



Spatial and temporal characteristics of rain intensity in the peninsular Malaysia using TRMM rain rate

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SUMMARY

The present study is focused on the intensity distribution of rainfall in different classes and their contribution to the total seasonal rainfall. In addition, we studied the spatial and diurnal variation of the rainfall in the study areas. For the present study, we retrieved data from TRMM (Tropical Rain Measuring Mission) rain rate available in every 3 h temporal and 25 km spatial resolutions. Moreover, station rainfall data is used to validate the TRMM rain rate and found significant correlation between them (linear correlation coefficients are 0.96, 0.85, 0.75 and 0.63 for the stations Kota Bharu, Senai, Cameron highlands and KLIA, respectively). We selected four areas in the Peninsular Malaysia and they are south coastal, east coastal, west coastal and highland regions. Diurnal variation of frequency of rain occurrence is different for different locations. We noticed bimodal variation in the coastal areas in most of the seasons and unimodal variation in the highland/inland area. During the southwest monsoon period in the west coastal stations, there is no distinct diurnal variation. The distribution of different intensity classes during different seasons are explained in detail in the results.

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1. Introduction

Studies of rainfall characteristics especially in terms of its intensity distribution in different temporal and spatial domains are imperative to quantifying the flood response of rivers (Niemczynowicz, 1984; Obled et al., 1994; Watts and Calver, 1991; Desa and Niemczynowicz, 1996; Webster and Hoyos, 2004) and modelling of soil erosion (Kumar et al., 2007), etc. Climate change studies are also aimed to analyse the rainfall intensity to find the decreasing/increasing trend for the different intensity rain episodes. The model study of Gordon et al. (1992) found that there was an increasing trend in rainfall intensity due to the 'green house effect'. A study in Australia revealed that number of rainy days was increasing in some regions whereas it was decreasing abnormally in certain other regions (Haylock and Nicholls, 2000). In view of this, a basic understanding of the rainfall intensities of different ranges in different spatial domains during different seasons is essential. In the present study, we made a thorough analysis of the rain intensity derived from rain rate of TRMM (Tropical Rainfall Measuring Mission) data over different geographically important

areas in the Peninsular Malaysia. In this present paper, we analysed spatial distribution of daily rainfall, diurnal variation, distribution of different intensity classes of rainfall and their contribution to the total rainfall in different seasons.

The studies of rainfall characteristics, its spatial and temporal distributions are very sparse in humid tropical regions especially in the Maritime Continent. Based on a few reports available, the characteristics of tropical rain spells are thought to regulate the rate of wet canopy evaporation (Schellekens et al., 1999; Chappell et al., 2001; Bidin and Chappel, 2003), shallow water table fluctuation (Bidin et al., 1993) and rainfall–runoff behaviour (Robinson and Sivapalan, 1997). Kumar et al. (2007) studied the rain intensity distribution over different parts of Kerala (a tropical region) and they found that the temporal distributions of rainfall intensity at different places show low intensity classes from 65% to 90% of the time possibly indicating prevalence of stratiform and cumuli-form clouds. There were also reported the temporal characteristics of rainfall such as diurnal variation (Morgan, 2004; Bidin and Chappell, 2006; Mori et al., 2004) and seasonal variation (Oki and Musi-ake, 1994). Studies based on the satellite data in the study area are rarely reported. This present work is a first step towards the rainfall intensity distribution studies based on the remote sensing data from the space.

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2. Data and methods

The data utilized for this study is rain rate derived from the TRMM (Tropical Rainfall Measuring Mission) satellite. The TRMM rain rate data are available at a temporal resolution of 3 h with spatial resolution of $0.25^\circ \times 0.25^\circ$ latitude–longitude grid (Kummerow et al., 1998). This high resolution data in temporal and spatial domains provide good opportunity to study the rainfall characteristics especially in the humid tropics. The TRMM rain rate dataset contains the output of TRMM Algorithm 3B-42, which is to produce TRMM merged high quality/infrared (IR) precipitation and root-mean-square (RMS) precipitation-error estimates. The combined instrument rain calibration algorithm (3B-42) uses an optimal combination of 2B-31, 2A-12, SSMI, AMSR and AMSU precipitation estimates (referred to as high quality), to adjust IR estimates from geostationary IR observations. Near-global estimates are made by calibrating the IR brightness temperatures to the high quality estimates. The 3B-42 estimates are scaled to match the monthly rain gauge analyses used in 3B-43. The output is rainfall for $0.25 \times 0.25^\circ$ grid boxes every 3 h. More details of the algorithm are available on website <http://trmm.gsfc.nasa.gov/3b42.html>. In addition to the satellite data, we utilized station rainfall data measured by Malaysian Meteorology Department (MMD) for comparison with the satellite derived rain rate. The comparison of TRMM rain rate to the ocean rain gauge data was studied by Bowman et al. (2003) and Bowman (2005) and the studies showed that the TRMM Microwave Imager (TMI) gives a correlation value of 0.97, indicating very little bias with respect to the rain gauges in the oceanic regions. Harikumar et al. (2008) compared TRMM rain rate with disdrometer rain rate over the tropical station, Trivan-

drum, South India and found that they were significantly correlated with a correlation value of 0.6.

We selected Peninsular Malaysia for this study because rainfall amount in this region is highly variable due to the prevailing monsoon seasons (Tick and Samah, 2004) and it also exhibits short temporal changes such as diurnal variation (Oki and Musiaki, 1994). In addition, the terrain of Peninsular Malaysia is highly variable from coastal to highlands. In Peninsular Malaysia, we selected four different geographical regions to understand the features in each region. The four selected regions are in the south coastal, east coastal, west coastal and a highland region. These four locations are selected on the basis of box averaging. The latitude and longitude of the box area considered for averaging the TRMM rain rate for the regions in south coast, west coast, east coast and highland are 103.25°E – 104°E and 1°N – 2°N , 102°E – 102.75°E and 5.75°N – 6.5°N , 101°E – 101.5°E and 2.75°N – 3.5°N and 101.25°E – 101.75°E and 4.5°N – 5.25°N , respectively. The four regions selected of the study are marked in the topographical map of the Peninsular Malaysia in Fig. 1. We selected four seasons to understand the seasonal variability of the rainfall characteristics. The four seasons are northeast monsoon, pre-monsoon, southwest monsoon and early northeast monsoon for a period of 4 years (2005–2008). We considered here as the group of 3 months representing the respective seasons and they are December–February (DJF) for the northeast monsoon, March–May (MAM) for the pre-monsoon, June–August (JJA) for the southwest monsoon and September–November (early northeast monsoon).

Rainfall intensity distributions were studied based on the classification of the rain intensity in different classes. The rain intensity was classified at a rain rate interval of 2 mm/h. From this classifi-

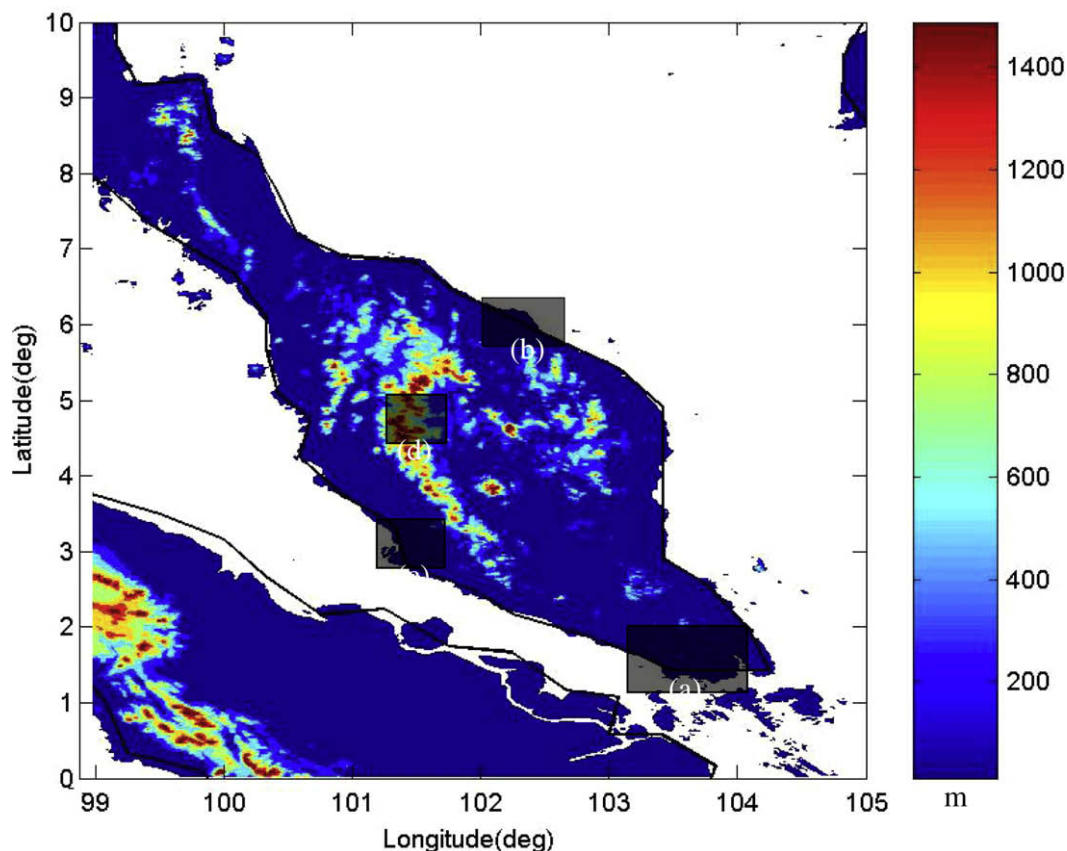


Fig. 1. Topography of the Peninsular Malaysia with the marked locations as: (a) south coast, (b) east coast, (c) west coast and (d) highland regions.

cation, we arbitrarily, but objectively classified rain intensity into low, medium and high class intensities. The low class rainfall intensity is determined when the rain intensity is less than 4 mm/h, medium class is when it is in the range between 4 and 8 mm/h and high intensity class is when it is more than 10 mm/h.

3. Results and discussion

3.1. Comparison between TRMM rain rate and manual rain gauge

For the comparison of rainfall data between TRMM and manual rain gauges, we selected four stations namely Kota Bharu (102.15°E, 6°N, 5 m above mean sea level) an east coastal station, Senai (103°40'E, 1°38'N and 37.8 m above mean sea level) representing southern station, KLIA (101°42'E, 2°44' and 16.3 m above mean sea level) representing west coastal station and Cameron highlands (101°22'E, 4°28 and 1545 m above mean sea level) representing a highland station. One year daily data of each station was analysed to know the correlation and root mean square error of each station. The year was selected based on the maximum availability of the rain gauge data set in a year and therefore the number of missing data was minimum and the remaining missing data was filled with linear interpolation. We selected the year 2008 for Kota Bharu station, 2007 for Senai station, 2005 for Cameron highlands and 2006 for KLIA station. Rainfall in these stations is highly vulnerable to the seasonal activities such as cold surges during the northeast monsoon season and southwest monsoon rainfall during the summer monsoon season. In the east and south stations, rainfall was observed maximum during the northeast monsoon period because the frequent arrival of cold surges over the Peninsular Malaysia are marked by the distinct increase of the northeasterly wind over east coastal belt (Chen et al., 2002) and hence the triggering of organised convective cloud clusters. These cloud clusters contribute rainfall in the station. In the western station, the rainfall was observed maximum during the southwest monsoon period. In the highland station, rainfall is almost contributing uniformly; however, a small increase in rainfall is noticed during the northeast monsoon period. The MMD has set up manual rain

gauges at the stations as part of their routine meteorological measurements and we gathered rain gauge data for the comparison with the 3 hourly TRMM rain rate. In order to understand the comparability of the TRMM rain rate with the manual rain gauge rainfall data, we converted the 3 hourly TRMM rain rate into daily rainfall. A scatter plot is given in Fig. 2 to find the correlation of the TRMM rain fall with station rain gauge rainfall data. We made comparison for the four stations from different geographical locations such as east coastal, south coastal, west coastal and highlands of the Peninsular Malaysia. The correlation coefficient and the RMSE (root mean square error) are given in each panel of the figure. We found that the TRMM box for Kota Bharu is highly correlated with the station rain gauge data with a correlation coefficient of 0.96 which is significant at 99% confident level based on the student t-test. Among the four stations, the correlation value is least for the KLIA station, even though the level of confidence is high. This comparatively low value of correlation is may be due to the averaging effect of the area which is taken for the TRMM rain rate. The TRMM data for the location of KLIA is not available and therefore we take the area average of a 25 km square box as centred the KLIA station. For all the stations, the correlation value is significant at 99% confidence level because the number of data points is 365. In general, the TRMM satellite captures the signal of rainfall well in comparison with the rainfall measurement from the manual rain gauges situated in different locations of the Peninsular Malaysia. These higher values of correlation coefficient for different locations indicate good agreements between the TRMM and the manual rain gauge. Based on this we can study the rain intensity characteristics of the Peninsular Malaysia using the high resolution TRMM rain rate.

3.2. Spatial distribution of rainfall during different seasons

Averaged daily rainfall from the 3 hourly TRMM rain rate for the prominent four seasons in the Peninsular Malaysia is given in Fig. 3. From the figure, it is evident that the rainfall characteristics during different seasons are markedly different. We found that high rainfall was received during the northeast and early northeast

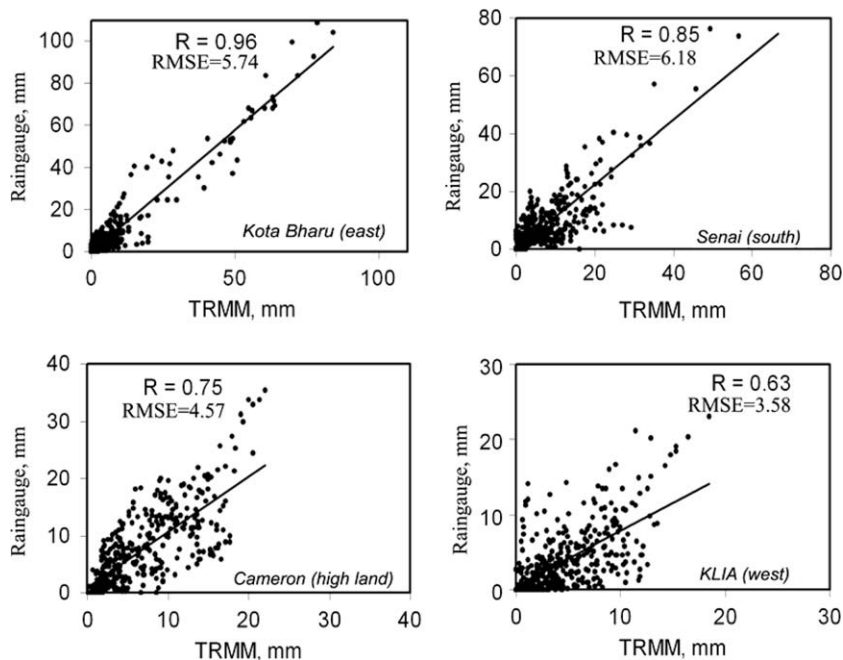


Fig. 2. Regression analysis of rainfall from TRMM and manual rain gauge station data for the stations Kota Bharu representing east coastal area, Senai representing southern belt, Cameron Highlands representing highland station and KLIA to represent the west costal belt. The linear correlation coefficient and RMSE are given in each panel of the figure.

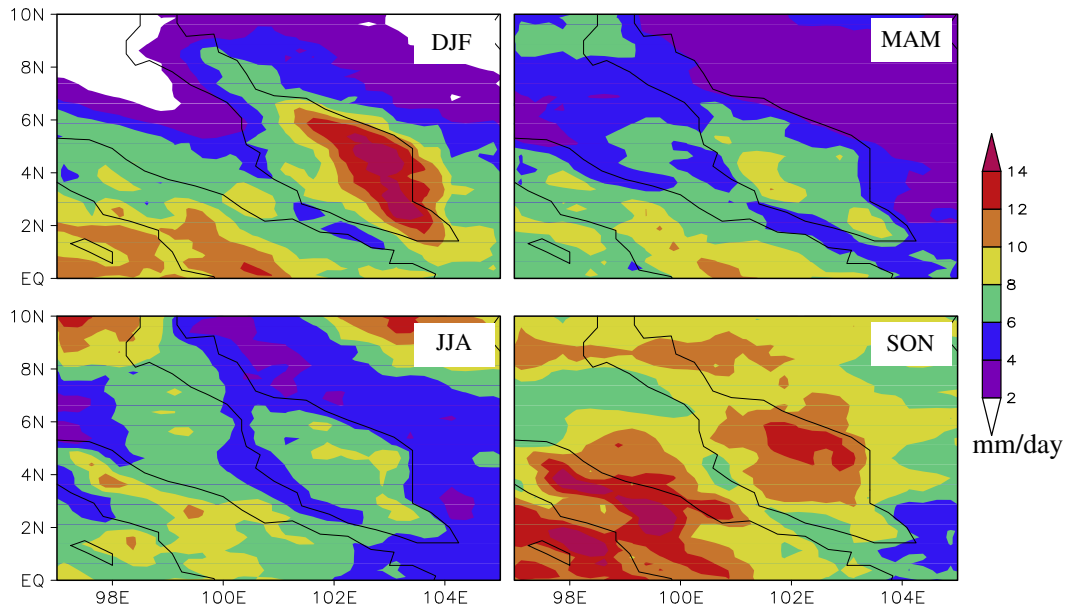


Fig. 3. Average daily average variation of rain intensity during the four seasons. The seasons are NDJ (northeast monsoon), MAM (pre-monsoon), JJA (southwest monsoon) and SON (early northeast monsoon).

monsoon periods and the least was observed during pre-monsoon period. Moreover, the spatial variation of the rainfall was also noticed in different seasons. During the northeast monsoon season, the daily average rainfall was above 14 mm/day in the east coastal stations and the high rainfall area covers from 1.5°N to 6.25°N: almost entire Peninsular Malaysia. The high precipitation zone in the east coastal area was due to the dominance of the northeast monsoon and associated cold surges. The cold surges are characterised by abnormally high rainfall in the Maritime Continent (Neale and Slingo, 2003). In the early northeast monsoon period, the high rainfall zone is concentrated over the area 4°N–6°N in the western Peninsular Malaysia. In the pre-monsoon season, average daily rainfall amount was relatively low and the zone of high rainfall (>8 mm/day) was seen in the west coastal stations and it might be due to the onset and further progress of the southwest monsoon season. In general, Peninsular Malaysia was received high amount of daily rainfall during the northeast monsoon season and followed by the early northeast monsoon season.

3.3. Diurnal variation of rainfall in different topographical regions

Diurnal variation of rainfall has been studied in many places over the world. In Peninsular Malaysia, diurnal variation of rainfall was reported by Oki and Musiaka (1994). However, they studied the diurnal variation using the station data set for different clusters of stations. They classified the clusters as east coastal, west coastal and inland locations and found morning peak in the coastal stations and evening peak in the inland stations. Similar studies were made by many researchers in different parts of the world (Ramage, 1964; Prasad, 1974; Haldar et al., 1991; Sorooshian et al., 2002). Most of the studies are based on the station data and therefore the poor spatial coverage of manual rain gauge stations may be contributing systematic errors. In addition, for the study of the diurnal variation, it requires high temporal resolution data. Due to the frequent manual observations, there is a chance to add the manual errors. Therefore, we utilized the satellite derived TRMM rain rate for the study of the diurnal variation. Fig. 4 shows the diurnal variation of the TRMM rain occurrences for the different locations during the different seasons. The ordinate of the figure gives the occurrence of the rain in the station. We counted the number of rain occurrence for the month and plotted against the

time in abscissa. In the south coastal region, high frequency of rain occurrence (number of rain occurrences in the study period) was observed at 1400 h (all the time referred here are local time: UTC + 08:00) in January and April indicating northeast and pre-monsoon seasons respectively. However, in July and October (representing southwest monsoon and early northeast monsoon) high number of rain occurrences was observed during 1700 h. In January and April, an additional peak was also noticed in wee hours even though the number of events is low while comparing with the after noon peak. The minimum number of rain occurrences was noticed in 2300 h for all the seasons. In east coastal stations, diurnal variation was evident in all the seasons. Here also we noticed two peaks: one in early morning around 0200 h and another one in after noon hours around 1400 h, except in July (after noon peak is around 2000 h), this result is coinciding with the findings of Oki and Musiaka (1994). The early morning and after noon peaks have the same intensity in the northeast and pre-monsoon seasons. However, number of rain occurrence was minimal during the northeast monsoon season. At the highland station (an inland station also), only one peak was noticed. In northeast and pre-monsoon seasons, the after noon peak was observed at 1700 h and in other seasons it was in 2000 h. Apart from the other coastal stations, the pattern of the highland station is different. It has only one peak and that was too broad indicating the number of rain occurrences were gradually increasing from 1200 h to 1500 h and then gradually decreasing until the early morning. The minimum was observed at 1100 h and it was same for all the seasons. In the west coastal stations, the bimodal pattern of the rain occurrence was seen only in the pre-monsoon season. As in the case of other seasons, the early morning and afternoon peaks were at 0200 and 1400 h respectively. In April and October, a small but negligible peak was observed in the early morning and afternoon periods. However, there was no distinct diurnal pattern during the southwest monsoon season.

3.4. Distribution of rainfall intensity and its relative contribution

3.4.1. South coastal region

Fig. 5 shows the distribution of intensity in different intensity ranges along with their contribution to the total rainfall in different seasons. During the northeast monsoon period, the smallest

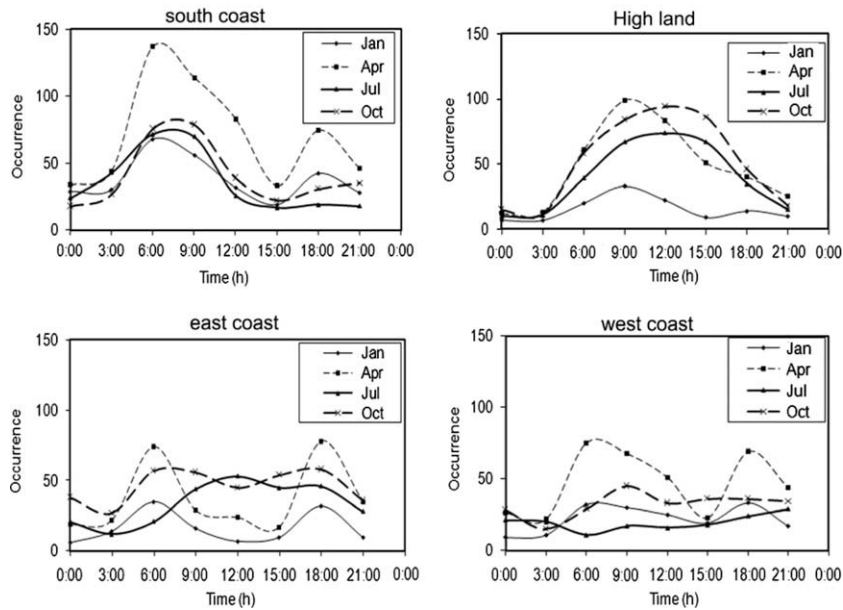


Fig. 4. Diurnal variation of rainfall occurrence for different geographical stations namely south coastal regions, east coastal region, highland regions and west coastal region during January representing northeast monsoon, April representing pre-monsoon, July representing southwest monsoon and October representing early northeast monsoon.

intensity range (<2 mm/h) occurred 81% of the total rain events. However, this intensity range contributes only 29% of total rain amount in the season. It is important to note that the high intensity ranges play a significant role in contributing rain amount to the total rainfall. The high intensity range (>10 mm/h) occurs only about 1.4% of the total number of rain events and contributes 13.1% of the total rainfall indicating substantial amount of rain within a short period. This kind of information is essential to the country because thunder showers cause the geographical slides and flash floods and hence they threaten the economy and human life. The middle class intensity ranges (4–10 mm/h) contributes 34.5% to the total rain-

fall and low class (<4 mm/h) contributes 52% to the total rainfall. During the pre-monsoon season (MAM), low rain intensity class occurred 96% of the total rain events and this contributes 74% of the total rainfall in the south coastal stations. The middle class (4–10 mm/h) intensity range contributes 4% and this adds 25% to the total rainfall. Therefore during pre-monsoon season, the high intensity rain events are negligible and this contributes only 1% to the total rainfall. This indicates that during the northeast monsoon period, high intensity rainfall (e.g. shower) is not at all present and hence there is no chance for the land slides or geographical transformation. In the southwest monsoon season, number of low

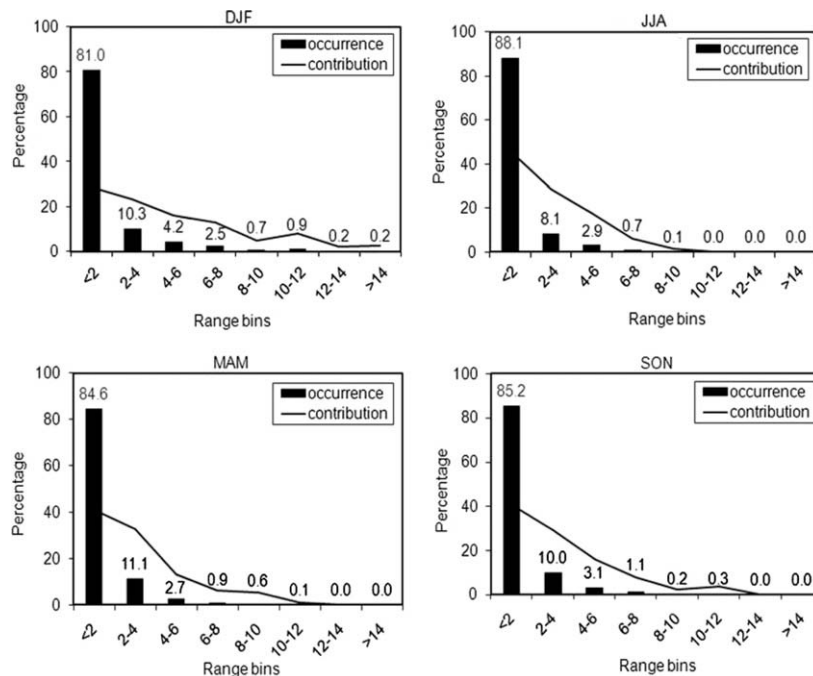


Fig. 5. Rain intensity distribution in different intensity classes and their relative contribution to the total rainfall in the south coastal region during different seasons in the Peninsular Malaysia.

intensity class rain events occurred 96% and it contributed about 75% of the total rainfall. The 25% was contributed by the middle class. During this season no high intensity rain spells was observed. The low intensity type rainfall is prominent in the southwest monsoon season. In the early northeast monsoon season, 95% of rainfall was low intensity type and constitutes 70.1% of the total rainfall. 26.3% of rainfall was contributed by the middle class and merely 3.6% from the high rain intensity classes.

3.4.2. East coastal region

To study the rain intensity characteristics in the east coastal stations, we archived the 3 hourly rain rate derived from TRMM over the area 102°E–102.75°E and 5.75°N–6.5°N for different seasons. The intensity distribution of different classes and their relative contribution to the total rainfall are given in Fig. 6. During the northeast monsoon period (DJF), the low intensity class registered around 90% of the rain events, however, low intensity rain alone contributes 45% of the total rainfall. The middle class intensity was registered only 7.3% of the rain events and this contributed about 33% of the total rainfall and the 2.3% was high intensity rain episodes. Even though, the registered number of high rain intensity spells was lower, it constituted a good contribution to the total rainfall (~22%). This reveals that during the season in the east coastal stations, rainfall with considerably large rain drops are falling to the ground and it ultimately leads to the soil erosion and geographic transformations. The middle and high class intensity ranges were contributed almost uniformly to the total rainfall. In the pre-monsoon season, low, middle and high intensity rain events were occurred 97.3%, 2.5% and 0.2% and they contribute 77%, 20% and 3%, respectively. During the southwest monsoon, entire rainfall was registered in the relatively low intensity range (<8 mm/h). It was important to note that there was no high intensity rain spell during the southwest monsoon season. 82% of the total rainfall was in the low class intensity. During the early northeast monsoon period (SON), the high intensity rain events contribute 8.5% of total rainfall even though the total number of rainy events was only 0.7%.

3.4.3. West coastal region

The rain intensity distribution in the west coastal region is entirely different from the east coastal region. Fig. 7 gives the intensity distribution along with the relative percentage of individual class of rain events to the total rainfall amount. During the northeast monsoon period, the high intensity class was not pronounced. In all other seasons, rainfall in all the three intensity classes was registered reasonable amount even though the number of rain occurrences was relatively lower in the high intensity ranges. During the northeast monsoon season, sub range of middle class intensity range contributes almost uniformly and these classes together contribute 37% of the total rainfall. In the pre-monsoon season, almost 14% of the total rainfall was noticed in high intensity class. Similarly the high intensity class during the southwest and early northeast monsoon seasons were 13.6% and 16.2%, respectively. While comparing to the south and east coastal regions, the west coastal region has a little effect to the northeast monsoon and associated cold surges activities. This means that the high rainfall intensity range was contributed mainly from these cold surges during the northeast monsoon season in south and east coastal regions.

3.4.4. Highland region

In this section, we present the rain intensity distribution in different seasons averaged over the box 101.25°E–101.75°E and 4.5°N–5.25°N. The rain intensity distribution and its relative contribution is given in Fig. 8. As in the case of the west coastal station, the highland area also registered 2% rain occurrence in high intensity range and this contributes about 17% of the total rainfall. This amount of rainfall is high even though the number of rainfall events is low. The consequences in highland area are different from that of the coastal stations. The slope of the highland is considerably high in comparison the coastal area. The land transformation the steepness of the terrain and the high frequency of rainstorms make landslide occurrence a common phenomenon (Dai et al., 2001). In view of this, the basic knowledge of the rain events in different classes of rain intensity and their relative contribution to the total rainfall is imperative to scientific community and planners.

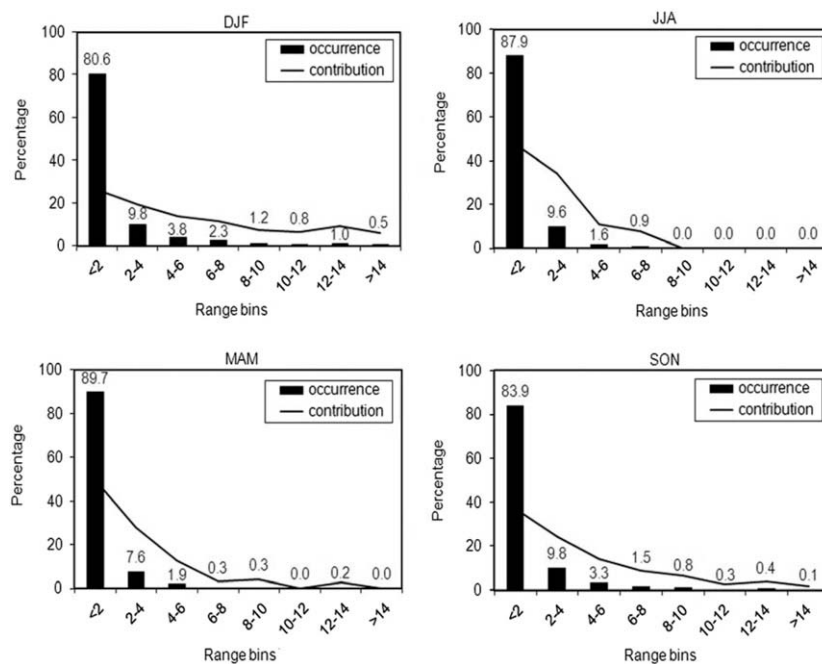


Fig. 6. Same as that of Fig. 5 but for east coastal region.

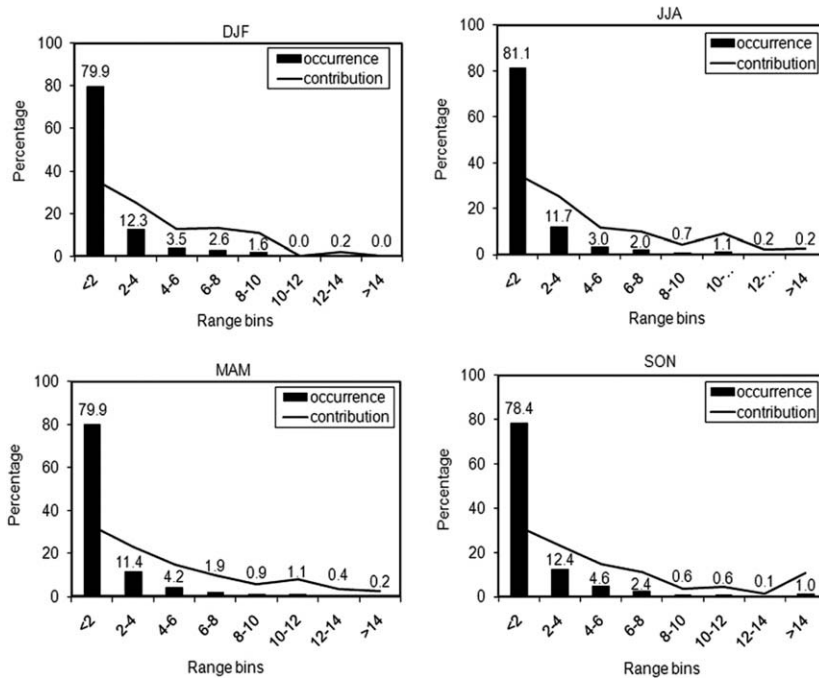


Fig. 7. Same as that of Fig. 5 but for west coastal region.

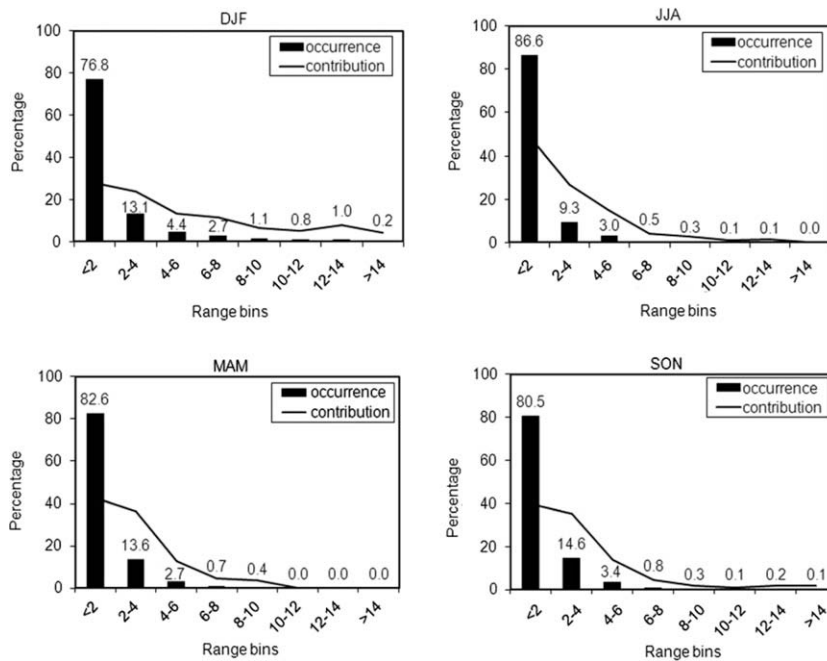


Fig. 8. Same as that of Fig. 5 but for highland region.

In all other seasons, the frequency of the rain events in the high intensity class is almost negligible especially in the pre-monsoon period. In the southwest monsoon and early northeast monsoon seasons, 97% and 95% of the rainfall was from the low and middle class intensity ranges respectively. Out of this, 75% was registered in the low class intensity ranges of rainfall indicating low intensity type rain events.

4. Conclusion

This paper deals with the seasonal distribution of rainfall in spatial and temporal domains. We also made a comparison between

TRMM rain rate and rainfall data collected from the manual rain gauges for different topographical regions and found that they agree well with a coefficient of determination (R^2) of 0.92 for east coastal station, 0.72 for south coastal station, 0.56 for highland station and 0.4 for west coastal station. These significant values of correlation coefficient in different locations in the Peninsular Malaysia indicate that the TRMM rain rate data is enough to study the diurnal variation and spatial distribution of different intensity classes in different seasons. The spatial distribution of the TRMM rain rate shows that the rainfall is high during northeast monsoon and followed by the early north east monsoon and least observed during the southwest monsoon period. During the southwest

monsoon season, the rain prone area is in the west coastal belt whereas in the northeast monsoon, it is in the east coastal regions. The diurnal variation was also different in the different geographical areas. In most of the coastal areas, we found bimodal variation in the diurnal pattern of rain events, however, in the highland/ inland areas unimodal variation was prominent. There was no distinct diurnal variation in west coastal region during the southwest monsoon season.

We also studied the distribution of rain intensity in different classes such as low, medium and high intensity classes. In the northeast and early northeast monsoon seasons, considerable amount of rainfall is contributing from the high intensity class in most of the areas except west coastal region. In the west coast region, high intensity class was mainly contributed during the early northeast monsoon period. The high intensity class is absolutely absent during the southwest monsoon period except in the west coastal stations. This may be due to the organisation of the clouds in the Maritime Continent leading to low intensity type rainfall that falls in the low and medium intensity classes. In all the stations, low intensity class constitutes more than 60% of the total rainfall except during the northeast monsoon period.

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