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Intraseasonal rainfall variability in North Sumatra and its relationship with Boreal Summer Intraseasonal Oscillation (BSISO)

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Abstract. The Boreal Summer Intraseasonal Oscillation (BSISO) is a mode of climate variability on intraseasonal timescales that dominantly occurs during Northern Hemisphere summer monsoon. Its propagation and activity can be monitored by using indices namely as BSISO1 and BSISO2. The rainfall anomalies and extremes in North Sumatra may be potentially affected by BSISO due to its location within the path of their propagations. This study analyzes the relationship of BSISO with daily rainfall anomalies and extremes during different phases and types of BSISO. The results of spectral analysis show some agreements in the periodicity of BSISO1 and BSISO2 with daily rainfall anomaly. This study also identifies extreme rainfall during different phases of BSISO, showing the increase in the number of extreme rainfall events. High number of extreme rainfall events beyond thresholds at 90th and 95th percentiles are mostly found during phase 1, 2 and 3 of BSISO1 and phase 1 and 2 of BSISO2. Composite analysis conducted separately for spatial standard deviations of daily rainfall anomalies are also performed in this study. Similar results are found, where BSISO influences on rainfall variability especially during phase 1, 2 and 3 of BSISO1, and phase 1 and 2 of BSISO2.

1. Introduction

Recent studies indicated the identification of new intraseasonal phenomena namely as Boreal Summer Intraseasonal Oscillation (BSISO). BSISO is a mode of climate variability resulted from the seaatmosphere interactions with the direction of movement from the Indian Ocean to the Western North Pacific Ocean [1]. The phenomenon has similarities with the Madden Julian Oscillation (MJO), a phenomenon around the equatorial climate characterized by the west to east propagation of convection processes from the Indian Ocean to the Pacific Ocean [2-4]. The main difference between BSISO and MJO is detected from the time of their occurrence; MJO dominates during the boreal winter while BSISO dominates during boreal summer [5]. Other differences were also found in their circulation period, MJO has a periods of 40-50 days [2], while BSISO consists of two types, i.e. BSISO1 that has 30-60 days oscillation periods and BSISO2 that has 10-20 days oscillation periods [1][6][7]. BSISO1 and BSISO2 also traverse differently according to their phases.

BSISO indices were constructed by using Principal Components (PC) of daily anomalies of outgoing longwave radiation (OLR) and zonal wind at 850 hPa (U850) in the region 10°S-40°N, 40°-160°E [1]. BSISO1 index uses the first two PCs, i.e. PC1 and PC2, while BSISO2 index utilizes the next two PCs,

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i.e. PC3 and PC4. Similar with the real time multivariate MJO (RMM) index [3], both BSISO1 and BSISO2 each consisting of eight phases, but with different area of propagations. BSISO1 has the first phase in the equatorial of Indian Ocean, phases 2-3 in the Indian Ocean and East Asia, phases 4-5 in India and maritime continent, phases 6-7 in the Bay of Benggala and the South China Sea, and phase 8 in the Western North Pacific Ocean. While BSISO2 has phase 1 and 2 in the Indian Ocean and the Philippine Sea, the phase 3 in India and South China Sea, phases 4-5 in the Bay of Benggala, phase 6 in Southeast Asia, phase 7 in Northeast Asia, and the phase 8 Western North Pacific Ocean [1].

BSISO phenomenon will affect rainfall variability in their propagation areas during their active phases. This includes the areas in the northern part of Indonesia, such as over North Sumatra province. North Sumatra is a region with the highest percentage of meteorological disaster on the island of Sumatra, accounting for 22% of flood events recorded from 1965 to 2007. The highest peak of rainfall and flood disasters is mostly found in December-January followed by the secondary peak in May [8]. The secondary peak coincides with the active period of BSISO during boreal summer season between May to October. Therefore, the rainfall during this period maybe related with the BSISO propagations. This study is conducted to identify the relation between rainfall variability and extreme rainfall during May-October periods in North Sumatra with the BSISO phenomenon.

2. Data and Methods

This study uses daily rainfall data over North Sumatra and BSISO indices (BSISO1 and BSISO2). The daily rainfall data is extracted from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) version dataset downloaded from the IRI 2.0 [9][10] Data Library (http://iridl.ldeo.columbia.edu/SOURCES/.UCSB/.CHIRPS/.v2p0/.daily/.global/.0p05/.prcp/). This is in addition to the daily rainfall data obtained from the record of several weather stations collected by Badan Meteorologi, Klimatologi, dan Geofisika (BMKG). BSISO indices are also downloaded from the IRI data library (http://iridl.ldeo.columbia.edu/home/mbell/.APCC/.BSISO/).

Several methods, such as spectral analysis, probability analysis and composite analysis, are used in this study. Spectral analysis is conducted to investigate and compare dominant oscillation of BSISO indices and rainfall. Probability analysis is performed to determine the threshold of extreme rainfall and investigate the probability of exceedance beyond the identified thresholds. The period of dataset used for this analysis is from May-October during 2008 to 2010 periods. Composite analysis is used to identify the rainfall characteristics in the region during different BSISO phases. Rainfall data used in the probability analysis and composite analysis is selected only for the periods between May to October during 1991-2010 periods. The criteria of the BSISO indices selected for the analysis is when the value more than 1 in order to focus only during active BSISO phenomenon.

3. Results and Discussions

3.1 Oscillation Periods of BSISO and daily rainfall in North Sumatra

Spectral analysis can be used to identify dominant oscillations of a time series data. We compare Power Spectral Density (PSD) graphs resulted from both BSISO indices (BSISO1 and BSISO2) and rainfall anomalies in the studied region. From this approach we can identify the influence of BSISO on rainfall variability by identifying whether the dominant spectrum found in PSD graph from the rainfall similar to the results found in both BSISO indices. The result of the analysis is shown in figure 1.





Figure 1a shows the PSD result calculated from BSISO1 index, showing several dominant power spectrals within the range of 10 to 70 days cycle with mostly dominant cycle found on 50-60 days oscillation. In figure 1b, there are three dominant power spectral from PSD of BSISO2 index, i.e. within the range of 10-20 days, 20-30 and 30-40 days oscillations. However, the strongest spectral is found in 10-20 days cycle. Both strong spectrals found in BSISO1 with 50-60 days oscillation and in BSISO2 with 10-20 days oscillation are the main distinguished characteristics as described by Lee et al. [1]. The results of PSD graphs in figure 1a and 1b are compared with PSD in figure 1c obtained from the rainfall data in North Sumatra. It is found that the rainfall have several dominant power spectrals that similarly occur within the time cycles where the BSISO are also dominant, especially within 50-60 days and 10-20 days oscilations, although the dominant cycle for 10-20 days between BSISO2 and rainfall did not perfectly match. Similar oscillations found in rainfall data indicate possible strong influence of BSISO phenomenon on intraseasonal rainfall variability in North Sumatra. Nevertheless, BSISO seems not the only phenomenon affecting the intraseasonal rainfall variability in the region since the PSD graph (figure 1c) also show strong spectral in 30-40 days oscillation. This strong 30-40 days cycle maybe related to the MJO phenomenon, which is more dominant in affecting the rainfall variability instead of the cycle within 50-60 days oscillation that is more representing BSISO.

3.2 Rainfall Extremes during active Phases of BSISO

Previous study used BSISO value more than 1.5 as threshold to define active strong BSISO indices [1]. However, as mentioned earlier, this study selects the BSISO index with value more than 1 in order to represent only active BSISO conditions. By referring to the BSISO occurrence with the value beyond this threshold, this study select and classify the rainfall data that occur at the same time with each BSISO phases. This approach is conducted separately for BSISO1 and BSISO2 indices and the results are shown in figure 2. From this figure, we can identify the phase(s) where the occurrence of extreme rainfall are dominant. The extreme rainfall is defined by the value beyond certain thresholds, i.e. at 90th, 95th and 99th percentiles of daily rainfall data based on Gamma distribution. Respectively, the identified extreme rainfall thresholds for the region are 16.91 mm/day for the 90th percentile, 21.62 mm/day for the 95th percentile, and 32.44 mm/day for the 99th percentile.

From the results show in figure 2a and 2b, we calculate the number of rainfall events occured beyond those three thresholds (Table 1). High number of extreme rainfall events beyond thresholds are mostly found during phase 1, 2 and 3 of BSISO1. This is possible since during those three phases the BSISO1 propagations are mainly located in the equatorial of Indian Ocean for phase 1 and in the Indian Ocean and East Asia in phase 2 and 3, which is relatively near to North Sumatra and could affect the increase of frequency and intensity of extreme rainfall in the region. Between those three phases of BSISO1, the highest number of rainfall event for the selected 20 year periods (1991-2010) is found when BSISO1 mainly located in the Indian Ocean during phase 2, with 59 rainfall events exceeding 90th percentile threshold and 17 rainfall events exceeding 95th percentile threshold. In addition, the extreme rainfall events are also found during other phases of BSISO1, but the number of events are not as many as in phase 1, 2 and 3.

During active BSISO2, the number of extreme rainfall events in North Sumatra are mostly high during phase 1 and 2 (Table 1), where the phenomenon is located in the Indian Ocean and the Philippine Sea, respectively. Similar with the result found in BSISO1, the highest number of extreme rainfall during the 20 year periods is also found during phase 2 of BSISO2 with the number of events is 54 for the rainfall exceeding 90th percentile and 16 for the rainfall exceeding 95th percentile. In addition, a number of extreme rainfall events is also found during phase 3 where the event is mainly located in India and South China Sea. The result also found with a relatively high number of event in phase 8, with 31 events of rainfall exceeding 90th percentile and 10 events for rainfall exceeding 95th percentile, but this is maybe considered irrelevant for directly affecting the extreme rainfall in the region since the main location during this phase is mostly in Western North Pacific Ocean. It is important to consider that other climate phenomena, such as MJO could also contribute to the increase in the frequency and intensity of extreme rainfall in North Sumatra.

3.3 BSISO-related Rainfall Variability in North Sumatra

Further analysis is performed in this study by selecting the rainfall data during the active phase of BSISO1 and BSISO2, separately. Instead of calculating the average values from the selected and classified rainfall data, we calculate the standar deviation of those rainfall data within each phase. The standard deviation is a statistical parameter used to determine the distance distribution of the data against the average value. By using this metric, we aim to investigate and compare the deviation of rainfall during different phases of BSISO. From this approach, it is expected that the spatial characteristics of the intraseasonal rainfall variability within North Sumatra influenced by BSISO can be identified.

Figure 3a shows the composite map of standard deviations of rainfall during different active phases of BSISO1. From the figure, it is clearly shown that the areas within North Sumatra dominantly have strong standard deviations during phase 1, 2 and 3. This is consistent with the results of previous analysis related to the number of extreme rainfall occurred during active phase of BSISO1. In figure 3a, the standard deviations are found to be weaker or smaller during other phases of BSISO1 (phase 4-8). Surprisingly, the area within Central Tapanuly Regency adjacent to Sibolga City is identified to have very strong standard deviations compared to the other regions in North Sumatra. This could indicates that BSISO1 event could strongly affect the intraseasonal rainfall variability in this specific region and it may be associated to the extreme rainfall conditions associated with climate-related disasters such as floods and landslides ever recorded in the region. For example, a flood event was recorded in Sibolga City on Wednesday, August 19, 2009 [11]. The flood consisting mud occurred due to heavy rainfall causing landslide and damaging hundreds of houses. Based on our analysis on the BSISO index during the day of the flood event, the BSISO1 index is located on phase 2 with the value of the index is 2.87. This value is far beyond 1 as the threshold of active BSISO or 1.5 as the threshold for strong BSISO index. In other word, the BSISO1 index during the flood event is very strong.



Figure 2. Daily rainfall in North Sumatra during active phase of a) BSISO1 and b) BSISO2. The thresholds used are of 90th percentile (pink line), 95th percentile (green line) and 99th percentile (orange line).

Threshold	BSISO1 Phase							
beyond	1	2	3	4	5	6	7	8
90 th Percentile	33	59	34	13	14	13	25	17
95 th Percentile	11	17	9	2	3	3	8	5
99 th Percentile	0	0	2	0	0	0	0	0
Threshold beyond	BSISO2 Phase							
	1	2	3	4	5	6	7	8
90 th Percentile	40	54	28	19	25	7	16	31
95 th Percentile	13	16	6	5	7	1	5	10
99 th Percentile	0	1	0	0	1	0	0	0

Table 1. The number of extreme rainfall events that exceed the defined thresholds

The composite maps of standard deviation of rainfall during active phase of BSISO2 are shown in figure 3b. Similar to the previous results, the BSISO2 is identified to have strong influence on rainfall

variability in North Sumatra especially during phase 1 and 2. This is shown by the composite maps of standard deviations that show strong value during those phases 1 and 2 of BSISO2.



In general, from figure 3a and 3b, the influence of active phases of BSISO (BSISO1 and BSISO2) on rainfall variability is not similar across different region in North Sumatra. The strongest sign of BSISO influence is mostly found on the area adjacent to Sibolga City and then followed by the areas near the coastal areas surrounding the central areas within North Sumatra. The central areas mostly show weaker standard deviations, indicating less influence of BSISO.

4. Conclusions

This study identifies that the intraseasonal rainfall variability and extreme rainfall events in North Sumatra during May-October are strongly affected by BSISO phenomenon. These are shown by the results of spectral analysis comparing PSD graphs between BSISO indices and rainfall anomalies during 2008-2010 periods, the analysis of extreme rainfall during active phases of BSISO1 and BSISO2, and the composite maps of standard deviations of rainfall during active phases of BSISO 1 and BSISO2 taken from the 20 year datasets during 1991-2010 periods. The study found that the extreme rainfall could increased during both BSISO1 and BSISO2. High number of extreme rainfall events beyond thresholds at 90th and 95th percentiles are mostly found during phase 1, 2 and 3 of BSISO1 and phase 1 and 2 of BSISO2. Similar results are found from composite analysis of spatial standard deviations of daily rainfall anomalies, where BSISO influences rainfall variability in North Sumatra especially during the same phase 1, 2 and 3 of BSISO1, and phase 1 and 2 of BSISO2.

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