TRMM PR Observed Spatial Patterns of The Convective-Stratiform Rainfall Over Indonesia and Their Response to ENSO

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Abstract. This study investigates the variability of convective and stratiform rainfall over Indonesia from 5 years (2004–2008) data of Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR). The remote sensing data was employed to analyze the seasonal means and seasonal differences between convective and stratiform rainfall values. In addition, the El Niño Southern Oscillation (ENSO) analysis impact on two rainfall types was also done with exemplification in 2006 and 2007 event. Two datasets were used namely the probability and the rainfall accumulation from both rainfall types. The results showed that the probability of Indonesian stratiform rainfall type was higher than convective rainfall type. In contrast, convective rainfall type more contributed to rainfall values. Spatial patterns of convective-stratiform rainfall types have different spreads. Generally, convective rainfall supplied more rainfall over the land, whereas stratiform rainfall supplied more rainfall over the sea, except in December-January-February (DJF) season. The ENSO impact was clearly seen during September-October-November (SON) season from both rainfall types over the south. Moreover, the stratiform rainfall type was more affected by ENSO during June-July-August (JJA) season.

Keywords: Rainfall, Convective, Stratiform, TRMM PR, ENSO, Indonesia

1. Introduction

Understanding space-time variations of rainfall is an important topic in climate research, in which modern, high quality, global-scale rainfall observations are essential [1]. The tropical Indonesian archipelago is a central atmospheric heat source characterized by huge quantities of rainfall, which are important contributions to understanding the world's climate system [2]. Rainfall information is especially important in the tropics because such a large fraction of the planet's rain falls within low latitudes and because there are large variations therein that are related to climatic events [e.g. El Nino–Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD)] [3,4,5,6]. Many studies have shown that Indonesia rainfall tends to decrease (increase) during warm (cold) ENSO events [e.g. 7,8,9]. Changes in rainfall can be attributed to the anomalous sea surface temperature (SST) and the associated anomalous Walker circulation over the tropical Pacific [10]. Annual and interannual

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climate variability in Indonesia is somewhat unusual, as it is not homogenous over the whole region and the coherence of rainfall patterns varies seasonally [11,12,13]. That's way Indonesian rainfall information is necessary for the study of climatology, flood predictions, irrigation plans, and water resource problems.

Tropical precipitation system is characterized by extensive stratiform cloud directly associated with deep convective [14]. The separation between convective and stratiform is important for climatological studies because convective and stratiform precipitation is characterized by different types of weather events. Stratiform precipitation falls from nimbostratus clouds, while convective precipitation falls from active cumulus and cumulonimbus clouds. These cloud types may occur separately or entangled with each other in the same cloud complex. Convective areas are associated with heavy rainfall rates of shorter duration than stratiform areas. Although stratiform rain is associated with generally lower rain rates, it covers large areas contributing a significant portion of the rainfall region [15]. The convective and stratiform rain components are the outcome of distinct cloud dynamical processes that influence the atmospheric circulation [16]. The convective and stratiform modes of rainfall are especially important in the Tropics, where precipitating clouds often organize into mesoscale systems containing the two distinctive environments [17, 18].

Indonesia, covered mostly by the ocean, is the world's largest archipelago. Therefore, there are several problems in studying and simulating rainfall of the region for an appropriate land–sea representation and a complex topographical distribution [19]. Rainfall displays high space-time variability that requires frequent observations for adequate representation [15]. Rain gauge observations yield relatively accurate point measurements of precipitation. Thus, meteorological satellites observation may be the best solution for adequate temporal and spatial coverage of rainfall. The use of remote sensing which has better spatial and temporal resolution data in investigates the variability of convective and stratiform rainfall over Indonesia, thus, offers an exciting opportunity.

The Precipitation Radar (PR) onboard the TRMM satellite, which was developed by the Japan Aerospace Exploration Agency (JAXA, previously known as the National Space Development Agency, or NASDA) in cooperation with Communications Research Laboratory [20], is the first spaceborne precipitation observation radar designed to measure the vertical structure of tropospheric precipitation and three-dimensional rain structures over the tropics and subtropics [21,22]. The main components of the TRMM PR retrieval algorithm convert the intensity of backscattered energy from hydrometeors within a defined vertical interval [20,23]. The PR satellite enables capture of the three-dimensional rainfall structure over the ocean and land of tropical oceans and continents [20]. The PR operates at the frequency of 13.8 GHz and 250 m vertical resolution, allowing penetration of even the heaviest obscuring cloud layers and detection of underlying precipitation. PR is an effective platform for investigating shallow precipitation [24], able to detect rainfall intensities as low as 0.7 mm/h [21]. The algorithm of TRMM PR to separating convective, stratiform, or other rainfall types is based on the horizontal and vertical radar echostructure in each pixel. Several factors affect the accuracy of PR rain rate estimation: radar calibration, light rains sensitivity (minimum detectable signal), attenuation correction (moderate-to-high rain rates), drop size distributions variations (reflectivity-rain rate (Z-R) and attenuation-reflectivity (k-Z) relationships), horizontal/vertical gradients in Z (partial beam filling), and surface clutter rejection [25]. Over the years, several groups have been validated PR data with ground data (e.g. 22,26,27,28,29).

An especially useful aspect of the TRMM PR is its ability to discern convective rain from stratiform [30]. The TRMM PR observations can detect the vertical structure of precipitation which is important in convective-stratiform separation and thus provide the best means with which to classify rain as convective or stratiform [31]. Convective and stratiform rainfall are characterized by distinctly different processes and have distinctly different latent heating profiles. Convective systems are generally identified with intermittently strong vertical velocities (> 1 m/s in magnitude), high rainfall rates (> 3 mm/h), and small areas (1-10's of km), intense, horizontally inhomogeneous radar echo. Conversely, stratiform systems are characterized by small vertical velocities (< 1 m/s), low rain rates (< 5 mm/h), and widespread areas (10-100's of km), horizontally homogeneous radar echo [16]. The

algorithm [32] to separation convective-stratiform from TRMM PR 2A23 product is based on Steiner et al.'s [33] classification method for ground radars.

Convective and stratiform rainfall distribution information and the structure of precipitation systems from large areas of Indonesia are important. The spatial and temporal variations of convective and stratiform rainfall across Indonesia not yet clear break down, therefore now, is a great opportunity to conduct this research. This study examines the variation of the convective and stratiform rainfall determined by TRMM 3A25 products across Indonesian, showing the capability of these products to contribute to an analysis of climatic-scale rainfall in Indonesia.

2. Data and Method

The research was conducted in the archipelago of Indonesia composed of 17,508 islands of various sizes. Spatial data covered 8°00' N to 12°00' S and 93°00' E to 142°00' E. Figure 1 indicates the distribution of Indonesian topography. Indonesia is located between two continents and oceans with a population reaching 237,641,326 people in 2010. Sumatra, Kalimantan, Jawa, Sulawesi and Papua are five major islands with diverse topographical distributions. Several important mountains in Indonesia are Jayawijaya in Papua, Bukit Barisan in Sumatra, Kendeng in Jawa, Fenema and Gorontalo in Sulawesi, and Muller in Kalimantan.



Figure 1. The Study area includes the Indonesian topography

Monthly Rainfall data from 2004 to 2008, measured and collected by TRMM PR 3A25 version 6 (V6) satellite data, were employed to observe Indonesian convective-stratiform rainfall variability. The PR 3A25 is a space-time average of PR products [20] containing monthly 0.5°× 0.5° gridded rainfall estimates and structure statistics. The monthly rain accumulation for convective and stratiform of 3A25 (mm month^{-1}) is obtained by multiplying the unconditioned rain rate with the number of hours in a month. In fact, all 3A25 statistics are conditioned on the existence of one or more variables. To convert to an unconditioned mean rain rate the quantity is first multiplied by the probability of rain, given by the ratio of the number of rain counts to the total number of observations for the month [25].

The PR, operating at 13.8 GHz, is a 128-element active phased array that allows fast and sophisticated cross-track scanning over a swath width of 215 km with a cross-range spatial resolution of about 4.3 km [21]. After boosting the satellite from 350 to 402.5 km on August 22, 2001, the horizontal resolution increased to nearly 5 km and swath width increased to 245 km. The PR is subject to attenuation from cloud water, rain, and partially melted hydrometeors [22]. The major roles of the PR in TRMM are to provide 3-D rainfall distribution information, to achieve quantitative rainfall estimation over land and ocean, and to utilize data to improve the TRMM Microwave Imager (TMI) estimations of rainfall [21]. The TRMM PR data processing and analysis algorithms were developed by the International TRMM PR team [20], while the PR 3A25 algorithm was developed by Meneghini et al. [25]. The algorithm 3A25 gives various space-time statistics of conditional rain characteristics

over a month from the TRMM level 1C21, 2A21, 2A23 and 2A25 products [33,34,35). There are four types of statistics calculated: probabilities of occurrence, mean standard deviations, histograms, and correlation coefficients [25,33]. The statistics analyzed are conditioned to quantities such as the presence of rain, stratiform rain, or the presence of a bright-band.

Several statistical scores were used to determine the Indonesian convective-stratiform rainfall characteristics. Rainfall probability means, rainfall accumulation means, and value of rainfall mean differences, were used in the analysis. El Niño and La Niña events on 2006/07 and 2007/08, respectively were selected to illustrate spatial patterns of Indonesian convective-stratiform rainfall anomalously. Shuanglin and Qin [36] and Takahashi et al. [37] classified 2006/07 and 2007/08 as El Niño events and 2006/07 as a La Niña event. JJA and SON were chosen as the main season on the seasonal rainfall anomaly analysis because the ENSO usually have a peak in JJA and SON [3,9]. The percentage of rainfall anomaly (%) is given by the ratio of the values of rain to the rainfall average of observations for the month.

Seasonal analyses were conducted in this study. The monthly analysis compared data from the same months of annual observation. The seasonal analysis is conducted based on the monsoon activity, described by Aldrian et al. [12], over the entire observation period; in this analysis, the seasons were classified as December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON). DJF represents the peak of northwest Australia–Asia monsoon, and JJA represents the peak of the southeast Australia–Asia monsoon, and MAM and SON represent monsoon transitions. Likewise, long-term analysis observed all-time series data over the entire observation period [38]. The analysis is done using the coordinate as the reference identity and conducted in each pixel. Data extracted from the TMPA in each pixel to generate point-by-point data. The point has the information about coordinate, month, year, and rainfall values. Then, the data are sorted in accordance with the purposes of analysis. After obtaining the values, the point data is converted into a raster data format which has the same spatial resolution with the original data (0.5° ×0.5°).

3. Results

The probability of rain is defined as the percentage of the total rain pixel numbers with total pixel numbers within each 0.5x0.5-degree box (pixel for 3A25). The original horizontal resolution of PR data is nearly 5 km. In addition, the TRMM PR records locations once approximately every 3.6 days in the tropical region because of the non-sun-synchronous satellite orbit. Thus over the tropical areas has the numbers of the total pixel in each 0.5x0.5-degree box ranged among the 988 to 1759. Given by the explanation, Figure 2 and 3 illustrates the distributions of seasonally averaged of convective and stratiform rainfall probability over Indonesia during 2004–2008. Generally, the probability of stratiform rain values is higher compared with the probability of convective rain values, but with similar north-south seasonal changes. Seen from the land-sea spatial pattern, most of the convective rainfall type occurs over the land, in contrast with stratiform rainfall type but except during DJF season.

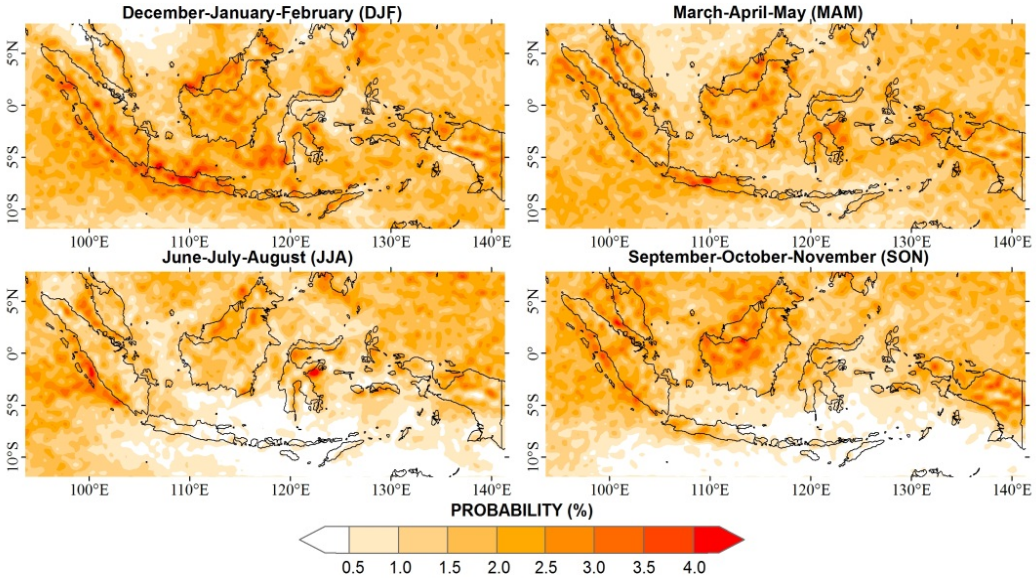


Figure 2. Spatial distributions of convective rainfall probability based on seasonal averages from January 2004 to December 2008.

Monthly rainfall accumulation is defined as the multiplying of the rainfall probability with a mean rain rate of the total rain pixel and the number of hours in a month within each 0.5x0.5-degree box. Figure 4 and 5 displays the spatial pattern of seasonal averaged of monthly convective and stratiform rainfall accumulation over Indonesia during 2004–2008. Low probability of convective rainfall does not impact the rainfall accumulation values because convective areas are associated with heavy rainfall rates than stratiform areas. Most high convective rainfall is occurring over the land, except over JJA season that happens outside the land such as in the west coast of Sumatra. An interesting phenomenon is seen from stratiform rainfall pattern, where the high rainfall values occur at the top of mountains such as in Papua and Kalimantan Islands.

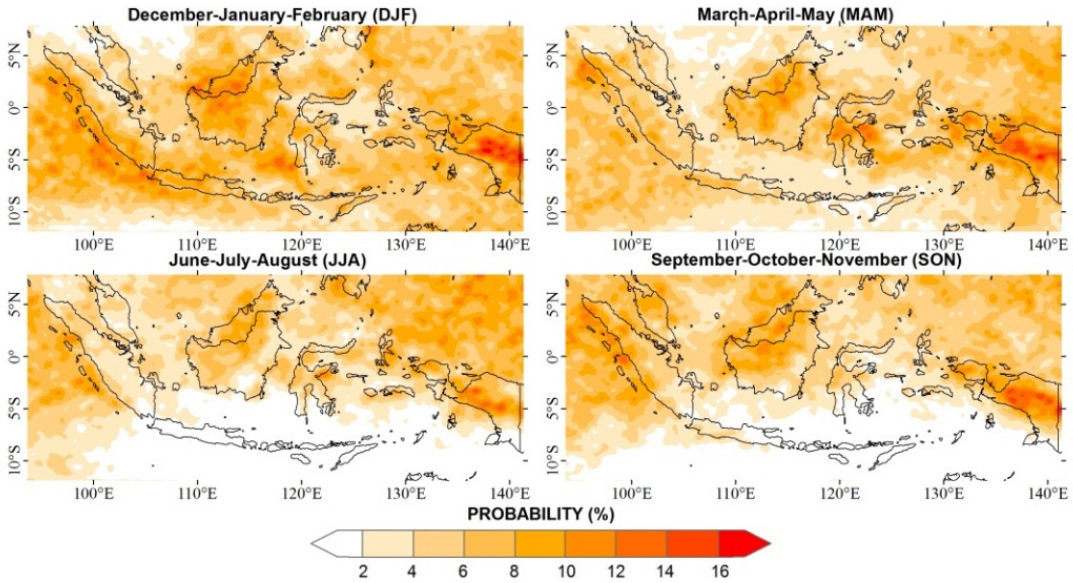


Figure 3. Same as Figure 2, but for stratiform rainfall type probability.

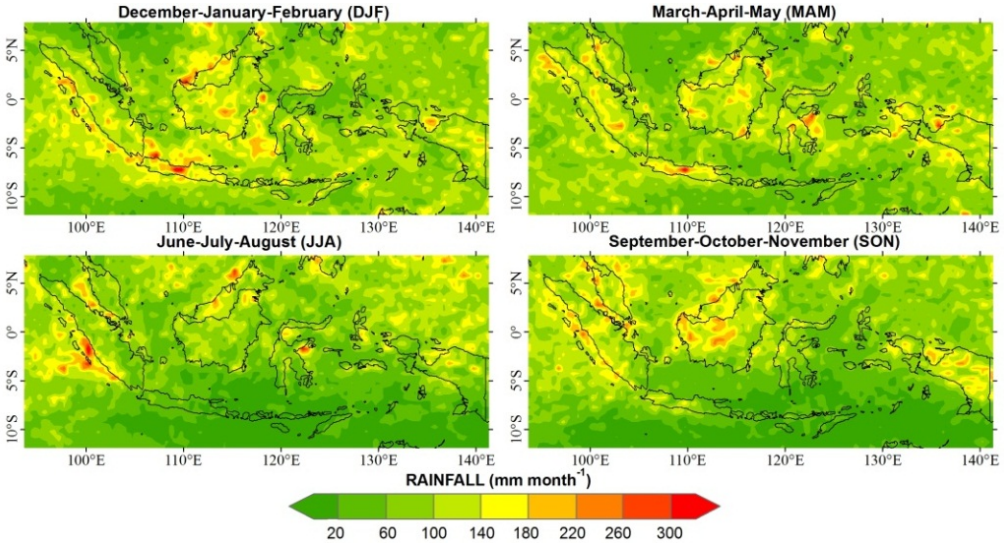


Figure 4. Seasonal mean distributions of convective rainfall accumulation based on monthly composites from January 2004 to December 2008.

The seasonal differences between convective and stratiform rainfall values are displays in Figure 6. Here the white-green colors show areas of more stratiform rainfall and the white-blue colors show areas of more convective rainfall clearly seen from that figure the values of convective rainfall are higher compared with stratiform rainfall values, especially over the land except during DJF season. During DJF, most of the convective rain occurred in the south, whereas the stratiform rain arises over the north. In addition, during JJA and SON, most of the stratiform rain happened the areas of poor rain.

Figure 7 and 8 shown spatial distributions of rainfall anomaly JJA and SON El Nino 2006 and JJA and SON La Nina 2007, respectively. Generally, stratiform rainfall type is dominantly influenced by ENSO compare with convective rainfall type. However, convective rainfall type is seen impacted by ENSO during El Nino 2006 with the same location as stratiform. The figure shows the areas of stratiform rainfall anomaly is wider than convective rainfall, where the most of stratiform rainfall anomaly is occurring over the south and influence rainfall in dry season over Indonesia.

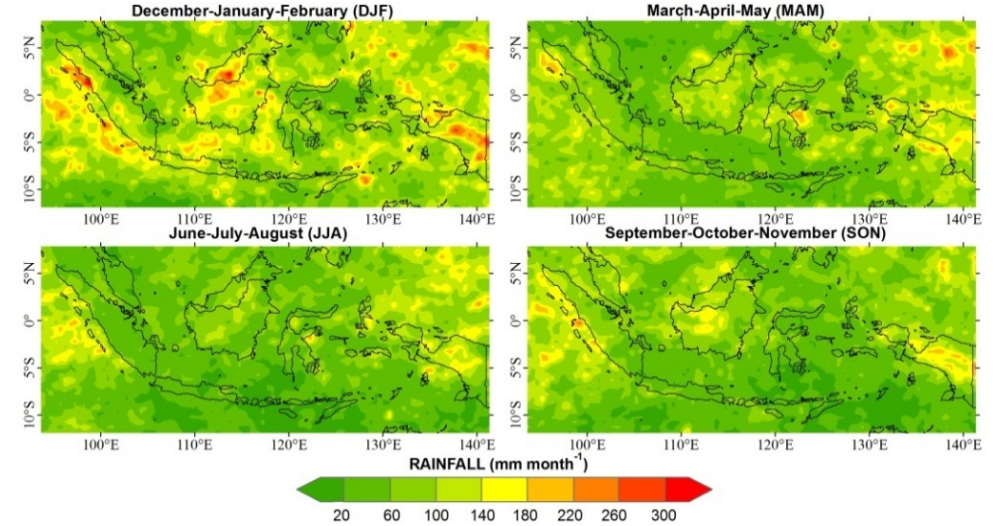


Figure 5. Same as Figure 4, but for rainfall accumulation of stratiform rainfall type.

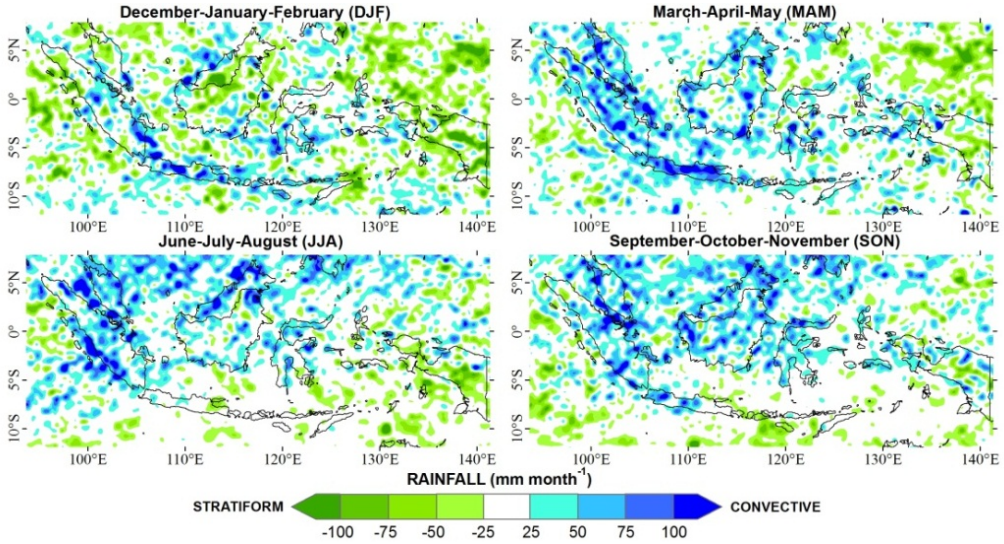


Figure 6. Seasonal analysis of rainfall differences. Blue color indicated high rainfall during convective fall, while green color indicated for stratiform fall.

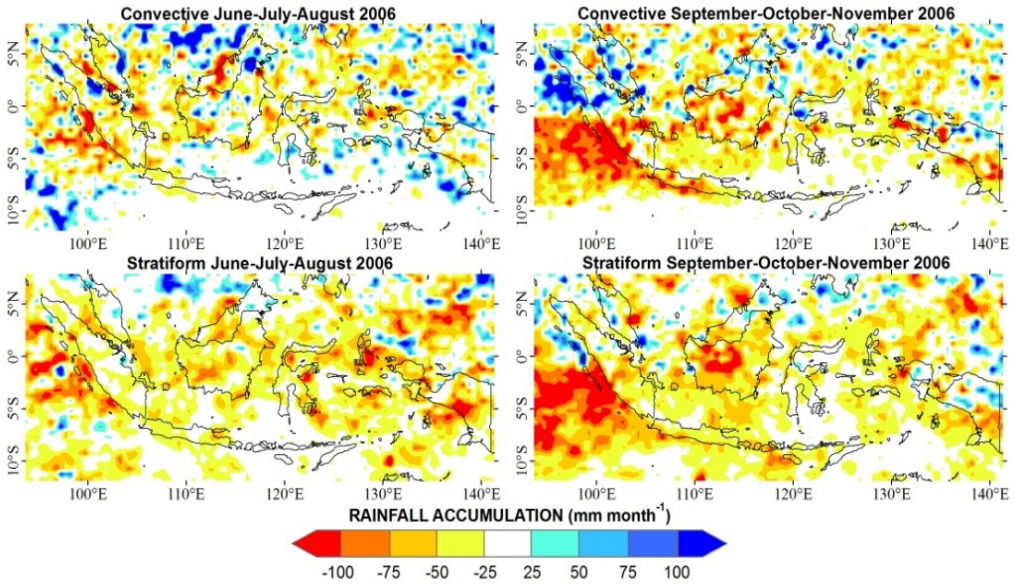


Figure 7. Spatial distributions of seasonal rainfall anomaly for periods JJA and SON 2006. The top is for convective rainfall type and bottom for stratiform rainfall type

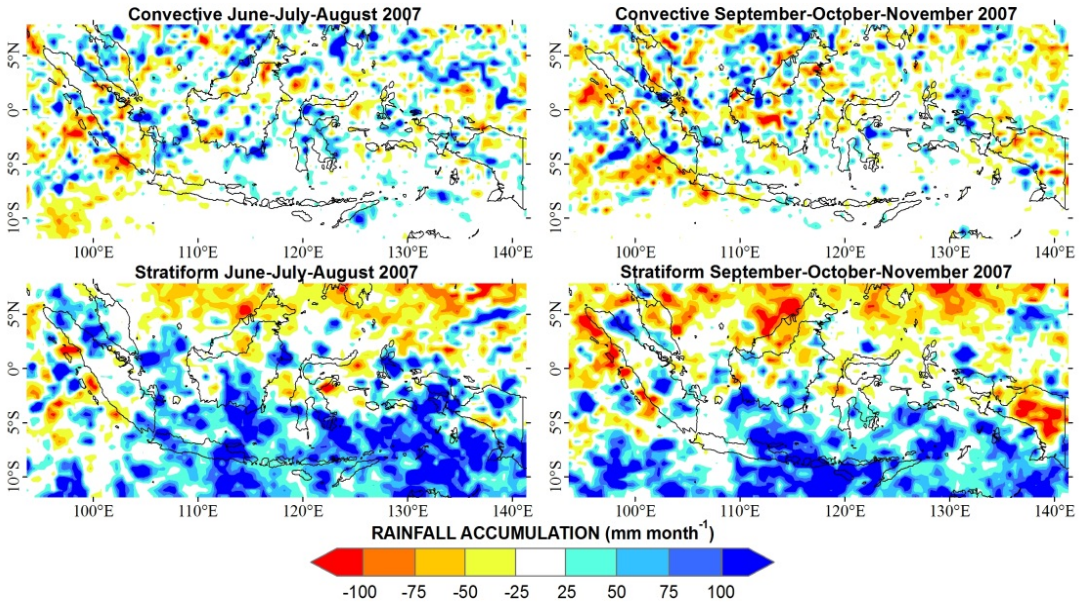


Figure 8. Same as Figure 7, but for rainfall anomaly for periods JJA and SON 2007

4. Conclusions

An investigation of Indonesian convective and stratiform rainfalls variability using satellite data from TRMM PR 3A25 over 5 years (from January 2004 to December 2008) is presented here. Monthly, seasonal and long-term time series analyses were conducted by applying several statistical methods. The seasonal mean difference in rainfall accumulation from convective and stratiform was analyzed to determine the most impact on total rainfall over Indonesia from both rainfall types.

The results show the probability of stratiform rainfall type is higher compared with convective rainfall type. In contrast, convective rainfall type more contributes to total rainfall values. Spatial patterns of convective-stratiform rainfall types have a different spread. Analysis of seasonal mean difference in rainfall accumulation from both rainfall types showed convective rainfall supply more rain values over the land, whereas stratiform rainfall supply more rain over the sea except in DJF season. In another analysis, the ENSO impact is clearly seen during SON season from both rainfall types over the south. Moreover, during JJA season the ENSO just have an impact on stratiform rainfall type.

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