



The Characteristics of Significant Wave Height and Sea Surface Temperature In The Sunda Strait

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Received: May 19, 2017

Accepted: June 05, 2017

Published: June 07, 2017

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Abstract

Sunda Strait has an important role in the water mass exchange from the Pacific Ocean and the Indian Ocean so that the oceanographic condition is strongly affected by seasonal factors. The purpose of this study is to observe the relationship and the characteristics of significant wave height (SWH) and sea surface temperature (SST) in the Sunda Strait and its relationship with IOD. The method employed is spatial analysis, low-pass filter, and spectrum analysis by S-Transform, beside that the correlation between SST and SWH is analysed by wavelet coherence. The period of SWH and SST is dominantly semiannual, at the time of winter monsoon (the Northeast Monsoon), the SWH was reaching up to 2,11 m, while at the summer monsoon, the SWH was reaching up to 3.62 m. Reversely, the SST increased during the winter monsoon. At the time of 2016 had been detecting by the negative IOD with the IOD index of -0.65 and it caused the SWH increased by 0.3 m than its average. Based on the wavelet coherence, the SWH and the SST have the coherence in the period of 8 to 16 days, especially in March to April, and June to August.

Keywords: Significant wave height, sea surface temperature, Indian Ocean Dipole, spectral analysis

1. Introduction

The Sunda Strait and the waters around it have coordinates at 2 - 3°S and 104 - 107°E and it has linked to the Indian Ocean directly. The Sunda Strait was the shallow water (20 m) (Potemra *et al*, 2016). Based on observations from Aquarius satellite that indicate periods of mass flow of water transport in the Strait of Sunda, stating that the Sunda Strait has an important role in the exchange of water mass from the Pacific Ocean to the Indian Ocean (Potemra *et al*, 2016; Susanto *et al*, 2016). Based on research conducted by Susanto *et al* (2016), oceanographic conditions in the Sunda Strait is strongly affected by seasonal factors. There is a flow of water mass transport from the Java Sea has a low salinity of the Indian Ocean to the east

through the Sunda Strait to improve the productivity of the sea. It was occurring in the summer monsoon (Setiawan *et al*, 2015; Susanto *et al*, 2016).

Based on previous research, the significant wave height (SWH) determination has been done by using wind velocity data information based on the relationship between wind and wave (Altunkaynak and Ozger, 2004). Long-term observation the SWH has an impact on the ecosystem of the waters, it was been observed by Woo and Park (2016) in which the long-term trend of SWH extremes in the waters of Japan will have an impact on the ecosystem



based on an increased mixing of the sea surface water mass.

The SWH observation has also been done in the North Indian Ocean and it was compared to wind velocity. The result is the SWH and wind velocity have a high correlation as high as 0.91 (Kumar *et al* 2015). The seasonal influence is highly dominant in the Indian Ocean due to the monsoon wind reversed direction twice a year (Tomczak, 2001; Anoop *et al*, 2015). Indian Ocean Dipole (IOD) is a sea - atmosphere interaction that occurred in the Indian Ocean, where it is determined from the difference in temperature between the West Sumatra to eastern Africa. IOD anomaly may affect rainfall and drought in Africa and Indonesia (Saji *et al*, 1999; Wang and Wang, 2014).

The purpose of this research is to observe the relationship between SWH and sea surface temperature (SST) in the Sunda Strait. In addition, this study would also analyse the characteristics of the SWH and the SST in the Sunda Strait and its relationship with IOD.

2. MATERIALS AND METHODS

2.1 Data

This research used the gridded reanalysis ERA-Interim daily SWH and MSLP data in the Sunda Strait area in the year of 2016 by six hourly interval step. They have the resolution as big as 0.125°, and it was downloaded by *European Centre for Medium-Range Weather Forecasts* (ECMWF) in the region of 3 S – 10 S and 103 E – 108 E. The IOD index was downloaded in http://www.jamstec.go.jp/frcgc/research/d1/iod/H_TML/Dipole%20Mode%20Index.html and the ONI index was also downloaded in <https://data.noaa.gov/dataset/climate-prediction-center-cpcocceanic-nino-index>.

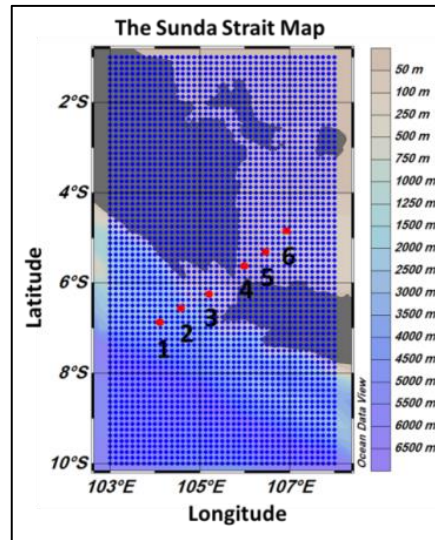


Figure 1 The bathymetry condition in around of the Sunda Strait with the several sample points.

That data would be processed by the methods of S-transform to observe the period distribution of the significant wave height, *Ocean Data View* and *Hovmoller* diagram as a visual analytic, *Cross Wavelet Transform*, and *Wavelet Coherency* by *Morlet Wavelet* with significance level 95 % (Grinsted *et al*, 2004).

Table 1. Sampling point coordinates

Point	Longitude	Latitude
1	6.625 S	104.5 E
2	6.5 S	104.875 E
3	6.125 S	105.375 E
4	5.75 S	106 E
5	5.375 S	106.5 E
6	5 S	107 E

2.2 Significant wave height (SWH)

The ocean waves were different to sea surface elevation. Determination of the wave can be done by two methods, such as the zero-crossing downward or upward zero-crossing (Holthuijsen, 2007). An ocean wave is a vertical movement of the sea surface in the horizontal position. The mean of the wave characteristics is commonly called by the SWH and significant wave period (T_s) (Holthuijsen, 2007). The wave height can be defined as the vertical distance between the highest sea surface conditions with the lowest sea level conditions in a wave. For the N number of waves, can be formulated as an average wave height as a bellow:

$$\bar{H} = \frac{1}{N} \sum_{i=1}^N H_i \quad (1)$$

Whereas i is the order of the wave recorded. In the wave height measurement, often use the term significant wave height (H_s), while it is an average of the highest one-third of the waves, which has been formulated by Holthuijsen (2007), as follows:

$$H_{1/3} = \frac{1}{N/3} \sum_{j=1}^{N/3} H_j \quad (2)$$

Whereas j was the number of the highest wave recorded.

The first method to observe the dominant period of SST is the *S-Transform*. It was a window variable from *short-time Fourier Transform* (STFT) or it would be the extension from wavelet transform (WT) (Wang, 2010). The time series spectrum component could be shown by the *Fourier Transform* and only contains the information about the time series spectrum components, but can't to identify the time distribution at different frequencies. Wavelet Transform either to extract the data information in time and frequency domains. However, the wavelet transform is sensitive to noise. Equation 1 shows the correlation between *S-Transform* and STFT. The STFT equation to $h(t)$ signal is shown in the below:

$$STFT(\tau, f) = \int_{-\infty}^{\infty} h(t)g(\tau - t)e^{-j2\pi ft} dt \quad (1)$$

Where:

- τ : Spectrum localization time
- f : Fourier frequency
- $g(t)$: Window function

Changing $g(t)$ value is the one of the ways to determine *S-transform* with the Gaussian function, such as:

$$g(t) = \frac{|f|}{\sqrt{2\pi}} e^{-\frac{t^2 f^2}{2}} \quad (2)$$

From the Equation 1 and 2, can be identified to *S-Transform* and it becomes the Equation 3:

$$S(\tau, f) = STFT(\tau, f) = \int_{-\infty}^{\infty} h(t) \frac{|f|}{\sqrt{2\pi}} e^{-\frac{(\tau-t)^2 f^2}{2}} e^{-j2\pi ft} dt \quad (3)$$

In the other words, the *S-Transform* is the other form of STFT with Gaussian window.

3. RESULTS AND DISCUSSION

3.1 Seasonal condition by spatial appearances

Figure 2 shows the seasonal variation in the average of the SST in the Sunda Strait. These seasonal changes also occur in a SWH (Figure 3). At the time of the winter monsoon (the northeast monsoon), the SWH was reaching up to 2.11 m, while at the summer monsoon, the SWH was reaching up to 3.62 m, where that condition is the highest wave condition in 2016. There was a difference of the SWH between in northern and southern of the Sunda Strait (Figure 3). The bathymetric difference between the north and south of the Sunda Strait is one of the factors that made these variations.

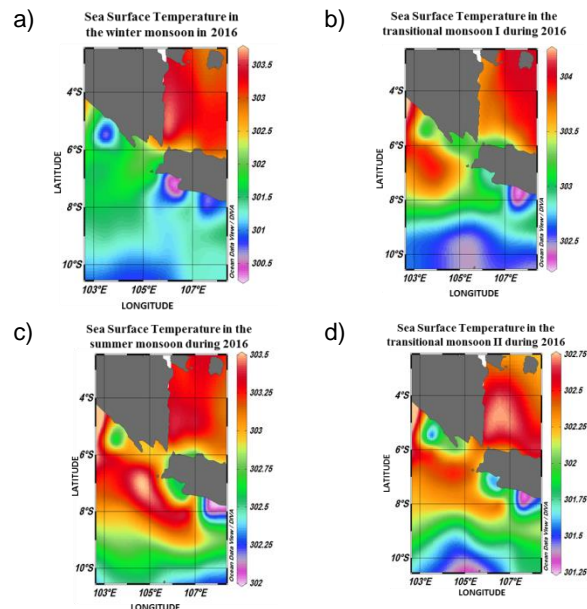


Figure 2 The condition of SST (K) in the Sunda strait in the year of 2016. (a) northeast monsoon (December – February), (b) northwest monsoon (March – May), (c) southwest monsoon (June – August), (d) southeast monsoon (September – December).

The bathymetry condition in the south of Sunda Strait is deeper than the bathymetry in the north of Sunda Strait. It makes a difference of SWH condition at around the Sunda Strait (Figure 3). In addition, the relation between the SWH and the SST in the Sunda Strait can be observed. Additionally, the negative correlation was also observed on the spatial distribution of the SWH and SST. The value of the SWH was increasing by 0.1 m during the winter monsoon. Meanwhile, the SST had been decreasing (Figure 2 and 3).

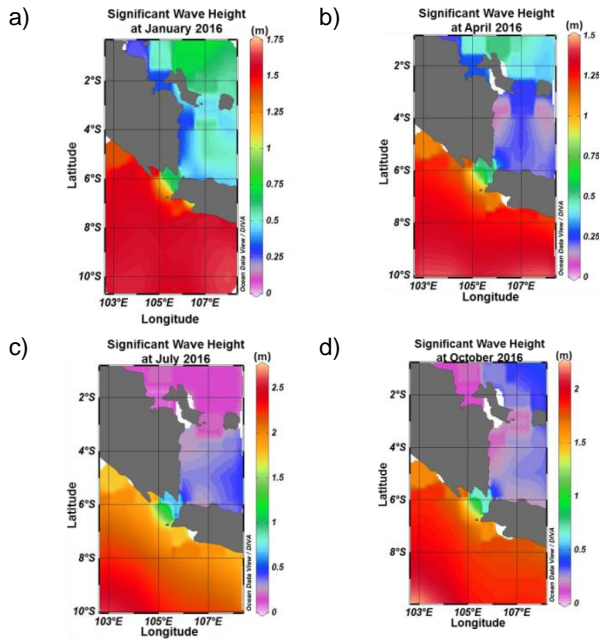


Figure 3 The condition of SWH (m) in the Sunda strait at the year of 2016. (a) northeast monsoon (December – February), (b) northwest monsoon (March – May), (c) southwest monsoon (June – August), (d) southeast monsoon (September – December).

3.4 The Time – Longitude Distribution

Figure 4 and **5** show the influence of the IOD on the SWH and the SST in the Sunda Strait. The SWH has been increasing when the negative IOD was occurring. Based on the studies that have been conducted, it was found that the incidence of negative IOD could increase rainfall in southern Australia (Cai *et al.*, 2012; Weller and Cai, 2013; Qiu *et al.*, 2014). The average of the IOD index during May until November 2016 as low as -0.6 (**Figure 5**). It can be called by the negative IOD and at this time, the SWH has been increasing by 0.3 m.

Based on **Figure 2**, there was a difference in SWH condition between north and southern of Sunda Strait. Similarly to **Figure 5**, the SWH difference caused due to differences in the condition of the bathymetry. The ENSO did not influence to the SWH condition in Sunda Strait. In June until the present has been occurring the weak La Nina. It was detected by the Ocean Nino Index (ONI) which has the value of -0.52. According to Izaguirre *et al.* (2011) stated that these climate patterns as the most relevant in the interannual extreme wave climate. When the negative IOD was occurring, the SST was increasing.

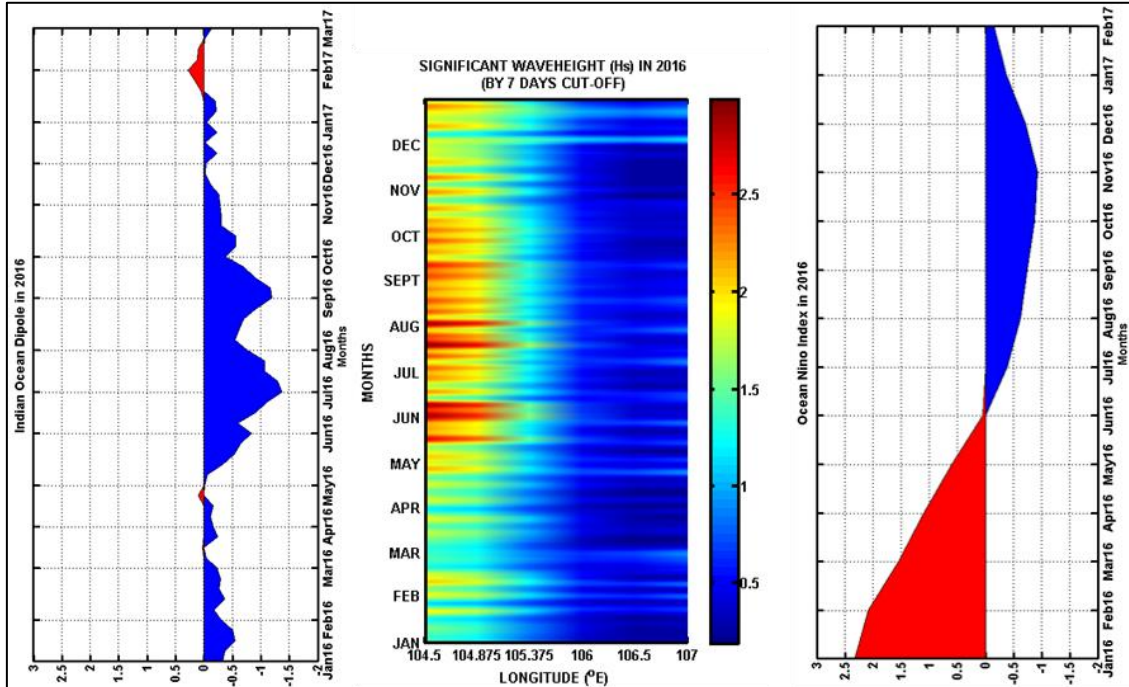


Figure 4 The time – longitude distribution of the SWH condition in 2016 by using the Hovmoller diagram and used the low-pass filter by 7 days cut off. The right side is an ONI and the left side is an IOD index.

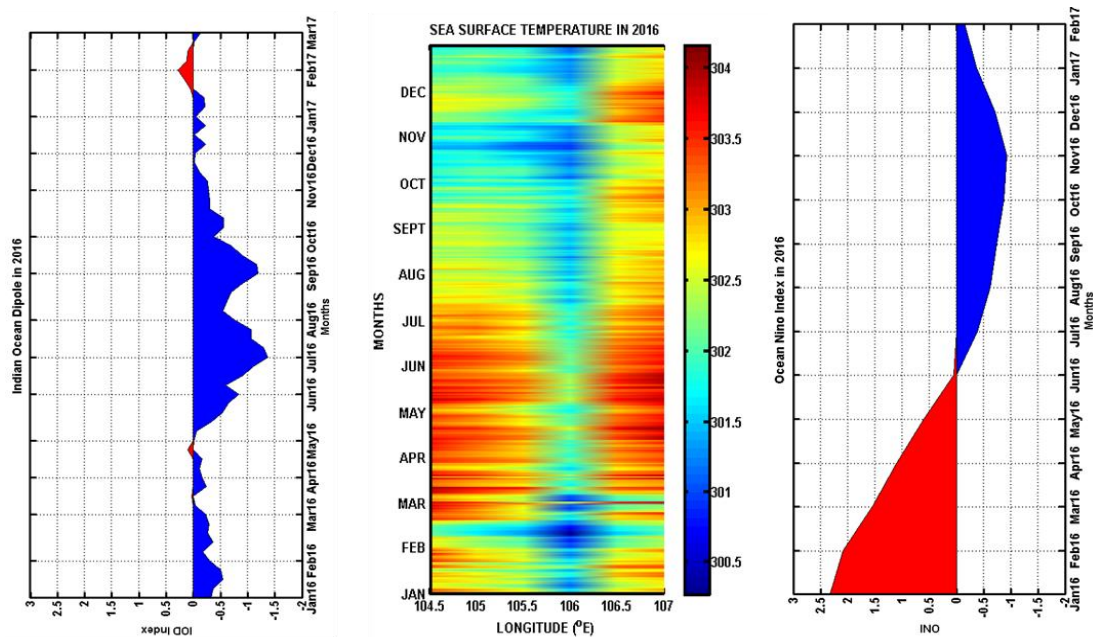


Figure 5 The time – longitude distribution of the SST condition in 2016 by using the Hovmoller diagram. The right side is an ONI and the left side is an IOD index.

3.5 Spectral Analysis

Figure 6 shows the results of the SWH energy spectrum in the Sunda Strait and it has a dominant period of 10 days. In addition, the SWH in Sunda Strait has the several periods, namely intra-seasonal (35-90 days) and semiannual (6 months) are the most dominant (Susan *et al*, 2001; Sprintall *et al*, 2000). The period of SWH in the Sunda Strait or at the point of 1, 2, and 3, dominantly were lower than 2 months.

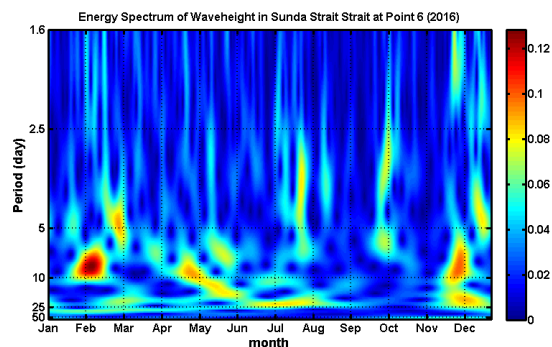
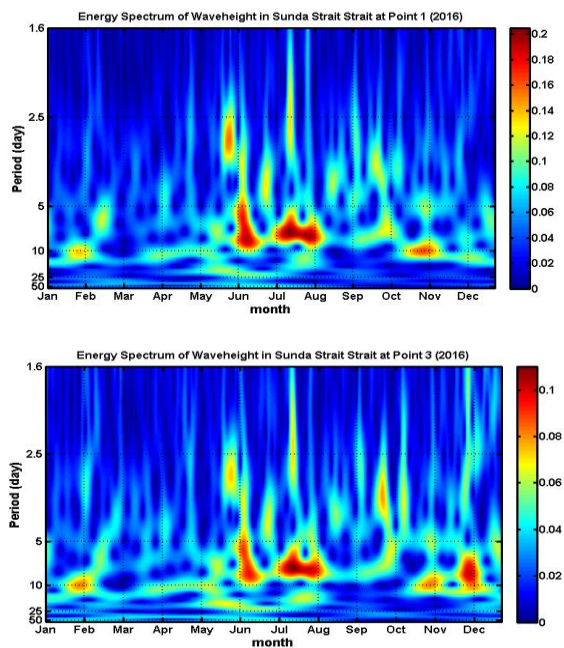


Figure 6. The energy spectrum of waveheight in the Sunda strait at the point of 1, 2, and 3 in 2016.

These show that the monsoonal factor was not dominant in the southern of the Sunda Strait. Meanwhile, the SWH in the Sunda Strait also had a period of the time period between 1-2 months. Semiannual variability is strongly influenced by the local wind. It is very interesting to study more about the Kelvin wave intrusion in the Sunda Strait. This is because the Kelvin wave propagates eastward through the west coast of Sumatra and southern of Java, and has a period of intra-seasonal, semiannual, inter-annual (Sprintall *et al*, 2000; Susanto *et al*, 2001; Syamsudin, 2004).

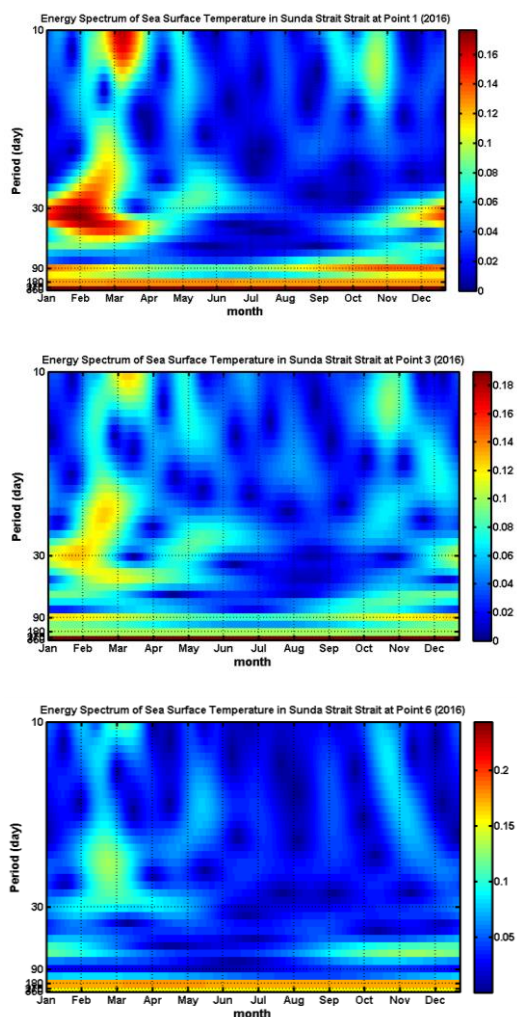


Figure 7. The energy spectrum of SST in the Sunda strait at the point of 1, 2, and 3 in 2016.

4. CONCLUSION

Based on the results and discussion of the research, it can be concluded that the IOD phenomenon has an influence on the significant wave height and mean sea level pressure. In 2016, negative IOD phenomenon was detected in June until November, it also results in a significant wave height and SST have increased. Based on the spectral analysis, there was the same period in both of SWH and the MSLP in the Sunda Strait.

This suggests that seasonal factors greatly affect the characteristics of the SWH and the SST in the Sunda Strait. For the further research, the Kelvin wave propagation in the Sunda Strait is potential to analyze.

From this study, the data source is developed by forecasting, automatically the data has an error compared with the real field condition. So that it will be more accurate if the forecast data is

evaluated by field measurement and calculate the error between forecast and field measurement result.

This study can be useful as a basis for fisherman awareness due to the seasonal oceanography condition in the Sunda Strait and also as a basis for the next research in the same field.

5. ACKNOWLEDGEMENT

The authors gratefully acknowledge to the *European Centre for Medium-Range Weather Forecasts* (ECMWF) since provided us the research data. So we had finished our research.

6. REFERENCES

Anoop, T.R., Kumar, V.S., Shanas, P.R. and Johnson, G., 2015. Surface wave climatology and its variability in the North Indian Ocean based on ERA-Interim reanalysis. *Journal of Atmospheric and Oceanic Technology*, 32(7), pp.1372-1385, doi:10.1175/JTECH-D-14-00212.1

Altunkaynak, A. dan M. Ozger, 2004. Temporal Significant Wave Height Estimation from Wind Speed by Perceptron Kalman Filtering. *Ocean Engineering*, 31, 1245 – 1255, doi: 10.1016/j.oceaneng.2012.08.005.

Cai, W., Rensch, P., Cowan, T. & Hendon, H. H. *An asymmetry in the IOD and ENSO teleconnection pathway and its impact on Australian climate*. *J. Clim.* 25, 6318–6329 (2012), doi: 10.1175/JCLI-D-11-00501.1.

Cochran, W.T., Cooley, J.W., Favon, D.L., Helms, H.D., Kaenel, R.A., Lang, W.W., Maling, G.C., Nelson, D.E., Rader, C.M. and Welch, P.D., 1967. What is the fast Fourier transform?. *Proceedings of the IEEE*, 55(10), pp.1664-1674.

Carr, P. and Madan, D., 1999. Option valuation using the fast Fourier transform. *Journal of computational finance*, 2(4), pp.61-73.

Grinsted, A., J. C. Moore, and S. Jevrejeva. 2004. *Application of the Cross Wavelet Transform and Wavelet Coherence to Geophysical Time Series*. *Nonlinear Processes in Geophysics*, 11: 561 – 566.

Izaguirre, C., F. J. Méndez, M. Menéndez, and I. J. Losada (2011), Global extreme wave height variability based on satellite data, *Geophys. Res. Lett.*, 38, L10607, doi:10.1029/2011GL047302.

Kumar, U.M., Swain, D., Sasamal, S.K., Reddy, N.N. and Ramanjappa, T., 2015. Validation of SARAL/AltiKa significant wave height and

wind speed observations over the North Indian Ocean. *Journal of Atmospheric and Solar-Terrestrial Physics*, 135, pp.174-180, doi: 10.1016/j.jastp.2015.11.003.

Studies in Oceanography, doi:
10.1016/j.dsr2.2016.09.003.

- Potemra, J.T., Hacker, P.W., Melnichenko, O. and Maximenko, N., 2016. Satellite estimate of freshwater exchange between the Indonesian Seas and the Indian Ocean via the Sunda Strait. *Journal of Geophysical Research: Oceans*, 121(7), pp.5098-5111, doi: 10.1002/2015JC011618.
- Qiu, Y., Cai, W., Guo, X. and Ng, B., 2014. The asymmetric influence of the positive and negative IOD events on China's rainfall. *Scientific reports*, 4, p.4943.
- Saji, N.H., Goswami, B.N., Vinayachandran, P.N. and Yamagata, T., 1999. A dipole mode in the tropical Indian Ocean. *Nature*, 401(6751), pp.360-363, doi: 10.1038/43854.
- Setiawan, R.Y., Mohtadi, M., Southon, J., Groeneveld, J., Steinke, S. and Hebbeln, D., 2015. The consequences of opening the Sunda Strait on the hydrography of the eastern tropical Indian Ocean. *Paleoceanography*, 30(10), pp.1358-1372, doi: 10.1002/2015PA002802.
- Sprintall, J., Gordon, A.L., Murtugudde, R. and Susanto, R.D., 2000. A semiannual Indian Ocean forced Kelvin wave observed in the Indonesian seas in May 1997. *Journal of Geophysical Research: Oceans*, 105(C7), pp.17217-17230, doi: 10.1029/2008JC005257.
- Susanto, R.D., Wei, Z., Adi, T.R., Zheng, Q., Fang, G., Fan, B., Supangat, A., Agustiadi, T., Li, S., Trenggono, M. and Setiawan, A., 2016. Oceanography Surrounding Krakatau Volcano in the Sunda Strait, Indonesia. *Oceanography*, 29(2), pp.264-272, doi: 10.5670/oceanog.2016.31.
- Tomczak, M., dan J. S. Godfrey. 2001. *Regional Oceanography: An Introduction*. Permagon. Tarrytown. New York.
- Wang, X., & Wang, C. (2014). Different impacts of various El Niño events on the Indian Ocean Dipole. *Climate dynamics*, 42(3-4), 991-1005.
- Weller, E. & Cai, W. *Asymmetry in the IOD and ENSO Teleconnection in a CMIP5 Model Ensemble and Its Relevance to Regional Rainfall*. *J. Clim.* **26**, 5139–5149. 10.1175/JCLI-D-12-00789.1 (2013), doi: 10.1175/jcli-d-12-00789.1.
- Woo, H.J. and Park, K.A., 2016. Long-term trend of satellite-observed significant wave height and impact on ecosystem in the East/Japan Sea. *Deep Sea Research Part II: Topical*