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by Diah Permata

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Study of inundation events along the southern coast of Java and Bali, Indonesia (case studies 4-9 June 2016)

I R Nugraheni[1,4], D P Wijayanti[1], D N Sugianto[2,3], A Ramdhani[4]

[1] Faculty of Fisheries and Marine Science, Diponegoro University, Jl. Prof. Soedarto SH. UNDIP, Tembalang, Semarang 50275, Indonesia
[2] Departement of Oceanography, Fisheries and Marine Science Faculty, Diponegoro University, Jl. Prof. Soedarto SH. UNDIP, Tembalang, Semarang 50275, Indonesia
[3] Center for Coastal Disaster Mitigation and Rehabilitation Studies, Diponegoro University, Jl. Prof. Soedarto SH. UNDIP, Tembalang, Semarang 50275, Indonesia
[4] Indonesian Agency for Meteorology Climatology and Geophysics, Jl. Angkasa I No.2, Kemayoran, Jakarta 10610, Indonesia

E-mail: imma.redha@yahoo.com

Abstract. It is important to understand the causes of costal inundation in order to supporting coastal hazard mitigation strategies, especially for the island nation like Indonesia. We investigated the interaction of waves, swell, tides and sea level variability at the coastal inundation events that occurred along southern coast of Java and Bali on June 4 to 9, 2016. The increase of high water level and low water level clearly seen compared to the same astronomic phase tides data before and after the inundation events. The high value of sea level anomaly (SLA) also indicates that there is sea level variability. The wave and swell analysis suggests that extreme waves and swell which occurs during the early of June 2016 has a contribution to the rising of the sea level during the inundation time span. Swell has a major contribution in the wave action that triggering this inundation event given that the significant waves that occur in the time span of the inundation were not affected by wind, but by the swell. This research has shown that the interaction of astronomical tides, SLA height, and high waves and swell along the southern coast of Java and Bali was causing the inundation events at 4-9 June 2016.

Keywords: Coastal Inundation, Tides, SLA, Wave, Swell

1. Introduction

Fifth Assessment Report (AR5) Intergovernmental Panel on Climate Change (IPCC) states that climate change had an impact on the changes of surface winds and sea waves, rise of sea levels and the increase of strong-intensity cyclones/hurricanes frequency in the ocean that potentially increases the incident of inundation / flooding in coastal areas [1]. Coastal inundation events may altering the coastline, damaging the infrastructure, causing contamination of freshwater reserves, and in the worst cases can leading to the loss of human life [2]. Coastal inundation generally caused by astronomical tides, tropical cyclone storm surges [3,4] and the regionally sea level variability such as due to El Niño/Southern Oscillation (ENSO) [5,6]. Understanding the processes that lead to coastal inundation/ flooding is very important to coastal hazard mitigation strategies, especially for the island nation.

In early June 2016, Indonesian Agency for Meteorology Climatology and Geophysics (hereafter referred to as BMKG) reported on the incident of high waves (>2 m) along the southern coast of Java and Bali. Furthermore, according to data from the Indonesian National Disaster Management Agency (hereafter referred to as BNPB), at least 5 coastal inundation incidents and 6 wave tides and abrasion incidents occur along the south coast of Java and Bali during June 4 to 9, 2016. This incident leads to the damage of infrastructure along the coast and severe abrasion [7].

The events reported here are by no means unprecedented. A similar case occurred in the Pacific Island in which the widespread coastal inundation occurred over several consecutive days in December 2008. These events were not associated with generally identified cause (such as: tropical cyclone, or unusually large astronomical tides), but instead the swell wave as the main cause [8].

Research on the inundation and extreme waves at the south coast of Indonesia has been done by previous researchers. The study on modeling of storm tide flooding along the southern coast of Java was conducted which the results showed that although the Cyclones Jacob and George in March 2007 did not generate high storm surges along the coast of Java (surge heights <20 cm), the southern coast of Java was still severely flooded [3]. This suggests that there are factors beyond the hurricane / cyclone that may contribute to the occurrence of the inundation. Furthermore, the simulation of extreme wave events in May 2007 was conducted using the wave model WaveWatch-III (hereafter referred to as WW3) [9] which occurred simultaneously with inundation along western coast of Sumatra and southern coast of Java to Nusa Tenggara. The results showed that the dominant factor causing these extreme events are swell that propagate from the Cape of Good Hope, Africa which caused by the hurricane /cyclone [10]. However, these researches have not shown how the interaction of wave, tides and swell contributed to the inundation incident.

Here, we present the documentation and analysis of the coastal inundation that occurred along southern coast of Java and Bali on June 4 to 9, 2016. We draw on data from a variety of sources, including the disaster report from BNPB, waves and swell modeling data from BMKG, oceanographic observation data by satellite altimetry from AVISO and tides data from Indonesian Geospatial Information Agency (hereafter referred to as BIG). The objective of this research is to investigate the interaction of waves, swell, tides and sea level variability at the inundation incident. The results of this present study would be provide the insight into the causes of coastal inundation events and could be significantly valuable for adaptation and mitigation strategies in coastal inundation hazard.

2. Methodology

2.1. Study area

Study areas of this research are the southern coastal areas of Java and Bali (figure 1). The southern coastal areas of Java and Bali are facing directly to the Indian Ocean. Bathymetric profile of southern Java and Bali are parallel to the coastline which relatively shallow near the coast, gradually deeper toward the open sea and at some point varies drastically drop due to the sea trench [11].

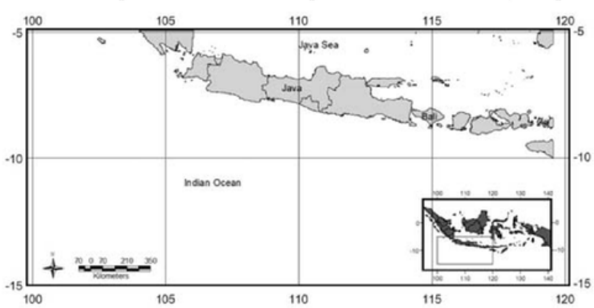

Figure 1. Map of study area (the southern coast of Java and Bali), the red dots show the location of inundation during 4-9 June 2016. Respectively: (1)Pandeglang; (2)Pangandaran;(3)Cilacap; (4)Lumajang; (5)Jembrana.

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Oceanographic dynamics in the coastal waters area in the southern coast of Java and Bali are strongly influenced by oceanographic and atmospheric dynamics that occurred in the Indian Ocean. Observed strong swell transmitted from the Southern Indian Ocean (due to hurricane/cyclone) moves in from the south-west to the south coasts of Sumatra and Java [12]. In some cases, the swell propagation leads to the incident of high waves and inundation on the west coast of Sumatra and the southern coast of Java to Nusa Tenggara [10]. Furthermore, the wave actions in the southern coast of Java and Bali are strongly influenced by monsoon activities. Between April and November (east monsoon) south-easterly winds are dominant over sea areas of the southern coast of Java and Bali and it leads to the relatively high wave occurrence [12]. In general, sea level variations of ± 16 cm are seen in the waters area of southern coast of Java and Bali [13,14]. Sea surface height anomaly follows a sinusoidal pattern, which reached the peak in May and the lowest in September [14].

2.2. Inundation reports

Reports of inundation (table 1) were collated from a variety sources including the Disaster Data and Information of Indonesia (hereafter referred to as DIBI) by BNPB (http://dibi.bnpb.go.id/) [7], as well as reports from BMKG. Information contained within the reports varied widely and significant interpretation was required, e.g. precise location of incident was sometimes difficult to ascertain and actual inundation may have occurred somewhat earlier than reported.

Table 1. Inundation reports in early June 2016.

No	Province	District	Date the incident	Source of information
1	Bali	Jembrana	4/6/2016	BMKG report
2	Central Java	Cilacap	6/6/2016 and 8/6/2016	DIBI-BNPB
3	East Java	Lumajang	7/6/2016	DIBI-BNPB
4	West Java	Pangandaran	9/6/2016	DIBI-BNPB
5	Banten	Pandeglang	9/6/2016	DIBI-BNPB

The inundation events occurred almost simultaneously in most areas of the southern coast of Java and Bali. In some areas, the inundation incident was also reported in conjunction with tidal waves and abrasion (in Cilacap and Lumajang) [7]. The report indicates that the incidents are not triggered by local causes, but regional. In addition, reports from BMKG shows that the southern coast of Bali was also experienced an extreme waves (South Karangasem, Gianyar, Sanur and Kuta) and inundation (Perancak - Jembrana District) on June 4 to 9, 2016.

2.3. Tides

The 6 minutely sea level which recorded by encoder sensor from BIG tide gauge data is used as the main data in the analysis of the tides. Tide gauge stations on the south coast of Java and Bali are found in four locations: Pangandaran, Cilacap, Prigi and Benoa. However, we only analyses the location of Cilacap (7.75 ° S - 109 ° E) and Benoa (8.77 ° S - 115.22 ° E) to represent the tides in southern coast of Java and Bali due to the lack of data availability, despite the location of inundation are in Pandeglang, Pangandaran, Cilacap, Lumajang and Jembrana.
Tide gauges data in April, May, July, and August in the same year was also used in the analysis. Tide data on the inundation incidents was compared with tides data in the months before and after the inundation incident which has a same astronomical tides phases to see whether there is any anomaly in the period of inundation events.

2.4. Sea level anomaly (SLA)

The satellite altimetry AVISO delayed-time gridded (1/4° x 1/4°) sea level anomaly daily product (DT-MSLA-H, hereafter referred to as SLA) [15] was used to examine regional sea level variation during the inundation events. This satellite product is gridded sea level anomalies data which computed with respect to a twenty-year mean. Hovmöller diagram was used to show the spatial and time distribution of SLA in period of 1-15 June 2016. Hovmöller diagram shows time on one axis of a picture and either latitude or longitude on the other.

2.5. Wave and swell

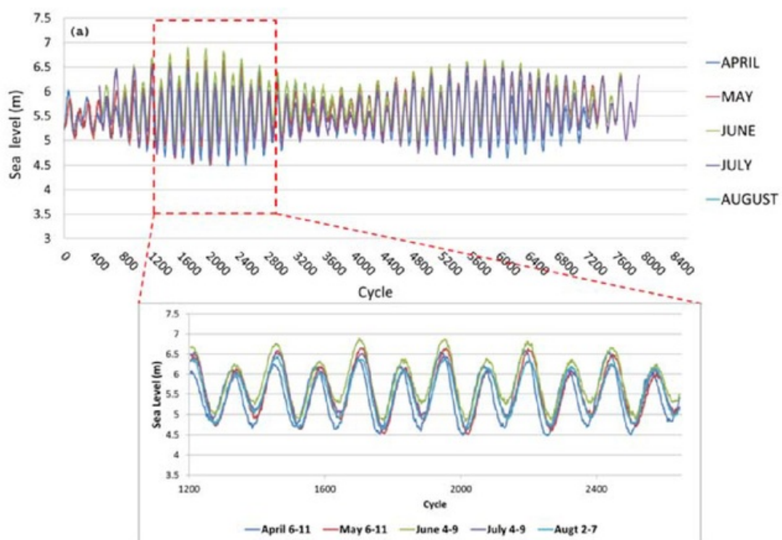
In situ wave and swell observations do not available in area and time of the study. Numerical hindcast provide the only source of wave and swell information at the study areas. Three-hourly significant wave height (Hs) and primary swell from BMKG [16] on 1-15 June 2016 was averaged to daily data. In addition we also used six-hourly wind speed and direction data to compare to the wave direction. The numerical hindcast of Hs and primary swell was modelled using wave model WW3 with a resolution of 0.125° x 0.125° [17] which has been operationalized by BMKG as a source of wave and swell information in Indonesia.

Parameterization used in the modelling and its validation can be referred to the research of Ramdhani (2015). Validation of the WW3 model show a good agreement with satellite altimetry and buoy data for the high wave condition (bias of 0.12 - 0.21 m to buoy data and 0.02 – 0.06 m to satellite altimetry data) [17].

3. Result and discussion

3.1. Tidal analysis

Spring tides (at the new moon phase) occur in between the inundation events, which was on June 5, 2016. In this condition, the rise of tide is a natural thing. However, on the two tides observation point, the increase of high water level (HWL) and low water level (LWL) during the inundation events (June 4-9) are clearly seen compared to the same astronomic phases tides data before and after the events (figure 2). This indicates the occurrence of sea level height variability during the inundation events.



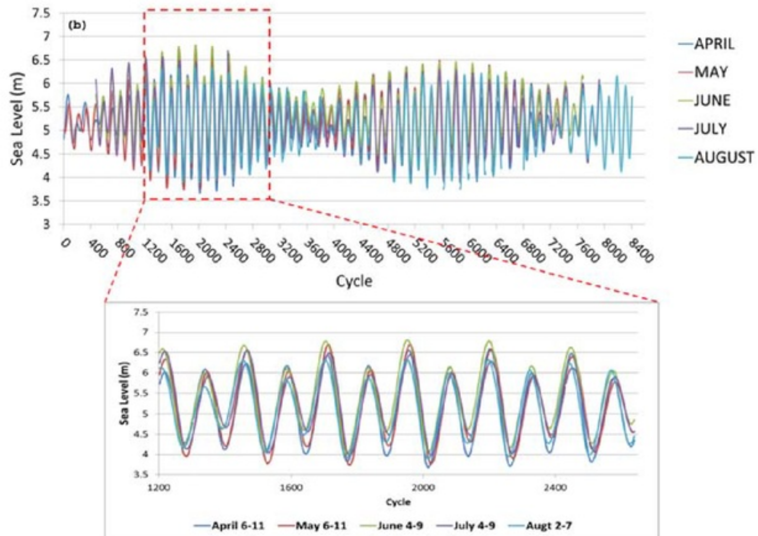


Figure 2. Sea level in (a) Cilacap and (b) Benoa. The main graphic shows the sea level at same astronomic tides phases in April, May, June, July and August and the insert shows the emphasis on June 4-9 as reference time (April 6-11, May 6-11, July 4-9 and August 2-7).

3.2. SLA analysis

The general condition of SLA in the southern coast of Java and Bali can be shown in Hovmöller diagram (figure 3). It shows the highest SLA occurred in the southern coast of Banten, West Java, Central Java and East Java (partially in eastern part). In general, the increase of SLA on the south coast of Banten and West Java (105°E - 108° E) began to occur on June 1 to 8 with the peak occurred on June 3 to 7. On the southern coast of Central Java (108°E - 110° E) to East Java (partially in eastern part, 110°E – 111.5° E), the increase of SLA began to occur on June 4 to 12 and the peak occurred on June 5 to 11. Next on the rest of southern coast of East Java, the SLA is relatively lower compared to the other area that has been mention before with the peak occurred on June 5-8. Furthermore, the highest SLA on the southern coast of Bali occurred in southern part of Bali Strait.

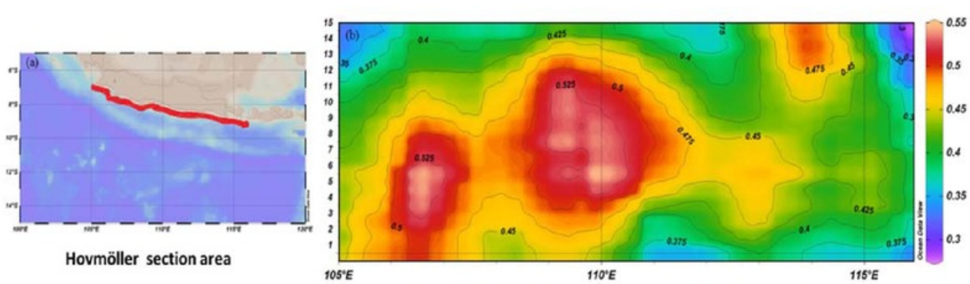


Figure 3. (a) Domain of Hovmöller diagram, red area shows the section area (30 km width) (b) Hovmöller diagram of SLA 1-15 June 2016 (x axis is longitude, y axis is days and the color contour is SLA height).

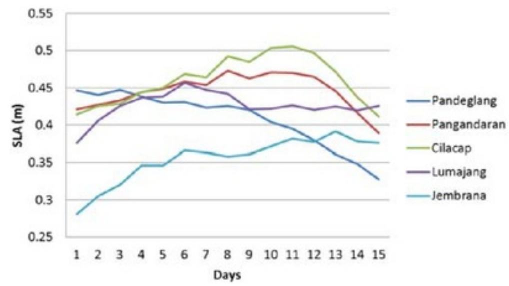


Figure 4. SLA height at the inundation locations during 1-15 June 2016.

SLA height at the location of inundation events (figure 4) respectively ranged between 33-45 cm in Pandeglang; 39-47 cm in Pangandaran; 41-51 cm in Cilacap; 38-46 cm di Lumajang; and 28-29 cm in Jembrana. Overall, the high of SLA in each of location was relatively high compared to the average of SLA variation in southern coast of Java that is ± 16 cm [13, 14].

3.3. Wave and swell analysis

In general, the condition of Hs and swell in 1-15 June 2016 have the same pattern in with the highest peak occurred on June 8, 2016 at all locations (figure 5). High Hs (wave height over 2 m) occur throughout 1-11 June in Pangandaran, Cilacap and Lumajang and at 1-4 and 8-10 June in Pandeglang. On the other hand, Hs in Jembrana is not included on the criteria of high waves.

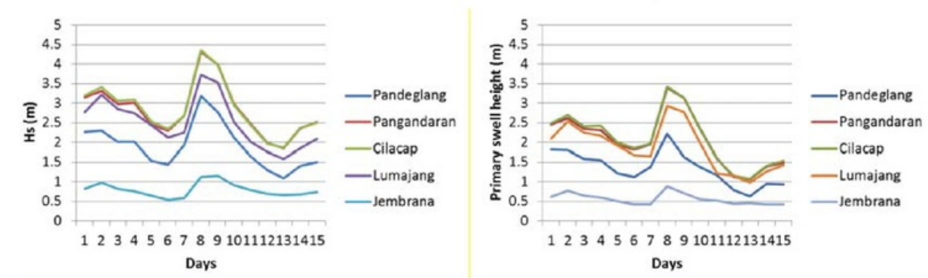


Figure 5. Daily average (a) significant wave height and (b) primary swell height on 1-15 June 2016.

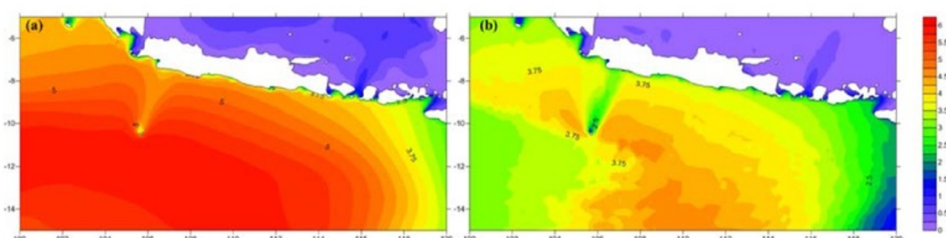


Figure 6. Spatial conditions of daily average (a) significant wave height (b) primary swell height on June 8, 2016.

The highest of Hs and swell height occurred on June 8, 2016, respectively ranging between 1.1 - 4.4 m for Hs and 0.9 - 3.4 m for swell. Spatial condition in the peak of the Hs and swell (8 June) is shown in figure 6. The propagation direction of Hs and swell is relatively same, that is from south to southwest.

Figure 7 is clearly shows that the propagation direction of Hs at 00:00 UTC and 12:00 UTC on 8 June are from south and southwest. In other hand, the wind direction is generally from east and southeast (figure 8). The difference of Hs propagation direction with the wind direction shows that the Hs condition on 8 June 2016 is dominantly influenced by the swell and not by the wind.

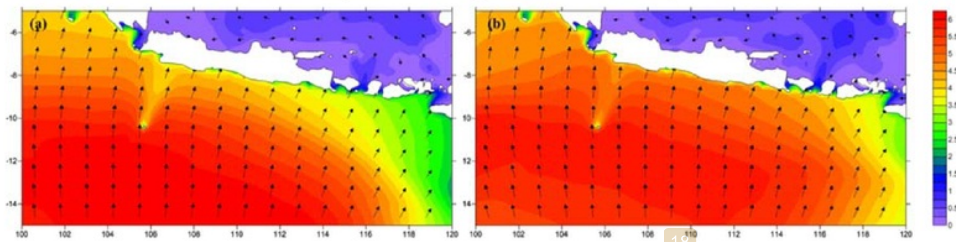


Figure 7. Overlay of Hs and peak wave direction on June 8, 2016 at (a) 00:00 UTC (b) 12:00 UTC.

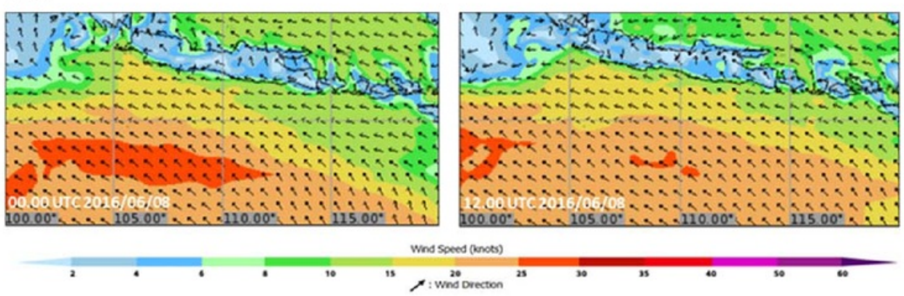


Figure 8. Wind conditions on June 8, 2016 at 00:00 UTC and 12:00 UTC [16].

3.4. Interaction of tides, SLA, wave and swell

The increase of high water level (HWL) and low water level (LWL) that observed in tides data show that there is sea level variability during the inundation events. The values of SLA also strengthen that information. Nonetheless, the rise in sea level that correlated with astronomical tides during this inundation event show a higher value than the sea level on the same astronomical tides phases in the months before and after the events. This suggests that there is another phenomenon that contributes to the rise of sea level. Furthermore, on the time span of the inundation events, the incidence of wave and swell that are relatively high was also observed in almost of all locations. Wave set-up, or the local elevation of the mean still water surface due to the breaking (dissipation) of waves has the potential to be a significant driver of extreme sea levels along the coastlines [8]. In addition, swell dissipation typically generates infra-gravity waves that causes the wave run-up (maximum level of the waves that reach on the beach relative to the still water level) [8]. This suggests that extreme waves and swell which occurs during the early of June 2016 may have a big contribution to the rising of the sea level during the inundation time span. Regardless, swell has a major contribution in wave actions that triggering these inundation events given that the waves that occur in the time span of the inundation were not affected by wind, but by the swell.

4. Conclusion

Our analysis has shown that the inundation events at 4-9 June 2016 was cause by the interaction of astronomical tides (spring tides), anomalously sea level height, high waves and swell along the southern coast of Java and Bali. Superposition of spring tide and SLA in the early June 2016 was causing the rising of sea level. Furthermore, the interaction of high waves that causing the higher wave set-up and swell that causing the higher wave run-up with rising of sea level due to spring tides and SLA, lead to the overflow/surging of sea water towards the mainland and causing coastal inundation. Regardless that the exact contribution by each phenomenon / parameter is beyond the scope of this work, this study provides insight that the superposition of these phenomena need to be considered in making a mitigation strategies in coastal inundation hazard.

References

[1] IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151

[2] Barnett J 2011 Dangerous Climate change in the Pacific island: food production and food security. *Journal of Regional Environmental Change* **11** (1), 229-237

[3] Ningsih, N.S., Hadi, S., B. Harto, A., Utami, M.D., P. Rudiawan, A. 2010. Modelling of storm tide flooding along the southern coast of Java, Indonesia. Advances in Geosciences (24), 87-103

[4] Walsh, K.J.E., McInnes, K.L., McBride, J.L., 2012. Climate change impacts on tropical cyclones and extreme sea levels in the South Pacific—a regional assessment. Global and Planetary Change (0), 149–164

[5] Church, J.A., White, N.J., Hunter, J.R., 2006. Sea-level rise at tropical Pacific and Indian Ocean islands. Global and Planetary Change 53 (3), 155–168

[6] Lowe, J.A., Woodworth, P.L., Knutson, T., McDonald, R.E., McInnes, K.L., Woth, K., von Storch, H., Wolf, J., Swail, V., Bernier, N.B., Gulev, S., Horsburgh, K.J., Unnikrishnan, A.S., Hunter, J.R., Weisse, R., 2010. Past and Future Changes in Extreme Sea Levels and Waves, Understanding Sea-Level Rise and Variability. Wiley-Blackwell 326–375

[7] BNPB. 2016. The Indonesian Disaster Data and Information-DIBI. Available at http://dibi.bnpb.go.id/

[8] Hoeke, Ron K., McInnes, Kathleen L., Kruger, Jens C., McNaught, Rebbeca J., Hunter, John R., Smithers, Scoot G. 2013. Journal of Global and Planetary Change 108 (2013), 128-138

[9] Tolman, H.L., 2009.User Manual and System Documentation of WaveWatch III Version 3.14. Tech. Note 276, NOAA/NWS/NCEP/MMAB

[10] Habibie, M.N., Permana, D.S., Suratno. 2013. The Simulation of Extreme Wave due to Swell in Indonesia Using WAVEWATCH-III. Journal Meteorology and Geophysics 14, 99-108

[11] Soeprapto, T.A.. 2004. The bathymetri of southern Java. Bandung: Centre for Research and Development of Marine Geology

[12] Bird, E.C.F. and Ongkosongo, O.S.R. 1980. Environmental changes on the coasts of Indonesia. Japan : United Nations University Press, 510 p

[13] Syamsudin, F. and Kaneko, A. 2013. Ocean variability along the southern coast of Java and Lesser Sunda Islands. Journal Oceanography. Published online: 16 July 2013, The Oceanographic Society of Japan and Springer Japan 2013

[14] Marpaung, S., Harsanugraha, W. K. 2014. Distribution characteristics of sea surface anomalies height in the waters of the north and south part of Java Island. National Seminar on Remote Sensing. Proceedings Sinasindraja 2014. LAPAN, 569-575

[15] AVISO. 2016. Aviso global sea surface height products. Available at http://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global.html

[16] BMKG. 2016. Ina-Waves. Available at http://peta-maritim.bmkg.go.id/2.0/

[17] Ramdhani, A. 2015. Effects of tropical cyclone and the Madden-Julian Oscillation (MJO) to the high wave events in Indonesian waters. Doctoral Dissertation Study of Earth Sciences, Bandung Institute of Technology

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