Diurnal Rainfall Propagation Relate to Cold Surge-Cold Tongue Interaction over The Northern Coast of West Java

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Abstract. Interaction of the diurnal cycle of rainfall systems between land and sea were investigated by hourly rainfall of 3B41RT TRMM dataset, daily SST dataset from OISST, 6-hourly wind and temperature data from NCEP-NCAR Reanalysis, during period of NDJFM 2000-2016. The results showed that the diurnal cycle of rainfall from sea to land and from land to sea randomly occurred on four combinations of CENS-CT, NCENS-CT, CENS-NCT, NCENS-NCT. Diurnal rainfall in northern coast of West Java for normal conditions without CENS-CT has two maximas, namely late afternoon and early morning rainfall. CENS-CT interaction changes the normal diurnal rainfall pattern into three diurnal rainfall systems: diurnal rainfall with propagate B pattern which is identified by the afternoon continuous to morning rainfall and there is an offshore propagation from sea to land that occurred in the morning, diurnal rainfall with a nonpropagate pattern, namely morning rainfall which has increased intensity and duration while afternoon rainfall is minimum, diurnal rainfall with propagate A pattern which experienced rainfall from land to sea and there was a merger between the afternoon rainfall system over the land and the morning rainfall system over the sea.

Keywords : rainfall, cold surge, cold tongue, TRMM.

1. Introduction

A very strong surface wind flow across the equator is called the Cross-Equatorial Northerly Surge (CENS). Based on the research of Hattori et al. [1], the CENS shown by strong north winds (5-8 m/s) lasts from the end of December to mid-February. The CENS phenomenon which does not always occur every year in a mechanism still simplified is an extension of Cold Surge formed on the Siberian plateau [2], which is characterized by a drastic drop in temperature and pressure for several days [3]; [4]; [5]; [6]; [7]; [8]; [9]; [10]; [11]) and caused disturbances to the weather system for East Asian countries [9], such as Hong Kong and Taiwan. This Cold Surge, when passing through the South China Sea can transform into very strong north winds ([12]; [2]) and propagate south across the equator. Climatological observations of the CENS further encouraged [1] to define the location of CENS focused on strengthening winds from north or northwest from the surface of the Java Sea, Karimata Strait, and parts of the South China Sea as shown in a box that limits the region (0 – 5°S, 105 – 115°E).
On the other hand, the process that occurs at sea level in the SCS South China Sea (SCS) region is also interesting because SST variability occurs from an intraseasonal to interannual scale ([13]; [14]; [15]; [16]) and is influenced by ENSO through weakening (El Niño) and Strengthening (La Niña) of the Asian winter monsoon, respectively ([17]; [18]; [19]). In addition, during the Asian winter monsoon period, the unique features of SST have been found, ([13]; [14]; [15]), which was called by Cold Tongue (CT) ([17]; [20]; [21]; [22]) with the coldest core in the waters near Vietnam's southeast coastal [22] and show that consistently strong CT has affected the increase in monsoon activity and has an impact on the addition of evaporation. In addition, CT has also been studied to influence the distribution of diurnal rainfall between Java and the Java Sea, namely in the form of a reduction in rainfall occurring over the Java Sea and conversely an increase in rainfall over the land [21].

The CS phenomena that occur on the atmospheric surface level (1000 – 850 mb) and CT that occur at sea level have been studied separately ([23]; [1]; [21]). In fact, atmosphere and ocean are components that interact with each other. Therefore, it is necessary to study CT and CS by using the atmosphere and the ocean as components that interact with each other. Monitoring of the disruption of CS-CT interactions in a diurnal context in West Java during the active period of the Asian winter monsoon is interesting to study.

Previous research shows that floods that occurred in northern West Java during the DJF period in 2002, 2007([24]; [25]; [26]), 2013 [27] and 2014 were related to high rainfall which persisted from morning to afternoon. Rainfall events that cause flooding in Jakarta and the north coast of West Java can be identified as a deviation from the diurnal pattern of rainfall, which is a shift in the diurnal cycle time of rainfall from afternoon to night to morning to afternoon. So far there has been no study discussing diurnal cycle deviations in northern West Java that are thought to be related to CENS activity and reinforced by CT formation in SCS. The interaction between CS-CT is considered to influence diurnal rainfall pattern deviation in northern West Java which has not been well studied. The current research particularly interested in investigating interaction between CENS-CT and its influence to the morning rainfall peaks over the northern coast of West Java.

2. Data and Method

In this study, we identified propagation of diurnal rainfall system on the north coast of West Java by hourly rainfall data from the TRMM 3B41RT Satellite with spatial resolution of 5 km during the NDJFM period of 2000-2016. Secondly, we calculate the CENS and CT indices using meridional wind parameters and SST were carried out, respectively. The CENS index is calculated from the surface meridional wind (925 mb) data over the area limited by 0 – 5oS, 105 – 115°E. Taking into account the definitions of CENS or Cold Surge which have a minimum of life cycle ([11]; [2]), the CENS index calculation using the 6-hourly wind data, the average is made into pentad or 5-daily data. By following the definition of Hattori et al. [1], the CENS index has a threshold of 5 m/s.

Thirdly, the CT index is calculated from the SST data in an area limited by 2 – 10oS, 105 – 112°E. Furthermore, the SST threshold for CT determination was calculated by following Koseki et al. [22] that is by calculating the average value of the SST then deducting it by doubling the data standard deviation. The result is an SST of 26.4°C as a threshold. CENS and CT incidence calculations are calculated for each month, by categorizing the events of CENS-CT, CENS without CT (CENS-NCT), CT without CENS (NCENS-CT), and normal conditions without CENS-CT (NCENS-NCT).
3. Result and Discussion

Figure 2 shows four categories of combinations between CENS-CT, CENS-NCT, NCENS-CT, NCENS-NCT during the event years in the 2000-2016 NDJFM period. Appeared during the CENS-CT events, there were at least 20 extreme conditions represented by strong northerly wind values (> 8 m/s). For the CENS category without CT (CENS-NCT), strong CENS occurs more than normal CENS. As for CT events without CENS (NCENS-CT), strong CT (< 26.4°C) occurred in almost half of all samples of NCENS-CT events.

Figure 3 describes the spatial formation of rainfall for four categories, namely: normal (32 months), nonpropagate (12 months), A propagate (20 months), B propagate (16 months). This shows that from 80 data, the most rainfall has a normal type with two separate rainfall systems over land and sea which are 32 months and without CENS or CT events (Figure 2-a). Meanwhile, non-propagating formations (12 months), most experienced CENS-CT (45%), both experienced CT without CENS (21.44%), CENS without CT (5%), and without experiencing both of them (15%).

Figure 1. Method to calculate CENS-CT indices with their area locations.
For the rainfall propagation, there are two types: propagation from land to sea (A propagate), propagation from sea to land (B propagate). For A propagate, rainfall over the mainland occurs from the afternoon (1600-0100 LT) to early morning. For the B propagate, the rainfall develops over the sea from morning 0700 LT to 1300 LT. The dominant propagate type (58.3%) experienced CT, CENS-CT (25%) and without CENS or CT was 16.7%. For B propagate (16 months), most experienced CENS-CT (93.8%) and the remaining 6.2% experienced CT.

![Figure 3](image-url)  
**Figure 3.** Spatial formation of rainfall system for (a) normal, (b) nonpropagate, (c) propagate A, (d) propagate B over the north coast of West Java.

![Figure 4](image-url)  
**Figure 4.** Rainfall evolution of the CENS-CT events during 11-15 January 2009.
Figure 4 describes the Jakarta flood events on January 11-15, 2009 which occurred simultaneously with CENS-CT. This is shown by the reinforcement (> 5 m/s) of the northerly wind through the equator (6°S) coincides with a decrease in surface temperature (Figures 3-a and 3-c). At the same time, SST has cooled (< 26.4°C) accompanied by a front of moist and dry air masses in the north and south of the equator (2°N – 6°S). This dry and humid air mass front has intensified the strong convection process so that heavy rainfall triggered the flood occurred during 11-15 January 2009 (Figures 3-b, d, f).

Figure 4 (g-h) is a rainfall evolution which exhibits that rainfall over the north coast of West Java occurred on 11 January from 1300 LT and persisted until 13 January 2009 (Figure 4-g). Besides that, persistent rainfall also occurs with large amplitude (blue) or high intensity (Figure 4-h).

Figure 5 explains the evolution of rainfall during CT without CENS, ie on 1-4 February 2012. It was seen on 1-4 February 2012 that SST had cooled to 2°N. In addition, there was a front between the dry and humid air masses in the region (Figure 5-f). Rainfall occur from the sea to the east on February 1 from morning to noon. On February 2, there was a spreading of rainfall from land to sea in the afternoon to night. Signals of rainfall propagation from sea to land then back to the sea are very clear in the evolution of rainfall events 1-4 February 2012.

Figure 6 describes the evolution of rain when CENS occurred without CT and coincided with flood events in Jakarta during 11-15 January 2013. It appears that the rainfall that occurred during 11-15 January 2013 did not propagate and was concentrated over the coastal area, which was preceded by rainfall formation over the sea near the coastal. Moreover, rainfall also persists for four days in the region.

Figure 7 shows the evolution of rainfall when neither CENS nor CT occurred on 1-4 January 2016. It appears that during 1-4 January, there was no strengthening of surface winds or cooling of surface temperature or sea surface temperature. In addition, the rainfall system over the land and the sea occurs separately in the afternoons (1300-1900 LT) and the morning (0100-0700 LT).

Figure 8 illustrates the synoptic conditions of the monsoon as a background wind for the four selected case studies representing: CENS-CT, NCENS-CT, CENS-NCT, NCENS-NCT. When CENS coincide with CT, it was seen that CT played a role in strengthening and increasing the intensity of the northerly
wind and reducing the westerly winds over Java Island. While the CT occurs independently, the westerly wind intensify and homogeneous over Java whereas the northerly wind does not develop over the South China Sea. When CENS occurs independently, northerly develop over the South China Sea and propagate to south (Java island). However, compared to when CENS occurred with CT, the intensity of the northerly wind was weaker and the westerly wind formed strongly over Java. Under the normal conditions, without the occurrence of CENS or CT events, both the northerly and westerly wind were weakened.

Figure 6. Same as figure 5, but for CENS-NCT events during 11-15 January 2013.

Figure 7. Same as Figure 6, but for NCENS-NCT events during 1-4 January 2016.
Figure 8. Spatial pattern of wind vector and meridional wind (shaded) for 4 cases: (a) CENS-CT (11-15 January 2009); (b) NCENS-CT (1-4 February 2012); (c) CENS-NCT (11-15 January 2013); (d) NCENS-NCT (1-4 January 2016).

4. Conclusion
The CT in SCS occurs almost every year during NDJFM rainy season period with duration between 1-3 months, except when there is strong El Niño occurred in 2011 and 2016. While CENS has a shorter duration, ie daily (2-30 days) and not always occur every year during the NDJFM period. CT is more influential than CENS in changing the diurnal pattern of rainfall over the northern coast of West Java. The presence of CENS is to strengthen the CT effect in extending the duration of the afternoon rainfall and increasing the intensity of the morning rainfall. Based on climatological statistics, diurnal rainfall over northern coast of West Java for normal conditions without the CENS or CT has two maxima, namely in the afternoon and in the morning. CENS-CT interaction resulted in changes in three diurnal system patterns, namely: (1) diurnal rainfall with B propagate pattern (93.8%), namely the afternoon rain experienced an extension to early morning and there was a spread of rainfall from sea to land which occurred in the morning; (2) diurnal rainfall with a nonpropagate pattern (45%), namely morning rainfall which has increased intensity and duration while afternoon rainfall is minimum; (3) diurnal rainfall with A propagate pattern (25%) which experienced raindrops from land to sea and there was a merger between the afternoon rainfall system over the land and the morning rainfall system over the sea.

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