The land-sea breeze effect on the diurnal cycle of convective activities in Eastern Coast of North Sumatra

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Abstract. The location of Eastern Coast of North Sumatera directly adjacent to the Malacca Strait indicates that there is the land-sea breeze circulation occurred. The land-sea breeze circulation affects the atmospheric dynamics. This study aims to simulate the land-sea breeze circulation and then analyze how it affects the diurnal cycle of convective activity. The convective activity was identified using the convective index, moisture transport, and rainfall distribution. ECMWF data processed to determine the land-sea breeze day based on Six Filtering Method and then simulate it. The Himawari-8 satellite data used to calculate the convective index to show the spatial distribution of convective area. The specific humidity and wind of each pressure level from FNL data used to calculate the moisture transport. The GSMaP rainfall data used to plot the diurnal rainfall distribution spatially and temporally. Based on the analysis of penetration and diurnal wind direction known that the sea breeze on the Eastern Coast of North Sumatera is the Northeast wind. The land-sea breeze circulation causes the formation of a convergence area with a high convective index value. The circulation of land-sea breeze caused the migration of day-night rainy areas which shown by patterns of the diurnal moisture transport and diurnal.

1. Introduction

Land-sea breeze is a mesoscale atmospheric circulation caused by a significant difference in temperature gradients between air on the surface of land and oceans [5]. The intensity and formation of Land-sea breeze depend on seasonal factors, latitude, and sun during the day [13]. Land-sea breeze circulation is related to weather dynamics in coastal areas, including the convective activity cycle and diurnal rainfall patterns [5,11]. Weather conditions that occur in coastal areas also have differences with those occurring in the oceans and mountains [16]. One indicator of these differences is the difference in characteristics of diurnal rainfall.

The sea breeze is the flow of wind that moves from the sea towards the land and generally occurs during the day while the land wind is a flow of wind that moves from the land towards the sea that occurs at night [9]. In general, diurnal rain in the land area is generally rain that occurs in mid to late afternoon [16]. While the characteristics of diurnal rain in the ocean region are rained in the late evening - early morning (Imaoka and Spencer, 2000).

Various topographic conditions make a diurnal variation and local circulation an important element that must be considered in conducting weather analysis and forecasts in the Indonesian Maritime Continent (IMC) [13]. Analysis of the diurnal mechanism of rain on the island of Sumatra has been carried out by Mori et al. [7] which shows the formation of migration patterns of peak rainfall from the oceans to the mainland and from the land to the oceans associated with land-sea wind circulation. Therefore, the location of the Eastern Coast of North Sumatra which is directly adjacent to the Malacca Strait indicates an interaction between the atmosphere on the land of the Eastern Coast of North Sumatra and the atmosphere in the Malacca Strait waters represented by the occurrence of land-sea wind circulation on the Eastern Coast of Medan [1].

This study aims to simulate land-sea wind circulation and then analyze how it affects the diurnal convective activity cycle. The diurnal cycle of convective activity in an area can be identified using several indicators, namely the diurnal cycle of convective, moisture transport, and rainfall [12]. The location of research related to the circulation of land-sea breeze varies greatly that can form on the shoreline which has more significant air temperature gradients on land and sea surfaces than synoptic pressure gradients [16].

Identification of land-sea breeze circulation can also be done using a model in addition to using observation data [4,10] The method that can be used to determine rainfall caused by land-sea breeze is the Six Filter Method [3]. The availability of meteorological data, topographic conditions and climate patterns in the study area are some of the factors that determine the accuracy of the identification of land-sea breeze circulation [2].

2. Method

North Sumatra is one of the provinces in the Sumatra region located at coordinates 1^0 - 4^0 N and 98^0 - 100^0 E [17]. The study was conducted on 1st January 2016 – 31st December 2017 which meant that the information generated from this study could describe the latest weather conditions in the Eastern Coast region of North Sumatra.

Data of the European Center for Medium-Range Weather Forecasts (ECMWF) reanalysis model used are 700 mb of layer wind data and moisture transport with a grid resolution of 0.125° (± 13.875 km). FNL reanalysis data from the NCEP Global Data Assimilation System (GDAS) with a grid resolution of 0.25° (± 27.75 km) and a 6-hour time interval are used as input data on the Weather Research and Forecasting (WRF) model. Himawari-8 satellite data channel IR1 with a wavelength of 10.4 μm and 2 km spatial resolution are used to calculate convective index values. GSMaP rainfall estimation data used in this study is GSMaP-Near Real Time (NRT) data with a grid resolution of 0.1° (± 11.1 km). As well as the meteorological observation data used in this study are observational data from meteorological observation stations located on the Eastern Coast of North Sumatera, namely Kualanamu (KNO), Belawan (BLW), and Deli Serdang (SPL) (Table 1).

Table 1. The coordinates of the meteorological observation station used in the study [18]

Meteorological Observation Station	WMO Number	Latitude	Longitude	Elevation
SPL	96031	3,621630°	98,714938°	25 MDPL
BLW	96033	3,788168°	98,714808°	3 MDPL
KNO	96035	3,6403°	98,8786°	23 MDPL

In this study, identification of rainy days caused by land-sea breeze was first done using Six Filter Method from Borne et al. [3] research with 700 mb layer wind data used as input data. After getting the rain events caused by the land-sea breeze circulation, a case study was carried out by choosing a day of land-sea breeze event in the North Sumatera region. Case study simulations were carried out using FNL data to be downscaled to 9 km, 3 km, and 1 km spatial resolution at one-hour intervals.

Land-sea breeze circulation was analyzed by studying moisture transport distribution as in the study of Xiaoxia et al. [15]. The results of Wu et al. [14] showed that moisture transport plays an important role in convective cloud formation activity in an area, which is called convective activity. The onset of sea-breeze is characterized by temperature drops and rising surface air humidity [9]. Analysis of the cloud peak temperature value (TB) from the Himawari-8 satellite is used to calculate the convective index value (CI). The temperature limit value of 230 K cloud peak is used in the convective index value calculation equation [8].

3. Result and discussion

Identification of the land-sea breeze day was carried out by applying the Six Filter Method which was carried out during 2016 – 2017. The first 3 filters that used 700 mb wind analysis data obtained 59% of the total filtered days. The next filter is done by considering the occurrence of heavy rain > 50 mm/day so that it gets 7% of the total days during 2016 – 2017. In this study, the sea-breeze simulations were conducted without being influenced by global and regional weather conditions related to weather dynamics in the Eastern Coast of North Sumatra. The simulation was carried out on the occurrence of land-sea breeze on 1st October 2017.

3.1. Case study 1st October 2017

3.1.1. Global-scale weather analysis

On 1st October 2017MJO was categorized as inactive and in phase six (Figure 1). The condition of the inactive MJO is indicated to have no effect on increasing rainfall in the Indonesian region. IOD values in June 2017 were +0.05 (Figure 2), which means that in May 2016 IOD did not occur, or in other words neutral IODs. The SOI index value in June 2017 was +8 (Figure 3) which means that it tends to be active in La Nina.

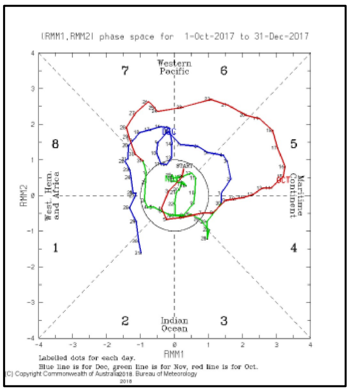

Figure 1. Diagram MJO phase period 1st October – 31st December 2017 [19]

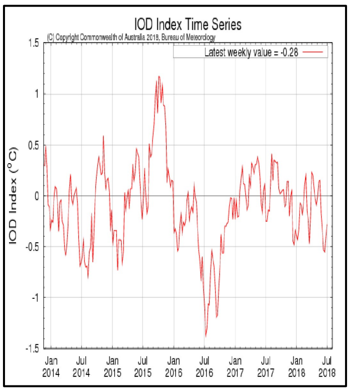

Figure 2. Graph of IOD value for the period January 2014 - July 2018 [19]

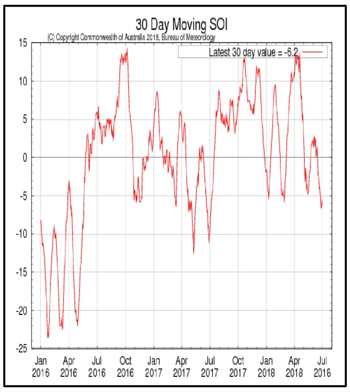

Figure 3. Graph of SOI value for the period January 2014 - July 2018 [19]

3.1.2. Regional-scale weather analysis

Gradient wind analysis on 1st October 2017 has shown a dominant pattern of wind movement moving from the direction of BBS towards BBU (Figure 4). Gradient wind patterns in the North Eastern Coast region at 00.00 UTC and 12:00 UTC are dominantly moving from the West-Southwest direction. There was a disturbance in the form of Eddy Circulation of the Indian Ocean in the western part of Sumatra.

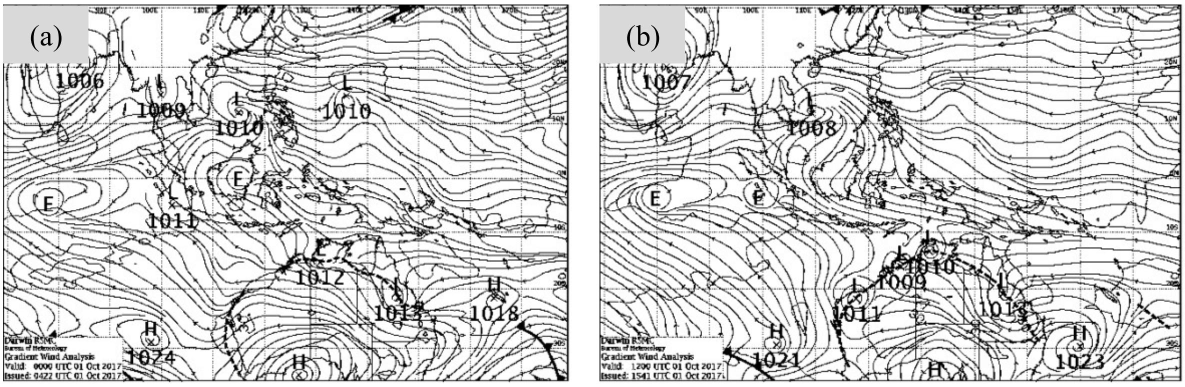

Figure 4. Gradient wind on 1st October 2017; (a) 00.00 UTC and (b) 12.00 UTC [19]

3.1.3. Surface air temperature and humidity analysis

The analysis of the decrease in temperature value and the increase in air humidity value based on observational data (Figure 5) has shown that the onset of sea wind on the Eastern Coast of North Sumatra on 1st October 2017 is more varied, occurring in the range between 11.00-14.00 LT.

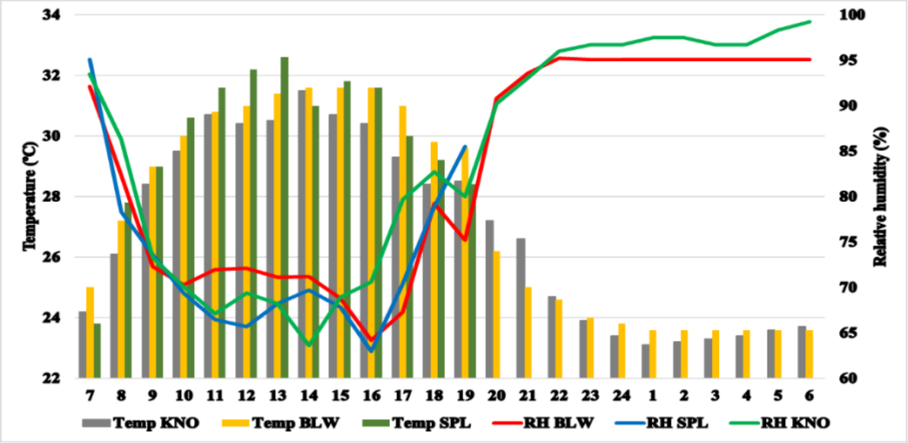

Figure 5. Time series of surface air temperature and humidity on 1st October 2017

Based on observations at Belawan, at 14.00 – 15.00 LT did not decrease surface air temperature and accompanied by an increase in surface air humidity at around 2.4%. For Kualanamu, at 11.00 - 12.00 LT measured a decrease in surface air temperature of -0.3℃, which accompanied by a rise in surface air humidity of 2.3%. Whereas in Deli Serdang, the decrease in surface air temperature and humidity occurred at 13.00 – 14.00 LT. with the sequential values of -1.6 °C and 1.5% respectively. Compared to the difference in the change in temperature and humidity of the surface air, then the onset of sea wind intrusion on 1st October 2017 is more clearly seen in Deli Serdang but first occurs in Kualanamu.

Meanwhile, based on the time series the surface air temperature and humidity values of WRF output data are seen below the time of onset of sea wind intrusion in Kualanamu experiencing an hour of slowdown compared to the observation data, while for Belawan experienced a four-hour acceleration. Based on WRF output data, at 10.00 - 11.00 LT indicated as the onset of sea wind intrusion in Belawan. This indicated by an increase in surface air temperature of around 0.7 °C and accompanied by an increase in air humidity of 6.9%. The time of onset of sea wind intrusion at Kualanamu and Deli Serdang identified at 12.00 - 13.00 LT. For Kualanamu, there was a decrease in surface air temperature of -0.1 ℃ and an increase in air humidity of 0.8%, while for Deli Serdang there was a decrease in air temperature of -0.1 ℃ which was accompanied by an increase in air humidity of 1.7%.

3.1.4. Surface wind analysis

Surface wind analysis has shown a clear difference between the period of the sea and land breeze events on the Eastern Coast of North Sumatra on 1st October 2017 (Figure 6). At 10.00 LT, there was sea wind that moved to the mainland coast of the southern part of the Eastern Coast of North Sumatra from the Southwest direction at a speed of 5-8 kt. At 14.00 LT, the sea wind pattern that was happening is getting clearer and intrusion into the coastline. At 18.00 LT, there was land wind moving from the Southwest direction with a speed of 6-17 kt on the northern part of the North Coast of North Sumatra. In the next hour, this land wind intrusion has seen to have increased speed but does not last long.

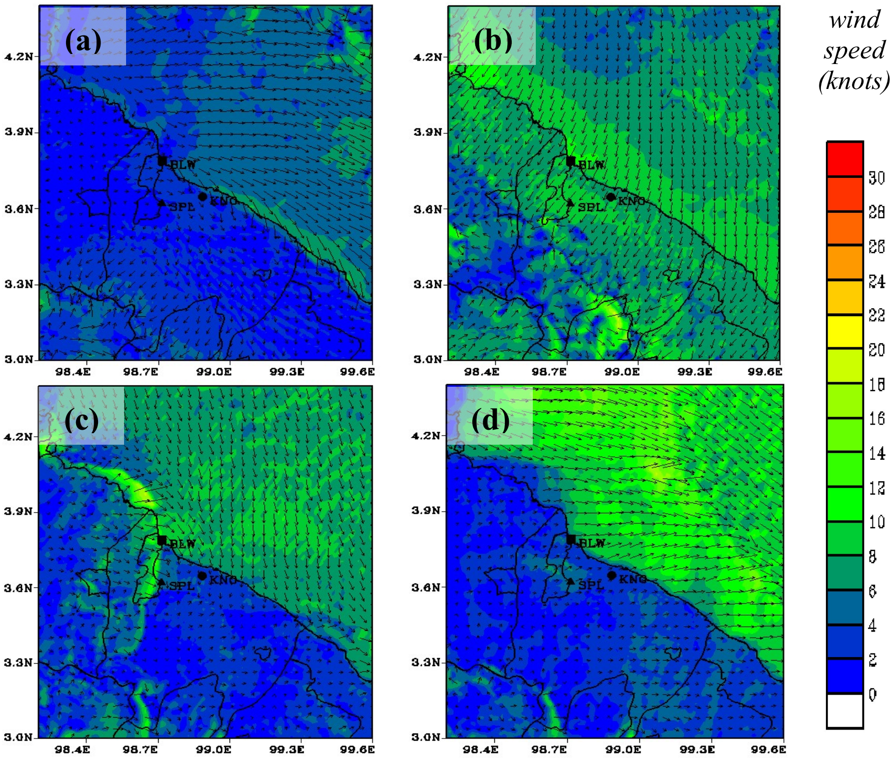

Figure 6. Surface wind on 1st October 2017; (a) 10.00 LT, (b) 14.00 LT, (c) 18.00 LT, and (d) 22.00 LT

3.1.5. Moisture transport analysis

Analysis of moisture transport on 1st October 2017 showed the mass of steam in the Malacca Strait (Figure 7). This mass of steam happened until 10.00 LT. At 12.00 LT, it saw that there was a mass of water vapor entering the mainland of Sumatra Island from the coastline of the East and West Sumatra. At 14.00 LT, there was an increase in the concentration of water vapor around the Bukit Barisan Mountains. At 18.00 LT, the mass of water vapor collected around the Bukit Barisan Mountains began to decrease and shift towards the North Sumatra Coast. The movement of this vapor mass indicated by the influence of the synoptic wind moving from the southwest direction. At 22.00 LT, there was a mass of water vapor moving from the southern part of the Eastern Coast of North Sumatra to offshore. In the following hours, this airspace saw moving towards the North-East Sea and intruding into the mainland of the Malay Peninsula.

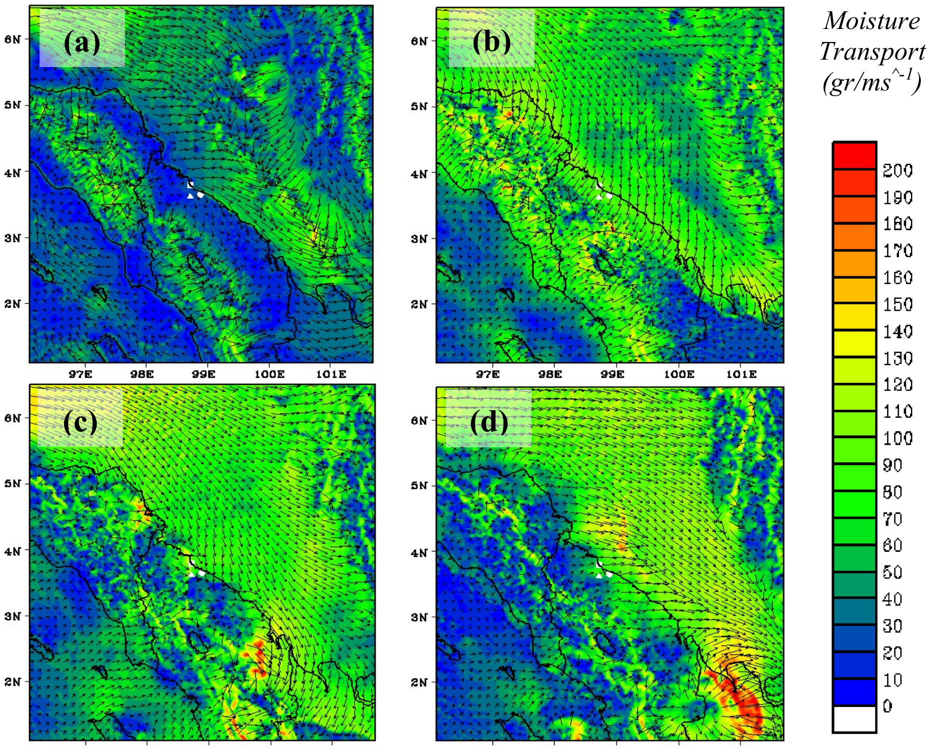

Figure 7. Moisture transport on 1st October 2017; (a) 10.00 LT, (b) 14.00 LT, (c) 18.00 LT, and (d) 22.00 LT

3.1.6. Convective analysis

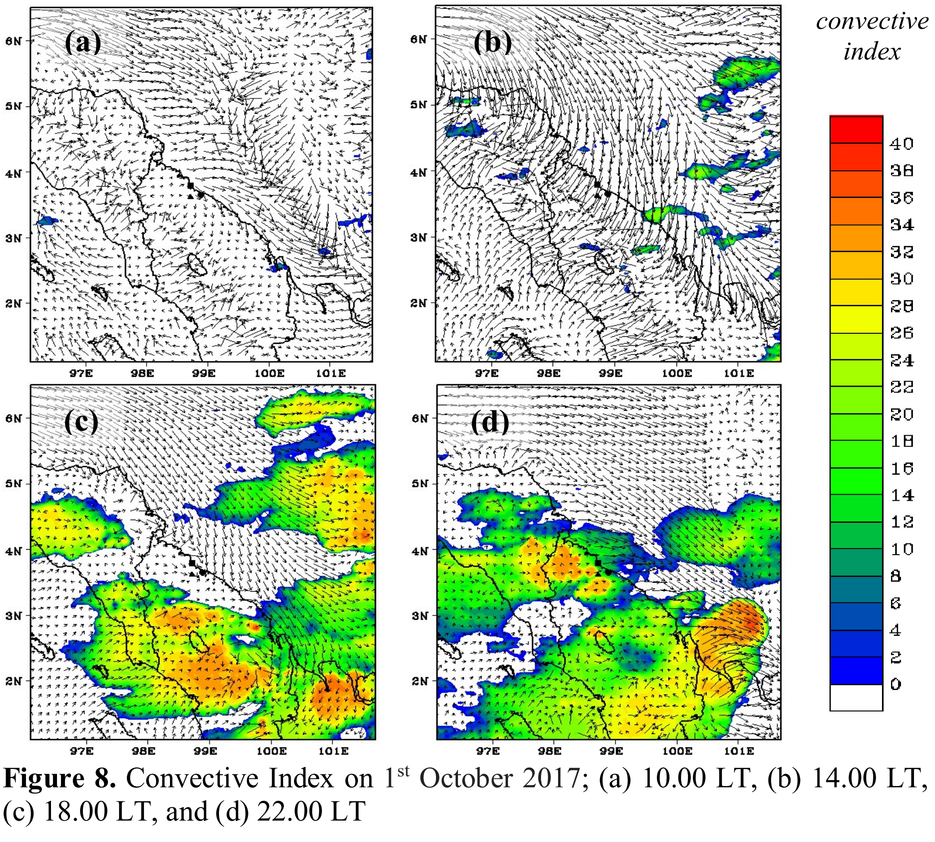

Figure 8. Convective Index on 1st October 2017; (a) 10.00 LT, (b) 14.00 LT, (c) 18.00 LT, and (d) 22.00 LT

Figure 8 is an analysis of the horizontal distribution of convective index on 1st October 2017 in the study area. Convective indices have shown that convective intensity at night is higher than in the early morning hours. The convective area began to form at 14.00 LT, which was around the Bukit Barisan Mountains. At 18.00 LT, it saw that convective is increasingly intense in the mainland region of Sumatra. At 22.00 LT, there was a convective area moving closer to the location of the three observation stations and reached the maximum convective at 01.00 LT. This convective area apparently to continue to move towards the southwest-west towards the Malay Peninsula. This convective area movement indicated due to the synoptic wind moving from the southwest direction.

3.1.7. Rainfall analysis

The following is an analysis of the horizontal distribution of heavy rainfall (rainfall ≥ 10 mm / hour) on 1st October 2017 in the study area (Figure 9).

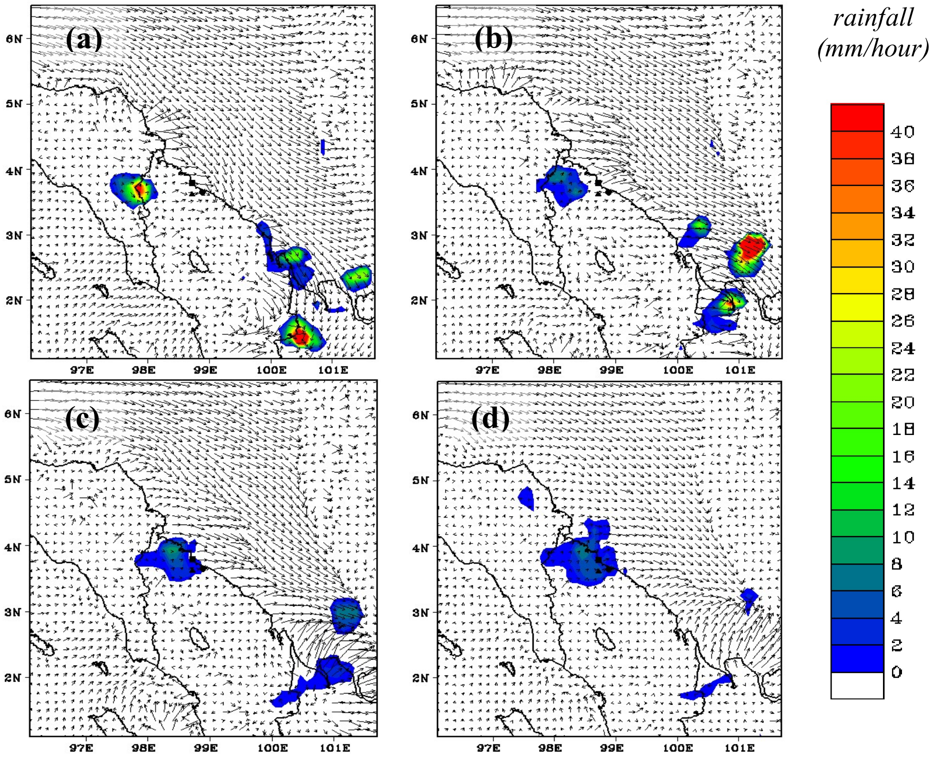

Figure 9. Heavy rainfall on 1st October 2017; (a) 19.00 LT, (b) 21.00 LT, (c) 23.00 LT, and (d) 01.00 LT

Table 2. Time series of rainfall on 1st October 2017 based on observation in KNO, BLW, dan SPL

Observation time (UTC)	Rainfall (mm/3-hours)		
	KNO	BLW	SPL
00.00 – 03.00	0	0	0
03.00 – 06.00	0	0	0
06.00 – 09.00	0	0	0
09.00 – 12.00	0	0	0
12.00 – 15.00	31.5	9.5	-
15.00 – 18.00	66.1	40.5	-

18.00 – 21.00	5.2	9.0	-
21.00 – 24.00	5.2	1.0	-
Accumulated	**108.0**	**60.0**	**47.2**

Spatial map of rainfall on 1st October 2017 shows that dominant rainfall occurs in the early evening. Rainy areas in Sumatra begin to form at 07.00 LT, which was about 2 hours after the maximum time of convective (Figure 9). This shows that under strong local influences, rain occurs around 2-3 hours after the maximum convective time. At 10.00 LT, there was rainfall area that occurred near the three observation stations. This rainy area appears to occur until 02.00 LT. Observation data shows that maximum rainfall occurs in Kualanamu at 3:00 p.m. - 6:00 p.m. (Table 2). Diurnal rainfall also shows that the total rainfall in the early evening hours is greater than in the early morning hours. This shows that local factors are very influential in the formation of diurnal rain on 1st October 2017.

4. Conclusion

In general, the onset of sea breeze on the Eastern Coast of North Sumatra occurs at 10.00 - 12.00 LT and can last until 18.00 – 20.00 LT. The prevailing sea breeze on the Eastern Coast of North Sumatra is the wind from the northeast. Sea breeze intrusion on the North Coast of North Sumatra is characterized by a decrease in temperature, rising humidity, and negative values of surface wind zonal components. Maximum diurnal rainfall in the Eastern Coast region of North Sumatra generally occurs in the early evening. The intrusion of sea breeze from the Malacca Strait and from the Indian Ocean in the western part of Sumatra carries a mass of water vapor collected in the Bukit Barisan Mountains. Strong land breeze can carry masses of water vapor collected in the Bukit Barisan region towards coastal and offshore areas. Spatially, there is a time lag of about 1-2 hours from the convergence event to the formation of convective clouds in the Eastern Coast region of North Sumatra.

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