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Review of the North-east Monsoon 2020/2021 in Malaysia

Fadila Jasmin Fakaruddin, Yip Weng Sang,
Nur Zu Ira Bohari, Diong Jeong Yik and
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CONTENTS

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Abstract

North-east monsoon (NEM) or winter monsoon is a major rainy season in Malaysia, especially over the east coast states of Peninsular Malaysia, eastern region of Sabah and western region of Sarawak. This paper had identified the onset, withdrawal and the monsoon surges and rainfall episodes during the NEM 2020/2021 by using the systematic method based on a previous study and analyses of the synoptic features. Results showed that the onset date was on 11 November 2020, while the withdrawal date was on 28 March 2021. The observed rainfall revealed a wetter than normal weather from November to January. A moderate La-Niña was recorded throughout this season. There were 12 monsoon surges, with nine episodes of heavy rainfall that coincided with the monsoon surges. Stronger easterly winds near the equator due to the influence of La-Niña was discovered as the cause of a decrease in number of pure cold surge events and an increase in the number of mixed surges. Different types of monsoon surge were shown to have significantly different impacts on rainfall intensities and regions. Stronger rainfall intensity was recorded in the mixed surges but not during the pure cold and easterly surges. Six developments of tropical cyclones (TCs) were witnessed in the western North Pacific Ocean (WNP) during this season. Only one TC was associated with the heavy rainfall episode because its track was far from the Malaysian region. Frequent monsoon surges in the South China Sea (SCS), especially during November to January, was also discovered due to less interference of TCs which propagated into the region. This paper is expected to contribute a good understanding of the NEM 2020/2021 features and provide guidance for a real-time weather monitoring during the north-east monsoon in Malaysia.

Keywords: north-east monsoon, winter monsoon, surge, heavy rainfall

1.0 INTRODUCTION

The winter monsoon, which is also referred to as the north-east monsoon (NEM) season has a significant impact on Malaysia's weather, especially over the east coast regions of Peninsular Malaysia which faces the South China Sea (SCS). They receive about 50 % of their annual total rainfall during the first phase of the NEM season, which is between November and December. Monsoon surge is a significant synoptic feature that occurs during this season and has become the main factor which causes heavy rainfall events in Malaysia. Four to six episodes of heavy rainfall are expected to occur every year during the monsoon due to monsoon surges.

Generally, there are three different types of monsoon surge which prevailed during the NEM season in Malaysia (Fakaruddin et al., 2020). One type of the monsoon surges is from the northerly winds, which is locally known as the cold surge (MS). The MS is an outbreak of cold air from the Siberian High which produces a strong north-easterly flow over the SCS. This strong north-easterly flow is the major cause of heavy rainfall events over the east coast areas of Peninsular Malaysia and western Sarawak. In addition to the MS, there is another surge called the easterly surge (ES), which is the zonal wind surge due to strengthening or equator-ward movement of the high pressure system in north-western Pacific caused by a Siberian High outbreak. The third type of surge is the mixed surge (MES), which is an event when both ES and MS occurred together. The MES has been proven to enhance the development of heavy rainfall during the NEM season, especially during their peak occurrences from December to January. The intensity and frequency of MS, ES and MES also vary annually (Fakaruddin et al., 2020).

This study reviews the onset, withdrawal and period of monsoon surges during the North-east Monsoon (NEM) 2020/2021 season in Malaysia. The synoptic and rainfall features are discussed to provide a good understanding of climate and weather characteristics during the NEM season.

2.0 DATA AND METHOD

Onset, Withdrawal and Monsoon Surges

In this study, the daily average wind data from global reanalysis wind dataset, ECMWF Reanalysis v5 (ERA5) data provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) were utilised to objectively define the onset and withdrawal dates as well as the surges episodes. ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate, covering the period from January 1959 to the present. ERA5 is produced by the Copernicus Climate Change Service (C3S) at ECMWF website and has a spatial resolution of 0.2° x 0.2° (Hersbach et al., 2020).

This study used the onset and withdrawal definitions of NEM based on Moten et al. (2014). Onset and withdrawal of the monsoon were determined by first calculating the average value of zonal wind component at the 925-hPa and 850-hPa levels over the box, as shown in Figure 1 (indicated by the red box). The onset was said to occur if the component of easterly wind (negative values) was sustained for at least seven days, with at least a day during this period recording a speed of greater than 5 knots (2.5 m/s). Meanwhile, withdrawal of the monsoon was said to occurred when the component of easterly wind weakens to less than 5 knots (2.5 m/s) for seven consecutive days and westerly wind component (positive value) starts to penetrate the Malaysian region.

The determination of monsoon surges in this study was based on Fakaruddin et al. (2020). The study used three different terms to define three different types of monsoon surge which moved towards the equatorial South China Sea (SCS). The terms were: (i) Meridional surge (MS) to define the surge-induced events due to the cold air outburst from the Siberian high, (ii) easterly surge (ES) to define the zonal wind surge due to equatorward movement of the high pressure system in the north-western Pacific, and (iii) mixed surge (MES) to define a mixture event of ES and MS. The MS was calculated as average of 925-hPa Meridional winds bounded by 110°E to 117.5°E along 15°N, while ES was calculated as average of 925-hPa zonal winds between 7.5°N and 15°N along 120°E. A MS/ES event was said to occur when this index exceeded 8 m/s for at least three consecutive days. As for the third type of surge (MES), it was considered when a MS and ES occurred concurrently for at least two consecutive days. The box that was used to calculate the monsoon surges is shown in Figure 2.

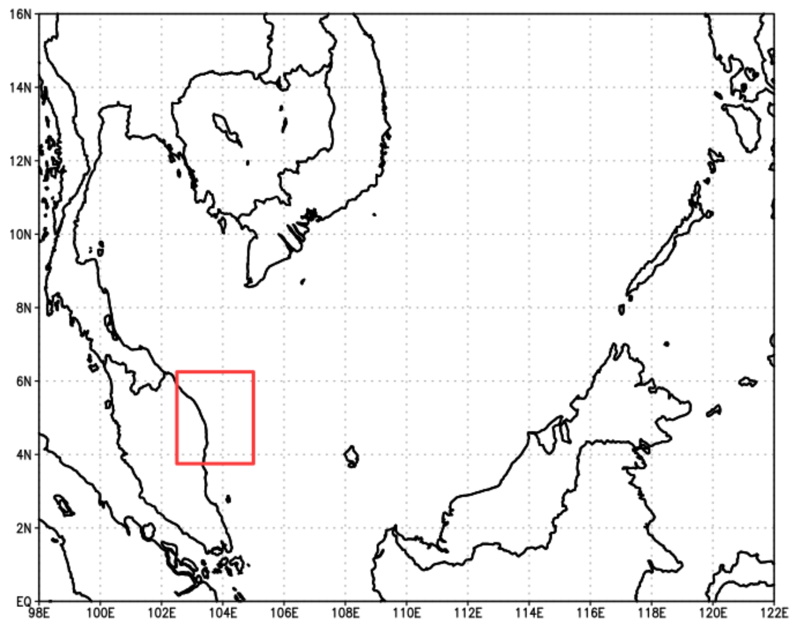

Figure 1. The area that was used to compute the onset and withdrawal of NEM based on Moten et al. (2014), expanding from 3.75 to 6.25°N and 102.5 to 105.00°E (red box)

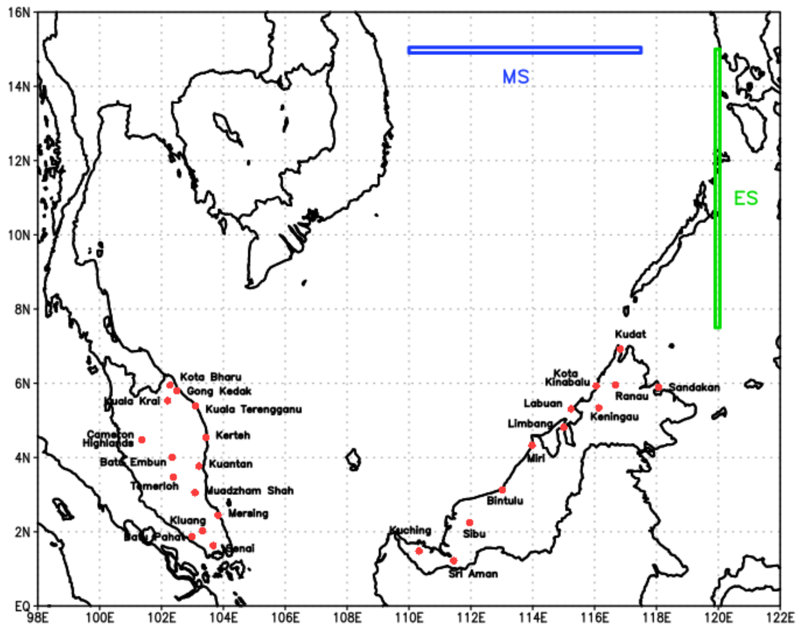

Figure 2: The area that was used to determine monsoon surges in the Malaysian region. MS bounded between 110°E and 117.5°E along 15°N (blue line), while ES bounded between 7.5°N and 15°N along 120°E (green line)

Heavy Rainfall Episodes

The daily rainfall data in this study were obtained from meteorological stations which are operated by the Malaysian Meteorological Department (MET Malaysia) and located in the east coast of Peninsular Malaysia as well as coastal regions of Sabah and Sarawak. The locations of these stations are shown in Figure 2. A heavy rainfall episode was determined when the daily accumulated rainfall during surge episodes exceeded 150 mm at certain stations (Fakaruddin et al. 2020). The nearby dates were considered one episode if they occur during the same surge period.

To observe the spatial distribution of heavy rainfall episodes during the monsoon surges, this study used daily precipitation from the Global Precipitation Measurement (GPM), Integrated Multi-satellite Retrievals for GPM (IMERG) – Late Run. This dataset was retrieved from the website of the National Aeronautics and Space Administration (NASA) on 11 April 2022. The dataset contains data from June 2000 to the present and has a spatial resolution of 0.1° x 0.1° (Moffitt, 2020).

Tropical Cyclones (TCs)

In this study, the data of tropical cyclone (TC) best track was obtained from the Regional Specialised Meteorological Centre (RSMC) Tokyo. It prepares information on formation, movement and development of TC in the western North Pacific Ocean (WNP) within the framework of the World Weather Watch (WWW) Programme of the World Meteorological Organisation (WMO).

Madden Julian Oscillation (MJO), Indian Ocean Dipole (IOD) and El-Niño Southern Oscillation (ENSO)

This study also reviews the intra-seasonal and interannual variations during the NEM 2020/2021. The Madden-Julian Oscillation (MJO) and Indian Ocean Dipole (IOD) data were obtained from Australian Bureau of Meteorology (BOM), while the El-Niño Southern Oscillation (ENSO) indexes were taken from the Climate Prediction Centre (CPC), National Oceanic and Atmospheric Administration (NOAA),which was from their website at: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php.

3.0 RESULTS AND DISCUSSIONS

Onset and Withdrawal

The onset and withdrawal of NEM 2020/2021 were determined by using methods based on Moten et al. (2014), as described above, which is better known as the North-east Monsoon Index (NEMI) by operational forecasters in MET Malaysia. The NEMI analysis is depicted in Figure 3. Based on the analysis, it was determined that the onset date was 11 November 2020 and the withdrawal date was on 28 March 2021. The onset and withdrawal dates fell within the normal range of the climatological onset and withdrawal dates. The climatology onset and withdrawal date were on 9 November and 22 March, respectively (Moten et al., 2014). Based on the study, the onset date before 24 October was considered an early onset, while the date after 25 November was considered a late onset. Similarly, the withdrawal date before 7 March was considered early withdrawal, while the withdrawal date after 6 April was considered late withdrawal. The distributions of onset and withdrawal dates for 2020/2021 NEM season are shown in Figure 4.

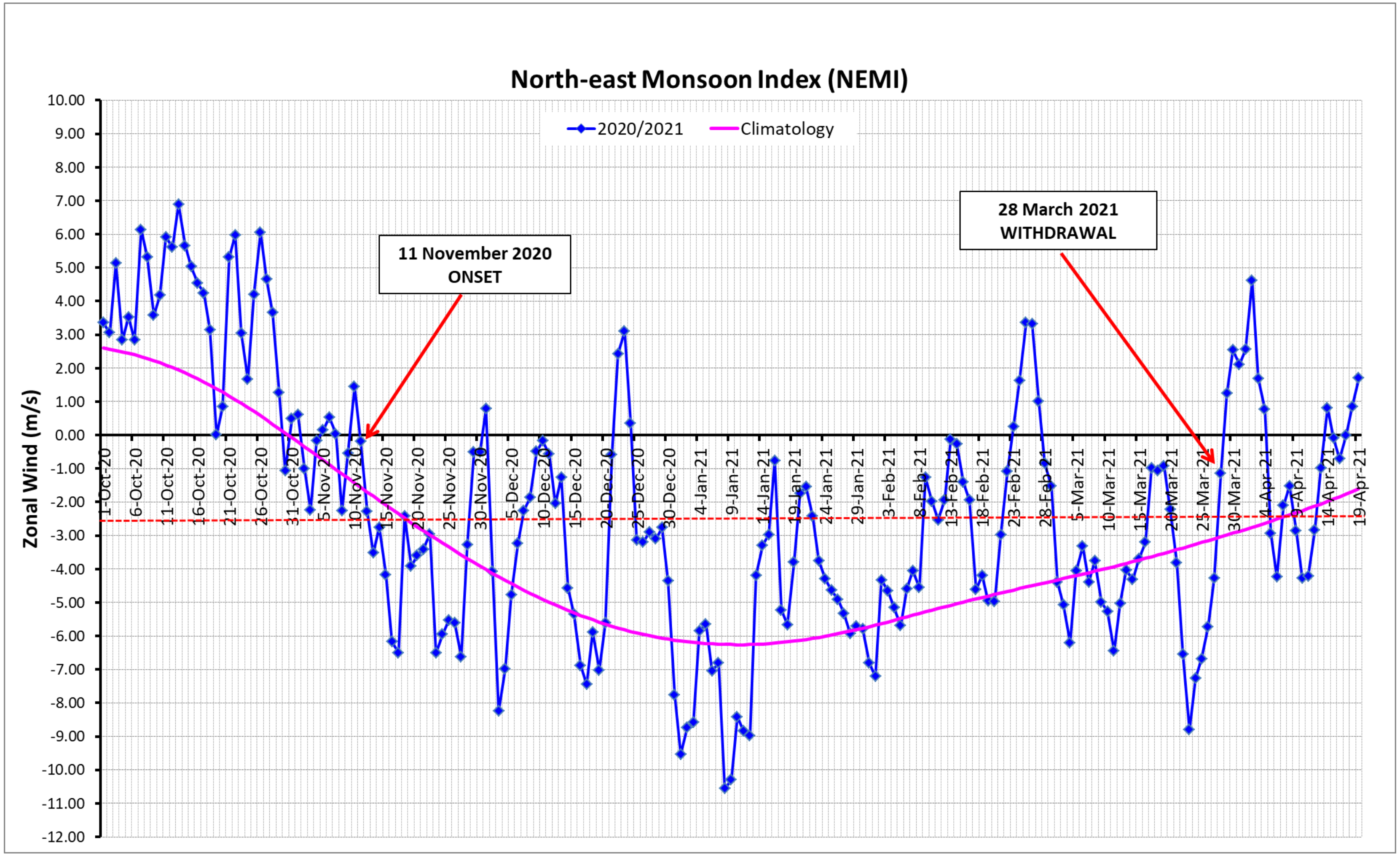

Figure 3. The onset and withdrawal dates during the NEM 2020/2021 calculated by using North-east Monsoon Index (NEMI)

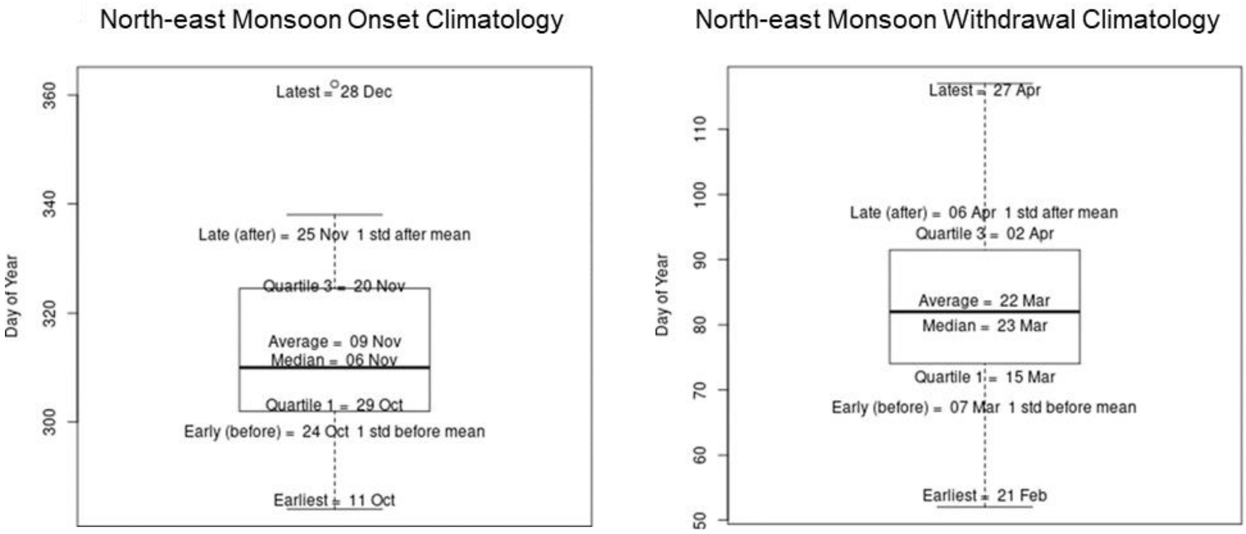

Figure 4. The distribution of onset and withdrawal dates during the North-east Monsoon based on Moten et al. (2014)

In addition to NEMI, the subjective analyses of zonal winds and synoptic winds at low-level from November 2020 to March 2021 were carried out to verify both onset and withdrawal dates of the NEM 2020/2021. As revealed by the zonal wind analysis at 850-hPa level in 5a, the onset date of NEM 2020/2021 was determined when the Malaysian region was dominated by the north-easterly winds from the East Asia continent. The analysis showed strengthening of the easterly winds and weakening of westerly winds over the Malaysian region (100 – 120°E) from mid-November 2020 onwards. The persistent easterly winds flew within the period indicated the beginning of NEM 2020/2021. At the end of March 2021, the easterly winds component over Taiwan and the SCS region weaken, followed by the gradual penetrating of the westerly winds component into the Malaysian region. It was an indicator for the withdrawal period of NEM 2020/2021. The zonal wind analysis was also supported by the mean sea level pressure (MSLP) analysis in 5(b). The analysis showed the strengthening of Siberia (90 – 120°E) pressure in mid-November 2020 and weaker MSLP in Pacific. This created a strong pressure gradient which formed the basis of monsoon flow. Situation reversed in late March, whereby pressure started to decrease in Siberian region and increased the SLP in the Pacific. This indicated the seasonal reversal of pressure gradient.

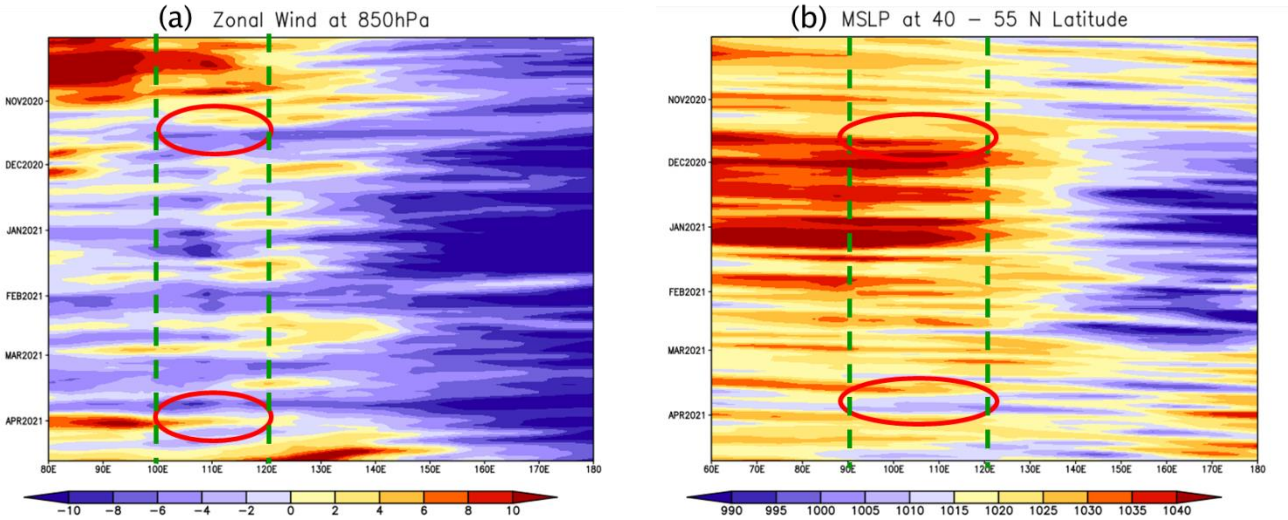

Figure 5. Time-Longitude of (a) mean zonal wind (m/s) at 850-hPa average between the equator to 10°N and (b) mean MSLP (hPa) average between 40 – 55°N. The Malaysian region is located between 100 – 120°E and Siberian region is located between 90 – 120°E

The analysis of low-level winds at 925-hPa during the pentad before and during onset are shown in Figure 6. On the pentad before onset, the strong north-easterly winds dominated over the coast of Vietnam. The north-easterly winds were unable to penetrate the SCS as the tropical storms, Atsani and Etau, intensified over the east and west of the Philippines. Therefore, light and variable winds dominated most Malaysian regions during the period. On the pentad during onset, the north-easterly winds that established over the coast of Vietnam strengthened and started to penetrate the central SCS region due to weakening and dissipating of tropical storms over east and west of the Philippines. During this period, the strong north-easterly winds penetrated towards the east coast of Peninsular Malaysia. At the same period, the central SCS was also dominated by the strong north-easterly winds.

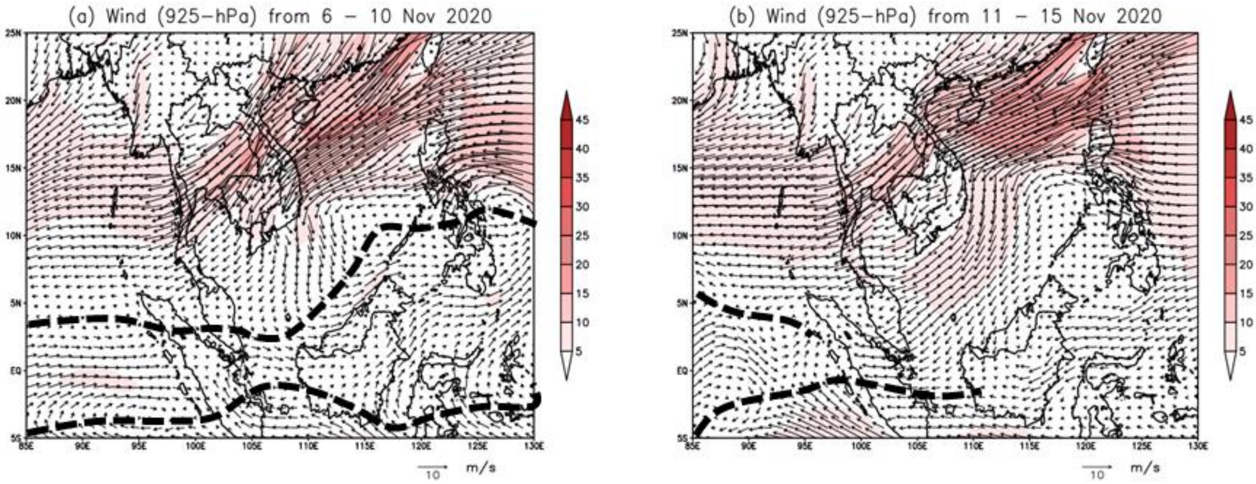

Figure 6. The low-level winds analysis at 925-hPa during the pentad (a) before and (b) during onset. The black-dashed line indicated the trough, while the shaded contour represented the wind speed

The details of analysis of low-level winds at 925-hPa level during the pentad, which were before and during withdrawal, is shown in Figure 7. On the pentad before withdrawal, the strong north-easterly winds persistently dominated the SCS and the Malaysian regions. The easterly winds also continuously penetrate into these areas Figure 7a. Meanwhile, on the pentad during withdrawal, the north-easterly winds gradually dissipated, and the easterly winds weaken. Wind near the equator also became more variable (Figure 7b).

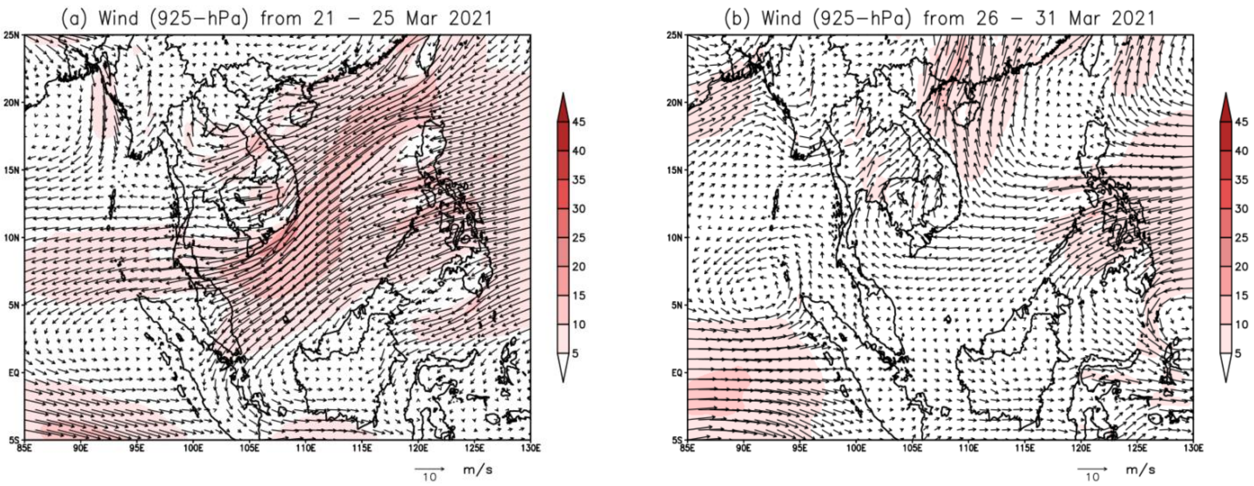

Figure 7. The low-level winds analysis at 925-hPa during the pentad (a) before and (b) during withdrawal. The shaded contour represented the wind speed

Duration of the Northeast Monsoon

Moten et al. (2014) described that the length of NEM season clearly showed a significant interannual variation. The average length of the season was 132 days. Based on onset and withdrawal dates, duration of the NEM 2020/2021 was within 138 days. It was close to the average length of the season (Moten et al., 2014).

Monsoon Surges

Rainfall during the NEM season in Malaysia was proven to be influenced by the occurrence of monsoon surges, especially from November to January (Hai et al. 2017; Tangang et al., 2008; Chang et al., 2016, 2020; Moten et al., 2014). Different types of monsoon surge also has been proven to stimulate different impacts on rainfall intensities and regions significantly (Fakaruddin et al., 2020). As described in the previous section, an episode of monsoon surge was determined by using the method by Fakaruddin et al. (2020), which is also known as the Meridional and Easterly Surge Index (MESI) by operational forecasters in MET Malaysia. The details of MESI analysis during the NEM 2020/2021 is depicted in Figure 8.

Based on the analysis, it was observed that the NEM 2020/2021 season experienced 12 monsoon surges, with two episodes of MS, five episodes of ES and five episodes of MES. The longest duration of surges was 15 days in the seventh surge of the season, which was identified as MES. Meanwhile, the -shortest duration of surge was three days, in the first, second and eighth surges of the season. They were classified as MS, ES and MES, respectively. The dates and type of monsoon surges in the NEM 2020/21 season are summarised in Table 1.

Table 1. Dates and classification of monsoon surges in NEM 2020/2021 season

Monsoon Surges		
MS	**ES**	**MES**
1st 31 Oct – 2 Nov 2020 (3 days)	2nd 14 – 16 Nov 2020 (3 days)	4th 26 – 30 Nov 2020 (5 days)
5th 1 – 8 Dec 2020 (8 days)	3rd 21 – 25 Nov 2020 (5 days)	6th 15 – 21 Dec 2020 (7 days)
	9th 28 Jan – 09 Feb 2021 (13 days)	7th 30 Dec 2020 – 13 Jan 2021 (15 days)
	11th 3 – 11 Mar 2021 (9 days)	8th 17 – 19 Jan 2021 (3 days)
	12th 22 – 25 Mar 2021 (4 days)	10th 17 – 20 Feb 2021 (4 days)

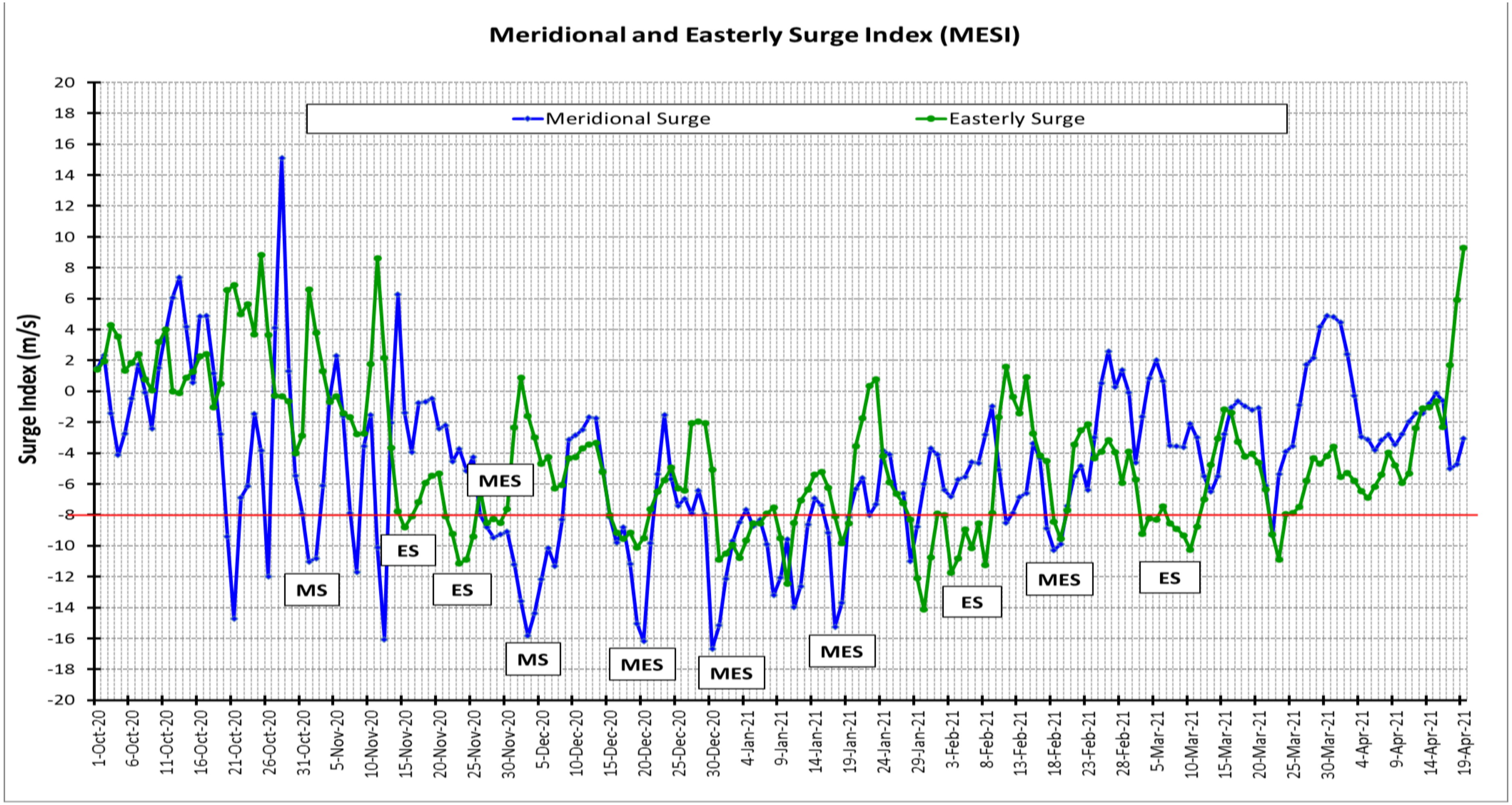

Figure 8. The monsoon surges of NEM 2020/2021 determines by using the Meridional and Easterly Surge Index (MESI) analysis

Based on climatology, the average number of surge episodes per season was 29, which was consisted of 11 episodes of MS, 13 episodes of ES and five episodes of MES. Meanwhile, the average surge days per season was 76, in which 28 days fell under MS, 38 days fell under ES and 10 days fell under MES. The average duration of surges per episode for both MS and ES was three days, while for MES was two days (Fakaruddin et al. 2020). The total number of surges during NEM 2020/2021 as compared to the climatology is depicted in Table 2, while the statistics of each surge is depicted in Table 3.

The analysis of surges during the NEM 2020/2021 showed a significant decrease in the total number of surges. However, the total day of surges per season was close to the climatology. The first surge of MS during the season occurred within the average period (22 October), while the last surge occurred earlier than the average period (25 February). Meanwhile, the first surge and last surge of ES occurred within the average period (17 November and 20 March, respectively). As for MES, the first surge occurred earlier than the average period (7 December), while the last surge occurred later than the average period (10 February). In summary, these results showed that the numbers of surges in this season were decreased. However, their duration of surges per episode was longer than normal season. In addition, the results also show that the total day of MES was increased significantly this season, while the total day of MS was decreased and the total day of ES was close to climatology, respectively. The decreasing number of MS days did not mean fewer cold surges events/ duration but because they were categorised into the MES statistics, whereby it accounted for both northerly and easterly surges. This suggested that the easterly wind component was truly active and they coincided with northerly surge more often than usual).

Table 2. The total number of surges and days per season during NEM 2020/2021 as compared to climatology

	Climatology	NEM 2020/2021
Number of surge episodes	29	12
Surge days	76	78

Table 3. Statistics of the monsoon surges during NEM 2020/2021

MS	Climatology	NEM 2020/2021
First Surge	22 October	31 October
Last Surge	25 February	8 December
No. of Surge	11	2
Days per Season	28 days	11 days
Average Days per Episode	3 days	6 days
ES	**Climatology**	**NEM 2020/2021**
First Surge	17 November	14 November
Last Surge	20 March	25 March
No. of Surge	13	5
Days per Season	38 days	34 days
Average Days per Episode	3 days	7 days
MES	**Climatology**	**NEM 2020/2021**
First Surge	7 December	26 November
Last Surge	10 February	20 February
No. of Surge	5	5
Days per Season	10 days	33 days
Average Days per Episode	2 days	7 days

Episode of Surges

The interaction between monsoon surges, cyclonic vortices and monsoon trough in the SCS were the most significant features which caused heavy rainfall in the Malaysian region during the NEM season (Moten et al., 2014). These features were conducive to form a widespread torrential rainfall which lasted for a few days and affected the coastal regions of east coast states of Peninsular Malaysia as well as eastern regions of Sabah and Sarawak. During the heavy rainfall episodes, the rainfall per day could exceed more than 100 mm. During each episode the total rainfall could be several hundreds to more than 1,000 mm of rain (Moten et al., 2014).

The spatial distribution of monthly rainfall anomaly during NEM 2020/2021 is shown in Figure 9. The wind anomalies departured from the monthly means of 1979 to 2000, while rainfall anomalies departured from the average of year 2000 to 2020. During the early phase of the season, which was during November until December 2020, the low-level winds over the SCS and Malaysian region indicated anomalous southerlies. This showed that the monsoonal north-easterly winds were weaker than normal, which might be weaker than normal monsoon in the region. However, the rainfall anomalies showed wetter than normal weather over the northern east coast states of Peninsular Malaysia in November and December 2020. The wetter weather during the period was revealed to be influenced by the monsoon surges, especially mixed surges, which showed a higher frequency than usual throughout the period. The interaction of monsoon surges and heavy rainfall episodes were elaborated further in the next subsection. In addition to the monsoon surges, the wetter weather was also suggested to be affected by the seasonal variation and interannual variation that occurred in the SCS and Maritime Continent regions throughout the season, such as La-Niña and Madden Julian Oscillation (MJO) conditions. These variations will be discussed in detail in Section 3.7.

During later phase of the season, which was from January until March 2021, there was an abrupt change in the rainfall anomalies. The wetter weather in the northern region of Peninsular Malaysia now progressed to the southern region. Now the wetter weather was concentrated over southern region of the east coast states of Peninsular Malaysia and western Borneo, especially in January 2021 and March 2021. The low-level winds over the SCS and Malaysian region showed that the monsoonal north-easterly winds strengthen. There was also an anomaly cyclonic vortex sustained in central Philippines. The interaction of the north-easterly winds and this cyclonic vortex might suggest the reason for the wetter weather in western Borneo throughout the period.

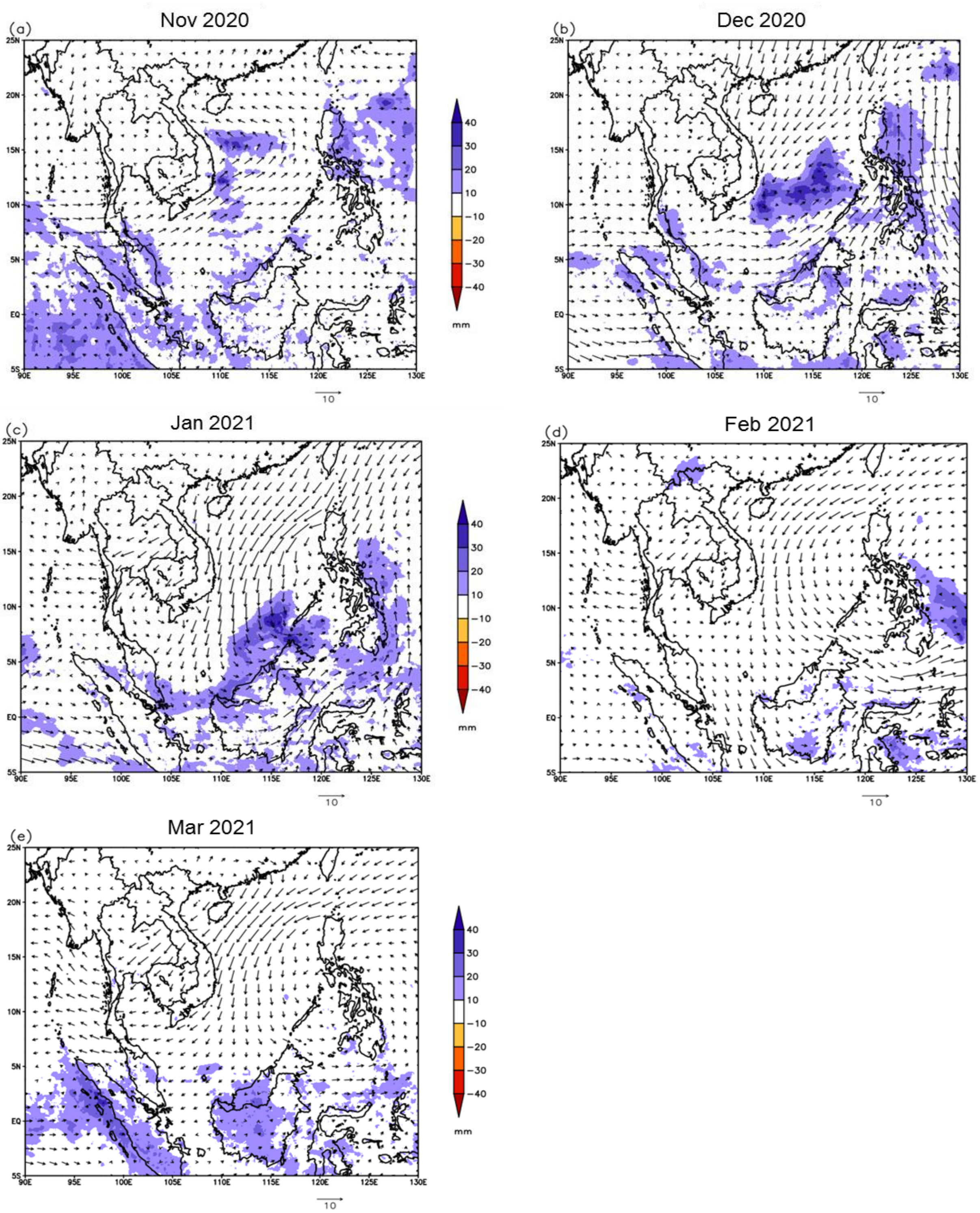

Figure 9. Anomalous monthly wind (m/s) at 925-hPa and anomalous monthly rainfall (shaded, mm) in (a) November 2020, (b) December 2020, (c) January 2021, (d) February 2021 and (e) March 2021

Episode 1: 31 October – 2 November 2020

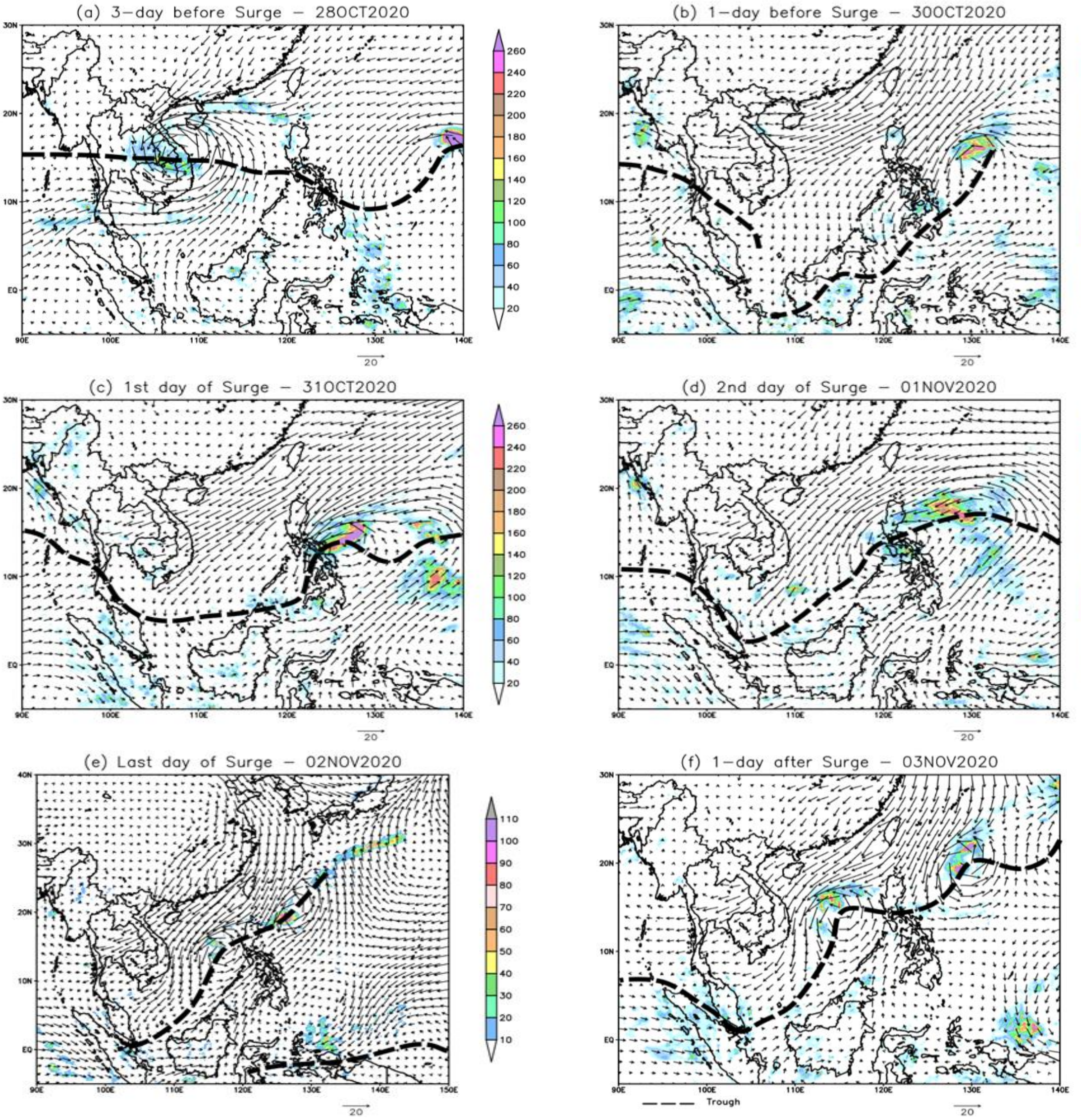

Figure 10. The daily wind at 925-hPa level and rainfall (shaded) during the first episode of surge (31October – 2 November 2020). The blue-dashed line indicated the trough, while the straight-blue line indicated the ridge

The first episode of surge was identified as MS, occurred from 31 October to 2 November 2020. It lasted for three days. Figure 10 shows the features before, during and after the episode of surge. Before the occurrence of surge (Figure 10a-b), two low pressure systems were observed and embedded in the monsoon trough, which was located between the equator to 20°N. Typhoon Molave was located at the east of the trough, while Tropical Storms Goni was at the west of the trough. The Typhoon Molave originally formed in east of the Philippines, then made landfall over Vietnam with maximum wind speed at the centre reached 80 knots. Meanwhile, the Tropical Storms Goni forms in the WNP moved eastwards towards the central region of the Philippines. Due to the presence of typhoon, wind over the Malaysian region was dominated by the south-westerly winds. As the Typhoon Molave dissipated, the Tropical Storms Goni strengthened and became typhoon category. Due to the dissipating of Typhoon Molave over Vietnam, the strong north-easterly winds that originally spin into the system now started to penetrate the Malaysian region (Figure 10c). It was the first episode of surge which occurred in the east coast states of Peninsular Malaysia. During this period, as the Typhoon Goni strengthened, the rain bands were observed mainly in vicinity of the centre of typhoon; hence, clear weather was observed over Malaysia. As the typhoon intensified, it moved eastward across the Philippines. During this period, clear weather continued to dominate over most areas in Malaysia. The clear weather continued until the last day of episode of surge, which was until Typhoon Goni made landfall over the coastal areas of Vietnam (Figure 10d-f). There was no heavy rainfall episode during this surge as most of the moisture in the SCS was drawn into the centre of the active typhoon system.

Episode 2: 14 – 16 November 2020

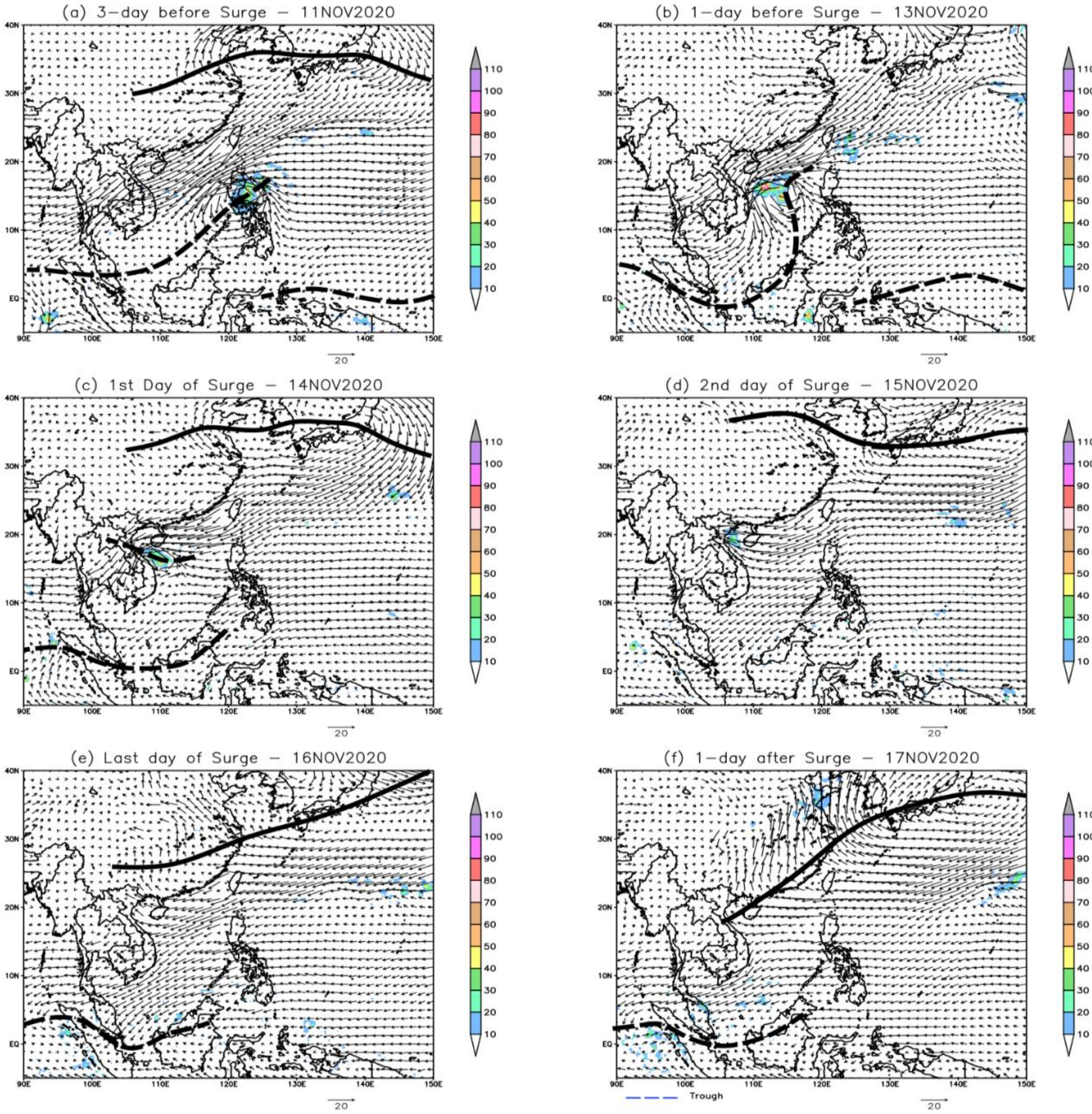

Figure 11: The daily wind at 925-hPa level and rainfall (shaded) during the second episode of surge (14 – 16 November 2020). The blue-dashed line indicated the trough, while the blue line indicated the ridge

The second episode of surge which was identified as ES, occurred from 14 to 16 November 2020. It lasted for three days. Figure 11 shows the features before, during and after the episode of surge. Before the occurrence of surge (Figure 11a), Typhoon Vamco was located over central of the Philippines. The observed monsoon trough was located within the equator to 20°N, extending from central Peninsular Malaysia to the centre of typhoon. During the same period, a ridge formed further west extended from southern Japan to mainland of Asia. A strong high pressure system could be seen between South Korea and eastern Japan. Due to the presence of TC over north of the SCS, the wind over Peninsular Malaysia was dominated by the light south-easterly winds over the southern region and light north-easterly winds over the northern region. The rain bands were observed to concentrate over the regions near the typhoon. As the systems moved westwards towards Vietnam, the winds over Peninsular Malaysia was shifted to light north-easterly winds over the whole region (Figure 11b).

As Typhoon Vamco made landfall over Vietnam (Figure 11c-f), a high pressure system was still observed on the vicinity of southern Japan to mainland of Asia. The near equatorial trough was shifted slightly southward, located near the equator, and expanded from Sumatra to Borneo. During this period, broad easterly winds from the WNP started to penetrate the SCS. It was the onset of second episode of surge in the SCS.

Episode 3: 21 – 25 November 2020

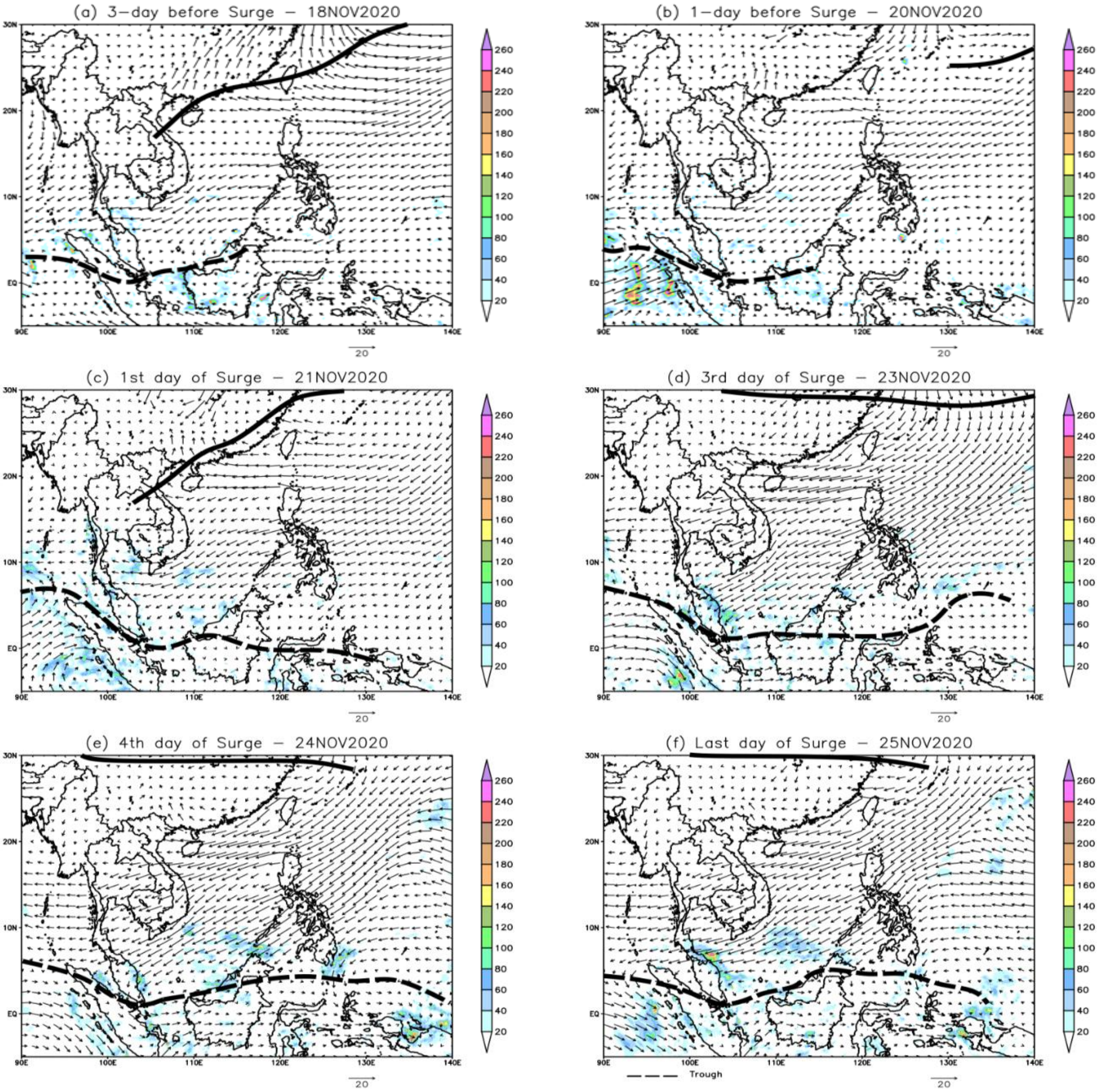

Figure 12. The daily wind at 925-hPa level and rainfall (shaded) during the third episode of surge (21 – 25 November 2020). The blue-dashed line indicated the trough, while the straight-blue line indicated the ridge

The third, fourth and fifth episodes of surge occurred consecutively over a period of 18 days. It was found that in the mid-latitude, rapid active short waves could intensify the Siberian-Mongolian High (SMH) continuously. This caused continuous pulses of cold surge which could be seen as the long-lived surges. Another reason could be the fast eastward movement of SMH coupled with a short wave trough which caused successive SMH to form (Chang et al., 2005; Hai et al., 2017; Tangang et al., 2008, 2017; Chang et al., 2016; Carrera & Gyakum, 2007; Li & Yang, 2010; Chang et al., 2020; Chang, 1977; Chang & Lu, 2012). The successive pulse of cold surge coupled with no circulation disruption from tropical disturbances such as TC in SCS during this time contributed to the continuous day of surge to be observed in the region. Figure 12, Figure 13 and Figure 14 show the features before, during and after the episodes of surges, respectively.

The third episode of surge was identified as ES, occurred from 21 to 25 November 2020. It lasted for five days. Before the occurrence of surge (Figure 12a), the ridge formed more to the west in northeast direction, which extended from southern Japan to mainland of China within the equator to 30°N. The monsoon trough was observed near the equator, located within the equator to 5°N, extending from Sumatra to Borneo. One day before the surge, the high pressure system was progressed eastwards and there was no longer ridge that stretched across the mainland of China (Figure 12b). During this period, there was no component of north-easterly winds from the mainland of China. The wind in the Malaysian region was dominated by the light easterly and north-easterly winds coming from the WNP.

On the first day of surge (Figure 12c), the ridge stretched again more to the west in northeast direction. The ridge extends from southern Japan to mainland of China within the equator to 30°N. The monsoon trough was observed near the equator located within the equator to 5°N, extending from Sumatra to Borneo. At the same period, the ridge that established in north of the SCS strengthened the easterly and north-easterly winds in the WNP which propagated into the Malaysian region. As a result, 15 to 20 knots north-easterly winds from the WNP were blown into the Malaysian region. During this period, a small amount of rainfall was recorded over the east coast states of Peninsular Malaysia, Sabah and Sarawak, mainly in vicinity of the trough.

The heavy rainfall episode during the surge was recorded from the second to third day of the surge, which was on 23 – 24 November 2020 in Kelantan (Gong Kedak) and Terengganu (Kuala Terengganu). The recorded rainfall amount was 209.22 mm on 23 November 2020 (Kuala Terengganu) and 182.21 mm on 24 November 2020 (Gong Kedak). During this period (Figure 12d-e), band of 20 to 40 knots of north-easterly winds surge from the WNP had blown into the Malaysian region. Interaction between the maximum winds over the central SCS and monsoon trough which lied in the southern region of Peninsular Malaysia increased the relative vorticity and mass convergence over the region. In addition, the maximum winds created convergence over the east coast of Peninsular Malaysia, and thus brought relatively unstable atmosphere, which impacted the northern region of east coast of Peninsular Malaysia.

Episode 4: 26 – 30 November 2020

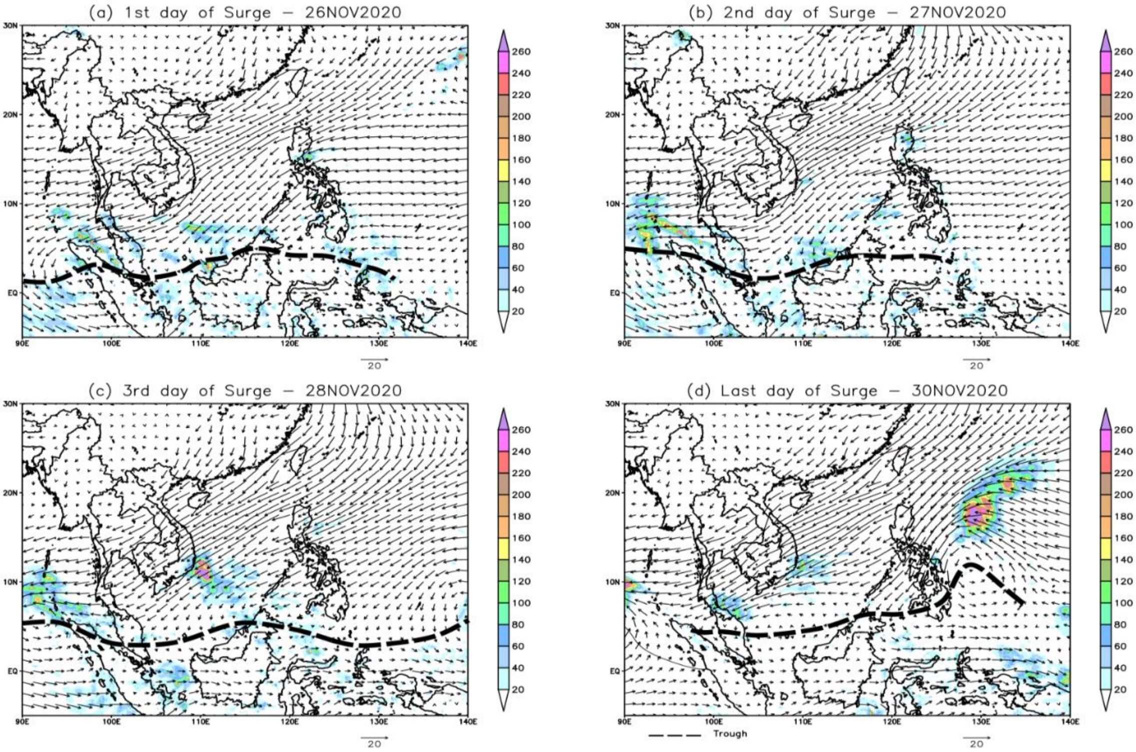

Figure 13. The daily wind at 925-hPa level and rainfall (shaded) during the fourth episode of surge (26 – 30 November 2020). The blue-dashed line indicated the trough, while the straight-blue line indicated the ridge

The fourth episode of surge was identified as MES, which occurred from 26 to 30 November 2020. It lasted for five days. The heavy rainfall episode during the fourth surge was recorded on 27 November 2020, in Bintulu, Sarawak, which was on the second day of surge. The recorded rainfall amount was 171.41 mm. During the fourth surge (Figure 13), the subtropical high that originally stretches from the southern Japan to mainland of China had moved eastwards, away from the mainland of Asia. During the period, the cold surge propagated into the SCS region. Freshening of the north-easterly winds occurred in phase with intensification of the WNP easterly winds, which brought in relatively high moisture into the Malaysian region. The enhanced moisture flux (figure not shown) and wind convergence; therefore, intensified a cyclonic disturbance in central of Borneo. From the analysis, it was observed that the cyclonic disturbance, known as the Borneo Vortex (BV), initially formed in the central region of Borneo on the first day of surge (Figure 13a) and became organised on the second and third day of the surges (Figure 13b-c). The monsoon trough positions slightly north of its original position a few days ago, within 1 to 5°N, stretching from Sumatra to the centre of BV in central Borneo. Slight rainfall was recorded over the northern region of Peninsular Malaysia and enhanced rainfall was observed in central Borneo due to this BV. Heavy rainfall could also be expected in the vicinity of BV. However, BV could draw moistures in the atmosphere and diminish rainfall over the surrounding areas. That was why there was no substantial rainfall near the trough in the southern Peninsular Malaysia during this period.

On the last day of surge (Figure 13d), due to active cyclonic vortex over the WNP the easterly winds over the SCS was weaken. As the north-easterly and easterly winds weaken, the BV was also gradually weakened. The trough now slanted further to the north, from northern Sumatra to centre of the cyclonic vortex in the WNP and -span over the northern region of Peninsular Malaysia and northern Borneo. The strong north-easterly winds and heavy rainfall were concentrated over the southern region of Thailand.

Episode 5: 1 – 8 December 2020

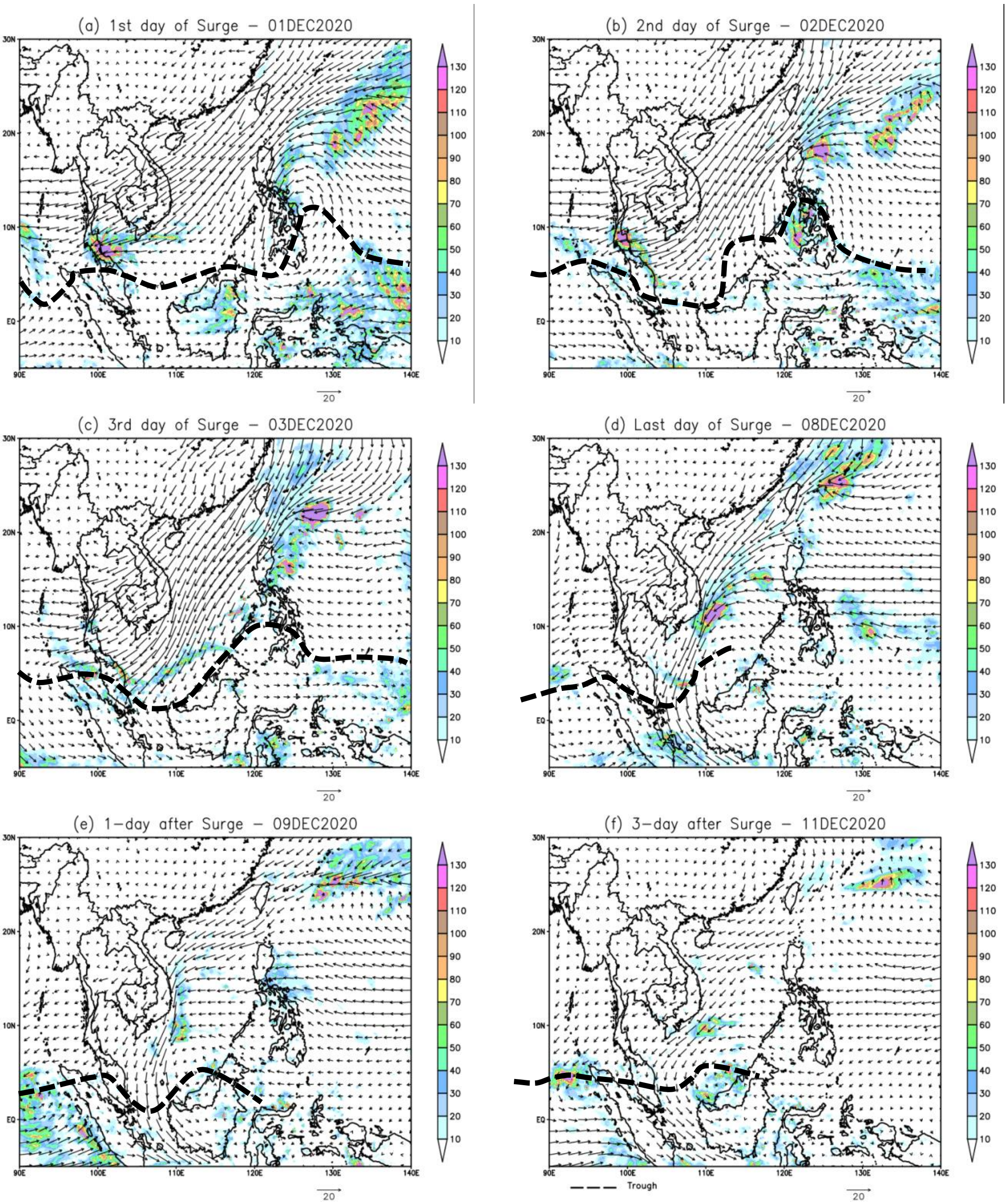

Figure 14. The daily wind at 925-hPa level and rainfall (shaded) during the fifth episode of surge (1 – 8 December 2020). The blue-dashed line indicated the trough

The fifth episode of surge was identified as MS, which occurred from 1 to 8 December 2020. It lasted for eight days. The cyclonic vortex which initially formed in the WNP on the last day of the fourth surge (MES) had amplified to form an organised cyclonic system (Figure 14a). The system prevented the intrusion of the easterly winds into the Malaysian region. As a result, the north-easterly winds which was intensified by the cold surge outbreaks, with a speed between 20 to 40 knots, thrusted into the SCS and Malaysian regions.

The heavy rainfall episode during the surge was recorded from 2 to 3 December 2020, in Kelantan and Terengganu, which was on the second and third day of surge. The highest recorded rainfall amount on 2 December 2020 was 157 mm (Kerteh), while on 3 December 2020 was 355.6 mm (Gong Kedak). During the period (Figure 14b-c), the north-easterly winds over the SCS strengthened as the WNP cyclonic vortex gradually weakened and the trough slowly migrated equatorward. The heavy rainfall was concentrated north of the trough, which was over Kelantan and Terengganu.

On the last day of surge (Figure 14d), the strong and persistent north-easterly winds dominated the SCS. However, due to the dissipating of the WNP cyclonic vortex, the easterly winds started to penetrate the SCS. During this period, intrusion of the easterly winds and the position of the monsoon trough near the equator, which was within the equator to 3°N, enforced the north-easterly winds to penetrate further south, crossing the trough, and thus created a cross-equatorial flow between Peninsular Malaysia and Borneo. The abrupt synoptic changes brought dry weather conditions over Malaysia. The withdrawal of the cold surge episode could be seen on 9 December 2020 (Figure 14e**)** as the north-easterly winds weaken and the easterly winds gradually dominated the SCS and the Malaysian region.

Episode 6: 15 – 21 Dec 2020

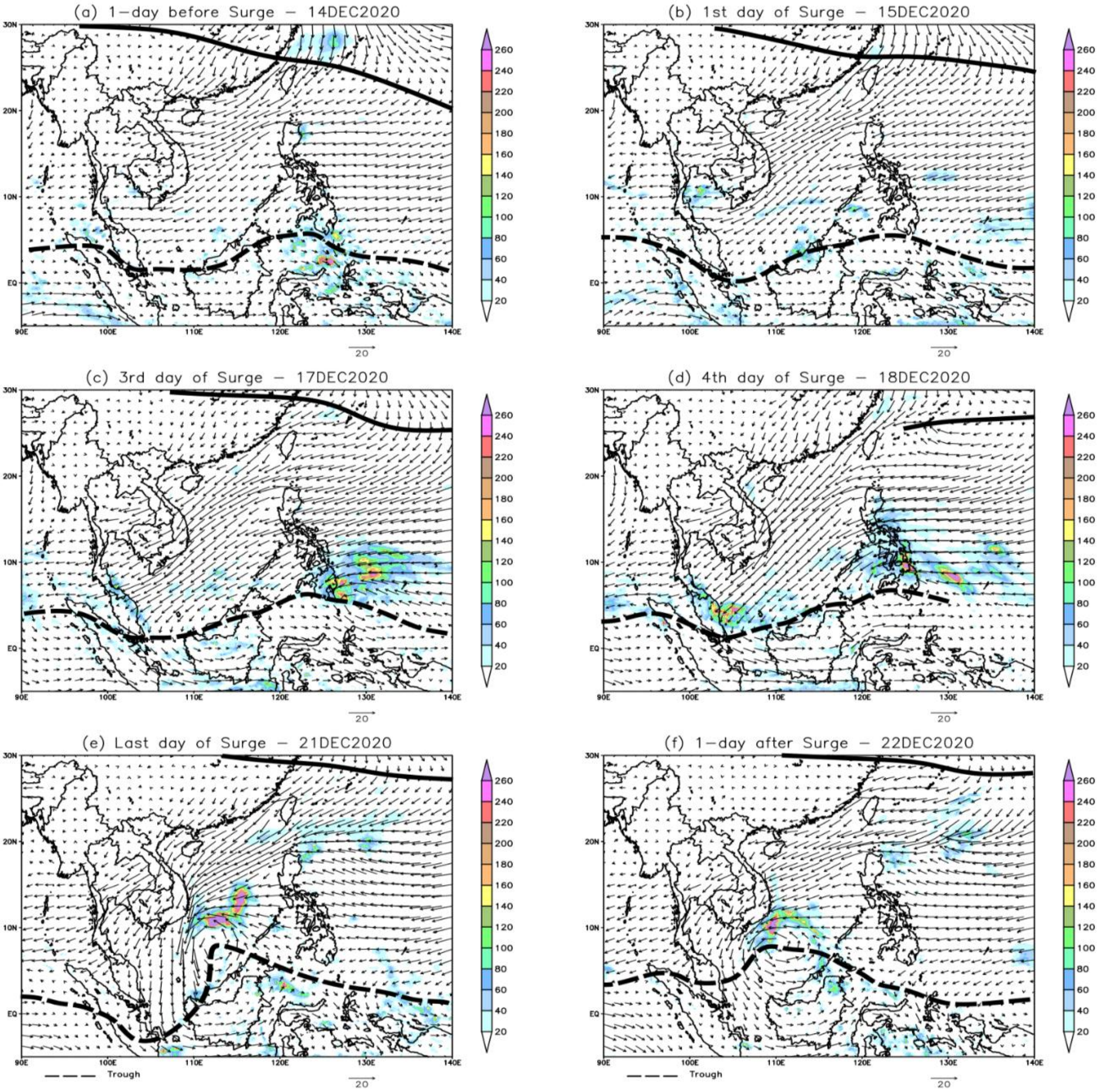

Figure 15. The daily wind at 925-hPa level and rainfall (shaded) during the sixth episode of surge (15 – 21 December 2020). The blue-dashed line indicated the trough, while the straight-blue line indicated the ridge

The sixth episode of surge was identified as MES, which occurred from 15 to 21 December 2020. It lasted for seven days. Before the surge (Figure 15a), the high pressure system was observed within 20 to 30°N, which extended from 100 to 140°E. The monsoon trough was located within the Equator to 5°N, stretched from northern Sumatra to the southern Philippines crossed southern Peninsular Malaysia and central Borneo. A cyclonic vortex formed over the southwest of Borneo and embedded within the monsoon trough. On the first day of surge (Figure 15b), the ridge and monsoon trough was located on the same location as the previous day. The cold surge intensified the north-easterly winds over the SCS. At the same time during the surge, broad easterly winds from the WNP, which carried relatively high moisture was observed. Due to the location of the trough over the southern Peninsular Malaysia, the strong north-easterly winds blew directly towards the northern region of east coast of Peninsular Malaysia. Heavy rainfall was observed to concentrate at north of the trough, which was over Kelantan and Terengganu. Heavy rainfall episode occurred during this surge was recorded on the third and fourth day of surge (on 17 – 18 December 2020) in Kelantan and Terengganu. During this heavy rain episode, the highest rainfall amount recorded in the east coast stations on 17 December 2020 was 171.8 mm (Kuala Krai), while on 18 December 2020 was 306.6 mm (Kerteh). The almost double-fold increase in the amount of rainfall on 18 December 2020 could be attributed to the increasing speed of north-easterly winds in SCS (Figure 15d).

A cyclonic vortex that originally formed in southern of the Philippines and embedded within the monsoon trough from 17 December 2020 was strengthened to become Tropical Storm Krovanh (Figure 15e). The tropical storm propagated to centre of the SCS and reached its maximum speed of 35 knots on 21 December 2020. Due to the presence of storm, the wind over Peninsular Malaysia was dominated by the north-easterly winds with average speeds of 10 to 20 knots. The wind confluence was observed over the coastal areas of Borneo as the wind spun to the centre of the storm. During this period, the rain bands were observed mainly in vicinity of the centre of storm and diminished the rainfall formation in Malaysia. As the tropical storm strengthened and moved westwards on 22 December 2020, the winds in Peninsular Malaysia were dominated by the north-easterly winds over the northern region and north-westerly winds over the southern region (Figure 15f). It was a signal for the withdrawal of the surge in the SCS region. The Tropical Storm Krovanh sustained its maximum speed until it dissipated in the Gulf of Thailand on 25 December 2020.

Episode 7: 30 Dec 2020 – 13 Jan 2021

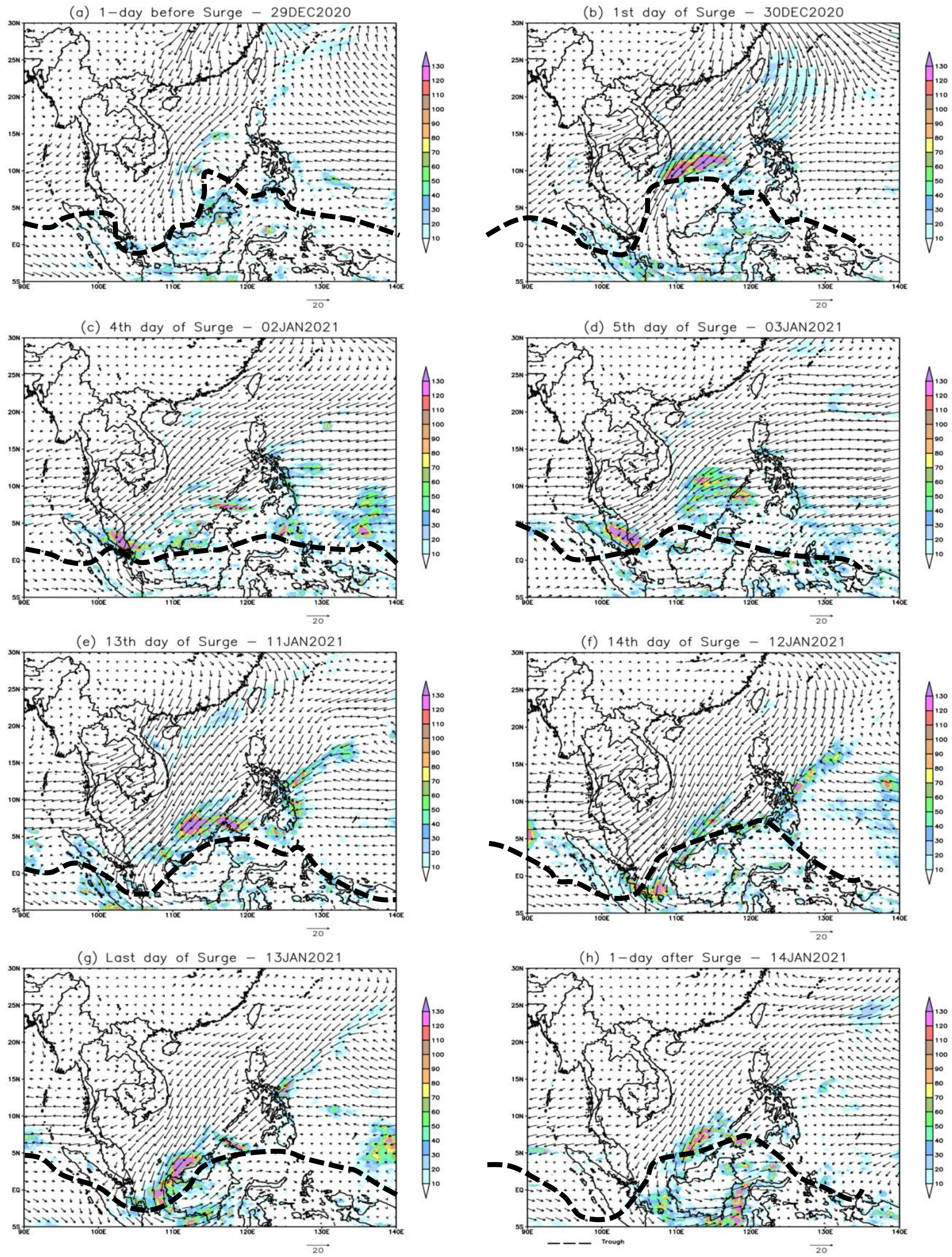

Figure 16. The daily wind at 925-hPa level and rainfall (shaded) during the seventh episode of surge (30 December 2020 – 13 January 2021). The blue-dashed line indicated the trough

The seventh episode of surge was identified as MES, which occurred from 30 December 2020 to 13 January 2021. It lasted for 15 days and was recorded as the longest episode of surge during the season. Before the surge (Figure 16a), an active high-pressure system developed over the WNP. The ridge was observed within 20 to 35°N, which extended from 100 to 180°E. The monsoon trough positioned within the equator to 10°N, stretched across Sumatra to the southern Philippines through southern Peninsular Malaysia and along the coast of Borneo. The north-easterly winds with speed of 10 to 20 knots dominated Peninsular Malaysia and 10 to 20 knots of north-easterly-south-westerly winds over Sabah and Sarawak due to occurrence of the vortex over northern Borneo.

On the first day of surge (Figure 16b), the ridge has tilted slightly to the south, within 15 to 35°N. The monsoon trough was located on the same location as the previous day, while a cyclonic vortex that embedded within the monsoon trough was located quasi-stationary over northern Borneo. As the high pressure system in WNP progressed eastwards, the cold surges now penetrate further south and strengthened the north-easterly flows towards the SCS. A branch of strong north-easterly winds in SCS flew into the cyclonic vortex located in northern Borneo. This caused a heavy rainfall in the convergence zone. Another branch of the strong north-easterly winds of 20 to 40 knots penetrated the east coast states of Peninsular Malaysia.

There were two episodes of heavy rainfall which coincided with this surge. One of the episodes occurred in Pahang and Johor, while the other episode occurred in Sabah and Sarawak. The heavy rainfall episode in Pahang and Johor were recorded on the fourth and fifth day of surge from 2 to 3 January 2021. The recorded amount of rainfall which met the criteria of a heavy rain episode (exceeds 150 mm) were164.8 mm (Muadzham Shah), 170.2 mm (Kluang) and 177.4 mm (Senai) on 2 January 2021, while 178.4 mm (Batu Embun), 187.4 mm (Muadzham Shah) and 213.8 mm (Kuantan) on 3 January 2021. Meanwhile, the heavy rainfall episode in Sabah and Sarawak were recorded on the 13^{th} to 15^{th} (last) day of surge from 11 to 13 January 2021. The recorded rainfall was 382.0 mm (Kudat) on 11 January 2021, 187.2 mm (Kuching) on 12 January 2021 and 207.8 mm (Kudat) on 13 January 2021 (Sandakan).

During the first episode of heavy rainfall in this surge (2 to 3 January 2021), the high pressure system moved slightly to north, which was within 20 to 35°N (Figure 16c-d). This led to the penetration of WNP easterly winds and brought a lot of moisture into the SCS. The trough located between the equator and 5°N crosses over Sumatra, south of Peninsular Malaysia and along the coastlines of Borneo. The north-easterly winds strengthened and channelled into BV near the equator. Convergence between the WNP easterly winds and the north-easterly winds over the southern region of Peninsular Malaysia, and enhanced the rainfall, especially over Pahang and Johor.

During the second episode of heavy rainfall (11 to 13 January 2021) within this surge, the high pressure system and the monsoon trough position on the same location as on the first episode (Figure 16e-g). The BV shifted slightly to the east, and centred in central Borneo. The convergence of the north-easterly and easterly winds also shifted eastwards. This resulted in the direct penetration of the strong north-easterly winds with maximum of 40 knots into the SCS and produced enhanced precipitation over central Borneo. The heavy rainfall over the eastern Sabah was due to the influence of the easterly winds. The withdrawal of the surge could be observed on 14 January 2021 (Figure 16h) as the north-easterly and easterly winds in the SCS weaken. This also caused the BV to gradually diminish.

Episode 8: 17 – 19 January 2021

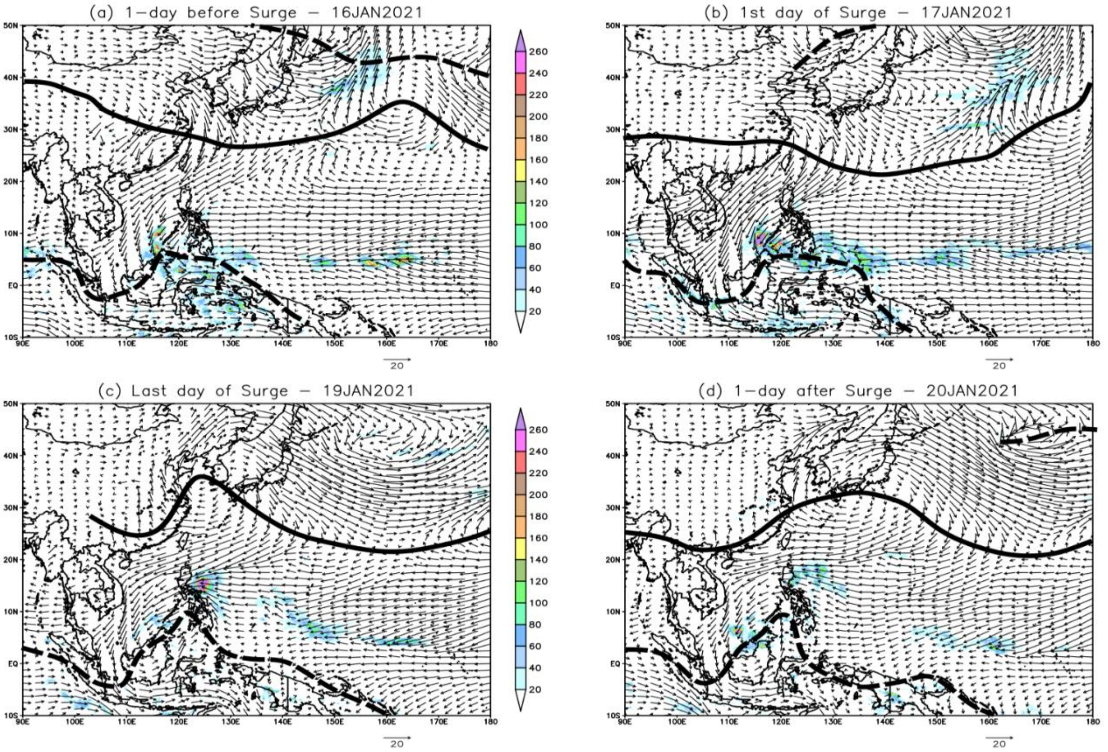

Figure 17. The daily wind at 925-hPa level and rainfall (shaded) during the eighth episode of surge (16 – 19 January 2021). The blue-dashed line indicated the trough, while the straight-blue line indicated the ridge

The eighth episode of surge was identified as MES, which occurred from 17 to 19 January 2021. It approached three days after the seventh surge and lasted for three days. Moderate rain was observed over its centre near western Sabah. On the first day of surge (Figure 17b), as the north-easterly winds strengthened in the SCS, a cyclonic system in the southern Philippines developed and gradually strengthened. The cyclonic system prevented the intrusion of the easterly winds into the Malaysian region. The strengthening of the system formed intense counter-clockwise turning in northern Borneo, which then forced the strong north-easterly winds to penetrate towards the equator. This intensification also strengthened the trough. As a result, the northern monsoon trough between Peninsular Malaysia and Borneo had shifted slightly to the south, which was located between 0 and 5°S. Supported by the strong westerly winds which blew into the southern hemisphere monsoon trough, this created a strong cross-equatorial flow and brought dry weather over Peninsular Malaysia and western Sarawak. The cyclonic system in the southern Philippines and the northern monsoon trough within the Equator and 5°S remain quasi-stationary throughout the episode. As the north-easterly winds weaken, the cyclonic system was also gradually diminished (Figure 17d) and lead the easterly winds to penetrate the SCS. This signalled the withdrawal of the surge in the SCS region.

Episode 9: 28 January – 9 February 2021

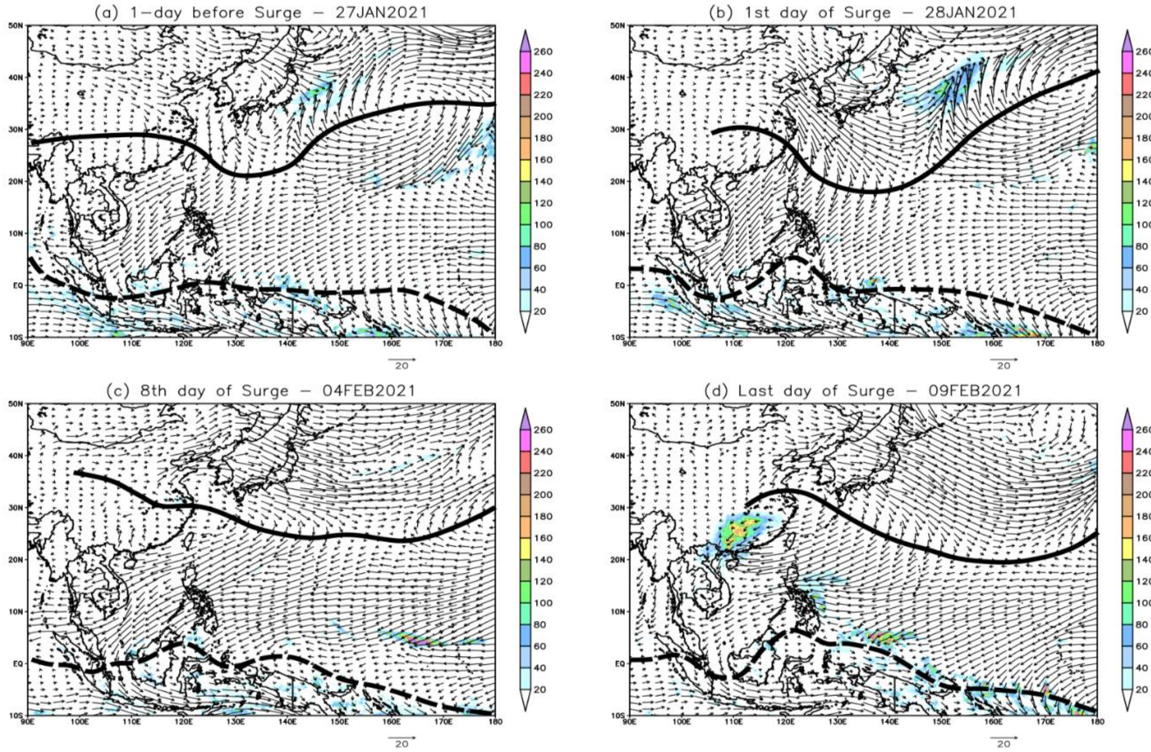

Figure 18. The daily wind at 925-hPa level and rainfall (shaded) during the nineth episode of surge (28 January – 9 February 2021). The blue-dashed line indicated the trough, while the straight-blue line indicated the ridge

The ninth episode of surge was identified as ES, which occurred from 28 January to 9 February 2021. It lasted for 13 days. During this surge (Figure 18a-d), the high pressure system persisted between 20 to 35°N, stretching from Tibetan Plateau and southeast coast of China to the WNP. Meanwhile, the monsoon trough remained between 5°N and 5°S with the cross-equatorial flow comprised between Peninsular Malaysia and Borneo. Due to a strong high pressure system developed in the east of Japan, and a low pressure system over the coastal between Taiwan and Japan, the cold surge follows an eastward path before veering at the ridge. Strong easterly winds over the equatorial WNP were maintained by the veering of strong westerlies from the anticyclone that moves eastward from the continent towards the WNP. Consequently, more easterly winds components were blown into the Malaysian region during this surge episode.

Although the surges prevailed over a longer period (13 days), due to persistent cross-equatorial flow between Peninsular Malaysia and Borneo, dry weather condition dominated most regions in Malaysia. The heavy rainfall episode occurred in western Sarawak on 4 February 2021, with a daily accumulated rainfall of 153.2 mm (Kuching). On 14 February 2021 (Figure 18d), the monsoon trough in the Malaysian region has shifted slightly to the north, within the equator and 5°N. Moisture that was transported by the easterly winds piled up over the wind convergence zone in western Borneo, and thus was conducive for the heavy rainfall growth (figure not shown).

Episode 10: 17 – 20 February 2021

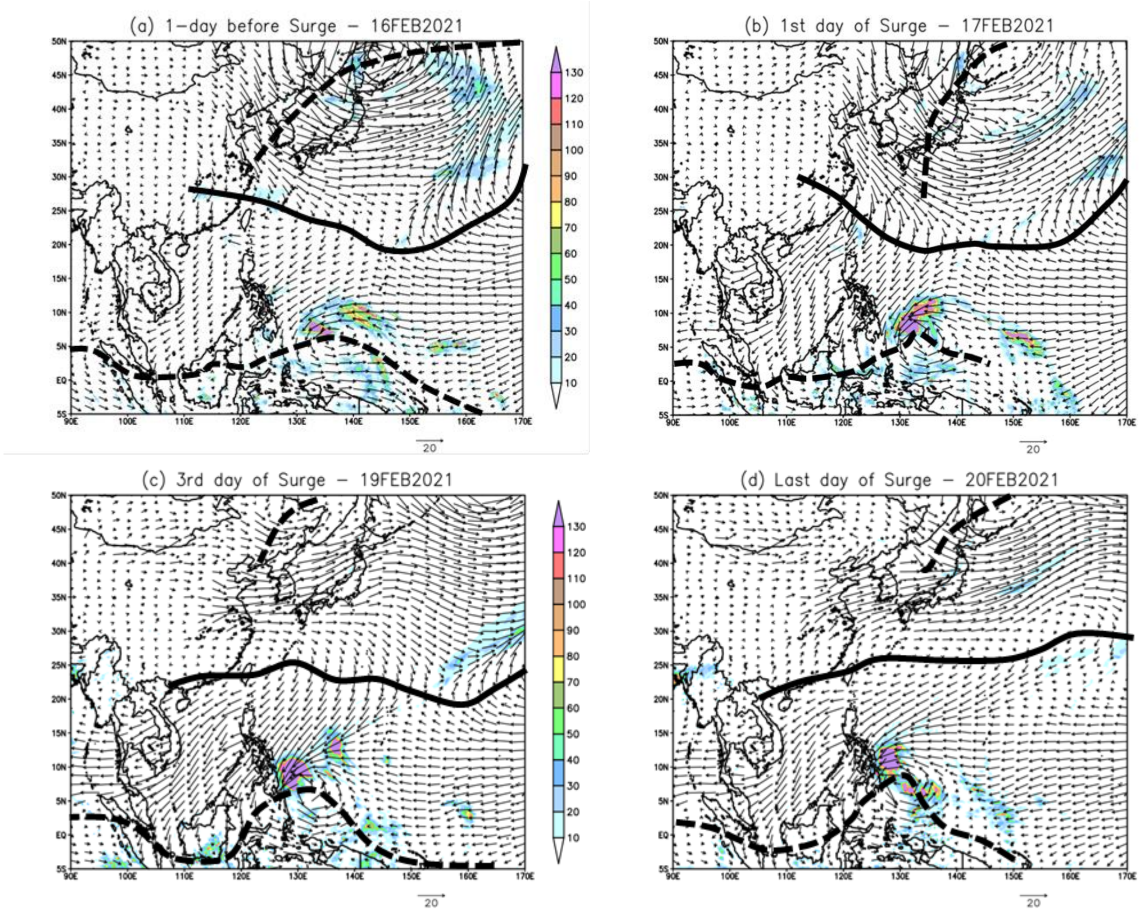

Figure 19.The daily wind at 925-hPa level and rainfall (shaded) during the tenth episode of surge (17 – 20 February 2021). The blue-dashed line indicated the trough, while the straight-blue line indicated the ridge

The tenth episode of surge was identified as MES, which occurred from 17 to 20 February 2021. It lasted for four days. During this surge (Figure 19a-d), the high pressure system stretched from central China to the WNP, between 20 and 30°N. Meanwhile, the monsoon trough remained between 5°N and 5°S with the cross-equatorial flows comprised between Peninsular Malaysia and Borneo.

On the first day of surge on 17 February 2021 (Figure 19b), the cold surges strengthened the north-easterly winds over the northern SCS, while the easterly winds from the WNP were obstructed by a cyclonic vortex which formed in the eastern Philippines. The winds speed of 10 to 20 knots was rigorous in the northern region, while it was less than 10 knots in the southern region, including Sabah and Sarawak. This created a strong shearing zone between the northern and southern region of the SCS. The winds speed in the Malaysian regions gradually increased on the second day of surge. The winds reached their peak on the third day (Figure 19c), with speeds around 20 to 50 knots. The strong north-easterly winds penetrated further south through the central region of the SCS towards the cross-equatorial flows between the terrains of Peninsular Malaysia and Borneo.

At the same period, a cyclonic vortex which initially developed in the central Pacific had increased in intensity into a tropical storm on 18 February 2021. This storm, named Tropical Storm Dujuan propagated north-westward, made landfall and dissipated over the central Philippines on 22 February 2021. The WNP easterly winds normally bring abundant moisture into the SCS. Though, during this surge, the moisture was intercepted by the tropical storm. This produced insufficient moisture into Malaysia. In addition, due to persistent cross-equatorial flow between Peninsular Malaysia and Borneo, dry weather condition dominated most of the regions in Malaysia. Nevertheless, heavy rainfall occurred in western Sarawak on 19 February 2021 due to monsoon trough in the Malaysian region has shifted slightly to the north. This created a convergence between the trough and the north-easterly winds flow near western Sarawak.

Episode 11: 3 – 11 March 2021

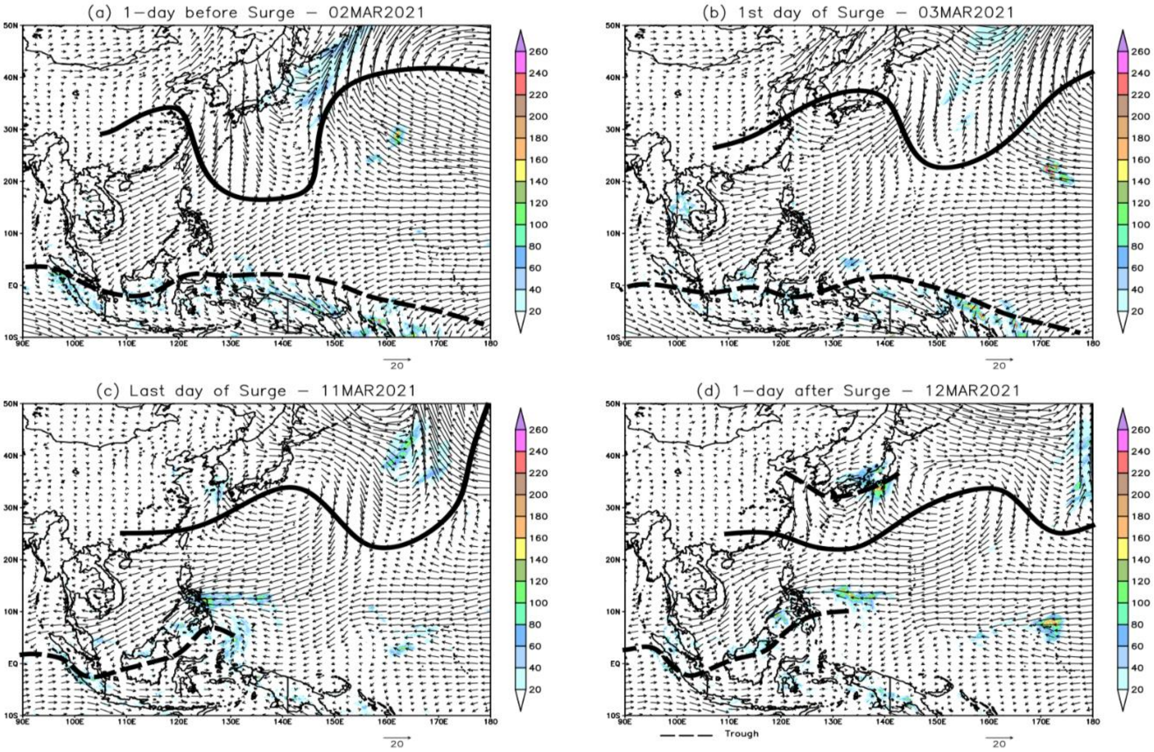

Figure 20. The daily wind at 925-hPa level and rainfall (shaded) during the eleventh episode of surge (3 – 11 March 2021). The blue-dashed line indicated the trough, while the straight-blue line indicated the ridge

The eleventh episode of surge was identified as ES, which occurred from 3 to 11 March 2021. It lasted for nine days. In general, the SMH pressure system began to weaken from March to April due to the gradual heating of the Asian landmass. Consequently, weaker north-easterly winds and stronger easterly winds components prevailed in the SCS and Malaysian region during this period.

During this surge (Figure 20a-c), there were two active high-pressure systems developed in mid-latitude. One system developed over the eastern China, while another developed in eastern Japan. A ridge fluctuated between 20 and 40°N, connecting these two high-pressure systems and extended from mainland China to the WNP. Meanwhile, the monsoon trough remained between 5°N and 5°S with cross-equatorial flow comprised between Peninsular Malaysia and Borneo. Strong easterly winds over the equatorial WNP were maintained by these high pressure systems. Consequently, the easterly winds of 20 to 40 knots dominated in the northern SCS and the north-easterly winds of 10 to 20 knots was prominent in the southern SCS and Malaysia throughout the surge period.

On 12 March 2021 (Figure 20d), the high pressure systems in mid-latitude had progressed eastwards. This caused the easterly winds in the WNP to weaken. In addition, a low-pressure system had formed in the southern Philippines. As this cyclonic system propagated north-westward, it prevented part of the easterly winds from entering the SCS. The easterly winds in the SCS were also gradually weakened, signalling the end of the surge episode in the SCS.

Episode 12: 22 – 25 March 2021

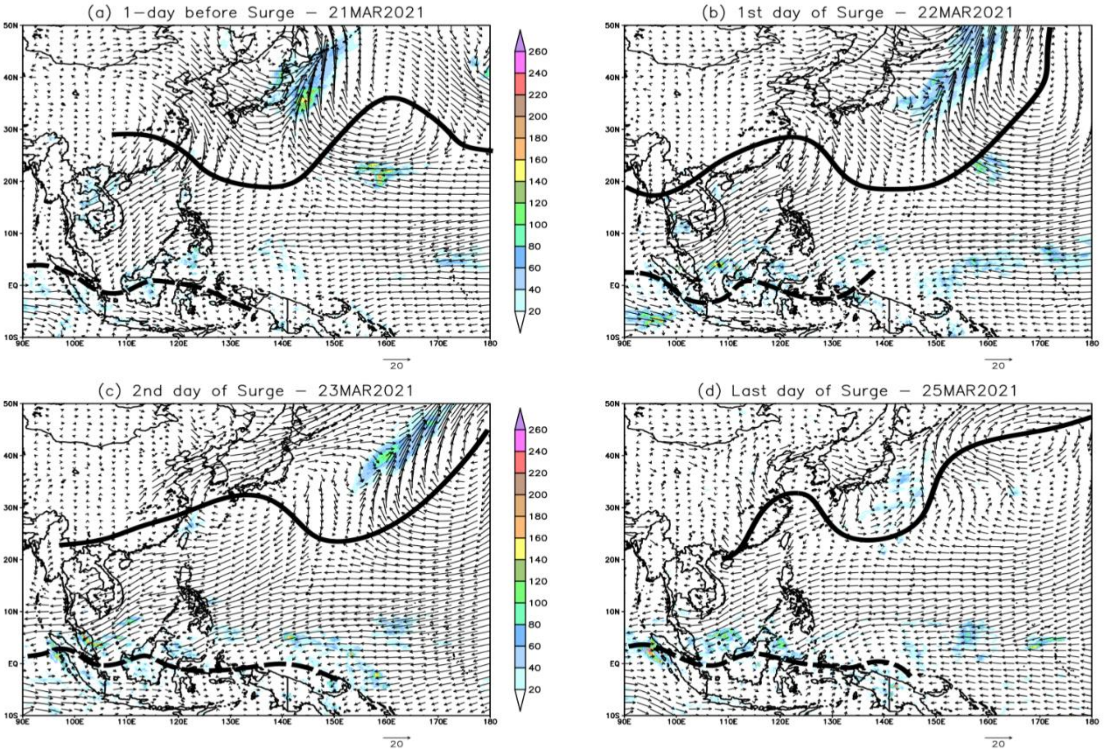

Figure 21. The daily wind at 925-hPa level and rainfall (shaded) during the twelfth episode of surge (22 – 25 March 2021). The blue-dashed line indicated the trough, while the straight-blue line indicated the ridge

The twelfth episode of surge was identified as ES, which occurred from 22 to 25 March 2021. It lasted for four days. Before the onset of surge (Figure 21a), an anticyclonic system developed in eastern China. At the same period, another active and strong anticyclonic system which had formed earlier in eastern Japan was strengthened. The high pressure system located between 20 and 40°N, connecting these two anticyclonic systems and extended from mainland China to the WNP. Meanwhile, the monsoon trough located between 5°N and 5°S with cross-equatorial flow was established between Peninsular Malaysia and Borneo. The north-easterly winds of 10 to 20 knots dominated in the SCS and Borneo, while the light north-easterly winds of 10 knots were prominent in Peninsular Malaysia.

During the surge (Figure 21b-d), as the anticyclone system in eastern Japan propagated eastward, the anticyclonic system in eastern China strengthened. This produced stronger north-easterly winds of 20 to 50 knots being blown directly into the SCS. Meanwhile, strong easterly winds over the equatorial WNP which are maintained by the anticyclonic system in eastern Japan, channelled the easterly winds of 10 to 20 knots towards SCS. During this period, the north-easterly winds over the central SCS penetrated further south to southern Peninsular Malaysia. The easterly winds were also restricted by the north-easterly winds and channel towards the equator. This contributed to the strengthening of the north-easterly winds over southern Peninsular

Malaysia. The low-level winds then interacted with the terrain, which resulted in a low-level convergence and widespread convection over the region, leading to heavy precipitation in southern Peninsular Malaysia, especially in Pahang. The enhanced convection was also related to the absence of the BV.

The intense rainfall was further enhanced on the second to last day of surge (Figure 21c-d), as the monsoon trough had shifted close to the equator. The widespread and heavy rainfall was induced by the winds convergence near the trough and increase in relative vorticity due the interaction between strong north-easterly winds and terrain over southern Peninsular Malaysia. Pahang was the most affected by the presence of this surge, with daily accumulated rainfall recorded at 267.6 mm on 23 March 2021, 105.01 mm on 24 March 2021 and 203.08 mm on 25 March 2021.

During the withdrawal of the surge (Figure 21e), the anticyclone systems in eastern Japan weaken, caused the easterly winds in the WNP also weaken. The anticyclonic system in eastern China had progressed eastwards. The north-easterly flows which were induced from this system were converted into the easterly flows. As a result, the SCS and Malaysia were dominated by easterly winds between 10 to 20 knots, and heavy rainfall was no longer developing in southern Peninsular Malaysia. In addition, a low pressure system had formed in the southern Philippines. It prevented part of the easterly winds from propagating to the SCS, also contributed to the weakening of the easterly winds penetration.

Summary of Heavy rainfall episodes associated with surges

As discussed in Section 4, some of the monsoon surges caused a series of heavy rain episodes in Malaysia. A heavy rainfall episode was said to occur when the daily accumulated rainfall during surges exceeded 150 mm at a certain observation station (Fakaruddin et al., 2020). In this analysis, the heavy rainfall events that occurred during the same dates or nearby dates were considered an episode if they occur during the same surge period.

In general, nine episodes of heavy rainfall were recorded during the 2020/2021 NEM season. Five episodes of heavy rainfall occurred in Peninsular Malaysia, while another four episodes of heavy rainfall have occurred in Sabah and Sarawak. It was revealed that three out of six episodes of ES contributed to heavy rainfall events in Kelantan, Terengganu, Pahang, Johor, Perak, Sabah, and Sarawak, while one out of four episodes of MS contributed to heavy rainfall events in Kelantan and Terengganu. This made the total number of ES and MS which contributed to heavy rainfall episodes in this season to be at 50% and 25%, respectively. Interestingly, five episodes of MES had occurred this season, and all MES episodes contributed to heavy rainfall events. This made a total of 100% of MES episodes which contributed to heavy rainfall events this season. The detailed information about the heavy rain episodes throughout the season is summarised in the Table 4.

Table 4. The heavy rainfall episodes during the NEM 2020/2021 season

Rainfall Episode	Date	Associated Surge	Area	State
First	23 – 24 Nov 2020	ES	Gong Kedak Kuala Terengganu	Terengganu
Second	27 Nov 2020	MES	Bintulu	Sarawak
Third	2 – 3 Dec 2020	MS	Kota Bharu	Kelantan
			Gong Kedak Kuala Terengganu Kerteh	Terengganu
Fourth	17 – 18 Dec 2020	MES	Kuala Krai	Kelantan
			Kerteh	Terengganu
Fifth	2 – 3 Jan 2021	MES	Batu Embun	Perak
			Muadzham Shah Kuantan	Pahang
			Kluang Senai	Johor
Sixth	11 – 13 Jan 2021	MES	Kudat, Sandakan	Sabah
			Kuching	Sarawak
Seventh	4 Feb 2021	ES	Kuching	Sarawak
Eighth	19 Feb 2021	MES	Kuching	Sarawak
Ninth	23 – 25 Mar 2021	ES	Kuantan	Pahang

Tropical Cyclones (TCs)

The NEM 2020/2021 witnessed six developments of TCs over the WNP. Two of these TCs developed into typhoon categories, which were Typhoon Goni (28 October to 5 November) and Typhoon Vamco (9 to 15 November). Based on the best track data from the RSMC, Tokyo, the record of TC during the season was close to the climatology, which was 4. The RSMC data consisted of the TCs record from 1981 to 2010.

It was observed that four of the TCs occurred during the presence of monsoon surges, which were Typhoon Goni, Typhoon Vamco, Tropical Storm Krovanh and Tropical Storm Dujuan. However, only one TC coincided with the heavy rainfall episode (8^{th} episode), which was Tropical Storm Dujuan. The best-track data showed that all of these TCs were in fact located near or pass through the surges determination areas. As for the events during Tropical Storm Dujuan, the storm weaken and dissipated over the east of the Philippines, ;therefore, the easterly surges could bring moisture towards the SCS region and enhanced the rainfall development over the region.

In general, the occurrence of TC in the SCS will interrupt the penetration of monsoon surges into the Malaysian region, and thus reduced the impact of the monsoon surges in modulating the heavy rainfall episodes. The details information about TCs and their tracks during the season is summarised in Table 5 and Figure 22**,** respectively.

Table 5. The details information of tropical cyclone (TC) that have developed in the Western North Pacific (WNP) during the NEM 2020/2021 season

No.	Name	Period	Maximum Wind near the centre (knots)	Associated Surge
1.	Typhoon Goni	28 Oct – 5 Nov 2020	120	MS
2.	Severe Tropical Storm Atsani	2 – 7 Nov 2020	50	–
3.	Tropical Storm Etau	8 – 10 Nov 2020	45	–
4.	Typhoon Vamco	9 – 15 Nov 2020	85	ES
5.	Tropical Storm Krovanh	20 – 22 Dec 2020	35	MES
6.	Tropical Storm Dujuan	18 – 22 Feb 2021	40	MES

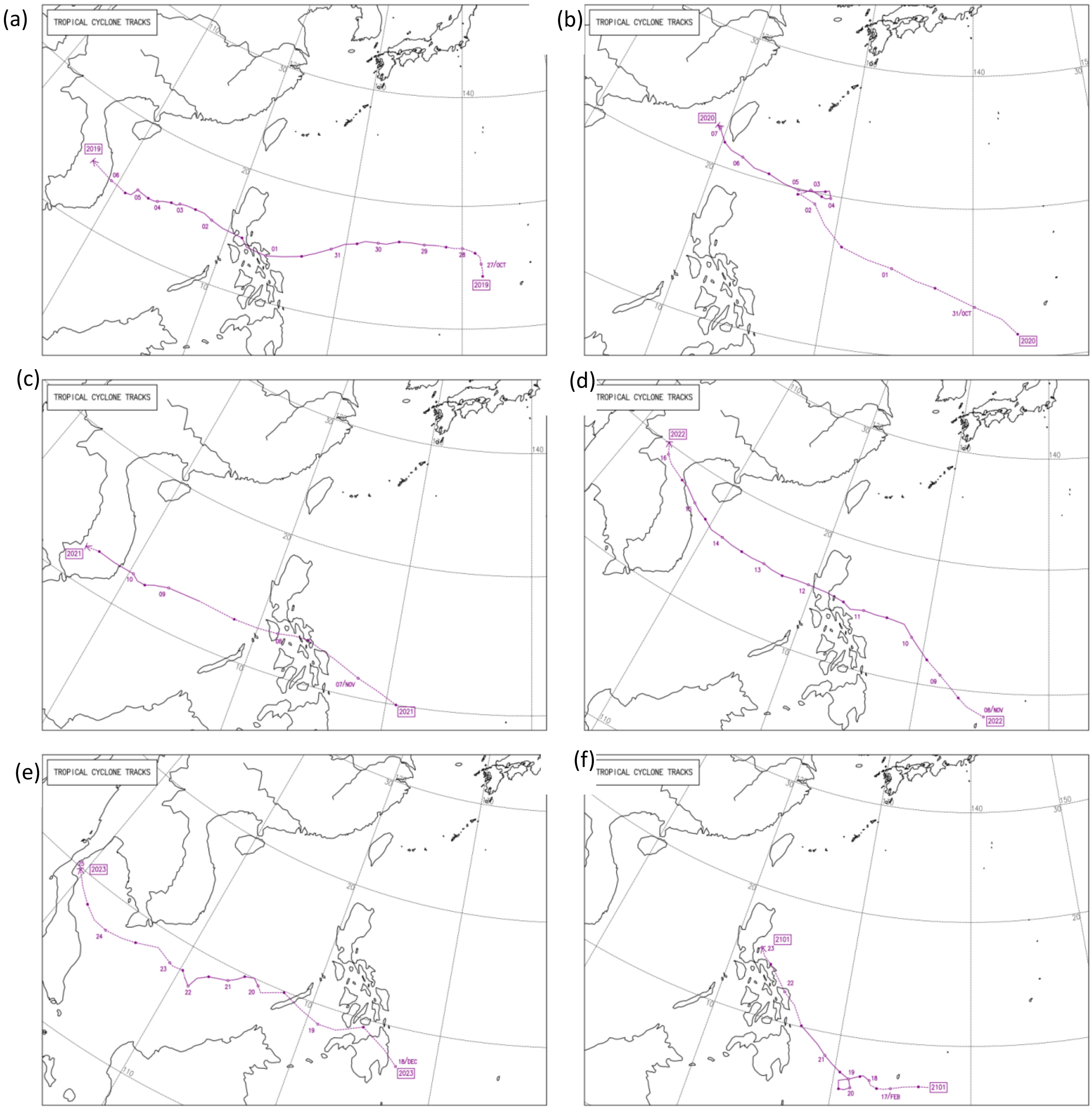

Figure 22: The tracks of (a) Typhoon Goni; (b) Severe Tropical Storm Atsani; (c) Tropical Storm Etau; (d) Typhoon Vamco; (e) Tropical Storm Krovanh; and (f) Tropical Storm Dujuan as archived from the Best-Track data of RSMC, Tokyo, JMA

Conditions of Madden Julian Oscillation (MJO), Indian Ocean Dipole (IOD) and El-Niño Southern Oscillation (ENSO)

Generally, the intra-seasonal variability in the tropics is often related to the MJO. The MJO can significantly impact surface and subsurface conditions across the Pacific Ocean. The active and weakening of the MJO events over the MC region in this study were classified based on Barrett et al. 2021. The active MJO events over the MC region were defined as events that entered Phase 4 and Phase 5 with an amplitude that was greater than 1.0. The MJO condition during the 2020/2021 NEM is depicted in Table 6. The MJO indexes depicted weak activities over the MC and SCS regions during November 2020 and January 2021. This resulted in normal weather development over these areas. Meanwhile, in mid-December 2020 and end of March 2021, there were slightly active MJ0 events over the MC and SCS regions. The active MJO events may enhance the weather development over these regions during the period. In the Indian Ocean basin, the IOD is neutral throughout the NEM2020/2021 season.

The coupled ocean-atmosphere system showed persistent La-Niña condition throughout the NEM 2020/2021 season. The analysis from the CPC, NOAA showed that during the period, the equatorial SSTs were mostly below average from the west-central to the eastern Pacific Ocean. In the meantime, the SSTs in the western Pacific Ocean were observed to be above average. The low-level easterly wind anomalies were also weak across the equatorial Pacific, while the upper-level westerly wind anomalies prevailed over most of the tropical Pacific. The analysis also showed that the tropical convection was suppressed over the western and central Pacific and enhanced around the Philippines and parts of Indonesia. It was also revealed that both of the Southern Oscillation and Equatorial Southern Oscillation strengthened during November and December 2020.

The ONI by CPC, NOAA showed a moderate La-Niña throughout this NEM season. The centre recorded ONI index values of -1.2 in September-October-November (SON), -1.3 in October-November-December (OND), -1.2 in November-December-January (NDJ), -1.0 in December-January-February (DJF) and -0.8 in January-February-March (JFM).The details ONI information during the season is summarised in the Table 7. The ONI from CPC, NOAA used a three-month running mean of SSTs anomaly for the region of Niño 3.4 (5°N – 5°S, 120° – 170°W), whereby warm (red) and cold (blue) periods were based on a threshold of +/- 0.5°C for a minimum of five consecutive readings. Meanwhile, the intensity of ENSO was categorised as weak when the values indicated weak from 0.5 – 0.9, moderate when the values indicated from 1.0 – 1.4 and strong when the values indicated from 1.5 and above (Tangang et al., 2017). Based on the data, it was a moderate La-Niña season. The wetter weather from November 2020 to January 2021 during this season might be due to the influence of moderate La-Niña. In addition, this La-Niña condition might also cause stronger easterly winds near the Equator, which had increased the number of MES.

Table 6. The MJO indexes over the MC region (Phase 4 and Phase 5) during the NEM 2020/2021 season

Period	Phase	Amplitude	Relative Intensity
24 Nov 2020 – 7 Dec 2020	4	Between 0.5 – 1.0	Weak
8 Dec 2020 – 19 Dec 2020	5	Between 1.0 – 1.6	Active
15 Jan 2021 – 18 Jan 2021	4	Between 0.5 – 0.9	Weak
28 Mar 2021 – 31 Mar 2021	4	Between 1.5 – 1.8	Active

Table 7. The ONI information during the NEM 2020/2021 season

Year	**2020**			**2021**	
Month	**SON**	**OND**	**NDJ**	**DJF**	**JFM**
ONI	-1.2	-1.3	-1.2	-1.0	-0.9

4.0 CONCLUSION

In general, the onset and withdrawal date of the 2020/2021 NEM season occurred within their normal period. The onset date falls on 11 November 2020, which was within the average period (9 November) of the climatological onset date. Meanwhile, the withdrawal date fells on 28 March 2021, which was also within the average period (22 March) of the climatological withdrawal date. The season experiences 12 monsoon surges, with nine episode of heavy rainfall that occurred due to monsoon surges.

The wind and other atmospherics analyses revealed stronger monsoon surges from November 2020 to January 2021. This condition was reflected by less interfering of TC occurrences in the SCS during this season. There was only one TC in the WNP basin which coincided with the heavy rainfall episode in Malaysia during the 2020/2021 NEM season. This was due to the storm weaken and had dissipated over the east of the Philippines. Therefore, the easterly surges could bring the moisture towards the SCS region and enhanced the rainfall development over the region.

The coupled ocean-atmospheric analysis showed a moderate La-Niña prevailed during the season. The weather condition was generally wet, especially during November 2020 to January 2021. This was probably due to the influence of moderate La-Niña. The stronger easterly winds near the MC and SCS regions during La-Niña also probably increased the number of MES.

Throughout the 2020/2021 NEM season, the MJO depicted weak activity over the MC region. This condition would lead to normal weather development in the area. However, the coupled ocean-atmospheric analysis showed a moderate La-Niña prevailed during the season. The weather conditions over Malaysia in this period were generally wet, especially during November 2020 to January 2021. This was due to the influence of the moderate La-Niña. The stronger easterly trade winds near the Equator during La-Niña might also increase the number of MES.

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