Mode of Wind and Sea Surface Temperature Over the South China Sea During Rainy Season in Indonesia

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Abstract. Research on near-surface wind and sea surface temperature dynamics in the South China Sea (SCS) is important to understand their impact on Indonesia’s rainy season variations. In this study, we use daily wind data from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis and sea surface temperature (SST) from the Optimal Interpolated Sea Surface Temperature (OISST) during November-to-March (NDJFM) period of 2000-2016 to explore the dominant signal of temporal and spatial variations in the SCS. Results of the first EOF (EOF-1) show that the SST cooling occurred in the entire region (the South China Sea, local Indonesian sea, and the Indian Ocean nearly Sumatra), thus, is remarked as “Cold Tongue” (CT). Additionally, the CT coincides with the strengthening of northerly wind over the South China Sea (SCS) elongated in the equator’s vicinity, which is indicated as a cross-equatorial north wind (CENS). For meridional wind, the spatial pattern of the EOF-1 (17.75%) shows that the strength of this CENS is associated with SCS-type (remarked as South China Sea type) of Cold Surge (CS) pathway. This CS SCS-type could enhance the Asian winter monsoon flows over Indonesia. On the other hand, the spatial pattern of the second EOF (EOF-2) shows the enhancement of the northerly wind towards the Philippine Sea (12.65%) associated with PHP-type (remarked as Filipina sea type) of CS pathway (CS PHP-type). The CS PHP-type has a relationship with strong CT (12.65%). The CT, which is observed extending southward close to the Karimata Strait, appeared not to relate to the local CENS, which occurred early. Regarding the EOF-1 results, it appeared that the correlation between northerly wind and SST in the whole of the Maritime Continent region. It also shows that the CT developed from mid-December to mid-January. On the other side, the CENS occurred from mid-December to last-February.

1. Introduction
The Maritime Continent (MC) region, which is limited by 95-145°E; 10°S-15°N [1], geographically is an area with a complex land-sea and topographic composition [2], [3]. Consequently, the region has a predominant role in controlling an atmospheric dynamic from the weather to the seasonal scale [4]. In this case, the robustness of weather dynamics also have implications for the low performance of the numerical weather prediction models in simulating rainfall over the MC [5], [6], [7], [8], [9], [10], [11]. Climate models also cannot predict rainfall amplitude over the MC region accurately from intraseasonal to interannual scale. Systematic errors which are produced by model prediction also affected the inaccuracy of global models in predicting the global phenomenon of Madden Julian...
MJO) that oscillates 10-50 days [12], [13], [14], [15], [16]. Concurrently, the seasonal scale of rainfall prediction biases is always also produced by climate models predicting the onset monsoon both of rainy and dry seasons over the MC region.

The characteristics of the MC region that are not fully understood is one of the leading causes of the model’s inaccuracy in predicting and simulating rainfall in the region. One of the reasons is that the contribution of local waters in the MC to the atmosphere’s dynamics from the weather to the seasonal scale is not fully known [11]. This lack of understanding of the dynamics of local waters in influencing atmospheric conditions could occur because local waters’ connectivity in the Indonesian region with the South China Sea (SCS) has not been explored in studies on the ocean and atmosphere interactions.

For the weather scale, 4 (WT2, WT3, WT4, WT5, WT6) of 6 weather types over the MC region have been studied [4]. In this case, WT3 and WT4 show the characteristics of the Asian monsoon winds, representing the rainy season period during December-February (DJF). Meanwhile, WT2, WT5, and WT6 show weather characteristics during the transitional season due to equinox, which has the potential to cause extreme weather in the western and southern parts of Indonesia to include Sumatra, Kalimantan, Sulawesi, and western Java [4]. For the intraseasonal scale, MC is a barrier to the propagation of MJO, resulting in B type of MJO experiencing damping so that its propagating ends over the MC region [16]. The cause of the blocking of the MJO is a convection barrier over the local waters of the MC, which is thought to have occurred due to the interaction between the local waters and surrounding areas [16].

The dynamics of weather [4], [16], and intraseasonal over the MC are motivation in conducting research on the behavior of atmospheric and oceanic parameters that can show the connection between local waters of MC and SCS. The connection could represent both meridional wind and sea surface temperature (SST). Meanwhile, the rainy season period (DJF) was selected to study because most of the MC regions experience the peak of the rainy season in January [1]. In addition, during the DJF period, there were also unique phenomena in the atmosphere and sea, which both occurred in the surface layer. This is characterized by anomalies of surface wind strengthening [17], [18], [7], [19], [20] and cooling of SST in SCS [21] which can reach southward to the Java Sea and the island of Java.

This strengthening of northerly wind hereinafter referred to as Cross-Equatorial Northerly Surge (CENS), has been shown to cause positive precipitation anomalies over Java Island during the dry season in December to February (DJF) [19]. Likewise, the cooling anomaly of SST, hereinafter referred to as “Cold Tongue” in the South China Sea (CT), has also been observed to shift diurnal rainfall over the ocean closer to the coastal region [21]. Based on the previous study, while CENS coincides with CT, the diurnal rainfall over the coastal region has phase shifts from late afternoon rainfall to early morning rainfall [22]. This current study uses Empirical Orthogonal Function (EOF) analysis which aims to determine the relationship between meridional wind and SST in the SCS in revealing the connectivity between CENS and CT.

2. Material and methods

The SST data over the period of 2000-2016, derived from optimal interpolated sea surface temperature (OISST) [23] can be downloaded free via the following link address: https://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.highres.html. Whereas, daily meridional near-surface wind (925 mb), the height level of atmosphere that represented free of roughly surface friction, from 2000-2016. This data derived from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis [24] (2000-2016) which can be downloaded free via the following link address: https://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.pressure.html.

The method used to calculate the main components using EOF. This EOF uses an analytical method that has been widely used to understand the behavior of various ocean and atmospheric data to reveal various phenomena in the meteorological and climatological fields. This method basically calculates the main components that appear in each parameter being reviewed. To calculate the EOF, we determine the linear combination of all the original variables that has the largest variance sequentially and does not correlate with the previous main component based on the formulation:
1) \[ X = \sum_{i=1}^{r} u_i \sigma_i \nu_i(k) \]

2) \[ X = \frac{\sigma_i}{\sum_{i=1}^{r} \sigma_i^2} \]

Where \( i = 1, 2, \cdots, r \) is the singular value of the X matrix. In this case, the X matrix in the 1) and 2) equations is due to the calculated variable. In practice, k mode EOF-1 or the first principal component with \( k \ll r \) represents the largest proportion of the variance. EOF-2 mode is a linear combination of all observed variables, which is orthogonal to EOF-1 mode and has the second-largest variance. EOF analysis is used to find (n, x, k) the component score matrix with p time on k components containing the V matrix in equation 1) containing EOF coefficients from n variables on k components [25].

3. Results and discussion

The first EOF (EOF-1) spatial analysis of the surface wind (925 mb) in the SCS shows that a positive EOF score indicates the northerly wind, whereas a negative score indicates southerly wind (Fig. 1-a). The northerly wind amplification signal looks broad and homogeneous in the SCS and extends until it reaches the equator. The northerly wind represents the signal of the Asian winter monsoon which is amplified by the Cold Surge (CS) phenomenon. It could also have an impact on the strengthening of the northerly wind over the local SCS. This pattern corresponds to the SCS-type (represent to South China Sea pathway type, following [26]) of CS. It could be indicated by strong southward until close to the Karimata Strait region, bringing large amounts of moisture and precipitation around the region [26].

However, this spatial feature which has a significant variance (17.75%) shows that CS does not correspond to previous studies [27]. The study states that when CS occurs, wind strengthening not only occurs over the SCS but also over the Pacific Ocean and Philippines Sea. The strengthening of the northerly wind by the SCS-type [26] seems could extend across the equator as well as representing the Cross Equatorial Northerly Surge (CENS) signal [19]. Meanwhile, for SST, the EOF-1 shows a positive score means that SST cooling occurs, and a negative score indicates SST warming (Fig. 1-b). Cooling SST occurs evenly in the SCS and the Pacific Ocean. This shows a general description of SST conditions during the DJF period in SCS, the Pacific Ocean, and the local Indonesian sea.

Nevertheless, warming SST exhibits in the local sea of western Indonesia and the Indian Ocean near Sumatra and southern Java. These results also show that DJF in western Indonesia, particularly Sumatra, has more surface moisture rather than other regions. Thus, the two sources of moisture could modulate convective activity over Sumatra. The first source is from the Northern Hemisphere through the strengthening of the Asian monsoon accompanied by a strong northerly wind, whereas the other source was influenced by warming Indian Ocean SST close to western Sumatra.

For the second EOF (EOF-2), the spatial pattern of surface wind showed a strong signal identified over the Pacific Ocean region near the Philippine sea. This appears appropriate with the northerly wind amplification signal which is related to PHP-type (PHP is an abbreviation that represents Philippine pathway of CS type, following [26]) [26], [27]. However, this study also pointed out that the northerly wind over the SCS area appears to decrease and at the same time the local SST suggested strengthening the northerly winds locally around the Karimata strait (Fig 2-b). The strengthening of local northerly wind also referred to as a local CENS around the Karimata Strait, could be caused by a spreading of strong CT [22] as evidenced by Figure 2-b. This also confirmed that in the EOF-2, the CT signal is developed from the Northern Hemisphere near the east coast of Vietnam and extends southward across the equator until it reaches the Java Sea. Several other findings are also shown by the difference in contrast between the Indonesian seas’ western and eastern parts. The warming signal occurred in the eastern sea of Kalimantan, the Makassar Strait, the Maluku Strait, and its surroundings,
which appeared in contrast different from the SCS. Spatially, both EOF-1 and EOF-2 suggested that surface wind and SST in the SCS did not always show an opposite relationship during the rainy season (DJF) in Indonesia.

Furtherly, to understand more about the temporal relationship between meridional wind and SST, we proposed temporal analyses of both EOF-1 and EOF-2. For EOF-1, it appeared that the strengthening of the northerly wind as shown by the positive EOF value occurred after mid-January (Fig. 3-a). On the other hand, Figure 3-b shows cooling SST, which is shown by the positive phase, which occurred earlier, since early-January. This shows that the cooling SST occurred early and after attained an equilibrating condition, the northerly wind starts to increase. The results of the EOF-1 could also be interpreted that the cooling SST was followed by strengthening northerly time lag at about 2 weeks. In contrast, the EOF-2 shows that the strengthening of the northerly wind occurred early and shortly in early December, which is followed by cooling SST that occurred from mid-December to mid-January (Fig. 4). Meanwhile, the northerly wind, which occurred after mid-December appeared did not continuously and did not associate with the CT (Figure 4-b).

Furthermore, because both the meridional wind and SST of EOF-2 do not have a temporal corresponding thus, a temporal annual variation analysis is needed to carry out (Fig. 5). Figure 5-a shows that meridional wind data has high variation and a balanced number of years between the positive and negative EOF scores, as well as the SST (Figure 5-b). The annual variation of the meridional wind and SST EOF scores shows the variation and dynamics of both wind and SST in the MC region which is influenced by various factors.

In this case, meridional wind and SST for both the annual and interannual variations cannot be simplified by ENSO as the predominant factor determining the variation. The resulting spatial and temporal variations of meridional wind and SST in this study indicate that both wind and SST have internal factors that indicate variations in both the time and space scales. Likewise, the correlation between meridional wind and SST in the MC region does not always show a relationship both in space and time.

Figure 1. Spatial analysis of EOF-1 (mode 1) during December-February of 2000-2016 for: a) meridional wind (925 mb), b) sea surface temperature. EOF scores represented by shaded color.

Thus, to understand more about the local CENS, we analyze year by year scores of EOF in a time series diagram and separate the scores values as positive and negative to define the correlation between the CT and the local CENS (Fig. 5). The results show that the CT and CENS occurred in the same years, with the frequency of occurrences at 43.7% in all years during the DJF period (2000-2016). The strongest correlation of the EOF results of the two parameters is also shown by
EOF-2 from the meridional wind data and EOF-2 from the SST data through the EOF score distribution diagram (Fig. 6). A positive correlation also appears in the scatter diagram. It shows the increase of meridional wind shown by the EOF-1 score (northerly wind attenuation) followed by an increase of the EOF-2 score of SST (cooling) in the MC region.

Figure 2. Same as Figure 1, but for EOF-2.

Figure 3. Time series analysis of EOF-1 (mode 1) for: a) meridional wind at 925 mb, b) sea surface temperature. The red dotted line shows the zero value of the score.
Figure 4. Same as Figure 3, but for EOF-2 (mode 2).

Figure 5. Time series analysis of annual variability of mode 2 of EOF scores for: a) meridional wind (925 mb), b) sea surface temperature, both of meridional wind and sea surface temperature are averaged over the Maritime Continent (90-150°E, 20°S-20°N). The red-solid line shows a positive score of EOF which averaged during the DJF period. Conversely, the blue-solid line shows a negative score of EOF which averaged during the DJF period.

Figure 6. Scattering diagram of EOF scores between meridional wind and sea surface temperature in the Maritime Continent (90-150°E, 20°S-20°N).
4. Conclusions
The current study produced a relation between surface meridional wind and SST in the South China Sea to indicate rainy season variation in Indonesia, represented by both spatial and temporal scales of both of the EOF-1 and EOF-2 scores. The CENS signal, which is indicated by a northerly wind, appeared in both of EOF-1 and EOF-2. For EOF-1, the CENS signal was developed by SCS-type of CS pathway, which appeared connected to the Northern Hemisphere and related to the cooling SST (CT) that occurred early at about 2-weeks before. For EOF-2, the CENS signal that appeared was produced locally by the PHP-type of the CS pathway and did not relate to the strong CT that appeared elongated southward to the Java Sea. In addition, it was also found in the interannual variation that both the CENS and CT occurred in the same year, with the frequency of occurrence is 43.7%.

Acknowledgments
This research was supported by the Indonesia Educational Endowment Fund (LPDP) through the Mandatory Productive Innovative Research program under National Research Priority, Decree Number: 252/Menteri Ristek/Ka BRIN/E1/PRN/2020. Erma Yulihastin contributed as the main contributor of this paper, while Tri Wahyu Hadi and Muhammad Ridho Syahputra contributed as the supporting contributor of this paper.

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