sea level was investigated during 1993 to 1999(Sofian and Kozai, 2003a). The sea level rise from 1993 to 1999 in the Java Sea was 10 to 20 mm/year obtained from Surabaya, Jepara and Jakarta tide gauges (Sofian and Kozai, 2004). The highest sea level anomalies are also recorded during the end of 1997 to 1998 ENSO period (Sofian and K. Kozai, 2003b).

Bray *et al.* (1996) calculated correlation between wind stress and sea level in the Indonesian througflow. The correlation between sea level and wind was small. Also Bray *et al.* (1996) found that correlation between SOI and sea level anomaly was high in the eastern part of Indonesian Seas and small in the western part and in the South China Sea.

The characteristic of Indonesian throughflow was affected by ENSO. Ffield *et al.* (2000) found the high correlation between the thermocline temperature and the southward Makassar transport. Ffield *et al* (2000) also found that SOI has highly correlated with thermocline temperature. From these relationships during the El Niño period the southward Makassar transport is low and high during the La Niña period. Using the physical model, Waworuntu *et al.* (2000) explained that the strengthening of the pressure gradient in the lower thermocline between the Pacific Ocean and the Indonesian Seas during the La Niña period could increase the flow in the deeper thermocline from the Banda Sea to Makassar Strait. Gordon and Susanto (2002) reported sea level anomalies of Banda Sea were high during La Niña and drop to the lowest in the El Niño period. The same phenomena were also recorded in the Java Sea during the El Niño period. Sea level was dropped to the lowest and the highest was occurred in the La Niña period (Sofian and Kozai, 2003b). In the eastern Indian Ocean, the significant interannual variability of the upwelling along the southern coast of the Java and Sumatra islands is linked to the ENSO through the Indonesian troughflow and by anomalous easterly wind (Susanto *et al.,* 2001).

Wavelet analysis is becoming a common tool for analyzing localized variations of power within a time series. By decomposing a time series into time–frequency space, one is able to determine both the dominant space, one is able to determine both the dominant in time. As discussed by Kaiser (1994), the WFT (Windowed Fourier Transform) represents an inaccurate and inefficient method of time–frequency localization, as it imposes a scale or "response interval" T(time) into the analysis. The inaccuracy arises from the aliasing of high and low-frequency components that do not fall within the frequency range of the window. The wavelet transform can be used to analyze time series that contains nonstationary power at many different frequencies. Time series in geophysics exhibit nonstationarity in their statistics. While the series may contain dominant periodic signals, these signals can vary in both amplitude and frequency over long periods of time. Torrence and Compo (1999) applied wavelet analysis to obtain the ENSO impact on the NINO3 SST characteristics. Wavelet analysis was also used on NINO3 (the seasonal SST averaged over the central Pacific 5°S–5°N, 90°– 150°W) SST and monsoon indexes (Torrence and Webster, 1999). And Wang *et al.* (1999) applied wavelet analysis on the sea level anomalies of South China Seas.

3. Satellite altimeter observation for sea level changes

Over the last century long term sea level change has been estimated from tide gauge measurements, but the tide gauge has been two disadvantages comparing with the satellite altimeter data. The first is sea tide gauge drift and the second is the limitation of spatial distribution and poor spatial sampling of open ocean (Nerem and Mitchum, 2001). Nerem (1999) argued that combination between TOPEX/Poseidon (T/P) and tide gauges could achieve better accuracy to distinguish the sea level rise caused by climatic changes than tide gauges alone.

Based on the higher correlation between SST and sea level and between SOI and sea level Nerem (1999) developed simulated long term series of global mean sea level variations. Also Nerem (2001) explained that SST and sea level have several time lags during 1997 to 1998 ENSO events, suggesting that the temperature in the subsurface returned to the normal before the surface temperature.

During 1993 to 1998 high sea level rise reported in the several locations. Using ERS and T/P (TOPEX/Poseidon) altimeter data Cazanave *et al.* (2002) reported that sea level rise within the Mediterranean Sea was 7 ± 1.5 mm/year, and 27 ± 2.5 mm/year over the Black Sea. Emil and Peneva (2002) also reported that sea level trend of the Black Sea during 1993 to 1998 was 12 cm. The impact of ENSO on the high sea level trends in the Java Sea was 10 to 12 mm/year was recorded between 1993 to 1999 (Sofian and Kozai, 2004). Wang *et al.* (1999) using T/P and ERS from 1992 to 1997 found that the annual rising rate in the Yellow Sea, the East Sea and the South China Sea is +3.44 ± 0.61 mm/yr, +3.12 ± 0.47 mm/yr, and −1.41 ± 0.48 mm/yr, respectively. During the same period Nerem (1999) used the T/P altimeter data and reported that global mean sea level rate was 2.5 ± 1.3 mm/year.

4. Sea level changes and their connection with Makassar Strait

The Indonesian Seas consists of very deep basins in the east and the shallow Java Sea in the western part. The Java Sea is a shallow body of sea and has average depths of around 40 to 50 meters. It connects to the Sulawesi Sea to the northeast by the Makassar Strait, adjoins the Flores Sea to the east, connects to the South China Sea to the northeast via Karimata Strait, and Kalimantan to the north.

Fig.1 displays Indonesian Seas including the Java Sea. The largest and the deepest is the Banda Sea which has depths in excess of 4500 m in the southeast (also known as the South Banda Sea) and in the northwest (the North Banda Sea), separated by a ridge of less than 3000 m depth; largest depths are near 7440 m in the south and 5800 m in the north. The Sulawesi Sea (formerly known as the Celebes Sea) is a single basin of similar size deeper than 5000 m over most of its area. Between these two major basins are three basins deeper than 3000 m, the Molucca, Halmahera, and Seram Seas, the latter being deeper than 5300 m. North of the Sulawesi Sea and enclosed by the islands of the Philippines is the Sulu Sea, which has depths in excess of 4500 m. The Flores Sea is located in the south, connecting the Banda Sea with the shallow Java Sea and reaching nearly 6400 m in a deep depression. The Sawu Sea, which reaches nearly 3500 m depth, is the southernmost basin between Timor, Sumba, and Flores. Another important topographic feature is Makassar Strait between the Sulawesi and Java Seas. Makassar strait is shallow in the west but over 2000 m deep in the east where it is connected without obstruction to the Sulawesi Sea in the north (Tomczak, 2001).

The climate of the Indonesian Sea is characterized by monsoonal winds and high rainfall. Winds blow from the northwest during November to March, and reach to peak in January to February. High rainfall is occurred in the Java Island during this which sometimes caused flooding in the several locations in the northern part of Java Island. Winds blow from the southeast during May to September, and wind direction nearly opposite to the northwest monsoon. Dry season occurs in the most part of Java Island.

Past observations show that the water composing of the Indonesian throughflow is derived from the North Pacific thermocline, though at greater depth it is directly drawn from the Indian Ocean (Gordon and Fine, 1996). During the northwest monsoon from January to March, the Java Sea low-salinity surface water shifts into the southern Makassar Strait. During the southeast monsoon, from July to September, the southern Makassar Strait surface layer is more saline and less buoyant, as the southeast monsoon winds return the low-salinity water into the Java Sea. The buoyant surface water of the southern Makassar Strait inhibits southward transport within the surface layer during the northwest monsoon, despite southward wind within the Strait, lowering the temperature of the Indonesian Throughflow (Gordon *et al.*, 2003). The low surface salinities of the Java and South China Seas are due to heavy precipitation and large river runoff from Southeast Asia. During the northwest monsoon, the eastward zonal wind expels the low salinity, buoyant water of the shallow Java Sea into the surface layer of the southern Makassar Strait. During the southeast monsoon, more saline of the Flores and Banda Sea shift into the Java Sea, shifting the buoyant from the southern Makassar Strait into the western Java Sea and the South China Sea.

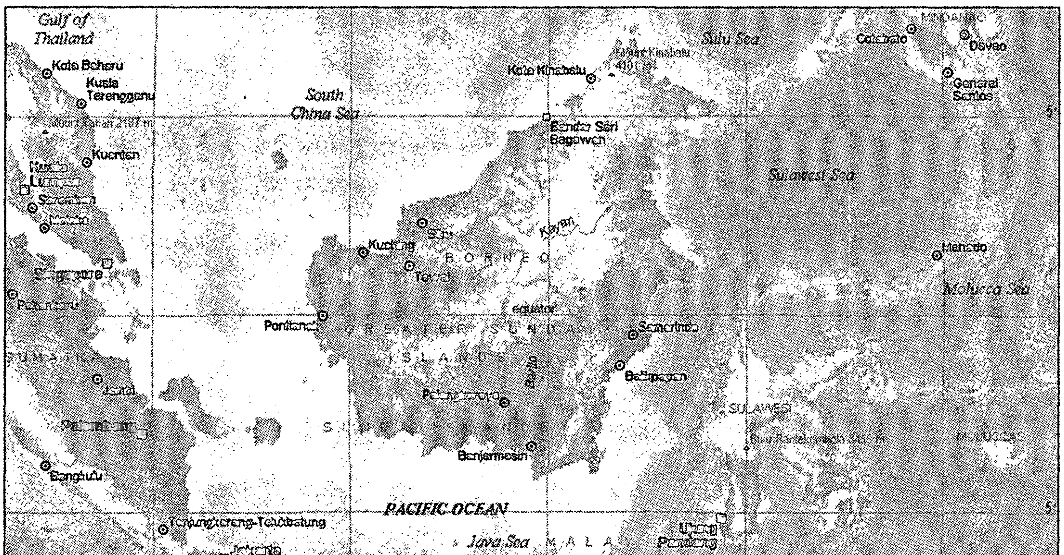

Figure 1. Indonesian Seas including the Java Sea

Connected with the monsoon period, sea level anomaly (SLA) of the Java Sea is low from September or October when the northwest monsoon begins to blow, and increasing to the highest in December. Then SLA decreases to the lowest in the middle of northwest monsoon (from January to February), and increases to the highest in the end of northwest monsoon (April)(Sofian and Kozai, 2003b).

Southward water transport within Makassar Strait shows high correlation with the temperature (averaged between 150 db and 400 db). During high (low) temperature, the volume transport is also high (low) (Ffield *et al.*, 2000). Gordon, *et al.* showed the result from the measurement using MAK-1 and MAK-2 moorings that the largest volume transport was occurred during the La Niña period, and getting smaller during the El Niño period. The direct measurements from MAK-1 and MAK-2 moorings were 12.5 Sv during the La Niña months of December 1996 through February 1997, and 5.1 Sv during El Niño months of December 1997 through February 1998 (Gordon *et al.*, 1999).

References

Arbiyakto, D. and D. Kardiyanto, 2002: Identifikasi pengukuran kerugian fisik bangunan rumah dan kerugian sosial penduduk kawasan pantai kota semarang, , Proceeding Kerugian pada bangunan dan kawasan akibat kenaikan muka air laut pada kota-kota pantai di Indonesia, pp 128-157.

Bray, N. A., S. Hautala, J. Chong, and J. Pariwono, 1996: Large scale sea level, thermocline, and wind variations in the Indonesian Throughflow region, Journal of Geophysical Research, Vol. 101, No.C5, pp 12239-12254.

Cazenave, A., P. Bonnefond, F. Mercier, K. Dominh, V. Toumazou, 2002: Sea level variation in the Mediteranian Sea and Black Sea from Sattelite altimetry and tide gauges, Global and Planetary Change, Vol. 34, pp 59-86.

Ffield A., K. Vranes, A. L. Gordon, R. D. Susanto, 2000: Temperature variability within Makassar strait, Geophysical Research Letters, Vol. 27, No. 2, pp 237-240.

Gordon, A. L., R. D. Susanto, K. Vranes, 2003: Cool Indonesian Throughflow as a consequence of restricted surface layer flow, Nature, Vol 425, pp 824-828.

Gordon, A. L. and R. A. Fine, 1996: Pathways of water between the Pacific and Indian Ocean in the Indonesian Seas, Nature, Vol. 379, pp 146-149.

Gordon, A. L., R. D. Susanto, A. Ffield, 1999: Throughflow within Makassar Strait, Geophysical Research letters, Vol. 26, No. 21, pp 3325-3328.

Gordon, A. L. and R. D. Susanto, 2001: Banda Sea surface layer divergence, Ocean Dynamics Vol. 52, pp 2-10.

Harrison, D. E., 1990: Mechanism of SST Change in the Equatorial Waveguide during the 1982-83 ENSO, Journal of Climate, Vol. 3, No. 2, pp 173-188.

Kaiser, G., 1994: A Friendly Guide to Wavelets. Birkhäuser, 300 pp.

Kumar, K. K., B. Rajagopalan, M. A. Cane, 1999: On the Weakening Relationship between the Indian Monsoon and ENSO, Science Vol. 284, pp 2156-2159.

McPhaden, M. J., 1993: TOGA-TAO and the 1991-92 EL Niño/Southern Oscillation Event, Oceanography, Vol. 6(2), pp 36–44.

McPhaden, M. J., 1999: Genesis and Evolution of the 1997-98 El Niño, Science Magazine Vol. 283, pp 950-954.

Nerem, R. S., 1999: Measuring very low frequency sea level variations using satellite altimeter data, Global and Planetary Change, Vol. 20, pp 157-171.

Nerem R.S., and G.T. Mitchum, 2001: Sea Level Change, in *Satellite Altimetry and Earth Sciences*: A Handbook of Techniques and Applications, edited by L. Fu, and A. Cazenave, pp. 329-349, Academic Press.

Nkendirim, L. C., 2000: El Niño Southern Oscillation: an Overview, El Niño Southern Oscillation and its impacts, A publication of the Commission on Climatology of the International Geographical Union, Bonn, pp 1-33.

Nur, Y., S. Fazi, N. Wirjoatmodjo, 2001: Towards wise coastal management proctise in a tropical megacity-Jakarta, Ocean and Coastal Management, Vol. 44, pp 335-353.

Research Institute for Human Settlements, 2001: Final report of the impact of sea level rise on Indonesian coastal cities.

Singh, O.P., 2002: Predictability of sea level in the Meghna estuary of Bangladesh, Global and Planetary Change, Vol. 32, pp 245-251.

Singh, O.P., 2001: Cause-effect relationship between sea surface temperature, precipitation and sea level along the Bangladesh coast, Theoretical and Applied Climatology, Vol. 68, pp 233-243.

Sofian, I. and K. Kozai, 2003a: ENSO Impact on the Sea Level Characteristics: Case Study in Java Sea, Proceeding on 30th International Symposium on Remote Sensing of Environment, TS-10.2.

Sofian, I. and K. Kozai, 2003b: Sea level change in the Java Sea during the ENSO years, 34th Proceedings of the annual meetings of Remote Sensing Society of Japan, pp 67-68.

Sofian, I. and K. Kozai, 2004: Estimation of mean sea level of the Java Sea by TOPEX/Poseidon including ENSO years, Proceedings of the second annual meetings of the Marine Meteorological Society of Japan, pp 47-51.

Stanev, E. V. and E. L. Peneva, 2002: Regional sea level response to global climatic change: Black Sea examples, Global and Planetary changes Vol. 32, pp 33-47.

Susanto, R. D., A. L. Gordon, Q. Zheng, 2001: Upwelling along coast of Java and Sumatra and its relationship to ENSO, Geophysical Research Letters, Vol. 28, No. 8, pp 1599-16202.

Tomczak, M. and J. S. Godfrey., 2001: Regional Oceanography: an introduction, online edition, pdf version 1.0, pp 220-228.

Torrence, C. and G. P. Compo., 1999: A Practical Guide to Wavelet Analysis, Bulletin of the American Meteorological Society: Vol. 79, No. 1, pp. 61–78.

Torrence, C. and P. J. Webster., 1999: Interdecadal Changes in the ENSO–Monsoon System, Journal of Climate, Vol. 12, pp 2679-2690.

Wang, H, et al, 1999: The Sea Level Anomalies in China Seas from Satellite Altimeter Data, GIS development-net.

Waworuntu, J. M., R. A. Fine, D. B. Olson, A. L. Gordon, 2000: Recipe for Banda Sea water, Journal of Marine Research, Vol. 58, pp 547-569.

Wuryanti, W., T. Utami, Kuswara, 2002: Pengukuran kerugian bangunan rumah akibat kenaikan muka air laut di Surabaya, Proceeding Kerugian pada bangunan dan kawasan akibat kenaikan muka air laut pada kota-kota pantai di Indonesia, pp 158-180.