Diurnal Rainfall Variation over Three Rainfall Regions within Indonesia Based on Ten Years of TRMM Data

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Abstract: Diurnal rainfall variations over three sub-domains with distinct annual rainfall cycles within Indonesia have been analyzed using Tropical Rainfall Measuring Mission datasets (3B42) for the period of 2000–2009. Empirical Orthogonal Functions (EOF) analysis was used to compare spatial-temporal variability among three selected areas (A, B and C). The EOF analysis revealed that the three regions showed dominant diurnal cycles of rainfall. The diurnal cycles of the three regions were marked by different amplitudes and phases, particularly over land and oceanic regimes. Region A exhibited an afternoon peak over land and a morning peak over ocean. Region B showed an evening peak over the land and a morning peak over the ocean. While Region C exhibited an afternoon peak over the land and an early morning to noon peak over the ocean. Over coastal areas, the same midnight peak was observed for the three regions. The result of this study provides relevant information to understand the effects of island size and land-sea formation on the characteristics of the diurnal rainfall variation, particularly over the Indonesian Maritime Continent.

Keywords: Diurnal cycle, rainfall, TRMM, EOF, Indonesia.

1. Introduction

Rainfall and its variability are important factors of the global hydrological cycle; they affect all living organisms on the Earth. The study of rainfall variability over short time scales is important and has a wide range of applications such as: to compare model predictions with atmospheric observations [1]; to understand the atmospheric physics [2]; to understand the local weather mechanisms [3], etc.

As a result of the advances in satellite remote-sensing techniques over the last few decades, large scale patterns of rainfall can be monitored using rainfall estimates with improved accuracy and spatial-temporal resolutions. The Tropical Rainfall Measuring Mission (TRMM) satellite is one such advance, providing more than 13 years (January 1998 to the present time) of precipitation rates distributed over tropical regions between 38°S and 38°N. The primary purpose of TRMM is to understand the diurnal cycle of tropical rainfall and its spatial variation [4].

This study was conducted to investigate the diurnal rainfall variation over Indonesia using TRMM data for revealing and comparing the features of the diurnal cycle over three dominant rainfall regions within Indonesia (Region A, B and C) based on the classification by Aldrian and Susanto [5]. All of the three regions show both strong annual and, except Region A, semi-annual variability [5]. The result of this study is expected to provide relevant information on the features of the diurnal cycle of rainfall over the three regions, and a better understanding of the short-term characteristics of the Indonesian climate.

2. Experimental

This study was conducted by following three main steps: (1) obtaining the TRMM (3B42) data and extraction for the study domain; (2) quality control (QC) of the data; and (3) analysis of diurnal cycle of rainfall using the Empirical Orthogonal Functions (EOF) method and interpretation of the results to reveal the features of the diurnal cycle of rainfall within the study area.

2.1 TRMM Data

The 3B42 product of TRMM data for a 10 year period (2000–2009) were used in this study. The temporal resolution of the data is 3 hour and the spatial resolution is 0.25°×0.25° TRMM 3B42 combines observations from several space-borne instruments, including the precipitation radar and microwave radiometer on board TRMM as well as infrared radiometers from other platforms. The data are available to the public at the Goddard Earth Sciences Data and Information Services Center (GES DISC) website. Since the TRMM data cover the global area, we need to further extract the data for our study domain, i.e. the three box areas A, B and C that represent the three rainfall regions A, B and C. The size of each box is 5°×5° and consists of some land (islands) and water (ocean) parts. Box A lies between 9°S to 4°S and 110°E to 115°E; Box B lies between 2°S to 3°N and 95°E to 100°E; and Box C lies between 6°S to 1°S and 125°E to 130°E. R programming language was used for extracting TRMM data. The three rainfall regions as well as the three box areas in the study domain are shown on Figure 1.

2.2 Data Quality Control

Quality control (QC) was undertaken prior to the data analysis in order to eliminate any erroneous values and non climatic biases in the time series. This QC procedure for TRMM data has been done by the TRMM Science Data and Information System (TSDIS) in the satellite data post-processing work. However, we have applied further QC procedure to TRMM data in this study to prepare for rainfall diurnal cycle analysis.

The QC procedures applied in this study consist of: (1) checking missing values of the data; (2) checking maximum and mean values of each grid of the data; and (3) checking the distribution of the data.

2.3 Diurnal Rainfall Cycle Analysis

Prior to the diurnal cycle analysis, the TRMM data were first converted from Coordinated Universal Time (UTC) unit to Local Solar Time (LST). LST instead of UTC are used to give a clearer picture of the diurnal distribution of rainfall, because the diurnal variations of rainfall are mostly due to the atmospheric response to solar radiation forcing [6]. The UTC can be converted to LST based on the longitudinal distance between each grid point and 0°. Then piece-wise cubic hermite polynomial interpolation was applied to obtain the rainfall data every three hours LST (0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 LST).

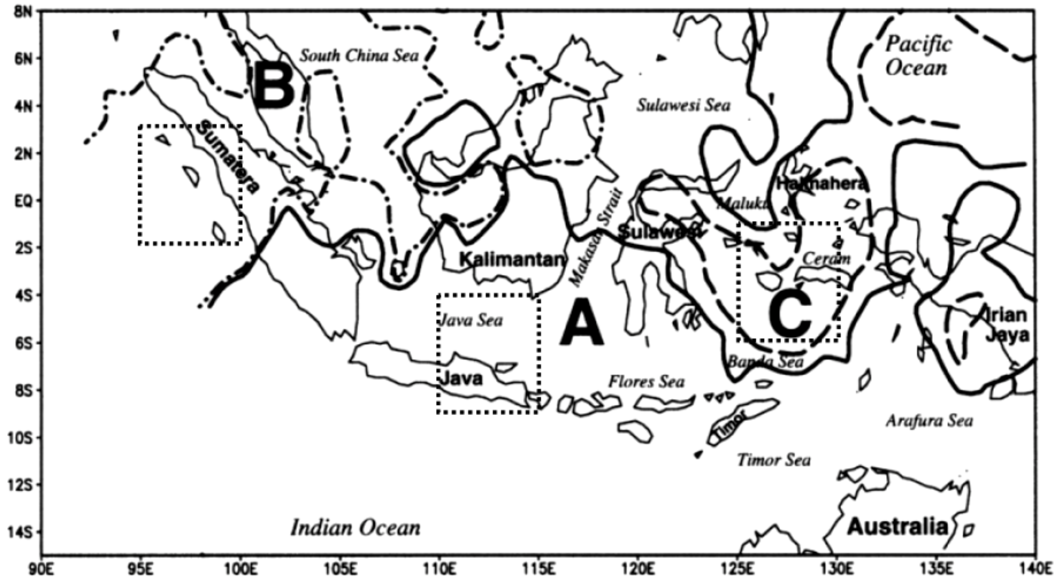

Figure 1. The three rainfall regions (A, B and C) within Indonesia [5]. Box areas A, B and C that represent the three rainfall regions, are illustrated by the dotted boxes.

The Empirical Orthogonal Functions (EOF) method, as described by Hannachi et al. (2007) [7] was then used to reveal the diurnal cycle of rainfall for the three box areas. EOF analysis (also known as principal component analysis (PCA)) is a useful technique for compressing the variability in time-series data. The advantage of EOF analysis is that it provides a compact description of the spatial and temporal variability of data series in terms of orthogonal functions, or statistical "modes". Usually, most of the variance of a spatially distributed series is in the first few orthogonal functions whose patterns may then be linked to possible dynamical mechanisms. This analysis technique has found wide application in both the time and frequency domains. Kikuchi & Wang (2008) have used this method to successfully explain the principal features of the diurnal cycle of rainfall in the global tropics [8].

3. Results and Discussion

3.1 Data Quality Control

The first step applied in the QC procedures was to check the missing values of the extracted TRMM data. We found that our data still contain a few missing values. Figure 2 indicates that the number of missing values varied for each year and each box area.

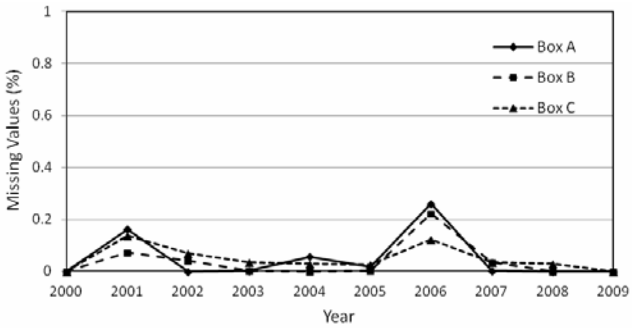

Figure 2. Percentage of missing values in the extracted TRMM data.

However, the total number of missing values in our data was very small, less than 0.3% from the total number of data for each year. It means that our data were sufficient to be analyzed, and the number of missing values would not influence the overall results.

Checking maximum and mean values for each year and each grid was the next step of the QC procedures. As shown in Figures 3 and 4, the maximum and mean values of the extracted TRMM data were reasonable for precipitation data in tropical area. We also observed that Box B has larger mean values for all years compared to Box A and Box C.

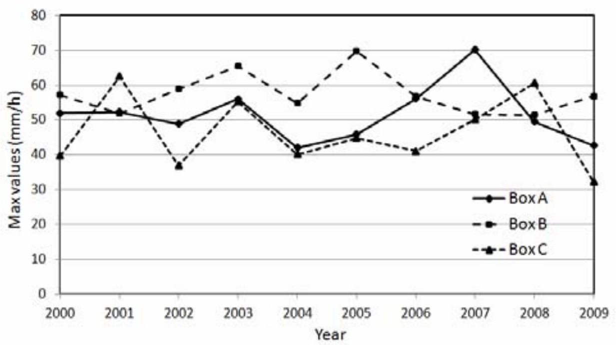

Figure 3. Maximum values of the extracted TRMM data.

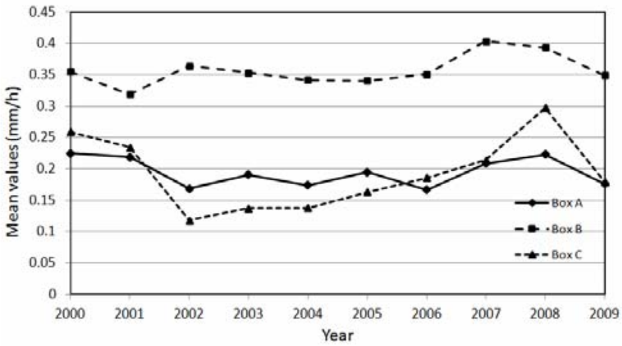

Figure 4. Mean values of the extracted TRMM data.

Finally, we checked the frequency distribution of the rainfall rates. For this purpose, we plotted histograms of the data for each year and each box area. Figure 5 shows the distribution in Box A for year 2000. The data in the other boxes and the other years (not shown in this paper) have similar distributions. We found that our data are skewed to the right (most have small values). This is typical of precipitation data which generally follow the Gamma distribution [9].

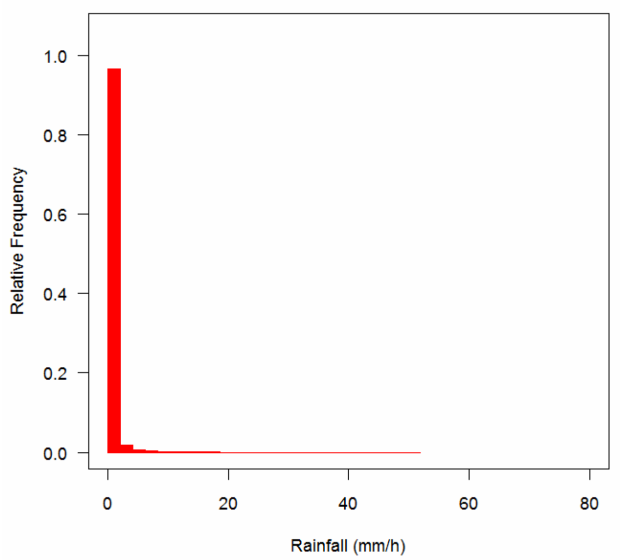

Figure 5. Data distribution for Box A (year 2000).

The results from the QC procedures that we have applied here confirm that the extracted TRMM data are of high quality and can be used in the assessment of diurnal rainfall variation.

3.2 The Eigenvalues

The first results of the EOF analysis are the eigenvalues of the data. The eigenvalues that represent the proportions of the variance are shown in Figure 6. We can see here that all of the three box areas have approximately the same pattern of eigenvalues. Mode 1 and mode 2 together represent a very large proportion of the variance, while mode 3, mode 4 and so on represent very small proportions of the variance. Mode 1 and mode 2 together explain about 97%, 93% and 93% of the total variances for Boxes A, B and C respectively. This means that the diurnal rainfall cycles in the three selected boxes over Indonesia can be represented mostly by mode 1 and mode 2.

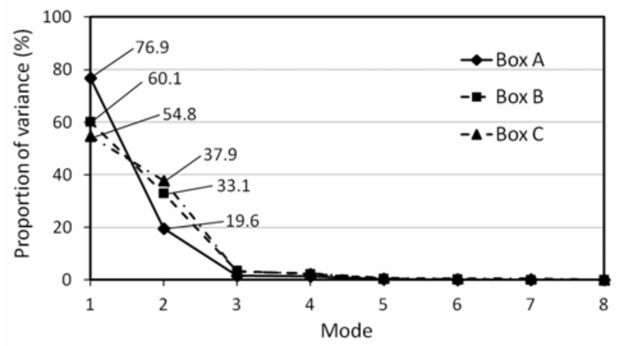

Figure 6. Eigenvalues of Boxes A, B and C.

3.3 The Principal Components

The principal component (PC) time series can illustrate the temporal variation of each mode. The PCs (PC_1 to PC_4) of Boxes A, B and C are plotted in Figures 7, 8 and 9 respectively. These figures show that the three boxes have similar temporal variations of each mode. PC_1 and PC_2 represent the diurnal cycle, while PC_3 and PC_4 represent the semi-diurnal cycle. The diurnal cycle is dominantly exhibited over these regions, as indicated by eigenvalues of mode 1 and mode 2 (see Figure 6), while the semi-diurnal cycle account for very small of the data variance (mode 3 and mode 4 in Figure 6). Therefore we will consider only mode 1 and mode 2 to reveal the features of the diurnal cycle of rainfall over our study domain.

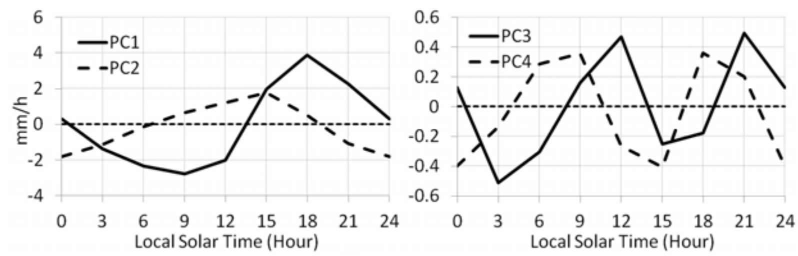

Figure 7. PC_1 and PC_2 (left), PC_3 and PC_4 (right) of Box A.

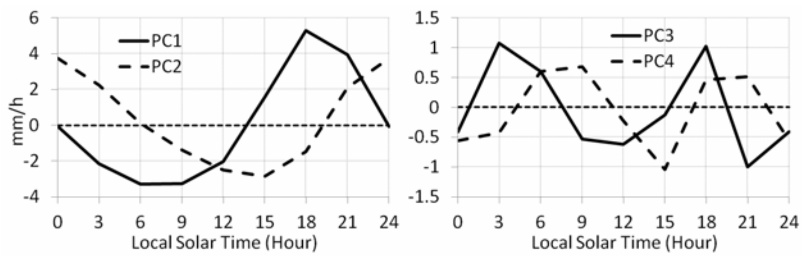

Figure 8. PC_1 and PC_2 (left), PC_3 and PC_4 (right) of Box B.

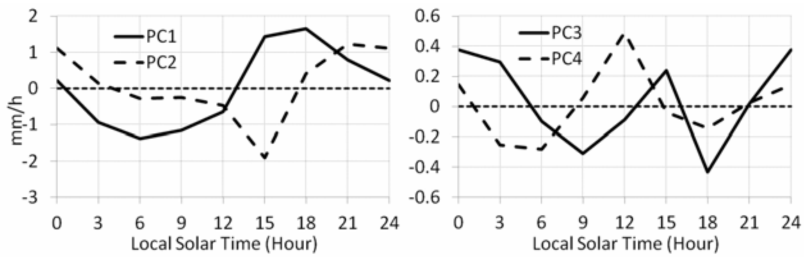

Figure 9. PC_1 and PC_2 (left), PC_3 and PC_4 (right) of Box C.

3.4 The Empirical Orthogonal Functions

The EOFs represent the spatial variation of rainfall of each mode. Here we only analyze EOF_1 and EOF_2 since mode 1 and mode 2 dominantly account for the data variance (Figure 6) and together represent the diurnal cycle (Figures 7–9). EOF_1 and EOF_2 of Box A, B and C are plotted on Figure 10, 11 and 12 respectively.

EOF_1 in Figures 10-12(a) represents a universal land-sea contrast, with opposite signs for the land and the ocean. This reflects the difference between land and sea in the atmospheric response to solar radiation forcing. Meanwhile, EOF_2 in Figures 10-12(b) represents a complementary geographical variation, which is a component deviating from the typical diurnal cycle that is expressed by EOF_1.

Examination of EOF_1 and EOF_2 reveals the diurnal cycle features of each box area which have slightly different positive-negative spatial patterns among them, particularly over land, over ocean and over coastal regimes (Figures 10–12).

3.5 The Diurnal Rainfall Cycle Features

By combining the PCs and the associated EOFs, we are able to interpret the diurnal cycle features of the rainfall in each area. Box A exhibits quite a large amplitude of the diurnal cycle with afternoon peak (1500–1800 LST) over land and morning peak (0900–1200 LST) over ocean (Figure 7 (left) and Figure 10). Box B shows a slightly larger amplitude than region A with evening peak (1800–2100 LST) over land and morning peak (0600–1200 LST) over the ocean (Figure 8 (left) and Figure 11). Region C exhibits the smallest amplitude among the three regions with afternoon peak (1200–1800 LST) over land and early morning to noon peak (0300–1200 LST) over the ocean (Figure 9 (left) and Figure 12). Over the coastal area, a midnight peak (0000 LST) is exhibited for the three regions. The diurnal cycle features that we found here are consistent with a previous study of the diurnal precipitation regimes in the global tropics by Kikuchi and Wang [8].

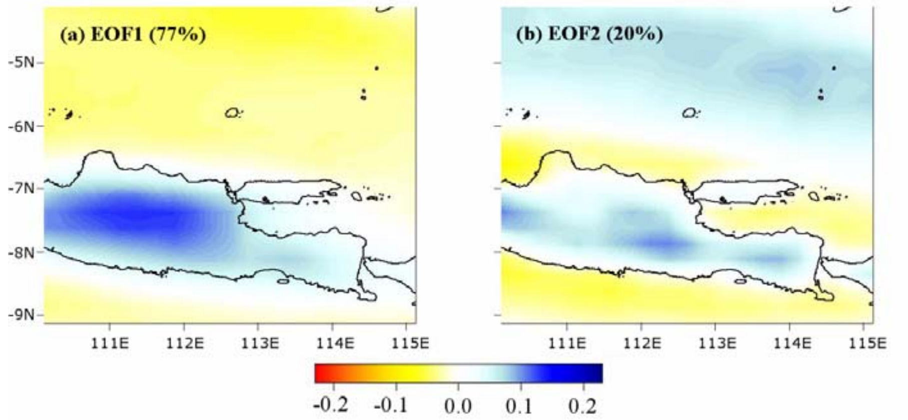

Figure 10. (a) EOF_1 and (b) EOF_2 of Box A.

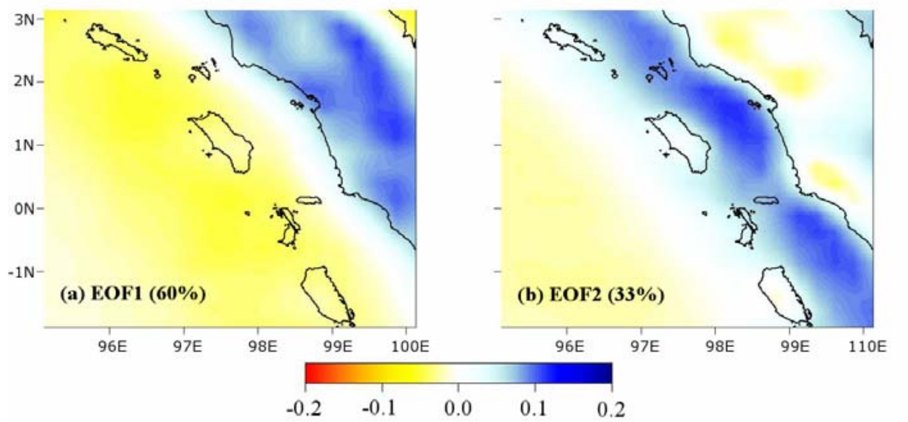

Figure 11. (a) EOF_1 and (b) EOF_2 of Box B.

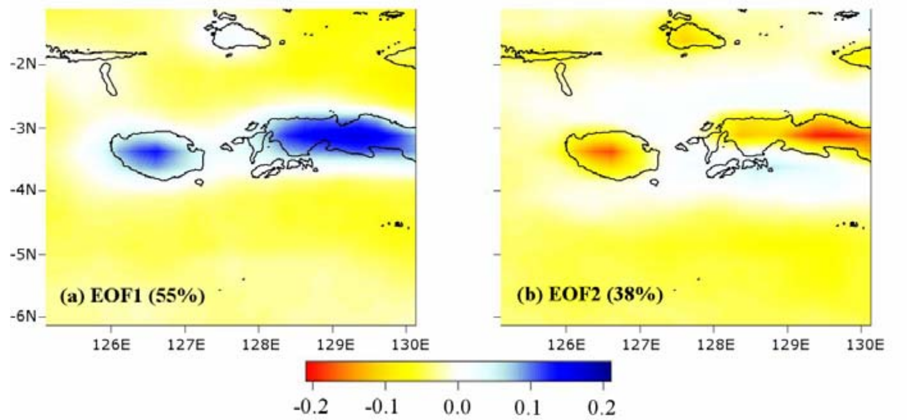

Figure 12. (a) EOF_1 and (b) EOF_2 of Box C.

The rainfall data can be reconstructed as a linear combination of the EOFs, with coefficients obtained by projecting each data vector onto each EOF. Here we used only EOF_1 and EOF_2 to reconstruct the rainfall data, since these two EOFs represent the diurnal cycle. Figures 13–15 show the spatial-temporal variation of the diurnal cycle of rainfall for the three box areas based on the reconstructed data.

Figures 13–15 show that the three box areas have similar features in the diurnal cycle. The amplitudes over land (islands) are much larger than over water (ocean). The peaks of rainfall over land tend to occur in the afternoon, while over the ocean in the morning. However, the three regions have slightly different diurnal cycle features, particularly over islands. Box B has larger amplitude than Box A and C. In terms of phase, Box C exhibits an earlier peak in the rainfall (around 1500 LST), followed by Box A (around 1500–1800 LST) then Box B exhibits the latest peak (around 1800–2100 LST). Over the ocean, Box A and B have almost the same amplitude, while Box C has the smallest amplitude among them.

The results of this study are consistent with some previous works using different data and methods such as Arakawa & Kitoh [10] and Qian [11]. Analysis of diurnal cycles of rainfall and winds indicates that the diurnal cycle variation over this region is predominantly caused by sea-breeze convergence over islands, reinforced by mountain-valley winds and further amplified by the cumulus merger processes [11].

Slightly different features of the diurnal cycle among the three regions (as shown on Figures 13–15) are likely due to different island sizes in each region. Region B, which has a relatively large island (see Figure 1), has the largest amplitude among the three regions, and the peak rainfall over this island last longer. On the other hand, Region C, which has relatively small islands, has the smallest amplitude, and the peak rainfall over land comes early. The land-sea formation also affects the diurnal cycle amplitude over the ocean. The ocean in Region A has relatively large amplitude. It is actually located in the Java Sea (see Figure 1). Therefore the diurnal cycle here is strengthened by land breezes from both Borneo and Java. This is in contrast with Region C, which has small islands that do not affect the oceanic diurnal cycle much. Therefore this region has a small amplitude over the ocean.

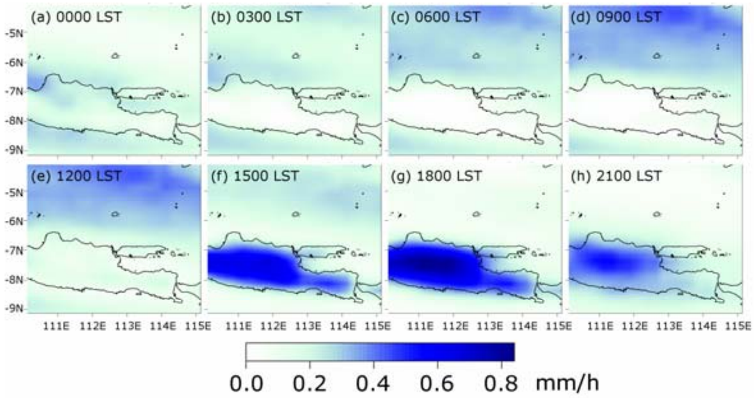

Figure 13. The diurnal cycle of rainfall over Box A, reconstructed using EOF_1 and EOF_2, accounting for 97% of the data variance.

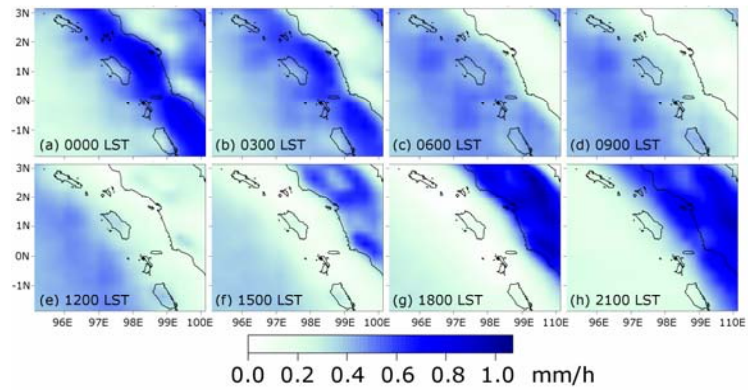

Figure 14. The diurnal cycle of rainfall over Box B, reconstructed using EOF_1 and EOF_2, accounting for 93% of the data variance.

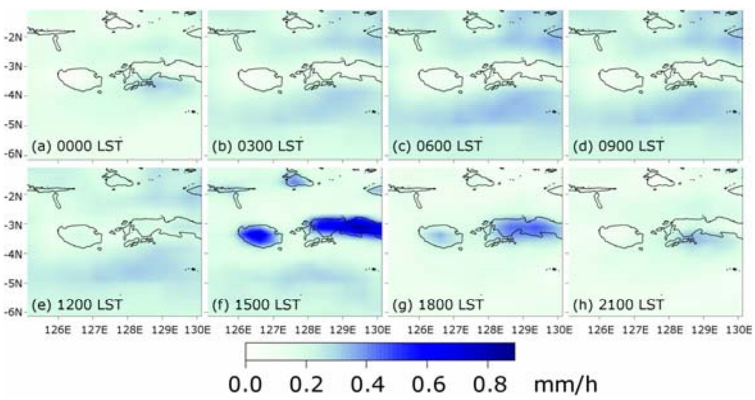

Figure 15. The diurnal cycle of rainfall over Box C, reconstructed using EOF_1 and EOF_2, accounting for 93% of the data variance.

4. Conclusion

In this study, we derived the diurnal cycle of rainfall over the three rainfall regions within Indonesia using TRMM data. EOF analysis that was applied in this study can successfully reveal the spatial and temporal variability of the diurnal cycle. The diurnal cycle is dominantly exhibited over the three regions with 97%, 93% and 93% explained variance for Boxes A, B and C respectively. Region A exhibits quite a large amplitude of diurnal cycle with afternoon peak (1500–1800 LST) over land and morning peak (0900–1200 LST) over the ocean. Region B shows a slightly larger amplitude than region A with evening peak (1800–2100 LST) over land and morning peak (0600–1200 LST) over the ocean. Region C exhibits the smallest amplitude among the three regions with afternoon peak (1200–1800 LST) over land and early morning to noon peak (0300–1200 LST) over the ocean. Over coastal areas, the same midnight peak (0000 LST) is exhibited for the three regions. The diurnal cycle variation over this region is predominantly caused by sea-breeze convergence over islands, reinforced by mountain-valley winds and further amplified by the cumulus merger processes. Slightly different features of the diurnal cycle among the three regions are likely due to different sizes of the islands in each region and different land-sea formations as well.

Acknowledgments

The authors would like to acknowledge the Joint Graduate School of Energy and Environment at King Mongkut's University of Technology Thonburi as well as the Center for Energy Technology and Environment, Ministry of Education, Thailand for providing scholarships intended for conducting this study.

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