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MJO modulation on diurnal rainfall over West Java during pre-monsoon and strong El Niño periods

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Abstract. This study was conducted to determine the MJO modulation on diurnal rainfall in West Java during the pre-monsoon and strong El Niño periods in 2015 over West Java. The data used is a combination of satellite data, reanalysis data, radar stations data, and numerical weather prediction of Weather Research and Forecasting (WRF) data with spatial resolution of 5 km. The results confirmed that the strong MJO in 4 and 5 phases has modulated the amplitude of diurnal rainfall increase significantly over West Java in phase of lag+1. Modulation on diurnal cycle of rainfall was also indicated by the persistence of the rainfall and the formation of two peaks of maximum rainfall in the afternoon and early morning. In addition, modulation of rainfall for the southern part of Java was 50% greater than the north. Moreover, the MJO modulation mechanism was characterized by the formation of an active and extending of Meso-scale Convective System (MCS) which has a cycle of up to 12 hours and persistent from November 7-9 over West Java.

1. Introduction

Madden Julian Oscillation (MJO) is an atmospheric equatorial waves propagating from the western (Indian Ocean) to the eastern (Pacific Ocean) with a period of 30-90 days or 20-50 days at a speed of about 4-5 m/s [1-4]. Activities of MJO broad impact on a wide range of global weather and climate phenomena, one of which is relate to rainfall variability [5-7].

Previous research suggests that MJO modulated to the diurnal cycle of tropical Deep Convective Cloud (DCC). The most significant of DCC occurred in the Indian Ocean (50%) compared to the Pacific Ocean and IMC (20%) [8]. In the IMC, diurnal rainfall has a high variability of response to the MJO, depend on the season and local conditions of geographical features [9-11].

For the northern part of the IMC, the influencing of MJO on diurnal rainfall occurred in Sarawak, Borneo [9] which are identified by enhanced of convergence, land-sea breeze circulation, and maximum of the rainfall occurred on the beach at midnight before the active phase of the MJO. They also found a dynamically difference of the modulation rainfall for coastal and inland regions in Borneo. For coastal areas, there is frequency increased of diurnal rainfall, while the increased in the frequency and intensity of diurnal rainfall occurs in interior regions. For the eastern part of IMC, in New Guinea, the most attractive feature of the diurnal rainfall placed in the central part of mountain which is identified through the propagation of the diurnal rainfall in the afternoon which spread to the



southeast and northwest associated with the easterly-westerly flow at the low level at speeds of 2-3 m/s [10].

Meanwhile, during the December-January-February (DJF) period in the western part of IMC (Sumatra and Java), convective activity increases when the MJO is in the active phase, otherwise it decreased when the MJO is in an inactive state [11]. While MJO reach a mature stage, large variation of the diurnal rainfall occurs between the mainland (minimum) and sea (maximum). Moreover, it appears that rainfall more intensify in the morning over the Java Sea, while minimum rainfall occurs in Sumatra in the afternoon. Maximum rainfall which occurred in the morning over Java Sea is influenced by interaction of land-breeze and low level westerly generated by MJO which is reinforced by the Asian winter monsoon over the Java Sea, and is affected by the blocking effect of the mountains. On the other hand, the nocturnal diurnal rainfall over Java mainland generally occurs from the afternoon to midnight. It probably occurred because westerly and seasonal flow has hampered the convergence so that reducing rainfall in the mainland.

On the other hand, diurnal rainfall over Java Island has different characteristics between the northern and southern parts associated with the different topography of the region. The mountains in southern Java impact on rainfall diurnal became more intensive in the southern than the northern part. Interestingly, the diurnal rainfall in the southern part has increased in the event of El Niño during the period of DJF [12]. However, no studies have revealed the relationship between the MJO and strong El Niño in the transitional period before the monsoon due to rainfall season in Java, especially associated with the diurnal cycle response in the region. In this case, West Java was chosen as the study area because it's geographically closer to the Indian Ocean, an area where MJO undergoing a process of initiation. In addition, West Java geographically is also adjacent to the island of Sumatra where MJO influence in the region proved to be a strong and significant in influencing the diurnal cycle of rainfall. Therefore, this study aimed to explain the influence of the MJO in modulating diurnal rainfall that occurred in West Java during the period of transition to Asian winter monsoon due to rainfall season during a strong El Niño period in October-November 2015.

2. Data and Method

The research methodology developed in order to prove the MJO events in associated with the increased rainfall in West Java, with a case study during the strong El Niño period from October to November 2015.

2.1. Data

To prove the examination of the MJO, we investigated MJO indices data available in <http://cawcr.gov.au/staff/mwheeler/maproom/RMM/RMM1RMM2.74toRealtime.txt>. Meanwhile, evidence of the occurrence of El Niño by Nino 3.4 index data derived from: <http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml>.

Hourly rainfall data of 3B41RT derived from Tropical Rainfall Measuring Mission (TRMM) satellite data and WRF models. Data from the model used to supplement rainfall data from satellites, based on verification of hourly rainfall data from TRMM satellite which under-estimated compare to station rainfall data. Meanwhile, to determine meso-scale processes that affect the increase in rainfall, an analysis using the reanalysis data of Era-INTERIM of 6-hourly data of wind and rainfall, also clouds data of IR1 from Himawari satellite. All of data in this study had a range of periods from October to November, 2015.

2.2. Method

The method used to examine the increase in rainfall and meso-scale processes that causes it, consists of several stages. Firstly, examine the MJO index and ENSO index of Nino 3.4. Secondly, to categorize the MJO activity based on movement and strength. Thirdly, we used the hovmöller diagram analysis to examine the evolution of convective activity and rainfall that occurred in West Java during the period from October to November, 2015. Fourthly, perform spatial analysis on rainfall patterns in

West Java, and examine the difference between northern and southern regions in response to modulation of the MJO. The last, performing a meso-scale analysis to draw the mechanism of rainfall during the period of MJO active and strong El Niño period. The MCS calculated adapted from Trismidianto et al. [13].

3. Results and Discussion

Table 1 shows the MJO propagation of phase 9 (Africa) towards phase 8 (the Pacific Ocean), which lasted from October 5 to November 4, 2015. As for the range of 5 to October 20, 2015, the MJO is in a period of weak or inactive over the IMC (blue box). Furthermore, on October 25, 2015 to November 4, 2015 the MJO is active and stronger (yellow color in the red box) over the IMC, then pass to the Pacific Ocean.

Table 1. MJO activity over IMC (phase 4 and 5) during periods of weak, begin to active, mature, and dissipate.

| Time\Fase | 9 | 10 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 20151005 | 1.27 | 1.87 | 1.86 | 1.36 | 0.54 | -0.60 | -1.71 | -1.75 | -1.14 | -0.12 |
| 20151010 | 1.58 | 2.31 | 2.32 | 1.70 | 0.68 | -0.75 | -2.13 | -2.18 | -1.41 | -0.14 |
| 20151015 | 1.03 | 2.08 | 2.27 | 1.92 | 1.12 | -0.20 | -1.73 | -2.14 | -1.68 | -0.64 |
| 20151020 | 0.39 | 1.56 | 1.86 | 1.85 | 1.37 | 0.36 | -1.11 | -1.81 | -1.69 | -1.01 |
| 20151025 | -1.12 | -0.08 | 0.14 | 0.98 | 1.45 | 1.51 | 0.71 | -0.42 | -1.15 | -1.48 |
| 20151030 | -1.56 | -1.06 | -0.83 | 0.03 | 0.80 | 1.45 | 1.44 | 0.60 | -0.28 | -1.09 |
| 20151104 | -0.94 | -0.97 | -0.88 | -0.44 | 0.09 | 0.70 | 1.06 | 0.78 | 0.28 | -0.32 |
| 20151109 | 0.09 | -0.42 | -0.47 | -0.59 | -0.54 | -0.28 | 0.20 | 0.54 | 0.61 | 0.51 |

Figure 1 describes the evolution of rainfall spatially in the area of West Java during the period of weak MJO (October 17-22, 2015), begin to initiate (October 23-31, 2015), and active (November 4-9, 2015) over the IMC. Seen over a period of weak MJO over IMC, but active in the Indian Ocean, based on rainfall data based on WRF model (0.1-10 mm/h) begin to occur in the southern region of West Java (Bogor and vicinity). This is supported by monsoon circulation at an altitude of 850 mb showing convergence over the area. Convergence was formed because there was a meeting of wind easterlies from the Java Sea and southeasterly from the Indian Ocean south of West Java. However, data from GSMaP not indicate formation of rainfall, as captured by the model WRF (Figure 2a and d). The inability of GSMaP data in capturing surface of rainfall has been studied previously for West Java, Jakarta and Bogor using surface station data, which shows the correlation <0.2 [14]. While the value of the model WRF rainfall is consistently showed values exceeding 3B42 TRMM satellite data (by a margin of 3 mm/3-time) for diurnal rain in parts of Indonesia [15].

Furthermore, when the MJO became active over IMC (October 26-31, 2015), rainfall began to increase and spread in the southern part of West Java with maximum rainfall occurs around the Bogor area (Figure 2b). The cause of the increase in rainfall is the same as the previous period, namely because there is convergence over the southern West Java. The maximum rainfall in the south around Bogor is confirmed by the GSMaP data (0.1-0.5 mm/h) despite the difference in intensity is very low when compared with data from the WRF model (25-30 mm h) (Figure 2e).

While MJO is an active period over IMC, rainfall in the southern West Java increased compared to the previous period. This is shown by the data of rainfall from WRF models (<20 mm/h) and GSMaP (<2 mm/h). This proves that the MJO activity is positively correlated with the formation of rainfall in the area of West Java, although it appears in the spatial pattern is not uniform between the intensity of rainfall in the northern and southern part of West Java.

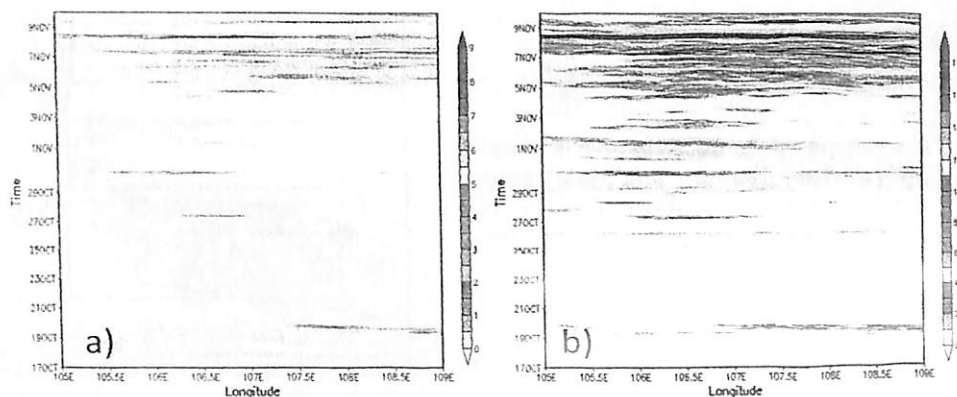


Figure 1. Hovmöller of Time-Longitude cross section during October 17 - November 9, 2015 based on TRMM 3B42RT hourly data (a) and convective activity based on Himawari satellite IR1 data (b).

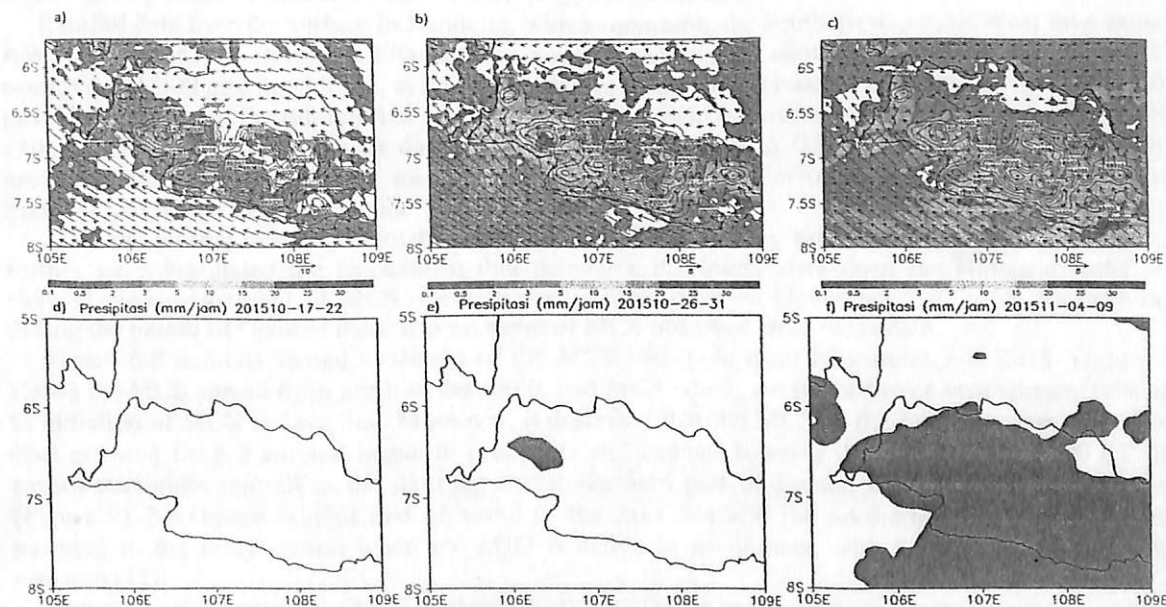


Figure 2. Rainfall at October 17-22 during weak MJO based on WRF model (a) and GSMaP (d), October 26-31 during MJO begin to active (phase 2 and 3) based on WRF model (b) and GSMaP (e), November 4-9 2015 during MJO active in phase 4 and 5 based on WRF model (c) and GSMaP (f).

Figure 3 draws the distribution of northern and southern regions in West Java where research was conducted. This is done because based on the results of the model WRF ((a) - (c)), there is a clear difference in rainfall between the northern and southern part during the pre-monsoon and MJO started and is active periods. Differences in rainfall between the northern and southern part in Java during El Niño was explained by previous investigation [12], which concluded that El Niño strengthen the diurnal cycle of rainfall in the southern part of Java so that the diurnal rainfall diurnal in southern Java climatologically increased during El Niño.

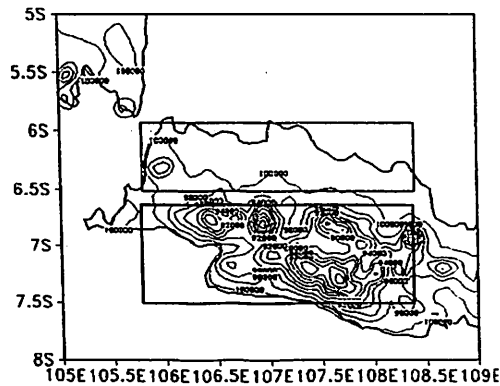


Figure 3. The division of the northern West Java region (blue) and southern (red) (a), the rainfall diurnal in West Java by WRF models for the northern region (blue) and south (red) on October 17-22 for weak MJO (b) and October 26-31, 2015 during the active phase of the MJO started 4 and 5 (c), November 4-9, 2015 for the active MJO phase 4 and 5 (d).

Figure 4 shows rainfall based on GSMaP data occurred in the third period (November 4-9, 2015), when the MJO is strong and intensive over IMC. In general, in the north and the south, rainfall is formed throughout the day with increased rainfall began to occur at 13:00 pm and experiencing the peak at 17.00 pm for the next downhill at 18.00 pm. In addition, rainfall in the southern part of the higher of 50 percent compared to the northern region of West Java.

Rainfall data over the surface in Bandung, which represents the southern region of West Java using AWS and radar, are shown in Figure 5 (a) and (b). AWS data shows that the maximum rainfall occurred at 13:00 pm. In addition, at midnight the rain resumed and reaches a maximum value at 24.00 pm. The intensity of the rainfall that occurred during the night is lower than in the day based on AWS data. While over Bandung, radar data showed a pattern similar to GSMaP, rainfall began to occur around 10:00 am and reaches a maximum at 17.00 pm. Persistent of rainfall seemed occurred in middle night with a maximum value.

After the diurnal rainfall modulation in West Java evidenced by satellite data, models, and radar, further we investigated the mechanism that generates it. Hourly data from the Himawari satellite showed the development of MCS intensify during three days on November 7-9, 2015. Meanwhile, during the month of October there was no event of MCS observed from these data.

Figure 6-8 exhibits spatial evolution of the MCS life cycle from November 7-9, 2015. Figure 7 shows the MCS spread from north to the south, and MCS which are formed over Java appears related to initiation of MCS in Java Sea. Moreover, it describes that the MCS in the Java Sea near coastal is start growing from 9 am and began to propagate and extends towards the mainland at 11:00 LT. It causes maximum rainfall in the morning in the northern part of Banten and the surrounding areas (Figure 9). Maximum rainfall that occurred in the Java Sea and the northern coast of Java in the morning in the rainy season when the MJO is active in accordance with the opinion of previous research [11].

Figure 7 and 8 explain the MCS to develop after 01:00 pm in the afternoon and reached the mature conditions in the evening. This is evidenced by the occurrence of rain in the afternoon until the evening on November 8-9, 2015 (Figure 9). Figures 7 and 8 also show that MCS is growing on the mainland come from local convective cells joined reinforce each other and then turned into MCS. Merging several local convective cells that arise in coastal regions and mountains of the western part of the southeastern part of West Java seems massive and widespread cover the entire region of West Java (Figure 7).

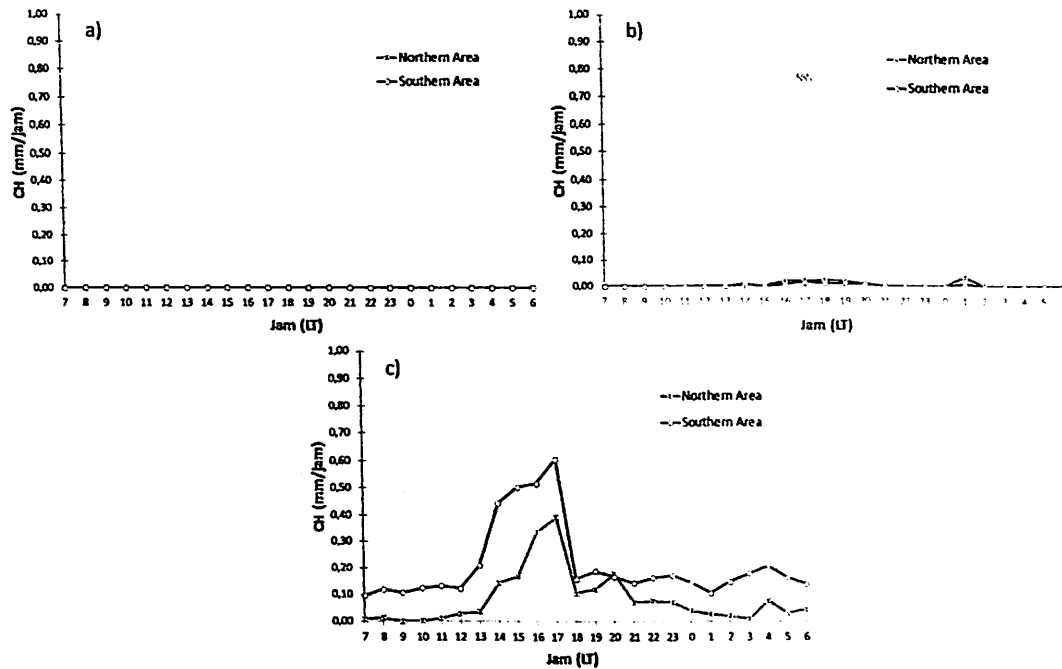


Figure 4. Diurnal rainfall in West Java GSMaP based on data for the northern region (blue) and south (red) on October 17-22 for weak MJO (a), October 26-31, 2015 during the active phase of the MJO started 4 and 5 (b), November 4-9, 2015 during an active MJO phase 4 and 5 (c).

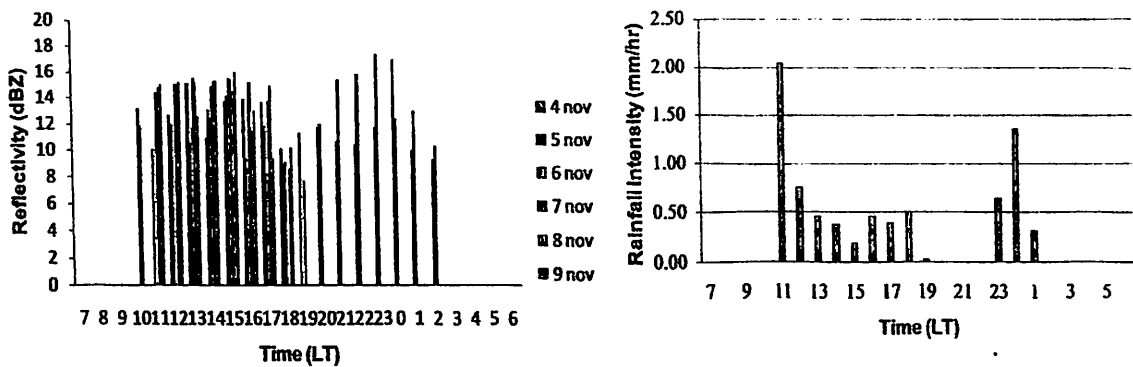


Figure 5. Diurnal rainfall over Bandung Space agency locations, Pasteur based on data from Furuno Radar (left-side) and the location of ITB Bandung, Dago (right-side).

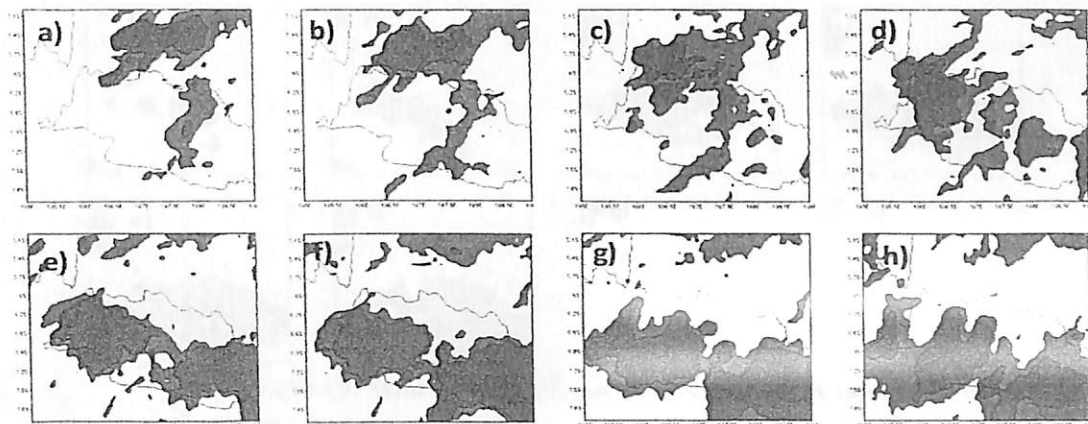


Figure 6. Evolution of MCS based on Himawari satellite at November 7, 2015 from 9.00 -16.00 LT (a-h).

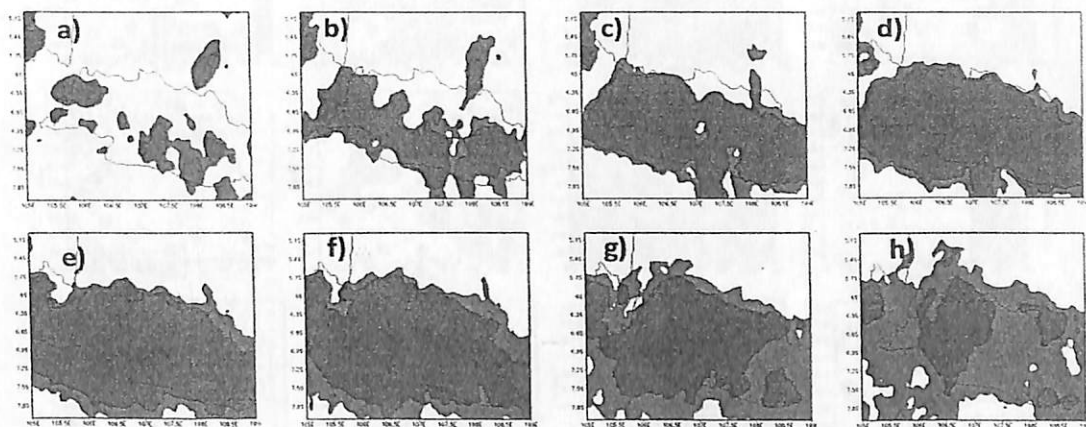


Figure 7. Same as Figure 6, but for 8 November 2015 from 01:00 -08:00 PM LT (a-h).

Meanwhile in figure 7 looks local convective cells initially developed over the mountainous area in West Java are joining the middle so that MCS widespread and extends only in the southern part of West Java. Figures 7 and 8 show that the diurnal convective activity generally occurs after the late afternoon, when the sun was warming in the atmosphere reached a maximum.

Having regard to the spatial patterns and the life cycle of MCS in figures 6-8, it appears that the diurnal aberration occurred on November 7, as evidenced by the occurrence of rain in the morning peak on land. This happens because of the influence of land-sea breeze circulation is increased, which looks very strong of sea breeze occurred during the day. Land-sea breeze circulation which appears clearly indicated that the influence of strong westerly circulation of MJO is omitted by a strong El Niño event so that local circulation factors emerge clearly and unambiguously. It also could suggested that strengthening land-sea breeze and this mountain-valley breeze circulation that have been modulate meso-scale rainfall increase over western Java on November 7-9, 2015.

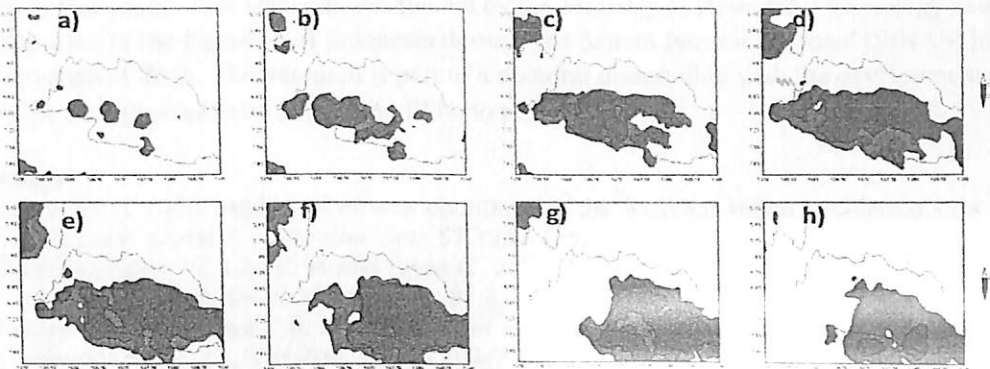


Figure 8. Same as Figure 7, but for 9 November 2015.

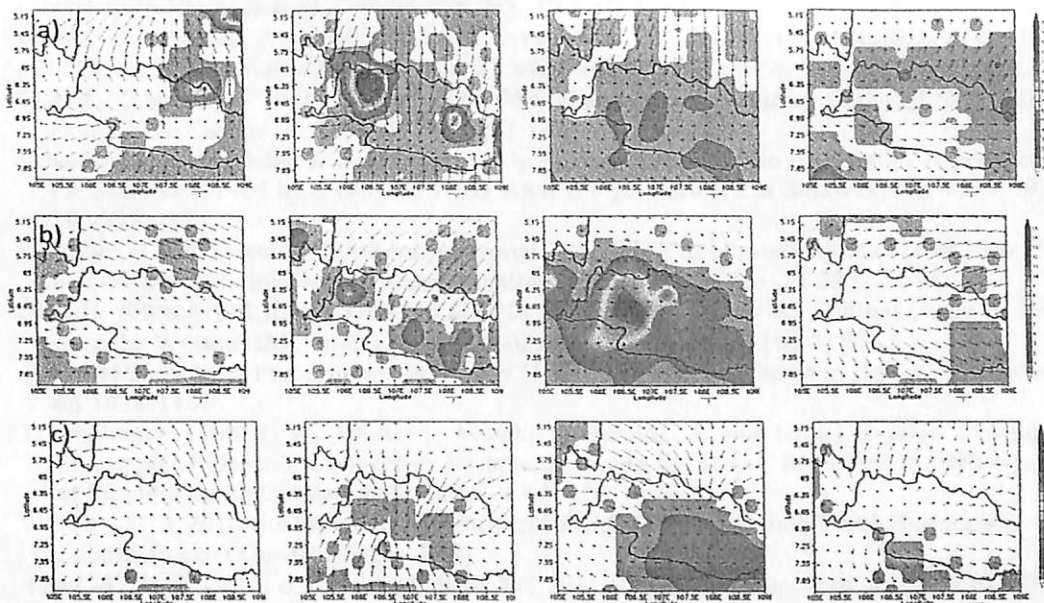


Figure 9. Rainfall and wind of 6-hourly reanalysis ERA-Interim data from left to right side of 07:00 AM, 01:00 PM, 07:00 PM, 01:00AM LT, 7 (a), 8 (b), 9 (c) November 2015.

4. Conclusion

Strong MJO from October 25 to November 4 in Indonesian Maritime Continent (IMC) has modulated the diurnal rainfall in West Java on November 7-9, which was affected by the formation of MCS and has a delay phase of two couple days with strong MJO of phase 5 occurrence. Northern and southern part of West Java have different response to the diurnal pattern of diurnal rainfall, where the southern part has greater in rainfall amplitude than it's northern part. The occurrence of strong MJO which coincides with the strong El Niño have damp of each other so that the local circulation of land-sea breeze and mountain-valley breeze tend to enhance and interact to produce MCS, which are raised by local convective cells on the surface level and extended by meso-scale convective activity in the Java Sea.

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