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The precursors of high rainfall intensity during June in Southern Central Java : A case study of flash floods 18 June, 2016 in Purworejo

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सार – **इंडोनेशिया में उच्च वर्षा तीव्रता, भले ही यह शुष्क मौसम के दौरान होती है, बाढ़ और भूस्खलन का कारण बन सकती है जिससे संपत्ति और जीवन का बहुत नुकसान होता है, जैसा कि पुरवोरेजो में हुआ था। आमतौर पर, शुष्क मौसम जैसे जून में थोड़ी वर्षा होती है, और इससे भी अधिक भारी वर्षा बहुत कम होती है। हालांकि, पुरवोरेजों में आपदा प्रचण्ड वर्षा के पूर्वगामी की पहचान करके आपदाओं की प्रत्याशा में एक महत्वपूर्ण अनुभव बन गई। इस शोध का उद्देश्य मध्य जावा के दक्षिण में विशेष रूप से पुरवोरजो में उच्च- तीव्रता वाले वर्षा पूर्वगामी का पता लगाना है। वर्षा तीव्रता वर्गीकरण का उपयोग करके पहचान की जाती है और यह वायुमंडलीय घटनाओं से संबंधित है जो इंडोनेशियाई वर्षा परिवर्तिता को प्रभावित करती है। परिणाम बताते हैं कि यदि समान रूप से वितरित बहुत भारी वर्षा होती है तो घटना से** 3 **दिन पहले पूर्वगामी की पहचान की जा सकती है, जैसे कम बहिर्गामी दीर्घ विकिरण** (OLR) **मान** <150 Wm^{-2}**। इसके अलावा, घटना से** 3 **दिन पहले के औसत विश्लेषण में, मध्य जावा क्षेत्र में** OLR **विसंगति का मान** 20 **से** 60Wm^{-2} **के बीच है। इस बीच, ऊर्ध्वाधर आर्द्रता प्रोफ़ाइल का मान** 500 **एमबी के स्तर तक** 80% **से अधिक है, क्योंकि जावा द्वीप के दक्षिणी भाग की सीमा से लगे हिंद महासागर में तापमान** 30.2 °C **से अधिक होने के कारण पुरवोरेजो रीजेंसी में अत्यधिक वर्षा की घटना से तीन से चार दिन पहले होता है। यह परिवर्तन तब होता है जब भारतीय द्विध्रुव विधा का मान नकारात्मक होता है और** ENSO **निष्पक्ष होता है। कालीमंतन के उत्तरी भाग और जावा के दक्षिणी भाग में मौजूदा निम्न वायुदाब, जो लंबे समय तक बना रहता है, जून में पुरवोरेजो में बहुत भारी वर्षा का कारण बन सकता है। खासकर अगर पवन गति** 4 **मीटर/सेकेंड से कम हो जाती है और एमजेओ के चरण** 3 **और** 4 **में होती है।** 20 **मिमी/**30 **मिनट की वर्षा जो बिना रुके** 7 **घंटे तक होती है, उस पर ध्यान देने की आवश्यकता है क्योंकि इससे पुरवोरेजो के रेतीले दोमट क्षेत्र में अचानक बाढ़ आने की संभावना हो सकती है।**

ABSTRACT. High rainfall intensity in Indonesia, even if it happens during the dry season can cause floods and landslides that cause a lot of loss of property and life, as happened in Purworejo. Generally, the dry season such as June has a little rainfall, and even more, heavy rain is very rare. However, the disaster in Purworejo became an important experience in anticipating disasters by identifying the precursors of extreme rainfall. This research aims to obtain high-intensity rain precursors in the south of Central Java, especially Purworejo. Identification is done using rainfall intensity classification and is related to atmospheric phenomena that affect Indonesian rainfall variability. The results show that if there is very heavy rainfall and evenly distributed, precursors, can be identified 3 days before the incident, such as a low outgoing long radiation (OLR) value of <150 Wm^{-2}. Moreover, in an analysis of the average 3 days before the incident, the value of the OLR anomaly in the Central Java region is between –60 to –20 Wm^{-2}.Meanwhile, the vertical humidity profile has a value of more than 80% up to a level of 500 Mb, as the temperature value of more than 30.2 °C in the Indian Ocean bordering the southern part of Java Island occurs three to four days before the extreme rain event in Purworejo Regency. This change occurs when the value of the Indian Dipole Mode is negative and the ENSO is neutral. Existing low air pressure in the northern part of Kalimantan and in the southern part of Java, which persists for a long time, can support very heavy rains in June in Purworejo. Especially if the wind speed decreases to less than 4 m/s and occurs in phases 3 and 4 of the MJO. The 20 mm/30-minute rainfall that occurs for 7 hours without stopping needs to be watched out for because it has the potential to cause flash floods in the sandy loam area of Purworejo.

Key words – Heavy rainfall, extreme, flood, landslide, Purworejo, Central Java.

1. Introduction

The flash floods that occurred in almost all areas of Purworejo Regency on June 18-19, 2016, resulted in landslides in Caok Village and its surroundings which killed 47 deaths (Kurniawan, 2016). Moreover, the disaster that occurred in this district was part of a wider scale disaster, namely floods and landslides in the southern region of Central Java which includes the districts of Purworejo, Kebumen and Banjarnegara. There was very heavy rainfall that occurred before the flood and landslide. In general, the month of June has started to enter the dry season, but in June 2016 the intensity of rain was still high, which was stated to be due to the influence of La Nina. The Indonesian Meteorology, Climatology, and Geophysics Agency (BMKG) is a non-departmental government agency in Indonesia whose task is to monitor, collect, process meteorological, climatological and geophysical data and then disseminate this information to the public and related agencies classify the wet-dry season for the rainfall as higher than the normal average in the dry season. Moreover, the Purworejo area is a disaster-prone area, based on data from the Indonesian National Disaster Management Agency (BNPB) is a non-departmental government agency in Indonesia in charge of disaster management which includes disaster prevention, emergency response management, rehabilitation, and reconstruction, and conveying information on disaster management activities to the public, regarding the Indonesian Disaster Risk Index (IRBI) for 2013-2018, this place occupied 18th rank out of 496 districts/cities in Indonesia with a 215 IRBI score and includes high-risk category area. On the other hand, Purworejo Regency is also in the second rank of 35 districts/cities throughout the province of Central Java as a disaster-prone area. Around 90% of 494 villages and sub-districts in Purworejo Regency are disaster-prone areas such as tornadoes, landslides, and floods (Hidayat *et al*., 2016; Bakti and Fadlurrahman, 2020).

Based on the rainfall data of 1991-2020 for the Purworejo district, the dry season takes place in May - September (5 months), while the rainy season takes place in October - April (7 months) and rainfall in the Java area generally starts to decrease in intensity from March to June before entering the dry season in July, so that the occurrence of heavy rains that even cause floods and landslides is an anomaly. The increase in rainfall intensity for a short duration is always associated with the emergence of the Madden-Julian Oscillation or MJO phenomenon, cold surge, and so on (Basri and Ahmad, 2019; Siswadi and Prima, 2021). The weather in the Indonesian Maritime Continent (IMC) is a water area with a stretch of islands in it, as a natural unit between land, sea, and air above it, uniquely arranged from the point of view of the climate and weather conditions of the water, the order of the earth's crust, the diversity of biota as well as the social and cultural order. The weather in IMC is strongly influenced by global phenomena such as monsoons, El Niño/Southern Oscillation (ENSO), Madden Julian Oscillation (MJO), Indian Ocean Dipole (IOD) (D'Arrigo and Wilson, 2008; As-syakur, 2010; Hidayat and Kizu, 2010; Giarno *et al*., 2012; Lee, 2015; Martono and Wardoyo, 2017) so that the occurrence of high-intensity rain is not necessarily the result of one weather phenomenon alone.

Rain events with very high intensity generally begin with signs that support or are commonly called precursors. If it occurs on a large scale, the phenomenon that is considered the cause is usually easy to identify, for example, the increase in rainfall in the southern part of Indonesia is caused by the global Asian monsoon (Supari *et al*., 2017). Meanwhile, rain with high intensity on a local scale, besides being caused by global phenomena, is usually also due to changes in the dynamics of many factors (Dayan *et al*., 2015; Hunt *et al*., 2018) The occurrence of high rainfall that causes flooding can sometimes be identified in one place, but sometimes there is also no specific anomaly (Champion *et al*., 2015; Champion *et al*., 2019). At the time of the incident, a local source of humidity was found and an unstable air mass was observed due to extreme conditions. This demonstrates the importance of a better understanding of the synoptic and thermodynamic scale drivers of extreme rainfall. Analysis of hydro-meteorological precursors on all timescales must coincide to produce the most extreme floods. The influence of abnormal temperature is thought to be related to the behavior of the flood pattern as it occurs in areas with warmer temperatures (Stucki *et al*., 2012).

Warning of high-intensity rainfall resulting in hydro-meteorological disasters requires knowledge of atmospheric preconditions that trigger increased rainfall. Predictions of various models show that long distances will reduce prediction accuracy (Ran *et al*., 2018). However, the big flood that occurred in Purworejo Regency is part of the extreme rain in a fairly large area, namely the southern part of Central Java, it is very possible to identify the preconditions of the incident. The purpose of this study is to analyze the reasons for weather dynamics that have the potential to cause heavy rainfall and cause landslides in Purworejo on 18-19 June 2016.

2. Data and method

2.1. *Research location and data*

The research is located in Purworejo Regency, Central Java. The population of this district in 2013 was 705,483 people with a composition of 49.33% male and

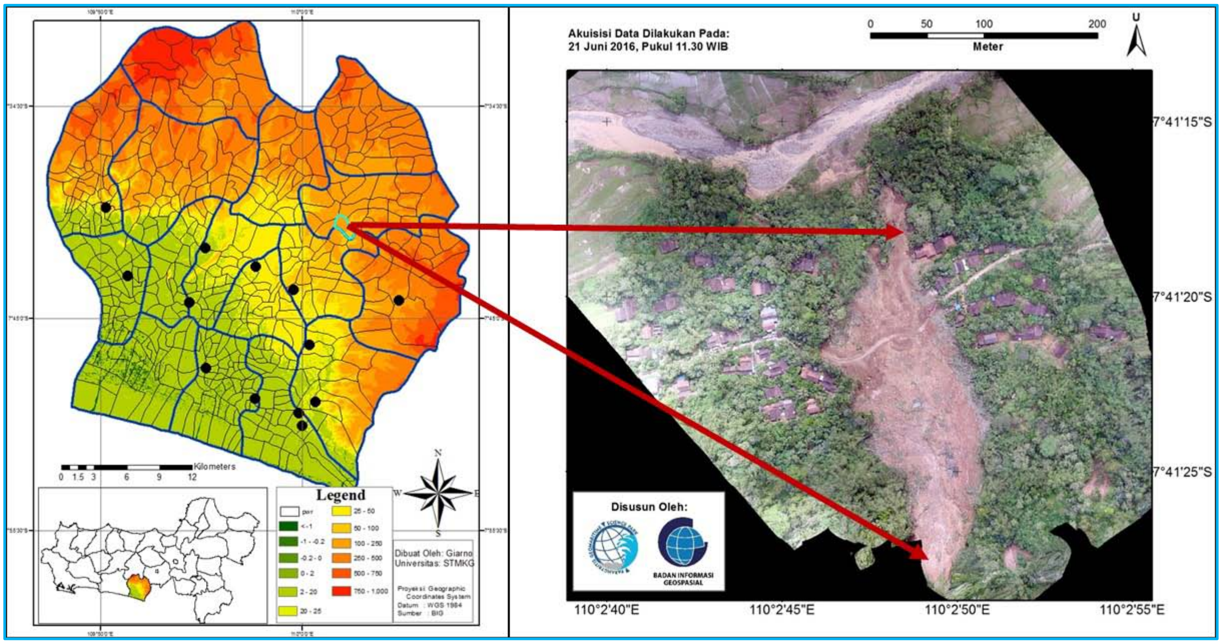


Fig. 1. Rain gauge position in Purworejo and landslide in Caok 2016

50.67% female. Moreover, its regency has an area of 1,034.82 km^2 with a density of 685 people/km^2 and the population growth rate in 2013 was 0.39%. Purworejo is located at 109° 47' 28" E - 110° 8' 20" E and 7° 32' S - 7° 54' S and approximately 40% of this area is plain and mountainous or hill area with the rain gauge network position as shown in Fig. 1. Moreover, regional boundaries: in the north of Wonosobo Regency and Magelang Regency. Meanwhile, the Kulonprogo Regency, as part of the province of the Special Region of Yogyakarta is located in the east of this regency and the Indonesian Ocean is in the south. Finally, in the west, Purworejo is bordered by Kebumen Regency. Administratively, Purworejo Regency is divided into 16 sub-districts and 494 villages, with Bruno district being the largest sub-district which covers 10,843 hectares or 10.47% of the district's area. Meanwhile, Loano, which was hit by a landslide, is close to the city center of Purworejo and part of the area is hilly as shown in Fig. 1.

The data used in this study is rainfall data at several daily rain posts throughout the Purworejo area during the 2010-2019 period. Since high rainfall intensity is associated with Sea Surface Temperature (SST) data from the AQUA-MODIS satellite imagery was obtained from ECMWF (European Center for Medium-Range Weather Forecasts). Reanalysis precipitation, wind, sea surface temperature and humidity were obtained from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR), while ENSO indexes were obtained from the Bureau of Meteorology (BOM) and the National Centers for Environmental Prediction Climate Prediction Center, the National Oceanic and Atmospheric Administration (NOAA). The IOD value is calculated using sea surface temperature from NCEP data. The MJO's phase taken from the Bureau of Meteorology (BOM) was used to complete the relationship between dynamic atmospheric conditions before the occurrence of extreme rainfall.

2.2. *Method*

In operational activities, observations and forecasts of rainfall, Indonesian Meteorological Agency (BMKG) classifies rainfall intensity into 6 groups, there are; light rain (1-20 mm/day), moderate rain (20 mm/day-50 mm/day), heavy rain (50 mm/day-100 mm/day), very heavy rain (100 mm/day-150 mm/day) and extreme rain (>150 mm/day). This criterion is used in both point and area data. However, insignificant rainfall does not have the potential to be a disaster, this study only considers moderate or higher intensity for analysis. Because of significant rain events associated with the MJO phases, the active phase relates to the increasing convective activity. Therefore, this research related the intensity and phase to determine the impact of the MJO. Moreover, the IOD circulation also has an impact on a significant increase in rainfall in Sumatra, and Java (Husna *et al*., 2016; Rahayu *et al*., 2018). Analysis of sea surface temperature (SST) in 1-5 days before the occurrence of

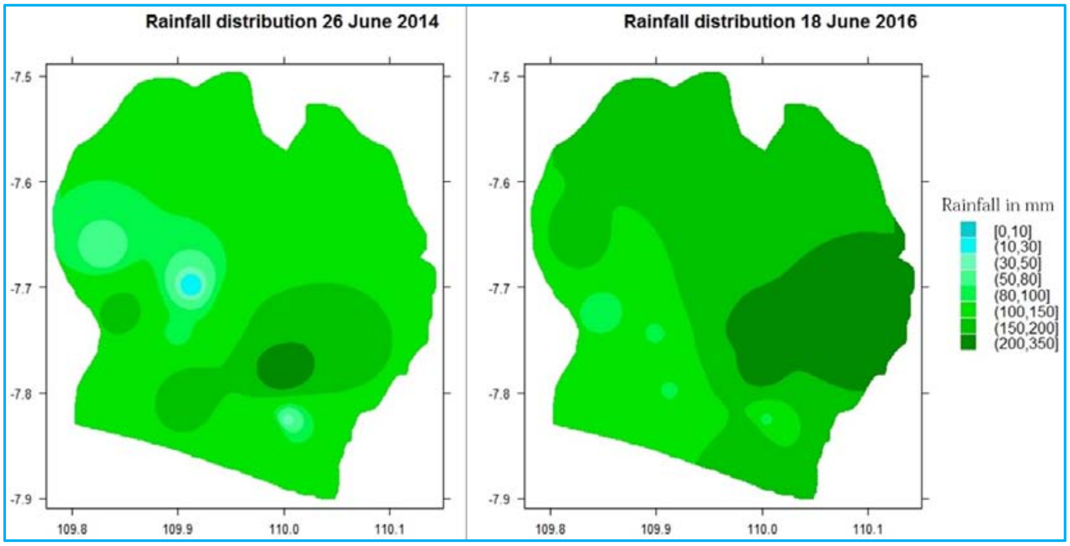


Fig. 2. Rainfall distribution (mm/day) on 26 June, 2014 and 18 June, 2016

heavy and very heavy rains is carried out to find out if there is a special pattern so that it can be declared as a precursor of extreme rain.

Identified precursors as a sign that there will be high-intensity rainfall in June, the dynamics of the atmosphere during and before the extreme rain event in Purworejo were identified using surface wind data analysis till 500 mb from NCEP and ECMWF reanalysis data. Several atmospheric phenomena such as the presence of low pressure, high-pressure, ridge, and trough also use the NCEP and ECMWF reanalysis results. The repetition and similarity of atmospheric dynamics patterns and high-intensity rain events were used to detect the presence of precursors of increasing rainfall in Purworejo Regency, especially during fast floods and landslides in June 2016 in Caok.

3. Result

3.1. *Rainfall during flood in Purworejo*

Based on the comparison between disaster data of the Indonesian National Disaster Management Agency (BNPB) and the average results of observations of rainfall in 11 rain gauge locations in Purworejo, showed that from 2000 to 2019, there were 2 floods and landslide events. While heavy rainfall events happened on 7 and 22 June 2016, there were no reports of floods or landslides. Moreover, there were 8 moderate-intensity rain events and there were not floods reported.

Although very heavy rainfall events in Purworejo on 26 June, 2014 and 18 June, 2016 had a high rainfall average, 112.3 mm/day and 138.8 mm/day respectively, the distribution of rainfall intensity in the area was uneven as illustrated in Fig. 2. Moreover, both of these events have different impacts where the flooding that occurred on 26 June 2014 was limited, in the Plipir and Pacekelan watersheds as seen from areas where the rainfall intensity is more than 200 mm/day. In contrast, in the flood that occurred 2 years later, the distribution of high-intensity rainfall was very wide, covering the districts of Loano, Kaligesing and Purworejo with high elevations. More than half of the district experienced rainfall of more than 150 mm/day on 18 July, 2016, while on 26 June, 2014, most of the rainfall intensity was 75-100 mm/day. Both of these incidents resulted in floods and landslides, with the incident on June 18, 2016, being the flood and landslide that caused the most loss of life and property.

Compared to the rains that occurred on June 26, 2014, and June 18, 2016 the rainfall events that occurred on June 7 and 22, 2016 averaged 52.5 and 51.9 mm/day of rainfall as shown in Fig. 3. Based on the distribution of rainfall intensity, places with rainfall between 75 and 150 mm/day are in a not too large area and are located almost the same as the rain incident on June 26, 2014 but in areas adjacent to the coast the rainfall intensity is the lowest. On the other hand, on June 22, 2016 the rainfall in coastal areas was higher than in areas with high elevations such as Kaligesing and Loano sub-districts.

Based on the comparison of the two events, when the average rain in Purworejo is more than 100 mm/day, floods and landslides occur, meanwhile, if the rainfall is 53 mm/day or less, there are no reports of floods and landslides. Because the identification in this paper focuses

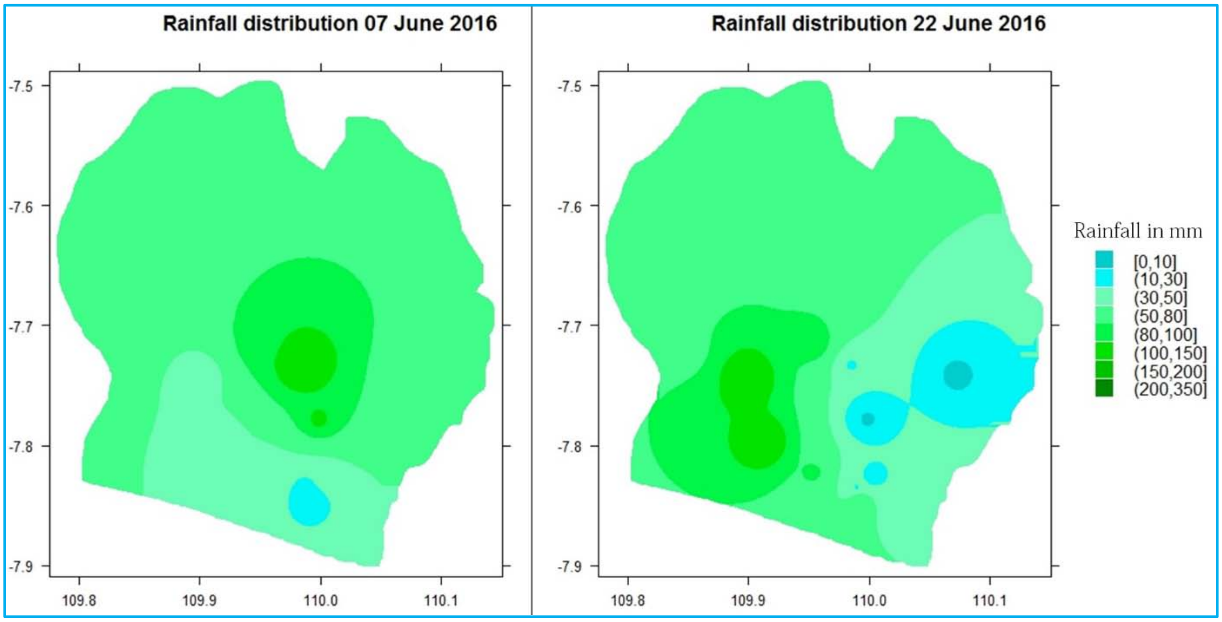


Fig. 3. Rainfall distribution (mm/day) on 07 June, 2016 and 22 June, 2016

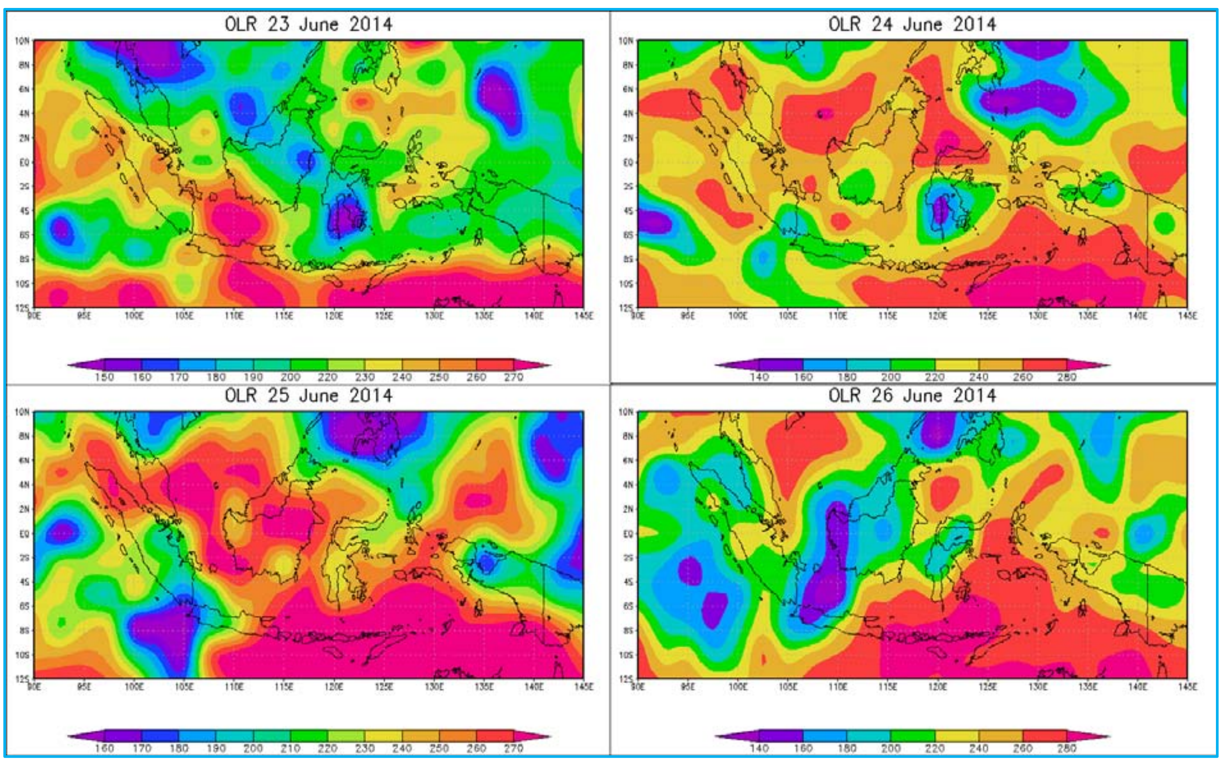
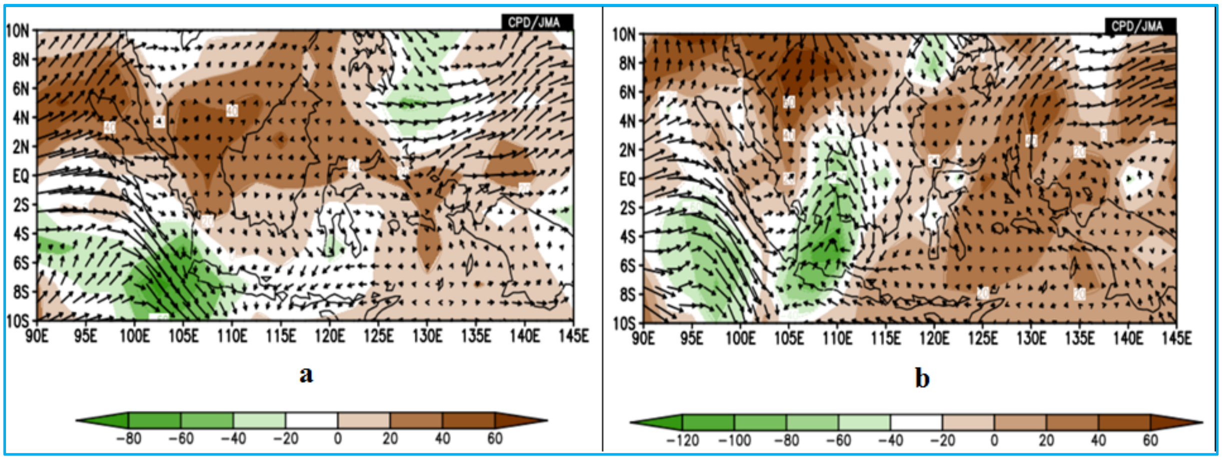


Fig. 4. OLR distribution pre and during very heavy rainfall on 26 June, 2014

more on rain events that have a detrimental impact in the form of floods and landslides, the analysis of atmospheric dynamics focuses more on events on June 26, 2014 and June 18, 2016.

3.2. *Dynamical atmosphere pre and during flood*

Marking the conditions that may be associated with a hydrometeorological disaster event will be useful to



Figs. 5(a&b). OLR anomaly and wind vector at 925 Mb (a) 23-25 June, 2014 and (b) 26 June, 2014 (*Data Sources* : ITACS 5 by JMA)

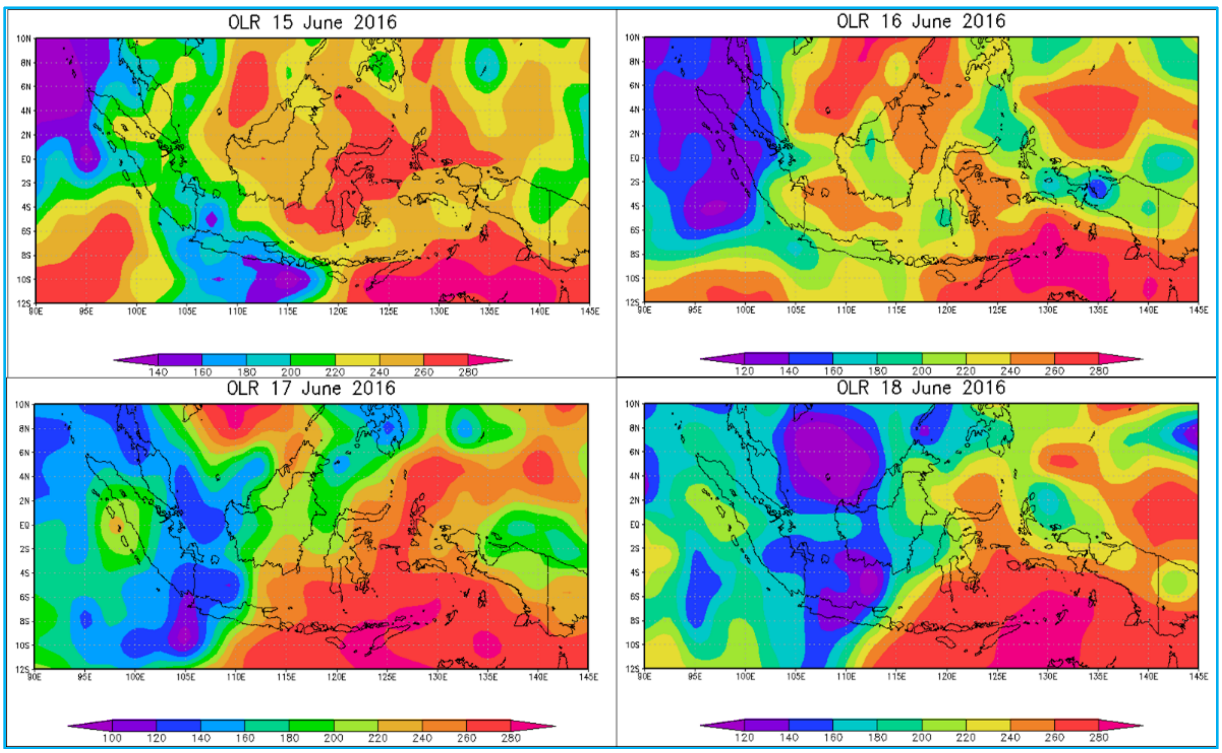
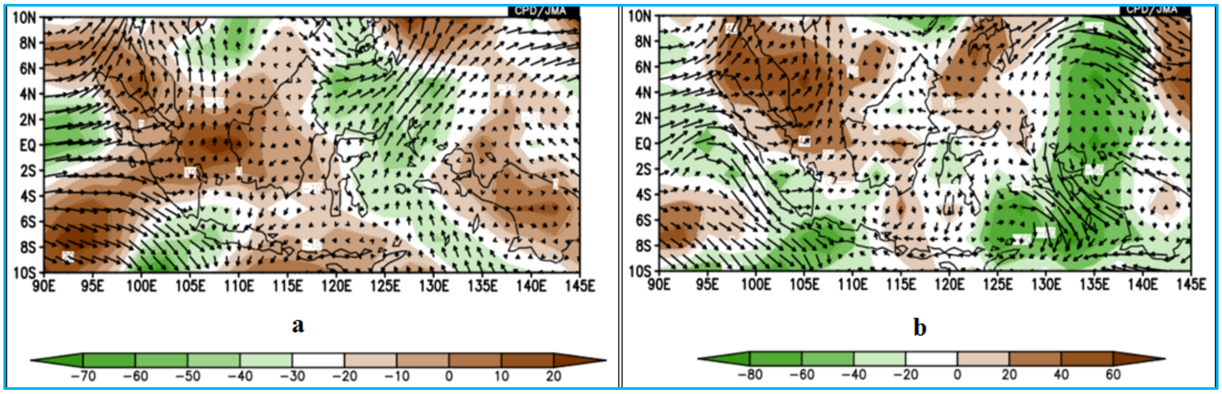


Fig. 6. OLR distribution pre and during very heavy rainfall on 18 June, 2016

anticipate hazards, therefore, it is necessary to identify the dynamics of the atmosphere beforehand. Re-analysis used NCEP/DOE 2 data that was provided by NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their website at https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html. The first is convection activity characterized by a low value of Outgoing Long Radiation (OLR), where the possibility of cloud growth reaches a low temperature so that the water droplets turn into ice. The use of OLR as a proxy of deep convection and cirrus/anvil clouds (in the tropics and middle latitudes), and is an easily quantifiable parameter related to the daily variability of the average diabatic heating adiabatic heating which is commonly used in the meteorological analysis. Although the OLR value of 240 Wm^{-2} can be used as a limit to diagnose deep convection (Fu *et al.*, 1990), for the Indonesian maritime continent where there is always convection activity, this study uses an OLR limit



Figs. 7(a&b). OLR anomaly and wind vector at 925 Mb (a) 15-17 June, 2014 and (b) 18 June, 2016 (*Data Sources* : ITACS 5 by JMA)

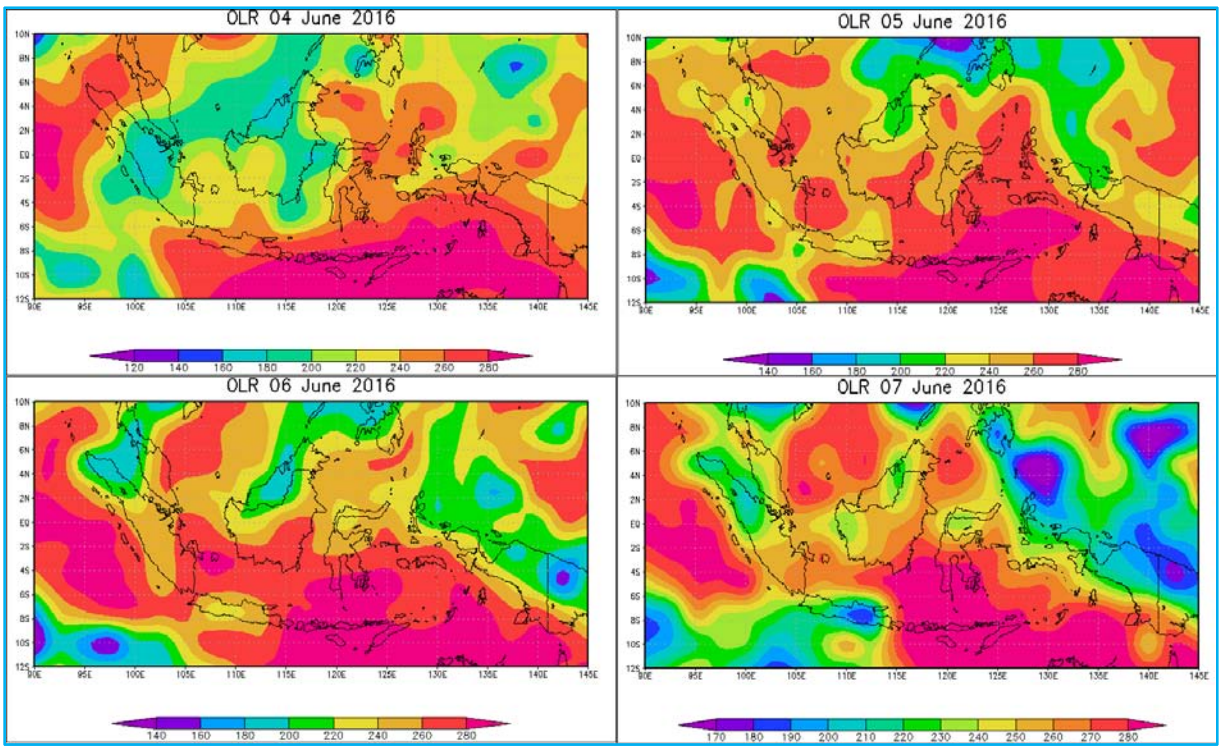
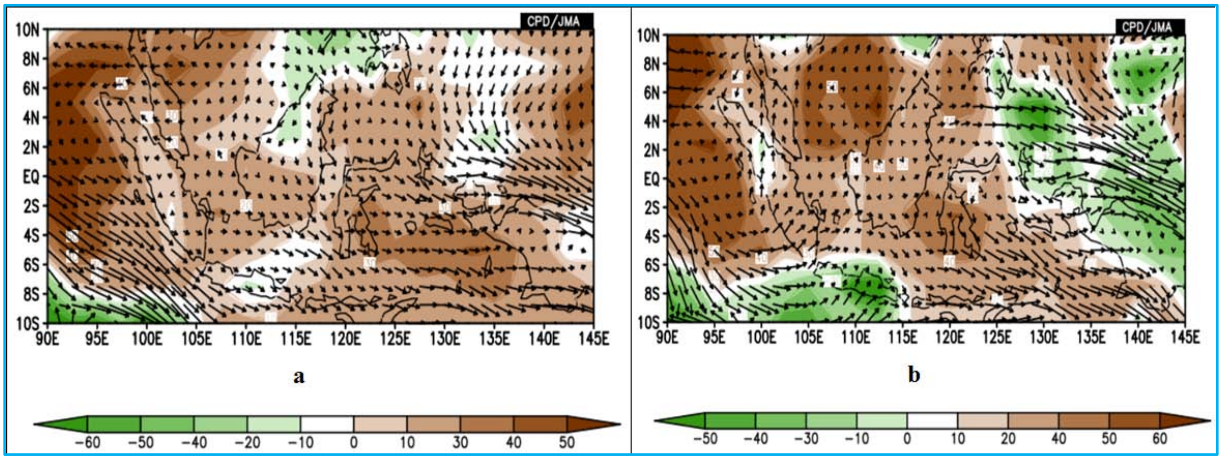


Fig. 8. OLR distribution pre and during heavy rainfall on 7 June, 2016

of 150 Wm^{-2} which is related to effective broadband emission temperature of 227 K (Pearson, *et al*., 2010).

Based on Fig. 4, the signs of strong deep convection have not been seen for 3 days before the heavy rainfall event. The low OLR value was only identified the previous day, namely June 25, 2014 where there was convection activity in the western part of Java and above Kalimantan. Deep convection in Java moves to the northeast, while those above Kalimantan move to the northwest. It seems that if the deep convection in the west of Java is rather large, it will affect the increase in rainfall in Purworejo in June.

The composite anomaly of wind and OLR on 23-25 June 2014 [Fig. 5(a)] shows the wind coming from the northwest, while the OLR anomaly in the Central Java region ranges from –20 to -40 Wm^{-2} (compared to normal). However, on June 26, 2014 [Fig. 5(b)] there was a change in the direction of the wind, which generally came from the South and Southeast to the Indian Ocean. Meanwhile, OLR shows increasingly negative anomalies



Figs. 9(a&b). OLR anomaly and wind vector at 925 Mb (a) 4-6 June, 2016 and (b) 07 June, 2016 (*Data Sources* : ITACS 5 by JMA)

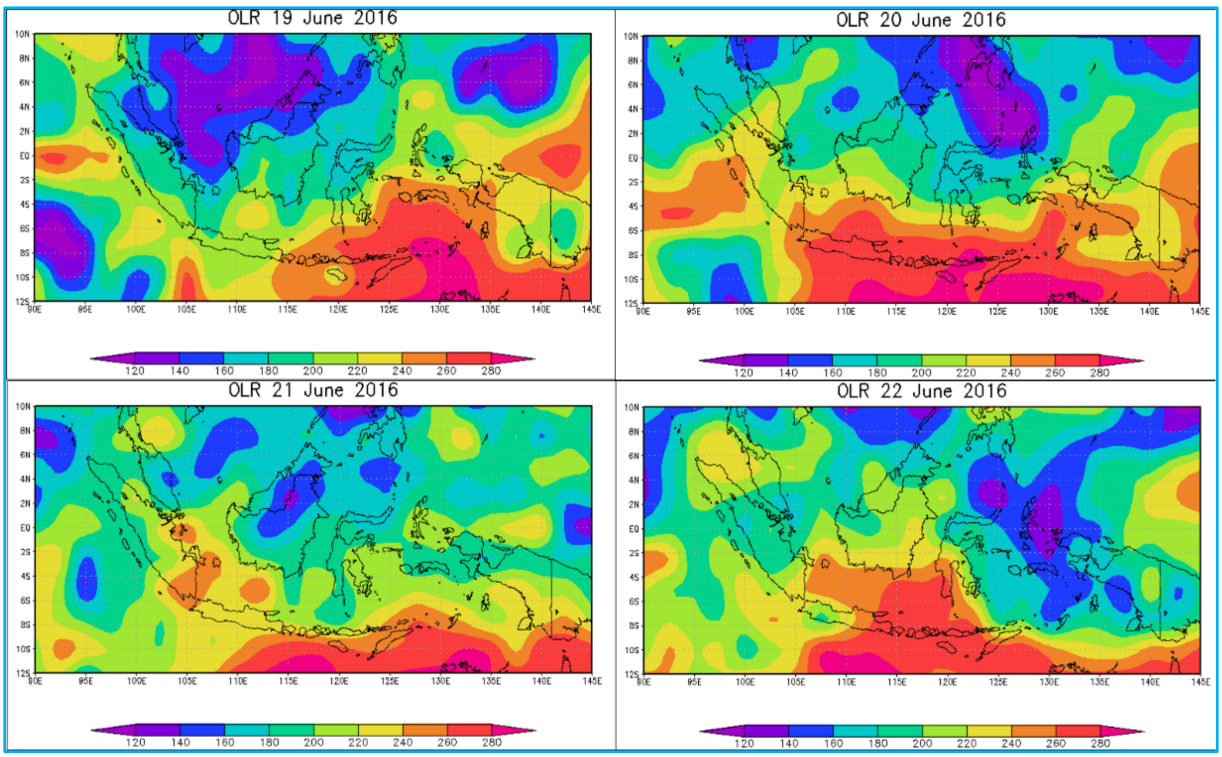
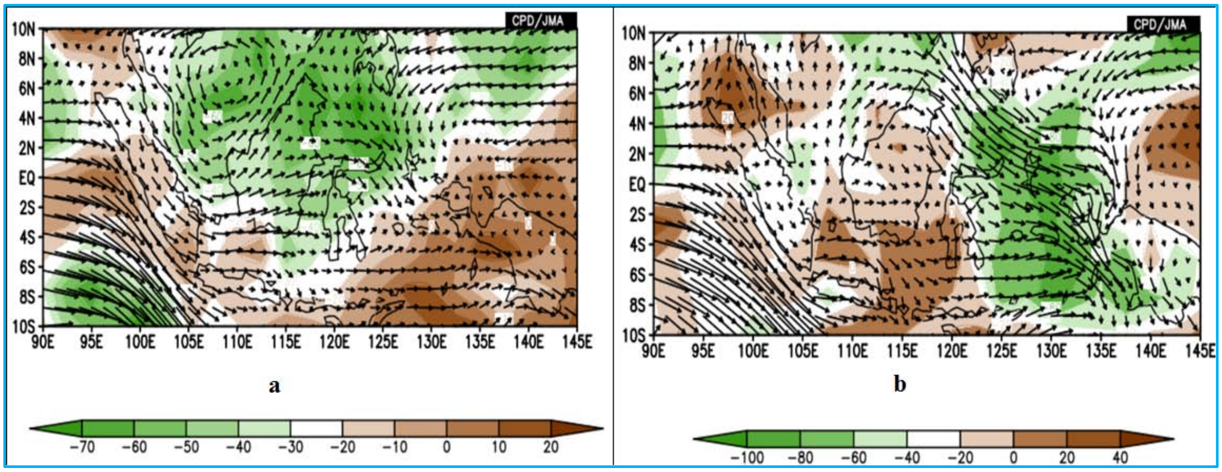


Fig. 10. OLR distribution pre and during heavy rainfall on 22 June, 2016

in the Central Java region ranging from -40 to -60 Wm^{-2} when compared to the previous 3 days.

Similar conditions to the occurrence of very heavy rain on June 18, 2016, where the emergence of deep convection was very massive in the western part of Sumatra Island and moved to the east. The day before the floods and landslides, on 18 June, 2016, deep convection was seen in the western part of Java and reached Purworejo the day after. Its effect on increasing rainfall in Purworejo was detected 3 days before the incident when the low OLR below 150 Wm^{-2} was widely distributed starting from west Sumatra as shown in Fig. 6.

The conclusion of this increase in deep convection is strengthened by the analysis of wind and OLR composites. Based on the distribution of the wind anomaly on 15-17 June 2016 [Fig. 7(a)] it came from the northwest



Figs. 11(a&b). OLR anomaly and wind vector at 925 Mb (a) 19-21 June, 2016 and (b) 22 June, 2016 (*Data Sources* : ITACS 5 by JMA)

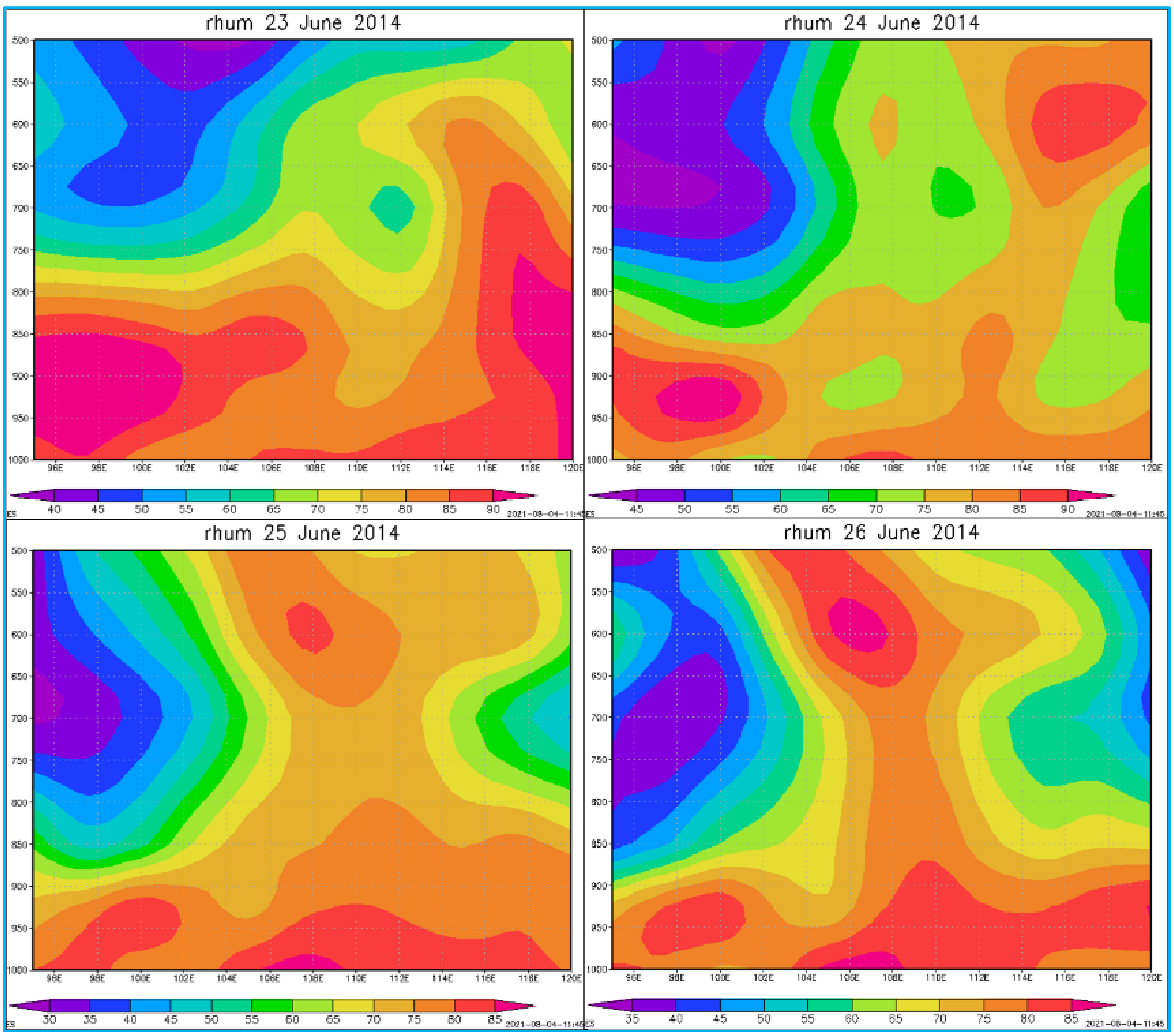


Fig. 12. Vertical humidity pre and during very heavy rainfall 26 June, 2014

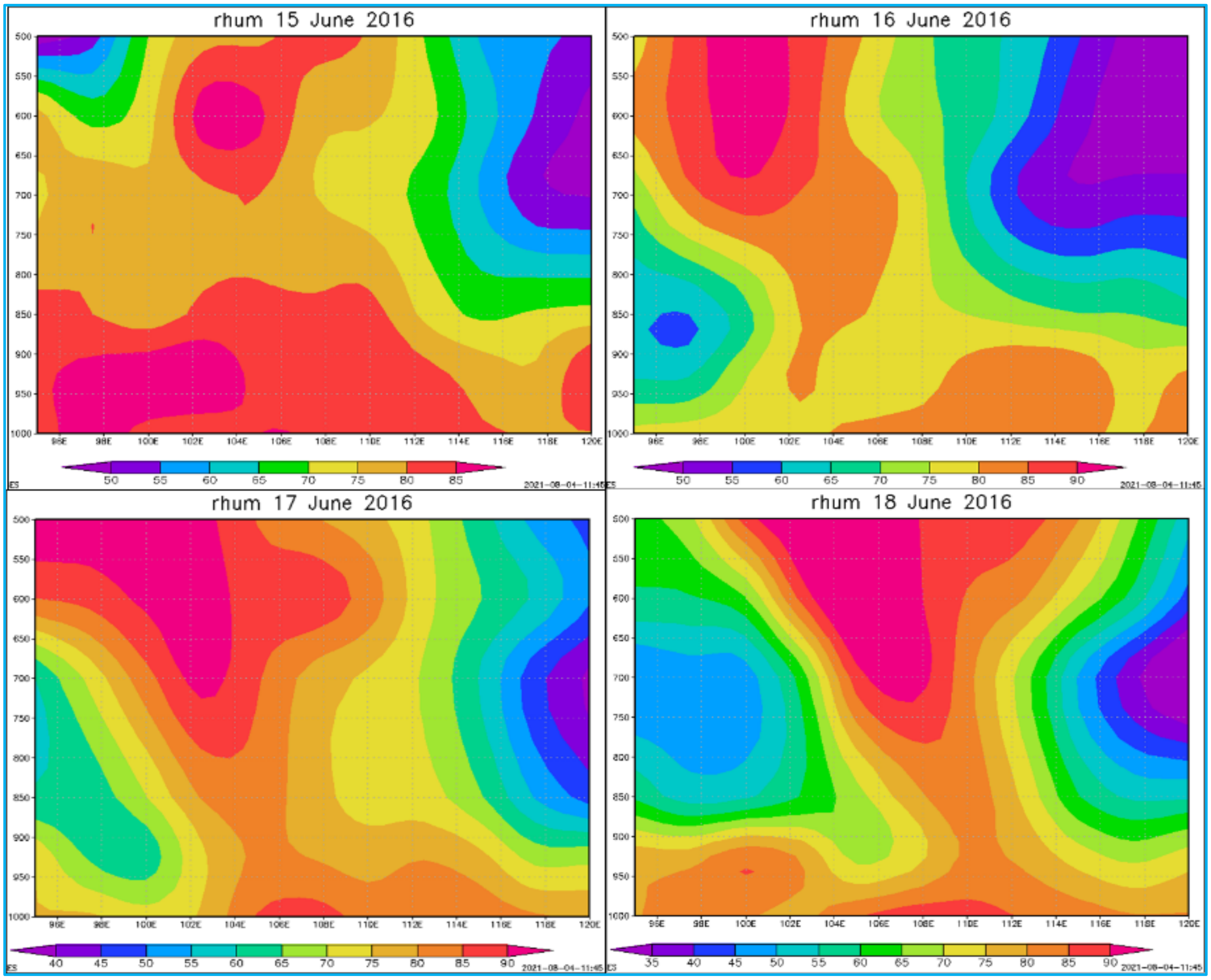


Fig. 13. Vertical humidity pre and during very heavy rainfall 18 June, 2016

and north while the OLR anomaly in the Central Java region ranged from -20 to -40 Wm^{-2} or minus below normal. This condition increased on June 18, 2016 [Fig. 7(b)] when it was seen that the wind was coming from the Northwest namely from the Indian Ocean while the OLR anomaly was getting more negative in the Central Java region ranging from -60 to -20 Wm^{-2} when compared to 3 the previous day.

Meanwhile, heavy rains that occurred on 07 and 22 June 2016 OLR distribution were very different, where the use of the 150 Wm^{-2} limits could not detect heavy rains that occurred at that time, as illustrated in Figs. 8 and 10. OLR values for rain on 07 June 2016 in Purworejo and its surroundings are 180-220 Wm^{-2}, while for June 22, 2016, the value is 220-260 Wm^{-2}. Signs of deep convection in the days before this incident were not visible except by changing the threshold to 240-260 Wm^{-2}. However, this change will risk misdetection because some places where the OLR value is below the threshold will not experience rain. Taking into account the heavy rains on 07 and 22 June, 2016 in Purworejo there were no reports of flooding or landslides, so for further analysis, this study focuses on the precursors of high-intensity rain on 26 June, 2014 and 18 June, 2016.

Based on the wind anomaly, it shows that on 4-6 June, 2016 [Fig. 9(a)] the wind came from the northwest, while the OLR anomaly in the Central Java region ranged from 0 to -20 Wm^{-2} (compared to normal). There was an increase when there was heavy rain on June 7, 2016 [Fig. 9(b)] where the wind came from the southwest direction, namely from the Indian Ocean into the Central Java region ranging from 0 to -50 Wm^{-2}.

Normally, in June, the Central Java region blows easterly wind and it is the beginning of the dry season. However, based on the wind anomaly on 19-21 June, 2016

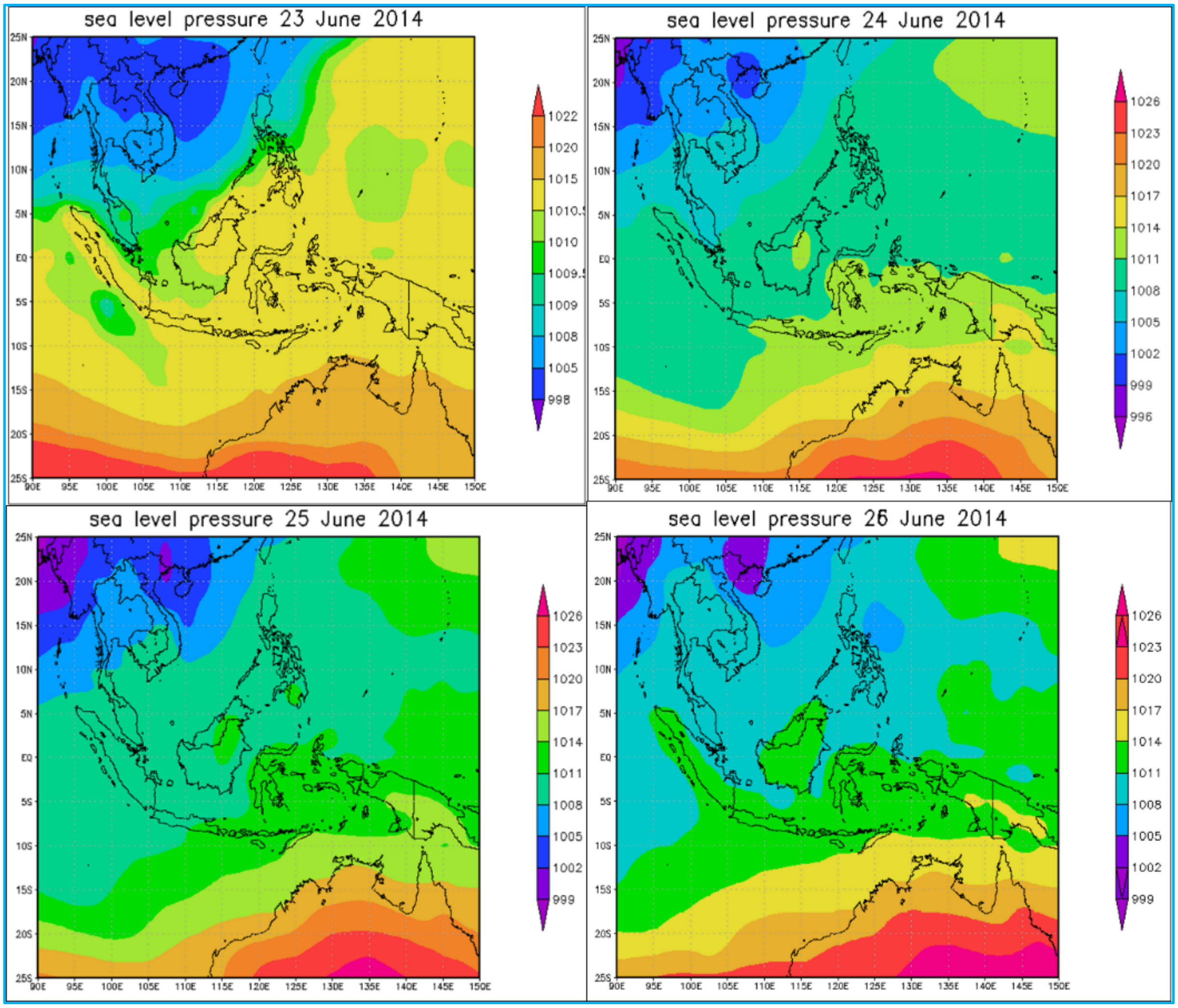


Fig. 14. Comparison of sea level pressure pre and during very heavy rainfall 26 June, 2014

[Fig. 11(a)] coming from the west, the wet air mass came from the Indian Ocean with an OLR anomaly ranging from -30 to -0 Wm^{-2} (compared to normal). Then it entered the Central Java region on June 22, 2016 [Fig. 11(b)] ranging from -60 to -20 Wm^{-2}.

The identification of atmospheric dynamics needs to be done to gain an understanding before the flood and landslide in Purworejo is the vertical identification of humidity. The movement of water vapor in the troposphere can indicate the potential for cloud growth at the location of the incident namely Purworejo which has an astronomical position of 7.7° S and 110° E. The change in relative humidity vertically before the very heavy rain on June 26, 2014, is depicted in Fig. 12.

On June 23, 2014 the high humidity profile was over the eastern area of Purworejo has not yet reached an altitude of 600 Mb as shown in Fig. 12. However, in the eastern part namely at 120° E, the vertical humidity is more than 90% and rises to a level of 750 Mb. Signs of increasing convection were seen on 25 June 2014, when the humidity of more than 80% reached the 500 Mb level connected to the surface. The abundant amount of water vapor at high-level ensures that convection activity in Purworejo increases and there is very heavy rain.

A similar incident was seen on June 26, 2016 where signs of increased convection activity caused very heavy rain to begin with high humidity in the upper atmosphere as shown in Fig. 13. On June 17, 2014, the vertical profile of humidity was striking above Purworejo connected from the surface to a layer of 500 Mb or more. The abundance of water vapor in the upper atmosphere caused convection activity in Purworejo to increase and on June 18 there was very heavy rain that caused floods and landslides.

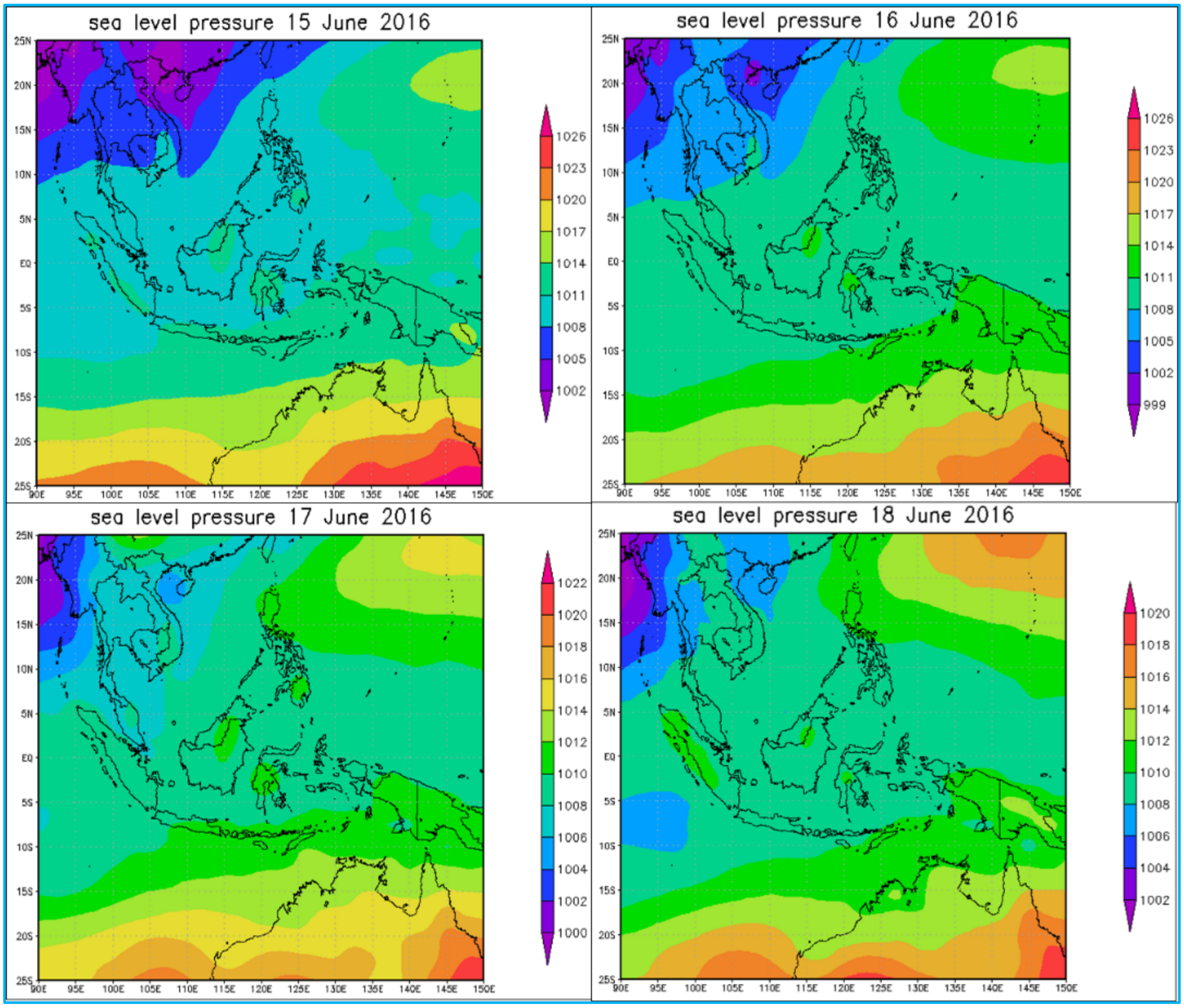


Fig. 15. Comparison of sea level pressure pre and during very heavy rainfall 18 June, 2016

Due to the differences in the pressures in the maritime continent of Indonesia, the identification of precursors for extreme rain events is not easy to do. However, based on the surface pressure in Figs. 14 and 15, it appears that there is a sea-level pressure value in the northern part of Kalimantan which appears 2 days before the high-intensity rain occurs. This low-pressure area that persists for a long time may trigger a converged wind flow towards the center of low pressure. Because in June the Australian area has relatively higher pressure than Indonesia, the wind will flow towards Indonesia, which is known as the east wind or southeast wind. The existence of this low pressure can make the Southern Java region more converging so that the growth of rain clouds is more persistent and causes an increase in rainfall.

The low pressure that appears before the occurrence of very high-intensity rainfall affects the movement of the wind. On June 25, 2014 at 0000 UTC, even the low pressure in Kalimantan Island caused the wind to flow toward the low-pressure area as shown in Fig. 16. In Southern Java where the wind deflects to low pressure, the wind speed increased more than 7 m/s. The high wind speed can disturb the formation of rain clouds. However, at 1200 UTC, the wind speed in Southern Java Island decreased and the convergence in Kalimantan is moving closer to Java Island, which results in an increased chance of convergence. The peak was on June 26, 2014, at 0000 UTC the wind speed decreased to less than 5 m/s, which at that time coincided with increasing rainfall in Purworejo.

The atmospheric conditions that occurred in the event of very heavy rain on June 18, 2016, are almost similar, where the pressure of the day before the very heavy rainfall in Purworejo that caused the landslide was

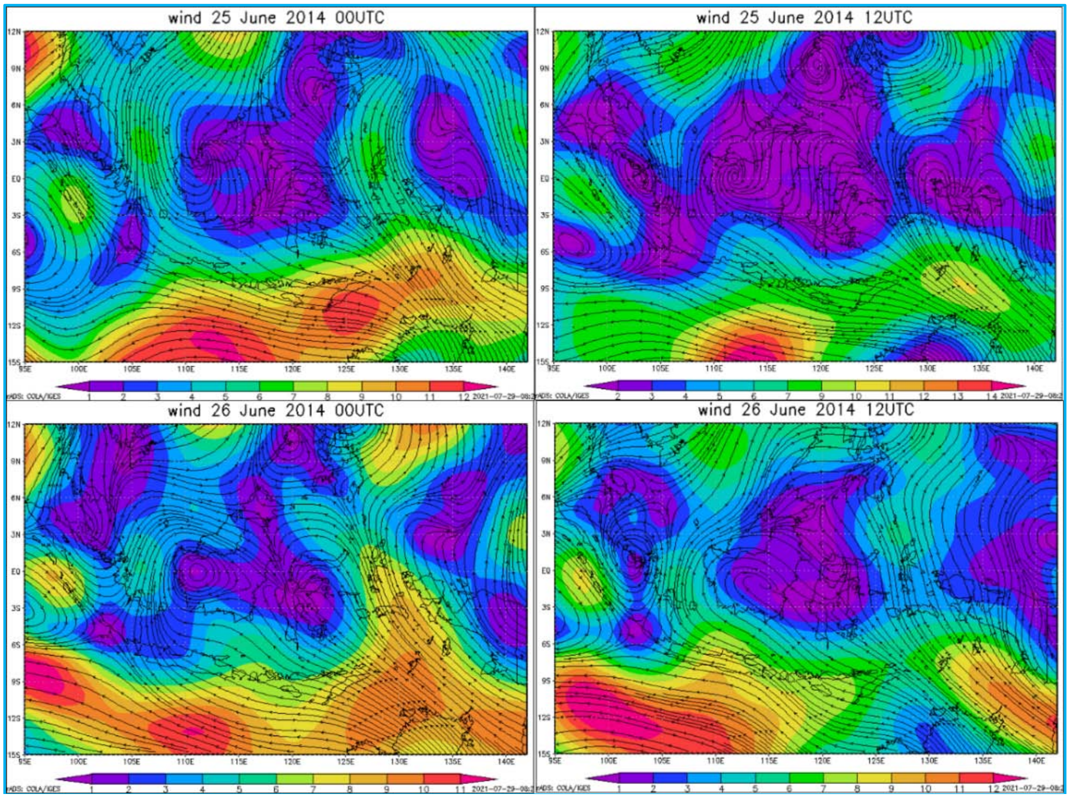


Fig. 16. Wind speed and direction pre and during very heavy rainfall 26 June, 2014

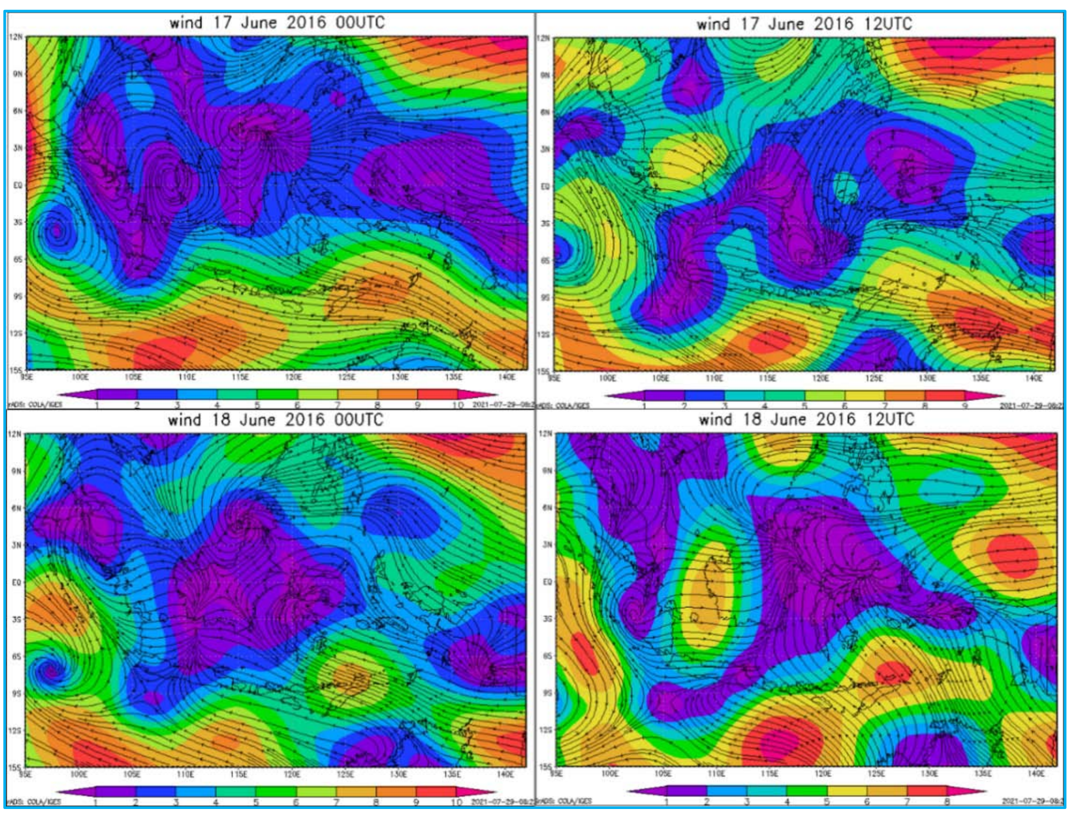


Fig. 17. Wind speed and direction pre and during very heavy rainfall 18 June, 2016

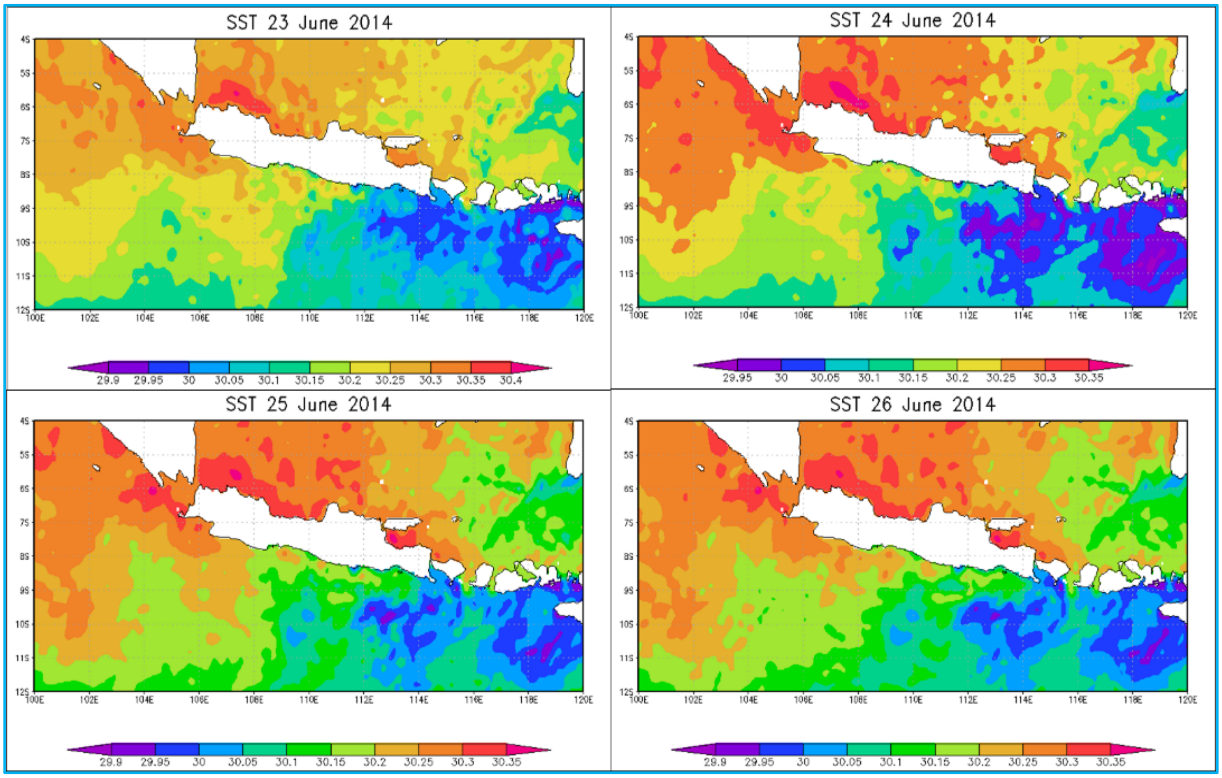


Fig. 18. Sea surface temperature pre and during very heavy rainfall 26 June, 2014

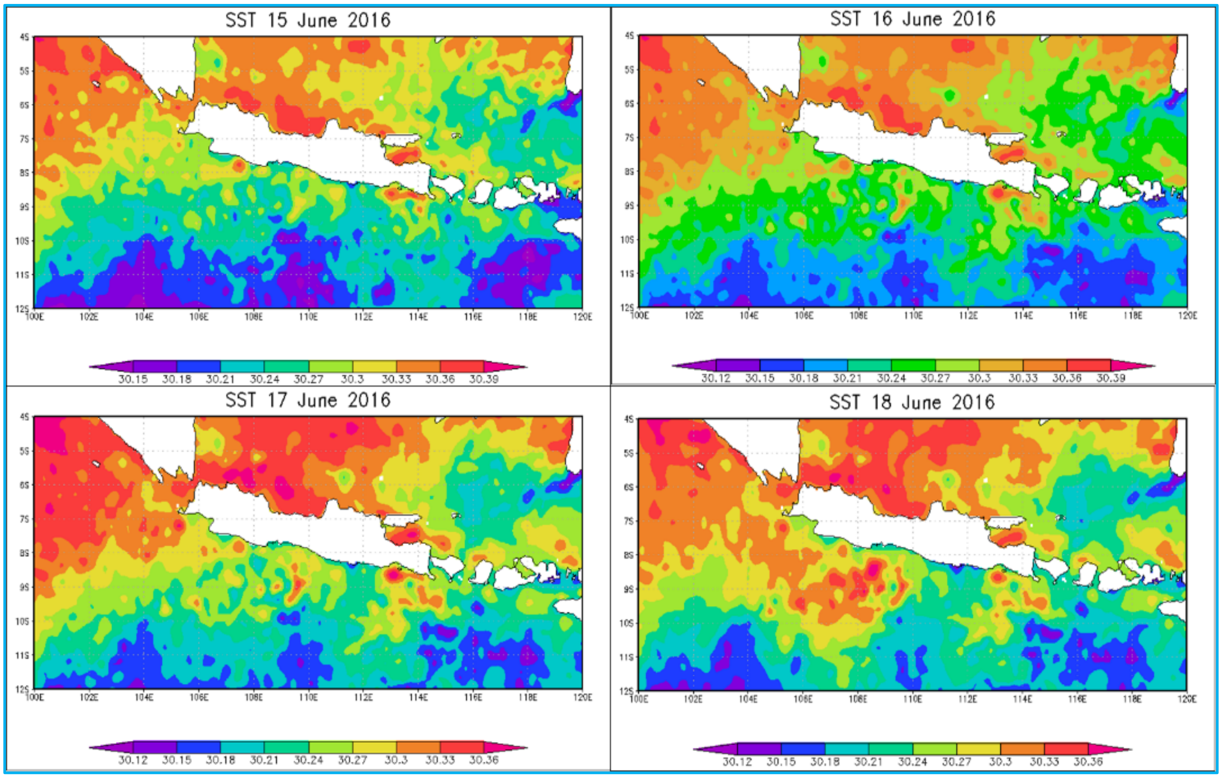


Fig. 19. Sea surface temperature pre and during very heavy rainfall 18 June, 2016

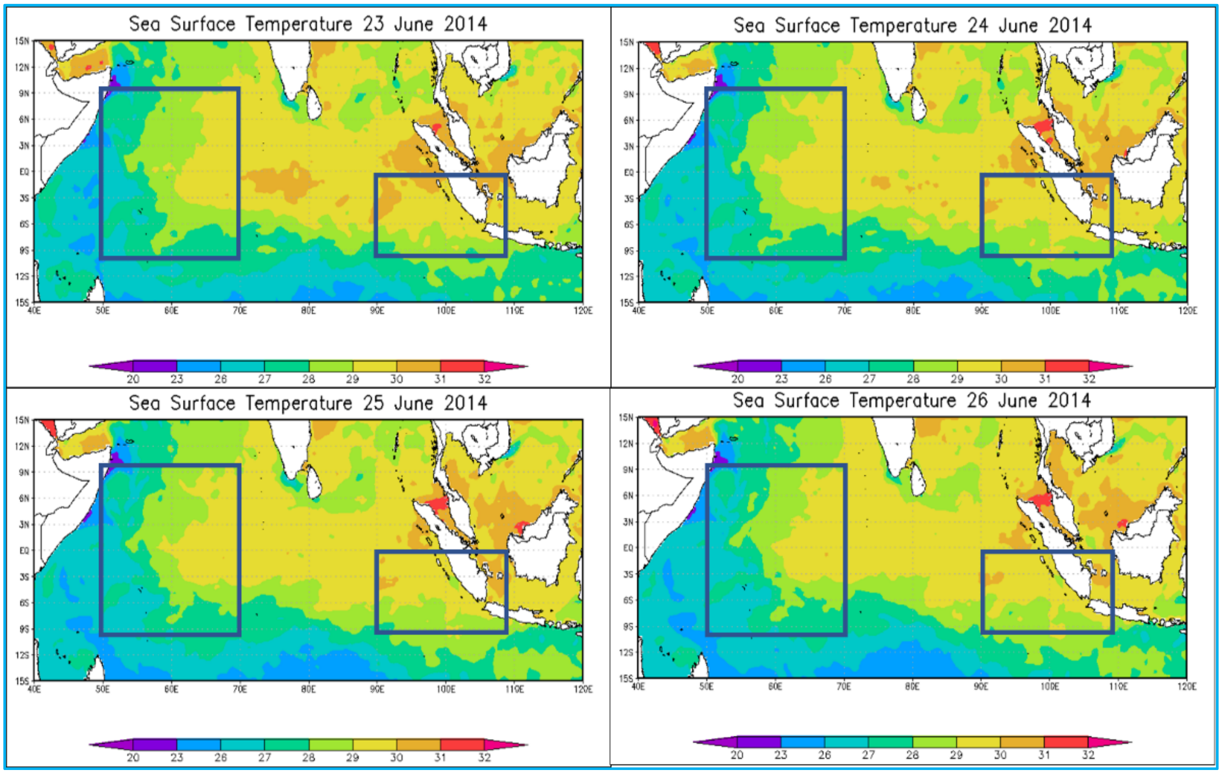
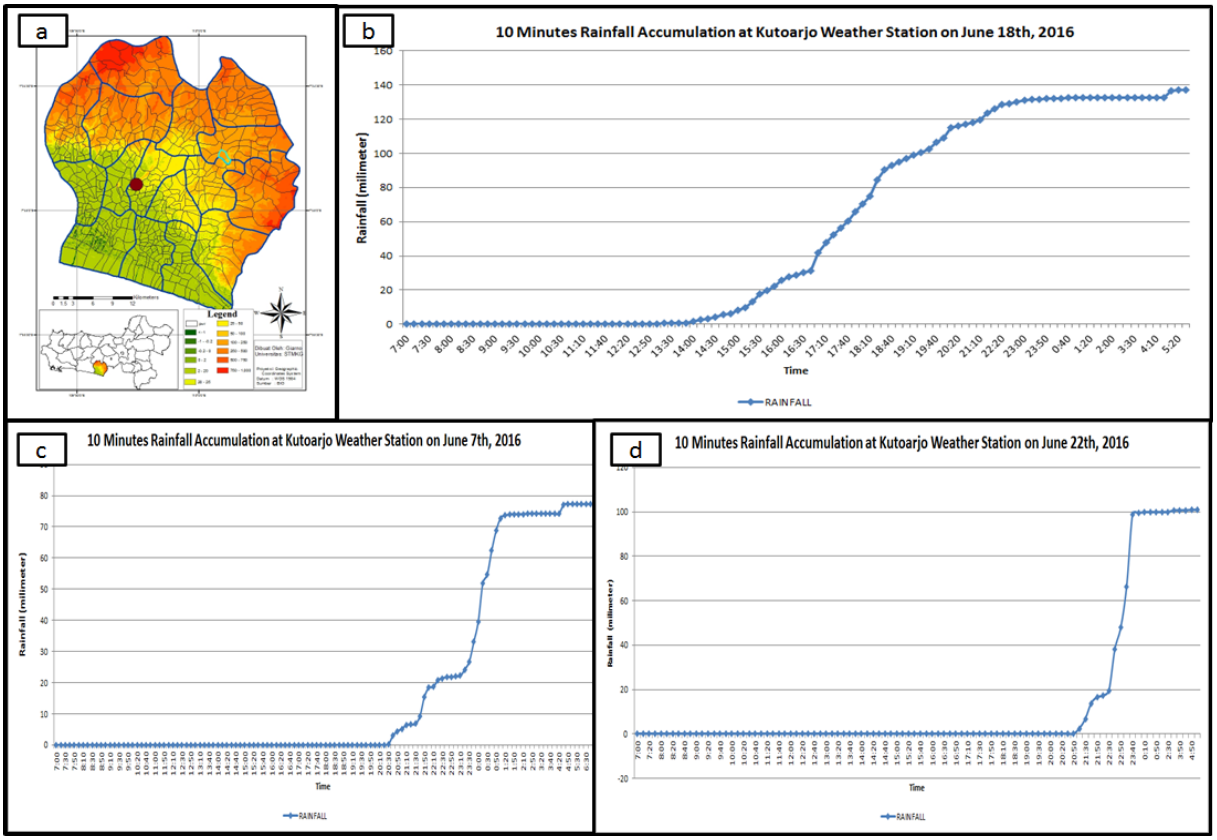


Fig. 20. Sea surface temperature in the Indian Ocean during very heavy rainfall 26 June, 2014



Figs. 21(a-d). (a) Position automatic rain gauge, (b) accumulation 10 minutes rainfall at 2016 June 18th, (c) 7th and (d) 22nd

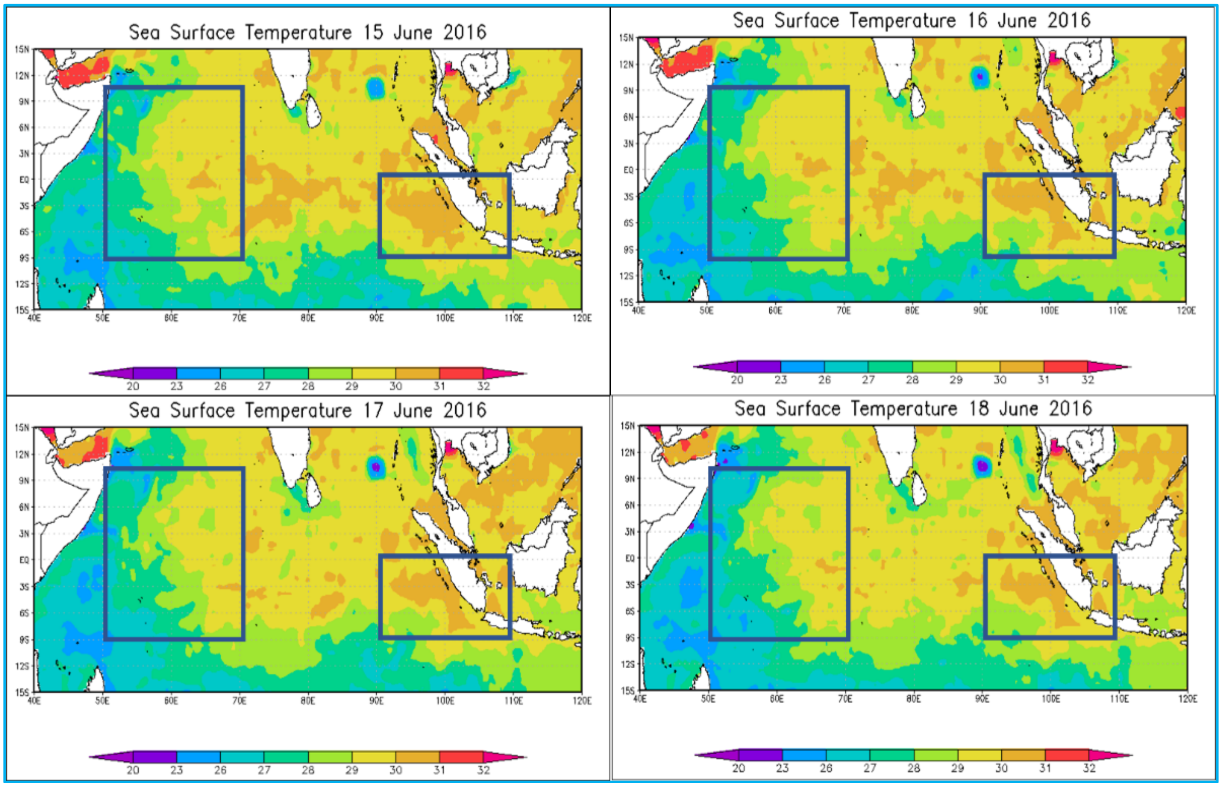


Fig. 22. Sea surface temperature in Indian Ocean during very heavy rainfall 18 June, 2016

TABLE 1

Dipole Mode Index during extreme rainfall

Date	IOD	Date	IOD
15/06/2016	-1.17920	23/06/2014	-1.21762
16/06/2016	-1.19191	24/06/2014	-1.17286
17/06/2016	-1.35792	25/06/2014	-1.23180
18/06/2016	-1.38656	26/06/2014	-1.31156

very clearly affecting the movement of the wind. On June 17, 2016 at 0000 UTC the wind convergence was visible in the western part of Kalimantan which extended southward to the island of Java as shown in Fig. 17. However, in the southern part of Java, especially Central Java and East Java, the wind speed was still more than 6 m/s. Moreover, decreasing wind speed (<4 m/s) on June 18, 2016, coincided with a very heavy rain incident on June 18, 2016.

3.3. *Sea surface temperature pre and during the flood*

In June, the month includes the dry season in the southern part of Indonesia, where the pressure in Australia is increasing and low in Asia. The difference in pressure causes a change in the direction of the wind that flows from high-pressure Australia to low-pressure Asia. Sea surface temperature is closely related to atmospheric pressure, where high pressure in a place corresponds to low temperature and vice versa. At this time, sea surface temperatures around Australia are lower and associated with high pressure in this region. The waters south of Java Island, which borders Australia, generally also have low temperatures, as shown in Figs. 18 and 19.

Based on the distribution of seawater temperature around the waters of Southern Java, it appears that the warm sea surface has moved to the north. In contrast, it can be seen that the temperature in the northern waters of Java is lower than in the southern part bordering Australia. The identification of the increase in temperature in the southern part of Java was not detected only in spots where the temperature was more than 30.2 °C. Further, an analysis of events on June 26, 2014 shows that since June 23, 2014 there have been spots of sea surface temperature with a value of more than 30.2 °C that persisted until June 25, 2014 as shown in Fig. 20. Moreover, the flowing of the warm sea surface in the very heavy rain event on June 18, 2016 was clearer whereas, on June 15, 2016 the warm sea surface temperature strengthened from west to east in the southern waters of Java. The spots on the

TABLE 2

Significant average rainfall and hazards reported and relation of the MJO phase to moderate rainfall intensity or above in June

Dates	Events	Rainfall (mm/day)	BMKG's Criteria	MJO Phase
6/26/2014	Flood and Land slide	112.3	Very Heavy	7
6/18/2016	Flood and Land slide	138.8	Very Heavy	3
6/7/2016	Not Reported	52.5	Heavy	8
6/22/2016	Not Reported	51.9	Heavy	4
6/8/2010	Not Reported	40.7	Moderate	2
6/12/2010	Not Reported	21.1	Moderate	1
6/2/2013	Not Reported	47.0	Moderate	2
6/11/2013	Not Reported	31.7	Moderate	3
6/13/2013	Not Reported	21.3	Moderate	4
6/27/2016	Not Reported	22.3	Moderate	5
6/29/2016	Not Reported	25.6	Moderate	7
6/15/2017	Not Reported	24.5	Moderate	1

surface of the warm waters increased by more than 30.2 °C and the scale of the area became very wide on June 18, 2016. The temperature value on that date is very different from the previous days as shown in Fig. 19. However, if the analysis is extended to the Indian Ocean, it can be seen that when very heavy rains occur, the IOD index is negative. In this phase the sea in the western part of Sumatra is warmer than the eastern part. This condition causes the Western Part of Indonesia to receive a lot of water vapor. However, based on Fig. 20, three days before the very heavy rain event on June 26, 2014 the temperature of the sea surface near the island of Java decreased.

On the other hand, although very heavy rains that caused flooding and landslides on June 18, 2016 occurred when the Indian Ocean in the eastern part was warmer than the western part, the same as the incident on June 26, 2014 there was a movement of sea surface temperature to the south. As shown in Fig. 22, the sea surface temperature in the southern part of Sumatra remained warm and did not change in the three days prior to the incident. This can be seen from the value of the Indian Dipole Mode index which shows a negative value which is < -1 and is increasing two days before the incident as shown in Table 1.

3.4. *Relation of Madden-Julian Oscillation's phase*

The dry season in Indonesia, especially in Central Java, generally begins in April, so in June the rain due to monsoon winds from Asia has decreased. Increased rainfall in the dry season in Southern Indonesia, such as Central Java, is usually associated with other weather phenomena. One of the weather circulations that is often associated with high rainfall is the Madden Julian Oscillation or MJO. During the active phase of the MJO, there is an increase in convective activity, so rainfall increases. Table 2 below shows the MJO phase when there is moderate to very heavy rainfall in Purworejo.

Based on the record of moderate or more rainy events in the MJO phase, all events do not coincide with the MJO phase 6. Meanwhile, when it rains with very heavy and heavy rainfall coincides with the 3rd, 4th, 7th, and 8th MJO phases. Moreover, moderate intensity occurs in all phases except phases 6 and 8. The MJO cycle starts from the first phase of activity of the Eastern Indian Ocean, then moves eastward and ends in the Pacific Ocean. The number of adjacent MJO phases with the rainfall in June showed the events coincided with all phases except 6 of the MJO phase. Moreover, the 8th phase and the 1st phase appear far away but the 8th phase continues to the first phase. Based on this fact, very heavy and heavy rainfall occurred in phases 3-4 and 4-8. The previous research concluded there are associations between increasing rainfall intensity with the MJO phase. This study found moderate rainfall to heavy rain (> 40 mm/day) occurred in the 2nd phase of the MJO. Moreover, the convection activity in phases 3 and 4 in June deserves attention.

The activity of MJO in phase 3 is more supportive of convection activities based on extreme rain events in mid-June 2016 compared to other phases. Convection activity is due to the heating of the earth's surface by solar radiation causes water vapor to evaporate into the atmosphere. When the air rises, it cools and condenses. If this process continues, convection rainfall will occur. Moreover, warming of the earth's surface occurs in the morning and afternoon and can cause convection rain in the afternoon or evening. In the event of extreme rain on June 18^{th}, 2016 it appears that the formation of convection clouds is very fast so starting at 1400 local time, rain has started to occur in Kutoarjo [Fig. 21(a&b)]. While rain on the 7^{th} and June 22^{nd}, 2016 [Figs. 21(c&d)], occurred at night and have a short duration. In these two cases, it started raining after 2000 local time. The duration of the rain on June 18^{th}, 2016 was also much longer than the two events. Unfortunately, the extreme rain incident on June 18, 2016, cannot be compared with the rain with an intensity that is close to the incident on June 26, 2014 because the automatic weather tool has not been installed.

Based on [Fig. 21(b)], the flash flood incident on June 18, 2016, was not caused by sudden high-intensity rain. The graph confirms the rain that day had a slope of 20 mm/30 minutes and occurred without a break for 7 hours continuously. Areas with high slopes cause a high potential for landslides.

3.5. *Discussion*

Very high rainfall intensity during the dry season is a rare occurrence, so often the adverse effects are not anticipated and sometimes there is no specific anomaly found (Champion *et al*., 2015; Champion *et al*., 2019). Based on the analysis of the occurrence of high-intensity rainfall in June in Purworejo, it was found that there were signs 2-3 days before this event occurred if the rainfall was very high. The distribution of rain greatly affected the occurrence of flooding in Purworejo as seen from the occurrence of very heavy rain on June 26, 2014, the flooding was only limited to the Plipir and Pacekelan watersheds. Meanwhile, a very heavy rain incident on June 18, 2020, caused extensive flooding in Purworejo. More than half of the district's high-intensity rains caused widespread flooding, while the very high intensity of rainfall in the hills of Kaligesing and Loano caused landslides. Meanwhile, the average rainfall of less than 100 mm/day in Purworejo did not result in a flood disaster.

Identification uses convection activity which is characterized by a low value of OLR which is the value of the day before the heavy rains occurred, it was identified that there was a low-value OLR movement in the western part of Java, and above Kalimantan which moved to the east and also appeared deep convection in the west of Java which was quite extensive. The wind and OLR composite anomalies also support this conclusion. For rainfall with a higher intensity as June 18, 2016, which can even be recognized 3 days before the occurrence of deep convection where the low OLR is below 150 Wm^{-2} (Pearson *et al*., 2010) which is widely distributed starting from west Sumatra. Meanwhile, in the case of heavy rain, the distribution of OLR is very different, where the use of the 150 Wm^{-2} limits cannot be used. Rainfall at this intensity is recognized with a limit between 180 to 260 Wm^{-2}, but a change in this threshold will risk misdetection (Fu *et al*., 1990). Based on the OLR anomaly, it can be seen that there is deep convection using average data 3 days before the incident where the OLR anomaly value in the Central Java region ranges from -60 to -20 Wm^{-2}.

The water vapor content, which was identified using a vertical humidity profile, was seen to increase the day before the occurrence of very heavy rains where the humidity value was over 80% reaching the 500 Mb level. If the intensity increases, then the vertical humidity reaches a very high level and the value is more than 80%. While the precursor using air pressure is not easy to do because the difference in pressure in Indonesia is not too big a difference. However, if there is a sea-level pressure in the northern part of Kalimantan and it persists for a long time, it is possible to trigger a convergent wind flow towards the center of low pressure in the southern part of Java. The decreasing wind speed along with this pressure condition needs to be watched out for, especially if the decrease in wind speed is less than 4 m/s. Changes in dynamics in the Indian Ocean are known to greatly affect rainfall on the surrounding land (Bala, *et al*., 2008; Ogwang, *et al*., 2020; Sarkar, *et al*., 2021). The identification of the increase in temperature in the southern part of Java was not detected only in spots where the temperature was more than 30.2 °C. Three to four days before the heavy rainfall, it was found that there were spots of sea surface temperature with a value of more than 30.2 °C in the Indian Ocean adjacent to the southern part of Java Island. In both cases of extreme rain that caused flooding in Purworejo, it occurred when the temperature on the west coast of Sumatra was warmer than the Western Indian Ocean or the value of the Indian Dipole Mode was negative. Although in general the Indian Ocean and the Pacific Ocean affect rainfall in Indonesia (Nur'utami and Hidayat, 2016). However, the impact of the dipole mode on this increase in rainfall will be stronger when the ENSO value is neutral (Yulihastin *et al*., 2010). The extreme rain event in Purworejo in June strengthened the neutral condition of ENSO as a condition for the influence of warm temperatures which had an impact on increasing rainfall intensity.

While the relation of signs of heavy rain to the MJO phase shows that although none of the events coincided with the MJO phase 6, heavy and very heavy rainfall in

June in Purworejo occurred simultaneously with phases 3-4 and 7-8. Many studies say that the increase in rainfall intensity in certain phases of the MJO or *vice versa* is less significant for the Java area (Hidayat and Kizu, 2010; Arbain, 2012; Arbain *et al*., 2017; Tallamma *et al*., 2016; Fajarianti *et al*., 2018; Suhardi *et al*., 2018; Lestaria *et al*., 2019). This study confirms that the effect of the MJO on increasing rainfall is not certain in certain phases. However, by analyzing the increase in rainfall with an intensity of more than 20 mm/day in Purworejo, convection activity in phases 3 and 4 should be watched out for, while phases 7 and 8 also need to be considered. There are still many variations in the influence of the MJO that need to be investigated, which not only affects the results of in situ rainfall observations and remote sensing and merging results (Giarno *et al*., 2018; Giarno *et al*., 2020).

In addition to soil conditions, rainfall is a major factor in the occurrence of floods and landslides. The analysis of rainfall limits that cause landslides in Java with the best accuracy of 0.71 is 39 mm/day or 81 mm/3 days (Yuniawan *et al*., 2022). Regarding soil type and rainfall threshold triggering erosion, andesite breccia is the most vulnerable soil type, followed by sandy clay and andesite (Mahendra, 2018). This study confirms that the rain that caused the flash flood was 20 mm/30 minutes and occurred without a break for 7 hours continuously.

5. Conclusion

Several parameters that must be considered are wind, outgoing long radiation (OLR), humidity, and sea surface temperature. The precursors of very high-intensity rain can be identified the day before the incident, where deep convection occurs with an OLR value of 150 Wm^{-2} or less. Even, if the rain is very heavy and evenly distributed, the previous 3 days can be identified. However, in moderate or heavy rain, identification is rather difficult because the OLR threshold is 150 Wm^{-2}, but the value of OLR data is obtained between 180 to 260 Wm^{-2}, so it is prone to errors. The average data is 3 days before the incident where the OLR anomaly value in the Central Java region ranges from -60 to -20 Wm^{-2}. Another sign that can be used is the vertical humidity profile, where when it rains very heavily, the humidity value is more than 80%, reaching the 500 Mb level, the day before or even more than a day if the rainfall is higher and evenly distributed. During very heavy rains, there were spots with temperatures over 30.2°C, three to four days before the incident with values of more than 30.2°C in the Indian Ocean adjacent to the southern part of Java Island. On a broad scale, the Indian Dipole Mode is positive, so it supports the movement of water masses to the Java region and occurs when the ENSO value is neutral. Meanwhile, for air pressure, there is low pressure in the northern part of Kalimantan and in the southern part of Java, which lasts a while. Moreover, decreasing wind speed along with this pressure condition needs to be watched out for, especially if the decrease in wind speed is less than 4 m/s. Then, the influence of the Madden-Julian Oscillation (MJO) on the increase in rainfall is uncertain in certain phases, but convection activity in phases 3 and 4 is the most noteworthy because it has been recorded to have occurred simultaneously with moderate to heavy rainfall. In addition rainfall of 20 mm/30 minutes that occurred for 7 hours without a break has the potential to cause flash floods in sandy clay areas. A more detailed study of soil moisture conditions is needed to see the condition of soil saturation to determine the threshold of rainfall causing flashfloods more thoroughly.

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