Early Morning Peaks in the Diurnal Cycle of Precipitation over the Northern Coast of West Java and Possible Influencing Factors

Erma Yulihastin[1], Tri Hadi[2], Sari Ningsih Nining[2], and Muhammad Syahputra[3]

[1]Indonesian National Institute of Aeronautics and Space
[2]Institut Teknologi Bandung
[3]Bandung Institute of Technology

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Abstract

Erma Yulihastin 1,2, Tri Wahyu Hadi1, Nining Sari Ningsih3, Muhammad Ridho Syahputra1 1Atmospheric Sciences Research Group, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung, Bandung, 40132, Indonesia 2Center of Atmospheric Sciences and Technology, National Institute of Aeronautics and Space, Bandung, 40175, Indonesia 3Oceanography Research Group, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung, Bandung, 40132, Indonesia The diurnal cycles of precipitation over the northern coast of West Java have been studied using the Tropical Rainfall Measuring Mission (TRMM) Real Time Multi-satellite Precipitation Analyses (MPA-RT) products with records spanning from 2000 to 2016, with emphasis on the occurrences of early morning precipitation peaks. Diurnal precipitation over the study area during November to March is basically characterised by precipitation peaks that occur in the afternoon to evening time (15:00–21:00 LT) but secondary peaks in night to morning time (01:00–07:00 LT) are also pronounced in January and February. Harmonic analysis method was then applied on data of January and February to objectively determine the diurnal phase and classify the timing of precipitation for each day into three categories, i.e. afternoon-to-evening precipitation (AEP), early morning precipitation (EMP), and late morning precipitation (LMP) with peaks that occur in the time windows of 13:00–24:00 LT, 01:00–04:00 LT, and 05:00–12:00 LT, respectively. In terms of frequency of occurrence, AEP, EMP, and LMP constitute 55 %, 26.1 %, and 18.9 % of total samples of precipitation events. In spite of the smallest percentage, EMP events are characterised by seaward (as well as landward) propagation, flat phase distribution, and large mean amplitudes. The propagating characteristics of EMP are more prominent, with indications of stronger connectivity between precipitation systems over land and ocean, when data are composited by taking the 99th percentile values in each grid to represent extreme precipitation events. The flat phase distribution of EMP events suggests that the timing of coastal precipitation is not necessarily locked to the phase of land/sea-breezes, thus, allowing precipitation to occur more randomly.

EARLY MORNING PEAKS IN THE DIURNAL CYCLE OF PRECIPITATION

OVER THE NORTHERN COAST OF WEST JAVA AND POSSIBLE INFLUENCING FACTORS

Erma Yulihastin[1,2], Tri Wahyu Hadi[1], Nining Sari Ningsih[3], and Muhammad Ridho Syahputra[1]

“We analysed Tropical Rainfall Measuring Mission Multi-satellite Precipitation Analyses (TMPA) Real-Time 3B41RT dataset spanning from 2000 to 2016, and found that diurnal cycles of precipitation in January and February over the northern coast of West Java are not phase-locked to daily insolation, rather their occurrences are associative to propagating systems and can be grouped into: afternoon-to-evening precipitation (AEP), early-morning precipitation (EMP), and late-morning precipitation (LMP). The EMP events are distinctly characterised by large mean amplitudes and randomly distributed phases between 01.00 to 04.00 LT; also marked with strong connectivity between precipitation systems over land and ocean.”

INTRODUCTION

A phase difference of diurnal rainfall between land and sea (Biasutti et al., 2011; Qian et al., 2010; Qian 2008):

- **Land**: afternoon-night with the peak on Late Afternoon (LA).
- **Sea**: Middle-Night (MN)-morning with a peak on Early Morning (EM).

The amplitude of the diurnal cycle can vary by season while the phase relatively constant (Yang and Smith, 2006).
Diurnal cycle variations are determined by (Biasutti et al., 2011):

- the wind direction changes,
- land-sea contrasts,
- variations in sea surface temperature in shorterm scale, orographic.

Globally, the phase of the diurnal rainfall has two types:

- Diurnal (EOF1 and EOF2: 80%,) in land and sea (Kikuchi and Wang, 2007).
- Semidiurnal (EOF3 and EOF4: 10%) (Kikuchi and Wang, 2007) was found over sea (Dai, 2000; Yang and Smith, 2006).

Phase for land: afternoon-EM (EOF1 51%) and can shift to: noon (EOF2 21%) (Kikuchi and Wang, 2007).
Phase for ocean: EM-morning (EOF1 38%) and morning-noon (EOF2 20%) (Kikuchi and Wang, 2007).

In this study, we are particularly interested in analysing the climatology of early morning precipitation (EMP) peaks over the northern coast of West Java. We analysing the prevalence of EMP peaks over the area of interest by classifying diurnal precipitation into several dominant patterns with regards to the phase or time of occurrences.

DATA AND METHOD

In order to investigate diurnal cycles of precipitation over the northern coast of West Java, we used the Tropical Rainfall Measuring Mission (TRMM) Real-Time Multi-satellite Precipitation Analyses (TMPA-RT) product of the 3B41RT dataset, the so-called TMPA-RT dataset with a spatial resolution of 0.25° × 0.25° at an hourly time interval during NDJFM 2000-2016.

In order to classify the phase or timing of precipitation, we picked samples of 24 h data (area-averaged over the red-line bordered polygon in Fig. 1). We then decomposed each sam ple into its harmonic constituents by fitting the data (after subtracting by the daily mean) using a sinusoidal function:

$$y_{k(t)} = c_{k(t)} Cos\,(2\frac{\pi k}{T} - \theta k)$$

y_k : *precipitation anomaly by harmonic component*
C_k : *amplitude* $(\frac{mm}{hr})$
T : *data period (24 hr)*
θk : *phase lag in radiant*

In this case, the **EMP occurs between 01:00 and 04:00 LT.**

CLIMATOLOGY OF DIURNAL CYCLE OF PRECIPITATION

Figure 2 show that the dominant pattern is characterized by precipitation peaks occurring in the afternoon to evening time (15:00–21:00 LT). However, diurnal precipitation patterns in the months of January and February exhibit significant secondary precipitation peaks in the early morning to morning time (01:00–07:00 LT).

It should be clear that the coastal region (marked by vertical black-dashed lines) is affected by precipitation systems of both inland and oceanic origins. Figure 2d and e also clearly indicate that the oceanic precipitation system penetrates further inland during January and February, which appear as secondary peaks occurring between 01:00 and 07:00 LT as shown in Fig. 2a.

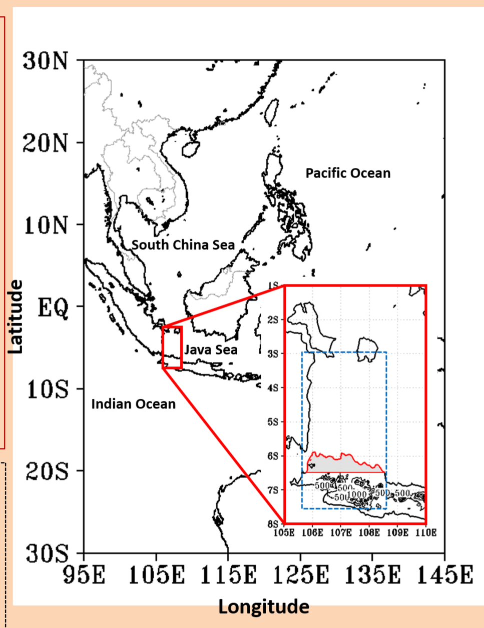

Figure 1. A map showing the Maritime Continent and its surrounding area. The main area of interest in this study is depicted as the inset, with coastlines and topographic contours. The red-line bordered polygon (with land masks over the northern coastal plain of West Java) defines the area for spatial averaging of gridded precipitation data. The blue-dashed rectangle defines the area for longitudinally (105.5–108.5° E) averaged precipitation in Hovmöller analysis of Fig. 2

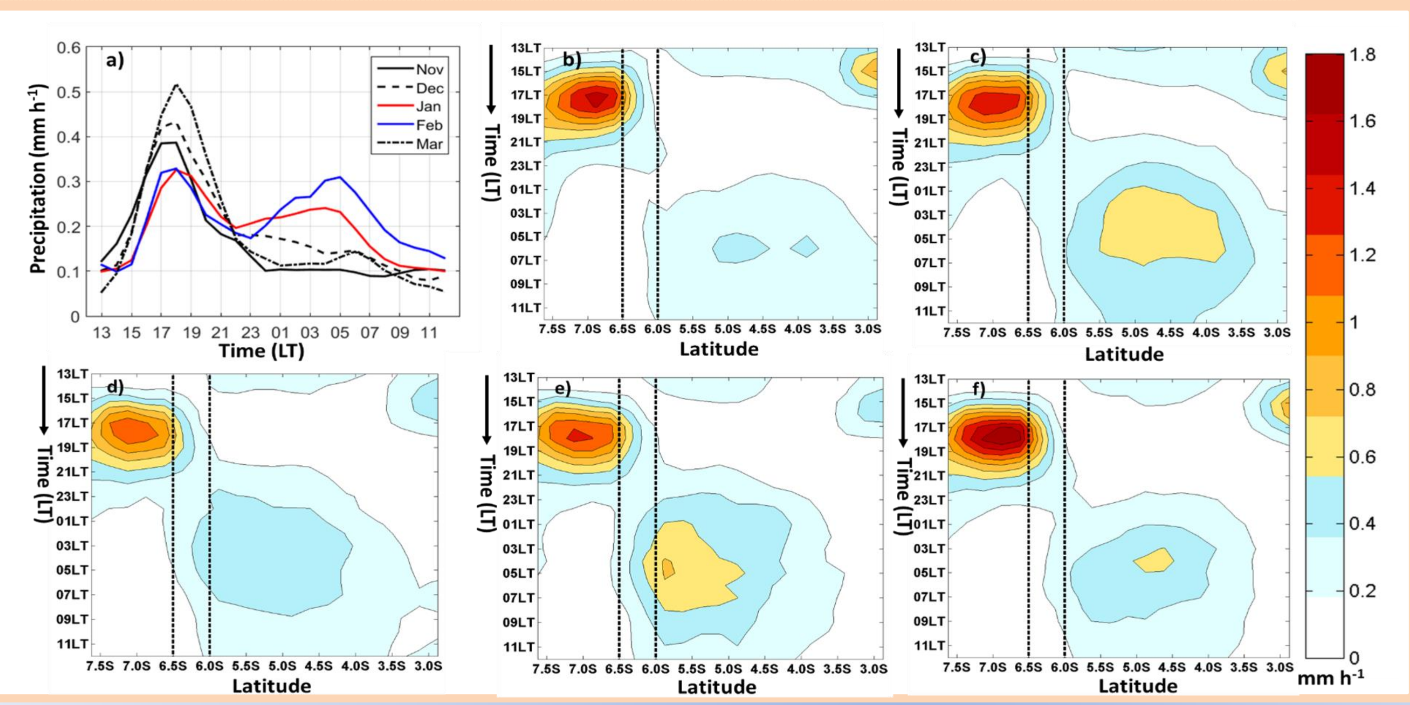

Figure 2. (a) Climatology of area-averaged diurnal precipitation over the northern coast of West Java, depicted as line plots of 24 h composite time series in different colours for the months of November (solid black), December (dashed black), January (solid red), February (solid blue), and March (dashed-dotted black) analysed from the TMPA-RT dataset of the 2000–2016 period. Other panels show the corresponding time–latitude cross sections (Hovmöller diagrams) of the diurnal composites for the months of (b) November, (c) December, (d) January, (e) February, and (f) March. Dashed vertical black lines in panels (b)–(f) denote the latitudes of the northern coastal area of West Java

EARLY MORNING PRECIPITATION (EMP) PEAKS

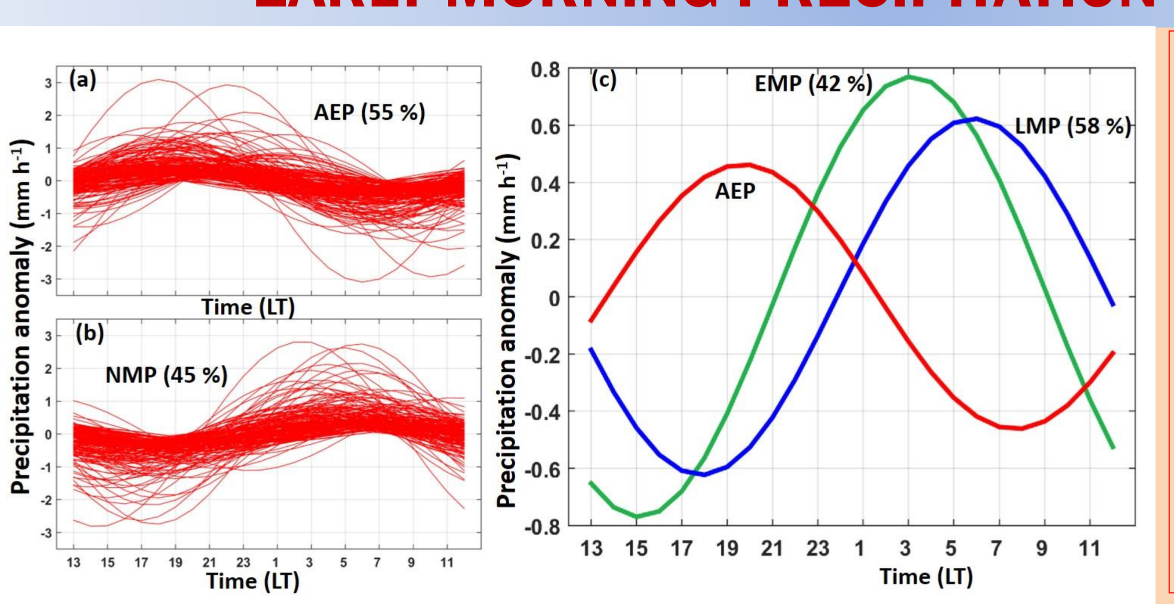

Figure 3 shows that Afternoon-to-Early morning Precipitation (AEP) is a dominant feature of the diurnal precipitation, which contributes 55 % of the diurnal rainfall patterns over the studied area. However, Night-to-Morning Precipitation (NMP) also has a high frequency of occurrence, contributing 45 % of the total samples in January and February throughout the 2001 to 2016 period.

The frequencies of occurrence of EMP and Late Morning Precipitation (LMP) are 42 % and 58 %, respectively, relative to total NMP samples, or 18.9 % and 26.1 % relative to all samples. It is of interest to note that, in spite of the smallest percentage, EMP has the largest mean amplitude.

RANDOM OCCURRENCE OF EMP

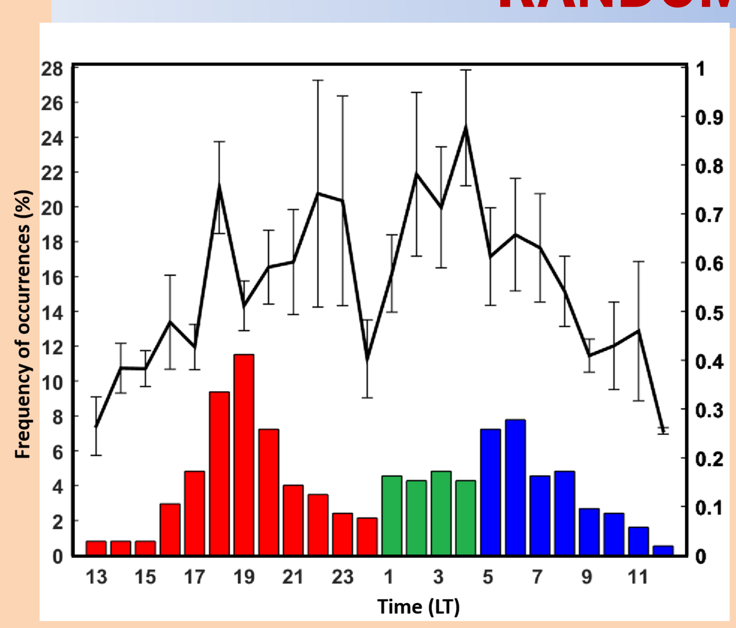

Figure 4 shows that phases of AEP exhibit a nearly normal distribution centred around 19:00 LT with two maxima of mean amplitudes around 18:00 and 22:00 LT. On the other hand, LMP shows a distribution that decreases with time, resembling a gamma-like distribution with a maximum mean amplitude around 06:00 LT.

However, it is quite interesting that EMP events have not only a flat phase distribution, which indicates more random events, but also high mean amplitudes with peaks around 04:00 LT.

The random occurrence of EMP might be closely related to propagating systems, as indicated from Fig. 2b–f, since their phases are not necessarily locked to the timing of sea–land breezes.

PROPAGATION CONVECTIVE SYSTEM

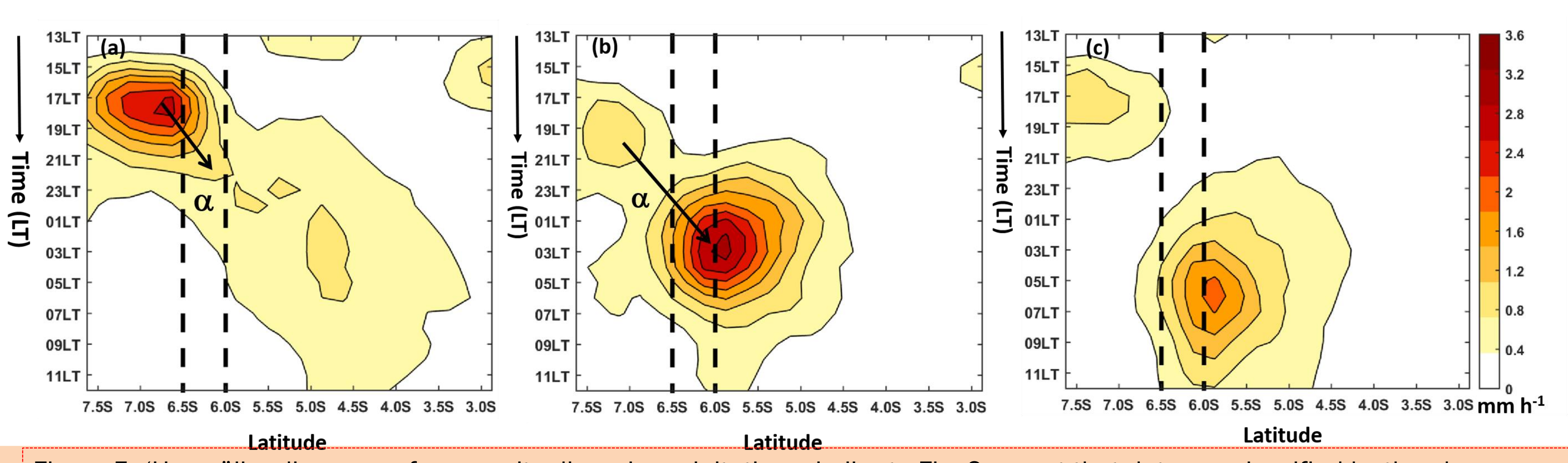

Figure 5. (Hovmöller diagrams of composite diurnal precipitation, similar to Fig. 2 except that data are classified by the phases or the timing of peak precipitation (as in Fig. 3) (a) AEP, (b) EMP, and (c) LMP. The black-dashed line indicates the boundary of the coastal area. The black solid arrows represent the direction of propagation (following Mori et al., 2004), with seaward propagation symbolized by α and landward propagation indicated by β.

The propagating precipitation can be associated with rainfall events that occur during the late night (Fig. 5a) and early morning (Fig. 5b) time over the coastal region. It should be noted that in Fig. 5a the direction is mainly one way from land to sea, while in Fig. 5b there is also a discernible landward pattern of propagation.

On the other hand, Fig. 5c illustrates more detached precipitation systems over land and sea. In this case, late morning precipitation over the coastal region can be seen as an extension of the oceanic precipitation system

RELATIONSHIP WITH EXTREME PRECIPITATION EVENTS

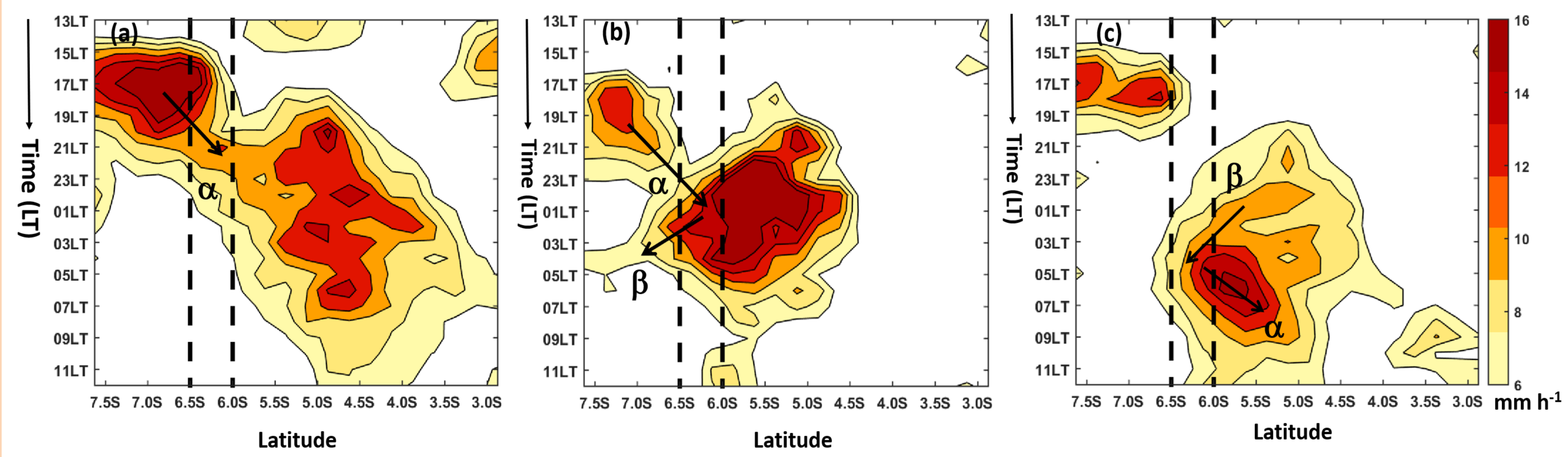

Figure 6. (Hovmöller diagrams of composite diurnal precipitation, similar to Fig. 2 except that data are classified by the phases or the timing of peak precipitation (as in Fig. 3) (a) AEP, (b) EMP, and (c) LMP. The black-dashed line indicates the boundary of the coastal area. The black solid arrows represent the direction of propagation (following Mori et al., 2004), with seaward propagation symbolized by α and landward propagation indicated by β.

Fig. 6 strongly suggest that extreme rainfall events over the coastal region mainly occur between 01:00 and 04:00 LT and are characterized by the existence of propagating systems from both land and ocean (Fig. 6b). On the other hand, extreme coastal precipitation events that occurred during late night (Fig. 6a) and late morning (Fig. 6c) seem to originate only from either land-based or oceanic convection.

RELATIONSHIP WITH CENS AND SCS-CT

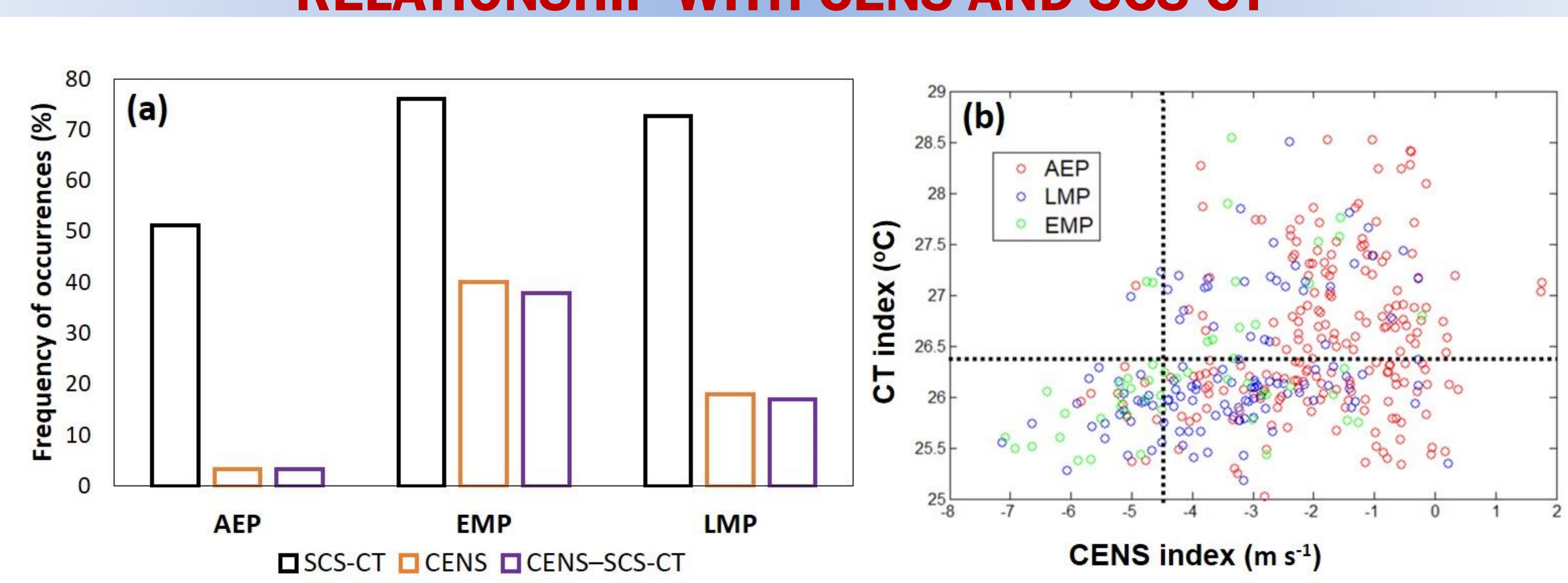

Figure 7. (a) Frequency of occurrence of SCS-CT (black), CENS (orange), and CENS-SCS-CT (purple) corresponding to the three diurnal phases of peak precipitation AEP, EMP, and LMP; (b) scatter plot between SCS-CT and CENS indices for AEP, LMP, and EMP as indicated by red, blue, and green circles, respectively. Threshold values for SCS-CT (26.4 °C) and CENS (−45 m s−1) indices are indicated by black dotted lines

While we have insufficient data to analyse the propagating precipitation systems in more detail, synoptic conditions favourable for their occurrence may be investigated from global reanalysis data. We also mentioned earlier that such favourable conditions may develop under the influence of Cross-Equatorial Northerly Surge (CENS), or Cold Tongue in South China Sea (SCS-CT), or the combination of both.

Figure 7 show that SCS-CT generally prevails, with a frequency of occurrence above 50 % in all classified events. However, SCS-CT exhibits stronger association with morning precipitation events, with a frequency of occurrence above 70 % in both the EMP and LMP categories. On the other hand, the frequency of occurrence of CENS is the highest for samples belonging to EMP and almost negligible for the AEP category.

CONCLUSION

The EMP contributes 18.9 % of the total samples analysed, which is a minority compared to that of the LMP (26.1 %) and AEP (55 %). However, we found that the EMP events are characterized by:

(1) seaward as well as landward propagation with indication of stronger connectivity between land-based and oceanic precipitation systems,
(2) flat phase distribution, and
(3) high mean amplitudes peaking around 04:00 LT.

These propagating characteristics of EMP are more prominent when data are composited by taking the 99th percentile (P99), which signifies the importance of EMP in association with extreme precipitation events. The flat phase distribution of EMP events suggests that the timing of coastal precipitation is not necessarily locked to the phase of land–sea breezes, **thus allowing precipitation to occur more randomly. This implies that, even for as short as 24 h lead time, probabilistic forecast may be necessary to assess the hazard of heavy precipitation in this region.**

CONTACT INFORMATION
[1]Atmospheric Sciences Research Group, Faculty of Earth Sciences and Technology, Bandung Institute of Technology, Indonesia
[2]Center of Atmospheric Science and Technology, Indonesian National Institute of Aeronatics and Space, Indonesia
[3]Oceanography Research Group, Faculty of Earth Sciences and Technology, Bandung Institute of Technology, Indonesia
Corresponding author: erma.yulihastin@lapan.go.id