Monthly variations of diurnal rainfall in north coast of West Java Indonesia during boreal winter periods

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Abstract. Diurnal rainfall during the active monsoon period is usually associated with the highest convective activity that often triggers extreme rainfall. Investigating diurnal rainfall behavior in the north coast of West Java is important to recognize the behavioral trends of data leading to such extreme events in strategic West Java because the city of Jakarta is located in this region. Variability of diurnal rainfall during the period of active monsoon on December-January-February (DJF) composite during the 2000-2016 period was investigated using hourly rainfall data from Tropical Rainfall Measuring Mission (TRMM) 3B41RT dataset. Through the Empirical Mode Decomposition method appears that the diurnal rain cycle during February has increased significantly in its amplitude and frequency. It is simultaneously shows that the indication of extreme rainfall events is related to diurnal rain divergences during February shown through phase shifts. The diurnal, semidiurnal, and terdiurnal cycles appear on the characteristics of the DJF composite rainfall data during the 2000-2016 period. The significant increases in amplitude occurred during February are the diurnal (IMF 3) and terdiurnal (IMF 1) of rainfall cycles.

1. Introduction

Research on diurnal rainfall is important to improving regional climate model output due to there are not yet high-resolution regional models which can accurately depict diurnal rainfall cycles in the tropics either in amplitude or phase [1-6]. Simulation of diurnal rainfall in the western part of Indonesia Maritime Continent using MIT Regional Climate Model (MRCM) with 12 km high resolution for 30 years (1982-2011) in DJF shows that the general model can capture diurnal rain amplitude but not able to capture the rainfall phase especially in the northern region of West Java with phase difference between 12-15 hours compared to rainfall from TRMM satellite [6].

In general, there are significant differences in diurnal rainfall patterns between land and ocean related to the phase and time of maximum rainfall. Diurnal rainfall in the mainland occurs from Late-Afternoon (LA) to Middle-Night (MN), while rainfall over the ocean occurs from MN to Early Morning (EM) [7-12]. In addition, based on maximum and phase, diurnal rainfall variability also has different patterns with respect to the frequency or number of peaks between on land and sea. Diurnal cycle patterns (one peak) and semidiurnal (two peaks) are formed on land and sea with different frequency of occurrence. Globally in the tropics, both on land and at sea, the main pattern with 45%
frequency (PC 1) and 22% (PC 2) is diurnal then followed by semidiurnal pattern with frequency 6% and 4% appearing on PC 3 and PC 4 [12]. Seasonal variability of diurnal rainfall occurred especially over the ocean. In the Pacific Ocean, diurnal rainfall reaches the maximum during the boreal winter period of DJF while in the Indian Ocean diurnal rainfall has maximum value in the May-June-July-August (MJJA) of boreal summer period [11] while convection activity reaches a maximum in September-November. In the South China Sea, the highest convection activity occurred in October-January and slightly increased in July and August at 07:00-19:00 LT (Local Time) [13]. Similarly, in the Java Sea, convection activity reached the maximum in October-January during the period of 07:00-19:00 LT [13].

In Java Island, which belongs to areas with strong monsoon activity, diurnal rainfall occurs from LA to MN [14-15]. However, interannual variation of diurnal rain shows that interaction between ENSO and topography in southern Java Island produces more intensive if compared the El-Nino years with normal periods [16]. On the other hand, in some cases of floods occurring in the north of West Java, especially Jakarta, the heavy rainfall over land occurred from EM to noon [17-20]. Also, there is evidence that daily rainfall tends to increase for over a hundred years [21]. In addition, diurnal variations in precipitation also affect diurnal variations of the Ciliwung River that supplies the main river flows that cause Jakarta floods [22].

Currently, there has been no research that discusses diurnal rainfall in monthly variations during the rainy season of DJF in the north coast of West Java. Though such knowledge is needed to understand the characteristics of diurnal rainfall pattern in the north coast of West Java from time to time in climatologically. Therefore, this study discusses month to month variations during the DJF period of diurnal rainfall in the north coast of West Java.

2. Data and Method
The rainfall data during the DJF in the period of 2000-2016 were obtained from the TRMM Multi-satellite Precipitation Analyses Real-Time (TRMM TMPA)3B41RT dataset, which has hourly temporal resolution and 0.25° × 0.25° spatial resolution [23-24]. This data provides a calibration-based sequential scheme for combining precipitation estimates from multiple satellites. TMPA is available both after and in real time, based on calibration by the TRMM Combined Instrument and TRMM Microwave Imager precipitation products, respectively. Only the after-real-time product incorporates gauge data at present. These data could be downloaded free from https://pmm.nasa.gov/data - access/downloads.

To analyze the seasonal variability of non-stationary rainfall data (DJF) on DJF related to trends, the power spectrum, and frequency of signals data were performed by Empirical Mode Decomposition (EMD) method. This method decomposes the signals by performing direct extraction of signal energy that can be regarded as an intrinsic function in the scale of space and time [25].

EMD decomposes a non-stationary signal into a set of intrinsic oscillatory modes. It component called Intrinsic Mode Functions (IMFs). By knowing the signal of each IMF, then we can calculate of multicomponent frequency instantly based on Hilbert transformation. In this way, the analysis of each IMF signal can be done in detail by localizing events in time and frequency scales [25]. In the current research, we composite DJF in the period of 2000-2016 and apply the EMD method to determine the characteristics of diurnal rainfall data during the period.

3. Result and Discussion
EMD analysis of DJF composite rainfall data during the period 2000-2016 have generated 10 IMFs and residuals. Based on the EMD analysis, IMF 1 represented to 3 peaks of cycles, then so-called “terdiurnal” pattern, IMF 2 showed 2 peaks of cycles or “semidiurnal”, and IMF 3 described “diurnal” pattern. Residual data shows a trend line of data that has a peak cycle during January (figure 1).
Figure 1. IMF 1-11 (a-j) based on hourly rainfall data of TRMM 3B41RT during DJF in the period of 2000-2016.

Figure 2 shows that at IMF 1, the rain cycle period is 5.5 hours or 0.3 daily or also known as the diurnal pattern ie 3 peaks in 24 hours (terdiurnal). In December and February, terdiurnal rainfall data variations were greater than in January. In addition, the soaring data variations appear at the end of February. Significant phase differences emerged in the first 1-3 hours indicating a shift in the afternoon rainy phase starting at 19:00 LT may shift to 20:00 LT until midnight at 22:00 LT. The phase shift from late afternoon to midnight or early morning corresponds to recent research results by Im and Eltahir [6] which show that the maximum diurnal rainfall phase in northern Java occurs at midnight or early morning. However, previous findings by Qian [14] show that diurnal rainfall in Java has a maximum phase in the afternoon.

Figure 3 shows that IMF 2 has a 14 hour or 0.6 daily cycle period (semidiurnal) with variations and amplitude in December and February larger than January. In addition, the signal amplitude also shows that semidiurnal cycles are larger than the terdiurnal cycles (IMF 1). The phase difference in the semidiurnal cycle is 1-5 hours faster or 7-15 hours late from the original phase. It indicated that there is a semidiurnal phase shift from the afternoon rain to the night into the night until midnight or morning until noon. The current results corresponds to earlier findings regarding the maximum phase of diurnal rainfall in northern Java occurring at midnight or early morning [6]. However, the semidiurnal rainfall pattern found in northern West Java is uncommon with the general pattern of diurnal rainfall in tropical regions that should occur over the oceans with frequencies less than 10% [28].
Figure 2. IMF 1 (a) and autocorrelation of hourly rainfall data of TRMM 3B41RT during DJF in the period of 2000-2016.

Figure 3. Same as figure 2, but for IMF 2 (semidiurnal).
Figure 4 shows IMF 3 which is represents a diurnal cycle with a peak of cycle during 24 hours. Regarding to figure 4, we can see that the variation and amplitude of December and February data are

Figure 5. Absolute value or amplitude (a) and frequency (b) of IMF 1 (terdiunal).
larger than January. In addition, there was a significant increase in data variations by the end of February. The phase difference for diurnal cycle categories can be faster between 1-10 hours than the original phase. It indicated that the phase of diurnal rainfall have shifted from Late Afternoon (LA)-Middle Night (MN) to MN-morning.

For semidiurnal patterns as shown in figure 5, the data amplitude looks large in December and February. However, the data frequency has a small value during that sharp rise. It indicated that the sharp increase in the data amplitudes corresponds to the decrease in data frequency. In contrast, the increasing the amplitude of the diurnal cycle occurs at the end of February which is also followed by a sharp rise in data frequency as shown in figure 6. It may indicate an increase in extreme rain events at the end of February for the diurnal cycle.

Figure 7 describes the category of diurnal cycles that shows the IMF 1 amplitude has increased significantly in February, especially at the end of February. However, the frequency of amplitude that experienced a significant increase is actually low or decreased when compared with data frequency in December and January. The EMD analysis was also shown the trend of changes in the data cycle pattern over time, ie IMF 5, 6, and 7 (figure 8). IMF 5-7 confirms that in the February, there was an increase in the amplitude of the cycle about 2-3 times compared with December or January. It indicated that the occurrence of extreme rain events during February that could be captured by IMF 5-7 results already added to the residu (figure 8).

![Figure 6](image_url)

*Figure 6. Same as figure 5, but for IMF 2 (semidiurnal).*
The EMD method has proved that in February there was a high variation of data in amplitude and frequency of terdiurnal, semidiurnal, and diurnal rainfall cycles. It was also found that the three types of cycles had undergone phase shifts into the maximum phase of rainfall occurring in the middle of the night or early morning and this corresponds to the recent discovery of diurnal rain in northern Java [6]. Figure 9 shows an example of the diurnal rainfall mean pattern that shifted the phase from the afternoon into the early morning to February 2002 (figure 9-a), terdiurnal pattern with the main peak occurring in the early hours of February 2008 (figure 9-b), semidiurnal pattern with the main peak occurred in the early hours of February 2011 (figure 9-c), and the normal pattern of diurnal rainfall with rainfall peak occurred in the afternoon until evening as it was in February 2012 (figure 9-d).
Figure 8. IMF 5-7 and its residu (a-c).

Figure 9. Diurnal rainfall cycle mean during February: 2002 (a), 2008 (b), 2011 (c), 2012 (d).
4. Conclusion
The monthly variations for the diurnal rainfall during the DJF period in the north coast of Java Island shows that there is a higher rainfall trend in January than in December and February. However, data variations in December and February were larger than in January. In addition, the diurnal rain cycle has three patterns: diurnal (one peak, IMF3), semi-diurnal (two peaks, IMF 2), ter-diurnal (three peaks, IMF 1). The amplitude of rain cycle with the diurnal pattern in February has increased by about 2-3 times compared to December or January. In addition, the frequency of rainfall also increased strongly in February. For semi-diurnal patterns, the amplitudes of cycles with semi-diurnal patterns larger in December and February, but the data frequency has minimum value during that sharp rose. For the category of ter-diurnal rainfall, amplitude increased significantly followed by a decrease in frequency in February, especially at the end of February. The phase difference for the diurnal category, the maximum rainfall can experience a phase shift from afternoon rain to evening into the evening until the morning. For semi-diurnal, there is a phase shift from the late afternoon to late night into the night until midnight or morning until noon. For the diurnal, there is a shift phase of the afternoon rain starting at 19:00 LT could be shifted to 20:00 LT until midnight at 22:00 LT.

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