Analysis of Multi-Scale Hydrometeorological Triggering Flash Flood Event of the 13 July 2020 in North Luwu, South Sulawesi

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Abstract. During 12-13 July 2020, heavy rainfall had caused Masamba, Rongkong, and Rada rivers to overflow, causing flash floods in the North Luwu regency. This event resulted in many casualties; at least 38 people died and displaced thousands of people. This study presents an analysis of the multi-scale hydrometeorological settings that led to the development of these intense storms in the North Luwu flood. Boreal Summer Intraseasonal Oscillation (BSISO) Normalized PC2 has entered phases 4 and 5 on 7-13 July 2020, associated with cloud growth in the Indonesian Maritime Continent. Besides, the sub-seasonal tropical disturbance of Kelvin Waves is convectively active in the Sulawesi region on 7-13 July, increasing the intensity of rainfall at the location. Sea Surface Temperatures (SSTs) were in warmer conditions in the Bonne Bay region south of North Luwu, supplying more water vapor into the atmosphere. The easterly wind (Australian monsoon) enhanced the diurnal cycle of the water vapor mass movement from Bonne Bay to the highlands of North Luwu. From the observation of GPM satellite imagery, the accumulation of spatial rainfall on July 12 and 13 was concentrated in the eastern region of Sulawesi, which reached >150 mm/day and >50 mm/day in North Luwu.

1. Introduction
In recent decades, the frequency of flood events has increased, and a warming climate exacerbates the potential damage and effects on human life [1]. In addition to the impacts of climate change, population growth, deforestation, and significant land-use changes have resulted in the shrinking of water catchment areas, making several countries currently highly vulnerable to flooding. [2-3]. This condition also occurs in the Indonesian Maritime Continent (IMC), which has a unique atmospheric dynamic and geographic conditions [4]. In 2020, flash floods and landslides significantly impacted, killing 38 people, losing 10 people, and displacing thousands of people in North Luwu, South Sulawesi, from the National Agency for Disaster Countermeasure (BNPB) report. Based on data from Andi Jemma Meteorological Station in Masamba on 12 July 2020, heavy rain occurred for about 10 hours from night to morning on 13 July 2020.
Furthermore, the rain again occurred almost 8 hours during the day to night which caused flash floods that occurred at night on 13 July 2020. Landslides followed Flash floods upstream of the Masamba, Rongkong, and Rada rivers. Similar conditions also occurred in the South Sulawesi floods in January 2019, where the atmosphere condition's complexity triggered a flood in the Jeneberang river basin [5].

Precipitation in the IMC region is affected by multi-scale variability, which causes disasters in the IMC region, such as severe storms, floods and droughts. [6-7]. Global and regional scale climatic variability are influenced by different timescale atmospheric circulation, including inter-annual, seasonal, intraseasonal, and shorter periods [4]. Also, IMC's topography and geographic location encourage local-scale atmospheric convective systems [8-10]. In the inter-annual period, presentation is modified by climatic modes such as the Indian Ocean Dipole (IOD) [11-12] and the El Nino Southern Oscillation (ENSO) [12], as well as in seasonal periods influenced by monsoon flow [13]. In the intraseasonal period, oscillations such as BSISO [14], Madden Julian Oscillation (MJO) [15-16], and equatorial waves play a role in controlling the dynamics of the atmosphere [17-18]. Based on this condition, this study aims to link the heavy rainfall in the North Luwu area, South Sulawesi, on 13 July 2020, with flooding and its meteorological causes.

2. Data and Method

Several datasets were used to analyze flood cases in North Luwu (Figure 1). Data on the NINO 3.4 Index and Indian Ocean Dipole (IOD) were obtained from the Australian Bureau of Meteorology (BOM: http://www.bom.gov.au/climate). The Outgoing Longwave Radiation (OLR) anomaly data used to analyze the MJO, and Equatorial Waves comes from the North Caroline Institute for Climate Studies (NCICS: https://ncics.org/pub/mjo/archive/). In addition to the equatorial wave data, Kelvin waves were obtained from models developed by the Australian Bureau of Meteorology (BOM: http://poama.bom.gov.au/project/maproom/OLR_modes/f.1.kelvin.html). The Sea Surface Temperature Anomaly (SPL) map was obtained from the Meteorology, Climatology and Geophysics Agency (BMKG). Wind gradient data were obtained from the Japan Meteorological Agency. Daily rainfall and climatological data for the North Luwu region were obtained from the BMKG rain gauge collected by the Andi Jemma Meteorological Station in Masamba. As a complement, spatial rainfall data was obtained from the Global Satellite Mapping of Precipitation (GSMaP) data processing with 0.1° resolution from JAXA.
The analysis is carried out by understanding the physical and dynamic processes of the atmosphere from various time scales. This analysis aims to determine the disturbance that drives the growth of convective clouds that caused heavy rains on 12 and 13 July 2020 in North Luwu. The first step is to analyze the accumulation of rainfall temporally and spatially to determine rainfall conditions during a flood. Furthermore, multiscale analysis was carried out by classifying weather and climate variability from large scale to local scale with different time scales (annual, seasonal, intra-seasonal, and daily). After the analysis was carried out, it was concluded that the factors affecting the dynamics and physical processes of the atmosphere were analyzed.

3. Result and Discussion

3.1. Precipitation Analysis

On 12-13 July 2020, heavy rainfall in North Luwu Regency caused landslide and flooding affecting almost all areas. The heavy intensity and extended rainfall period occurred in North Luwu, especially upstream of the Masamba, Rongkong, and Rada rivers. The heavy rainfall started on 12 July 2020 with accumulated rainfall of 56 mm/day and continued 34.2 mm/day on 13 July 2020 (Figure 2 (left)). Also, slight-moderate rainfall occurred in the first four days in July 2020, and slight rainfall frequently happened until 12 July 2020. Based on the bar chart on the right of figure 2, it can be discussed that the flooding in North Luwu was caused by the accumulation of rainfall that occurred for 15 consecutive days in early July with 205 mm.

The accumulated rainfall of 15 consecutive days in July 2020 (205 mm) has exceeded the monthly accumulated rainfall for July (~180 mm) in the last 5 years. Only the accumulated rainfall of July in 2017 was more significant than the accumulation in the half-month of July 2020. In general, the reasonably high rainfall conditions that hit North Luwu in early July 2020 impacted groundwater and rivers' capacity. The North Luwu region's condition, which has many slopes and rivers, makes the area prone to landslides and floods. This land or rivers that usually collect rainfall in a month suddenly receive rainfall in a much shorter time, resulting in the soil surface's inability to absorb rainfall anymore.

Spatial analysis for rainfall in flood events was carried out by utilizing data from satellite observations. The product used in this research is global rainfall data based on GSMaP satellite with high resolution and precision [19]. The day before the flood, precisely on 12 July 2020, rainfall occurred evenly throughout the North Luwu region (see Figure 3). Rain with higher intensity occurs in the south, directly adjacent to the Bone Bay area, where the maximum rainfall is observed to range from 57 - 69 mm/day. High rainfall also occurs in Tolo Bay (east of Sulawesi Island) and Bone Bay (south of Sulawesi Island). On the day of the flood, the intensity of rain in North Luwu was lower than the previous day, ranging from 34 - 52 mm/day.
3.2. Interannual and Seasonal precipitation variability

In general, understanding the possible causes of flood disasters by hydrometeorology must be discussed comprehensively. Inter-annual and seasonal variability is a significant factor that should be investigated, especially the El Niño Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), and Monsoon for the IMC region [20]. IOD is a large-scale and inter-annual phenomenon caused by an anomaly in sea surface temperature differences in the Indian Ocean [21-22]. When IOD is negative, the rainfall intensity in Indonesia is relatively higher [23]. Figure 4 shows the IOD index value of 0.07 (positive), which does not support high rainfall intensity at IMC at the time of the flood event. ENSO is a phenomenon similar to IOD but in the equatorial region of the Pacific Ocean. El Nino will cause a decrease in rainfall or drought, while La Nina will increase rainfall [24]. ENSO can be identified using the NINO 3.4 index, where the intensity of rainfall in Indonesia is relatively higher if the NINO 3.4 index shows a positive value. At the time of the flood in North Luwu, the NINO 3.4 index showed a positive value (+0.19), so that it did not support the increase in rainfall intensity in the IMC area (Figure 4).
The monsoons that affect rainfall over the Sulawesi area are the Western Pacific Monsoon and the Australian Monsoon. This circulation is a seasonal and regional scale phenomenon. In general, the Western Pacific monsoon circulation in the October-April period causes the rainy season, and the Australian monsoon in the May-September period causes the dry season. Although fluctuating, the

Figure 4. IOD index (above) and NINO 3.4 Index(under) from the Bureau of Meteorology.

Figure 5. Western Pacific Monsoon Index (left) and Australian Monsoon Index (right) from Japan Meteorology Agency (JMA).
Western pacific monsoon's value tends to increase from June to July 2020 compared to January (Figure 5). Meanwhile, the Australian monsoon has decreased in July compared to the previous months. The Australian monsoon and western pacific monsoon index did not significantly affect increased rainfall in North Luwu because the indices are still below the climatological average.

3.3. Intraseasonal precipitation variability

Intraseasonal Tropical Oscillation is a phenomenon of the ocean and atmosphere interactions with a periodicity of 20 to 100 days [25]. This oscillation has 8 phases of movement from the Indian Ocean to the east or north [14]. The intraseasonal tropical oscillations intensify in 2 modes, namely during the summer and winter in the northern hemisphere [25-26]. The first mode that is active during winter in the northern hemisphere or when the Asian monsoon occurs in Indonesia (November-April) is the Madden-Julian Oscillation (MJO) which has a periodicity of 40 - 50 days [27], which starts from the Indian Ocean moving eastward towards the Pacific Ocean [28]. The second mode that is active during summer in the northern hemisphere or when the Australian monsoon occurs (May-October) is the Boreal Summer Intraseasonal Oscillation (BSISO) which has a periodicity of 10 - 60 days which has movements from the Indian Ocean moving to the east or northeast [29].

The BSISO phenomenon has a higher complexity than MJO; this is because BSISO is influenced by the propagation of northward wind to the Indian Ocean and the west pacific monsoon region [30]; the Intertropical Convergence Zone (ITCZ) is moving northward. BSISO is a critical factor in the variability of rainfall in the Asian summer monsoon region [31]. BSISO is divided into two modes based on the primary component analysis of outgoing longwave radiation daily anomaly data. The first mode has a periodicity of 30-60 days and is known as BSISO 1. Another mode has a periodicity of 10-30 days and is known as BSISO 2. The BSISO phenomenon began in the Indian Ocean region close to Sumatra, which moved north and northwest. There is 2 type of BSISO movement patterns, BSISO 1 moves from the Indian Ocean to South Asia and Southeast Asia then moves to East Asia. BSISO 2 moves from the Indian Ocean and Southeast Asia then move northwest until it reaches East Asia [32]. The BSISO phenomenon affects rainfall variability in southern China, including in Indonesia [31]. Like MJO, BSISO grows in the Indian Ocean adjacent to Sumatra Island, so that BSISO has a strong influence on rainfall in Sumatra. Previous studies indicated an increase in the amount of extreme rain in North Sumatra during BSISO 1 phase 1 - 3 and BSISO 2 phase 1 - 2 [33].

During 7 - 13 July 2020, BSISO 1 was on phase 3-4 with amplitude less than 1 (weak BSISO1). Though BSISO had a weak amplitude, the convective region was over the Indonesian Maritime Continent (IMC) and East Asia (see figure 6). BSISO2 was on phase 7-8 with amplitude less than 1 (weak BSISO2), indicating the convective clouds grew over North-East Asia and the Western North Pacific. The reconstructed OLR anomaly based on the BSISO indices showed that the impact of BSISO1 is more dominant than BSISO2, and the negative OLR anomalies were observed along with the IMC from the southern part of Sumatra to the northern part of Papua and crossed the study area in North Luwu, South Sulawesi Province. This condition caused the increasing chance of convective rainfall over the center and South Sulawesi and contributed to the flood event in North Luwu on 13-14 July 2020 (Figure 7).
Figure 6. BSISO 1 (left) and BSISO 2 (right) from APEC Climate Center.

Figure 7. Reconstructed OLR anomaly based on the BSISO indices for 7 July 2020 (a), 9 July 2020 (b), 11 July 2020 (c), and 13 July 2020 (d) from APEC Climate Center.

In addition, the Equatorial Convectively Coupled Kelvin Wave (CCKW) is active in the Sulawesi region on 11 - 13 July 2020, increasing the chance of convective precipitation in the region. The MJO is inactive above the IMC (the black circle in Figure 8, see longitude 120 E). When the MJO is inactive or weak, South Sulawesi usually experiences negative rainfall anomalies, so the MJO is not part of the trigger for this extreme event. The Equatorial Rossby Wave was also not detected in South Sulawesi (circled in red in Figure 8, see longitude 120 E), so it did not contribute to the heavy rains in Masamba. However, an active CCKW moves eastward through South Sulawesi on 11-13 July 2020 (blue circled in Figure 8) with a shorter period. CCKW is also seen as a negative OLR anomaly over the study region in real-time Kelvin wave OLR (Figure 9). Although this Kelvin wave has a relatively
short period of about a few days in South Sulawesi, it can increase convection and produce MCS. Therefore, Kelvin waves contributed to the high rainfall in South Sulawesi during this period.

Figure 8. Hovmöllers diagrams of OLR anomalies for monitoring the tropical waves (MJO, ER, and Kelvin) in latitudinal averaging of 5S-5N (with black box is the location of North Luwu regency) from North Caroline Institute for Climate Studies (NCICS)

Figure 9. Monitoring (for 11-13 July 2020) and forecast (for 14-15 July 2020) of Kelvin wave from Bureau of Meteorology (BOM).

3.4. Diurnal Modulation
The diurnal modulation effect was obtained from sea surface temperature anomaly (Figure 10.) and gradient wind analysis. Sea Surface Temperature (SST) anomaly has a high value in the Maluku area east of Sulawesi. When flooding, the value of the SST anomaly is in the range of 1 degree Celsius. This condition can trigger heavy rains in the North Luwu area. SST anomaly is reinforced by the wind that blows from the east at 8 knots. Figure 11. shows a gradient wind over a 3000 feet layer. There are two eddies of wind around the northwest of Kalimantan and Maluku, so that this can affect cloud
growth in the Sulawesi area and its surroundings. The air masses entering North Luwu originate from the southeast direction, which has an anomaly of high SST reaching 1 degrees Celsius in Bone bay. Wind circulation and positive SST anomalies in Bone bay cause convective diurnal cloud growth in the southern part of the North Luwu region.

4. Conclusion

Heavy rain on July 12, 2020 and followed on July 13, 2020 was not classified as extreme. However, the 15 days accumulated from early July were above the accumulated average for July. From the results of multi-scale analysis, inter-annual variability and seasonal weather do not directly affect rainfall intensity such as IOD, ENSO, and MJO. However, BSISO 1, which is in phases 4-5, and the Kelvin Wave in the IMC region on 7 - 13 July 2020, impact the growth of convective clouds. In addition, the positive SST anomaly in Bone Bay, which is supported by wind moving from the southeast, adds to the supply of water vapour for diurnal modulation in North Luwu.

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