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Research Article

Climatic Factors Associated with Heavy Rainfall in Northern Vietnam in Boreal Spring

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Heavy rainfall occurs frequently in Northern Vietnam and causes severe floods and landslides. Heavy rainfall not only appears in rainy seasons (May–October) but also regularly occurs in spring (February–April). This study is devoted to identifying the climatic factors that influence the variation of rainfall, particularly heavy rainfall in Northern Vietnam in the dry season. Analysis based on the observed rainfall, PERSIANN satellite rainfall data, and ERA5 reanalysis reveals that spring should not be considered a dry season, but the first period of a rainy season in Northern Vietnam. Spring rainfall is caused by collaborative effects of cold surge, subtropical high, and the deepening of the low pressure over the Northeastern Tibetan Plateau and Bay of Bengal (BOB). Based on the composite analysis of heavy rainfall events in Northern Vietnam in the transitional season, two heavy rainfall patterns are recognized. The first is related to the southward movement of a meso-scale vortex and the cold surge, while the second one is induced by the interaction of cold surge and the deepening of an upper-level trough.

1. Introduction

Vietnam is in the transitional region of three monsoon systems, which are the India, East Asian, and Western North Pacific summer monsoon [1]. Furthermore, the topography is complex characterized by high mountains in the North, a long narrow mountain range in the Central, and a large plain in the south (Figure 1). Therefore, rainfall in Vietnam displays distinct seasonal patterns among the country's climatic subregions [2–4]. In Northern and Southern Vietnam, substantial rainfall is observed in summer months (May to October), coincident with tropical westerlies over these regions [2, 5, 6]. However, in Central Vietnam, summer is a hot and dry season because of the Foehn effect on the leeward side of the Truong Son mountain range. The rainy season in this subregion begins in October, when the maximum convection moves southward and the Asian summer monsoon changes into the Asian winter monsoon [7, 8].

Northern Vietnam is one of the most densely populated areas in Vietnam with many key economic zones. However, the subregion frequently experiences substantial floods caused by heavy rainfall [9–11]. In some heavy rainfall events, the total rainfall might reach over 1000–1500 mm, for example, during the heavy rainfall event from late July to August 2015 in Quang Ninh or the event in October 2008 in Hanoi [10, 11]. The heavy rainfall triggers landslides, which lead to severe infrastructure damage and loss of life, especially in mountainous areas. Therefore, identifying the mechanisms that are responsible for the occurrence of heavy rainfall has crucial socioeconomic importance for the subregion.

One of the major factors inducing heavy rainfall in Northern Vietnam is tropical cyclones (TCs). In general,

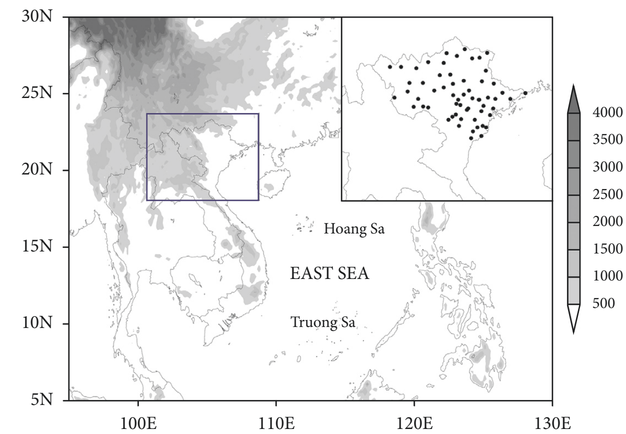

Figure 1: Geographical location of the study region, topography height (*shaded; m*), and selected meteorological observation stations (*closed circles*).

high TC frequently occurs in Northern Vietnam from May to November and the contribution of the TC rainfall to total rainfall can reach up to 15–20% [12]. However, almost all heavy rainfall events in the subregion are induced multiple-scale processes. Various tropical and extratropical synoptic systems affect the study region. From climatological perspective, Tuan [6] emphasized that heavy rainfall in Northern Vietnam is strongly modulated by the mutual interactions of large-scale subtropical wave and tropical disturbances. Xu et al (2009) also noticed that the Mei-Yu front and its associated meso-scale convective system frequently cause heavy rainfall in Northern Vietnam although it mainly affects Southeastern China and Taiwan.

The detailed mechanisms of some heavy rainfall events in Northern Vietnam were also investigated. Wu et al. [11] pointed out that the rainfall event in Hanoi from October to November 2008 was induced by the interaction of a tropical disturbance and cold surge. The disturbance was a part of a synoptic-scale tropical wave disturbance, which originated in the warm oceanic area to the south of the ES. When the disturbance traveled northwestward and approached Central and Northern Vietnam, heavy rainfall was generated over a large area for many consecutive days. Meanwhile, a large anticyclone associated with a cold air mass moved southward from Mainland China to Northern Vietnam. To the south of the air mass, persistent northeasterly flow was enhanced, which strengthened the low-level convergence of the preexisting disturbance. As a result, a large amount of moisture was transported from the ES into the study region to induce heavy rainfall there.

In a rainfall event over Northern Vietnam in August 2015, van de Linden et al. [10] revealed that the strong convection during the event was induced by a surface low in the Gulf of Tonkin. When the low moved slowly westward, the associated generated convergence initiated the heavy rainfall in the subregion. The major moisture source of the heavy rainfall event was maintained by the strong southwesterly flow, which was associated with a monsoon depression over the Bay of Bengal (BOB). It was emphasized that the low in the Gulf of Tonkin was linked with the retrogression of a 200 hPa subtropical trough, which was located over Southern China; therefore, the trough can be considered the indicator of extreme rainfall in Northern Vietnam. The representation of heavy rainfall event by numerical models can therefore be evaluated in connection with the prediction of the appearance and position of the trough.

Chen et al. [9] pointed out that the most important feature of the heavy rainfall in Northern Vietnam in December 2008 was the interactions of three different monsoon modes, namely, easterly disturbance (5-day mode), cold surge (12–24-day mode), and the Madden–Julian Oscillation (MJO) (30–60-day mode). At first, the interaction of the cold surge and the easterly disturbance led to a cold surge vortex, which is considered the most direct factor inducing heavy rainfall in the subregion. Second, the MJO created a large cyclonic shear flow in the Southeast Asia, which favored intensification of the cold surge vortex. Furthermore, positive sea surface temperature (SST) anomalies over Western North Pacific (WNP) induced an anomalous anticyclone, which facilitated the northward propagation of the vortex. That explains the occurrence of heavy rainfall far to the north in Hanoi over the past three decades.

These past studies have been conducted to investigate the mechanisms of extreme rainfall events in Northern Vietnam during the rainy seasons (May–October). In boreal spring (February–April), the prevailing of the cold air mass sets up a relatively stable environment, which is not favorable for the occurrence of deep convection in the study region [3,8]. Therefore, spring is often considered the dry season in Northern Vietnam and the rainfall variations in this season gain less attention. However, heavy rainfall and even hail sometimes occur in this season causing severe disasters. Therefore, this study is devoted to exploring the climatic factors, which are responsible for the occurrence of the rainfall in the subregion and why heavy rainfall can occur in such an unfavorable environment. Section 2 describes the data and methodology used in this study. The climatological mean of large-scale patterns and rainfall in spring in Northern Vietnam are addressed in Section 3. The large-scale circulation characteristics associated with the selected heavy rainfall events are analyzed in Section 4. Finally, conclusions are given in Section 5.

2. Data and Methodology

2.1. Data. The major dataset used in this study is the daily rainfall data measured at 60 surface stations in Northern Vietnam (Figure 1). The other rainfall data are the daily PERSIANN satellite rainfall [13], which is used to investigate the large-scale rainfall distribution. The ERA5 wind, geopotential height, and convective available potential energy (CAPE) were retrieved from the Copernicus Climate Change Service (C3S) Climate Data Store [14]. The daily ERA5 data were averaged from 0000, 0600, 1200, and 1800 UTC. The reanalysis data and the PERSIANN data were at 0.25×0.25 latitude-longitude resolution. Because the PERSIANN data began in 1983, the study time is restricted to 1983–2018.

2.2. Methodology. A heavy rainfall event is classified if rainfall of greater than 95th percentile is observed in at least 10 stations. As can be seen in Figure 2, the 95th percentile rainfall values are mostly excess 16 mm day^{-1}, which is considered the criteria of heavy rainfall in Vietnam. The 10-station criterion is used to exclude local heavy rainfall events such as thunderstorms. In the period from 1983 to 2018, there were 136 classified heavy rainfalls. These events were investigated extensively and classified subjectively into different synoptic groups based on their major forcing (i.e., cold surge, low-level vortex, and upper-level trough). The detailed mechanisms of each synoptic group were then explored based on composite technique.

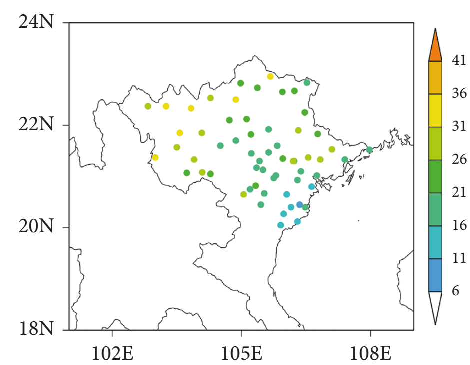

Figure 2: Composite of rainfall value at 95th percentile at Northern Vietnam stations from 1983 to 2018.

3. Large-Scale Pattern and Climatic Features of Rainfall

In this section, the characteristics of large-scale patterns over Northern Vietnam in Northern spring are explored to identify the key climate factors that are responsible for the occurrence of rainfall in the period. We also distinguish the nature of spring to early-summer rainfall in the subregion from that in the surrounding subregions. In general, spring is considered the dry season in Northern Vietnam because of the prevailing of cold air mass, which is unfavorable for the development of cumulus convection [2,3]. Because of the important of rainfall to the socialeconomic activities, rainfall is often used as an only indicator to determine the summer monsoon onset all over Vietnam [1, 5, 7, 15]. The results pointed out that the onset of summer rainfall in Northern and Southern Vietnam occurs in late April and mid-May. However, the earlier occurrence of rainfall in the northern regions is not consistent with the fact that the onset of the Asian summer monsoon is associated with the northward propagation of tropical rain bands from equatorial regions [16–18]. Therefore, there is another mechanism responsible for the early occurrence of rainfall in Northern Vietnam that might be not identified.

It can be seen that in February, the most prominent feature of large-scale circulation over the southeast of Asia is the domination of the anticyclonic circulation associated with the WNP subtropical high (Figure 3(a)). Northern Vietnam is mostly under the influence of strong southwesterly and descending motion in the northwestern flank of this high. The study region is also partly affected by a low pressure in the Southeast Tibetan Plateau. This low helps to enhance the southwesterly wind and establish a region of strong convergence, which is an important factor for the development of rainfall in the following months. In the mean sea level pressure pattern, a large high pressure prevails from Northeast China to the ES and Indochina Peninsula (IP), which reflects the penetrations of cold surge from Siberia into these regions. In the Northern ES, strong northeasterly wind is consequently induced; however, the flow is mainly directed equatorward instead of to Northern Vietnam. Therefore, less moisture is transported into the subregion and the atmospheric condition is relatively cold and dry at this time. Heavy rainfall is only found in the region from Southeastern China, across Japan to the north of Pacific Ocean that is induced mainly by the convergence of the cold air mass and the warm-moist flows northwest of WNP subtropical high [19, 20].

In March, while the WNP displays a slight southeastward movement, the low-pressure system deepens and influences the atmospheric conditions in Northern Vietnam. There is also a deepening of a low pressure over the northern BOB that enhances the westerly wind to the south of it. As a result, more air is drawn in, enhancing the convergence into the subregion (Figure 3(b)). At 1000 hPa level, the high pressure over the northeast of China weakens and skews to the east, leading to the wind change over the Northern ES. The wind direction is thus, changed from northeasterly to easterly wind, which helps to transport more moisture into Northern Vietnam. It should be noted that the 850 hPa southwesterly flow from the northwestern flank of the WNP subtropical high and BOB is also ascribed to bring additional moisture from the oceanic region to the subregion. This pattern suggests that the low-level condition is conductive for the establishment of rainfall there. As a result, rainfall of around 50 mm a month^{-1} starts to occur in the northernmost of the subregion and it is one of the earliest onset of rainfall in Vietnam. Meanwhile, in Southern Vietnam, the WNP subtropical high still occupies and sets up dry conditions there.

In April, while the WNP subtropical high continues to withdraw to the east, the two lows deepen and dominate Northern Vietnam. At 1000 hPa, the northeasterly wind is changed into easterly wind, allowing for abundant amount of moisture supplied from ES to the subregion (Figure 3(c)). As a result, rainfall becomes more intense there with the rainfall average exceeding 100 mm month^{-1}. Therefore, spring cannot be considered as dry season in Northern Vietnam. It can be seen that rainfall simultaneously starts to outburst in Southern Vietnam and other regions of the IP. However, the increment of rainfall in Northern Vietnam is favored by collaborative effects of the extratropical westerly wind, the cold surge, and subtropical high. Meanwhile, the rainfall in the mainland of the IP is related to the deepening of a trough of 300 hPa [21] and tropical disturbances [22]. Thus, the nature of the spring to early-summer rainfall in Northern Vietnam is distinct from the surrounding regions although they are merged.

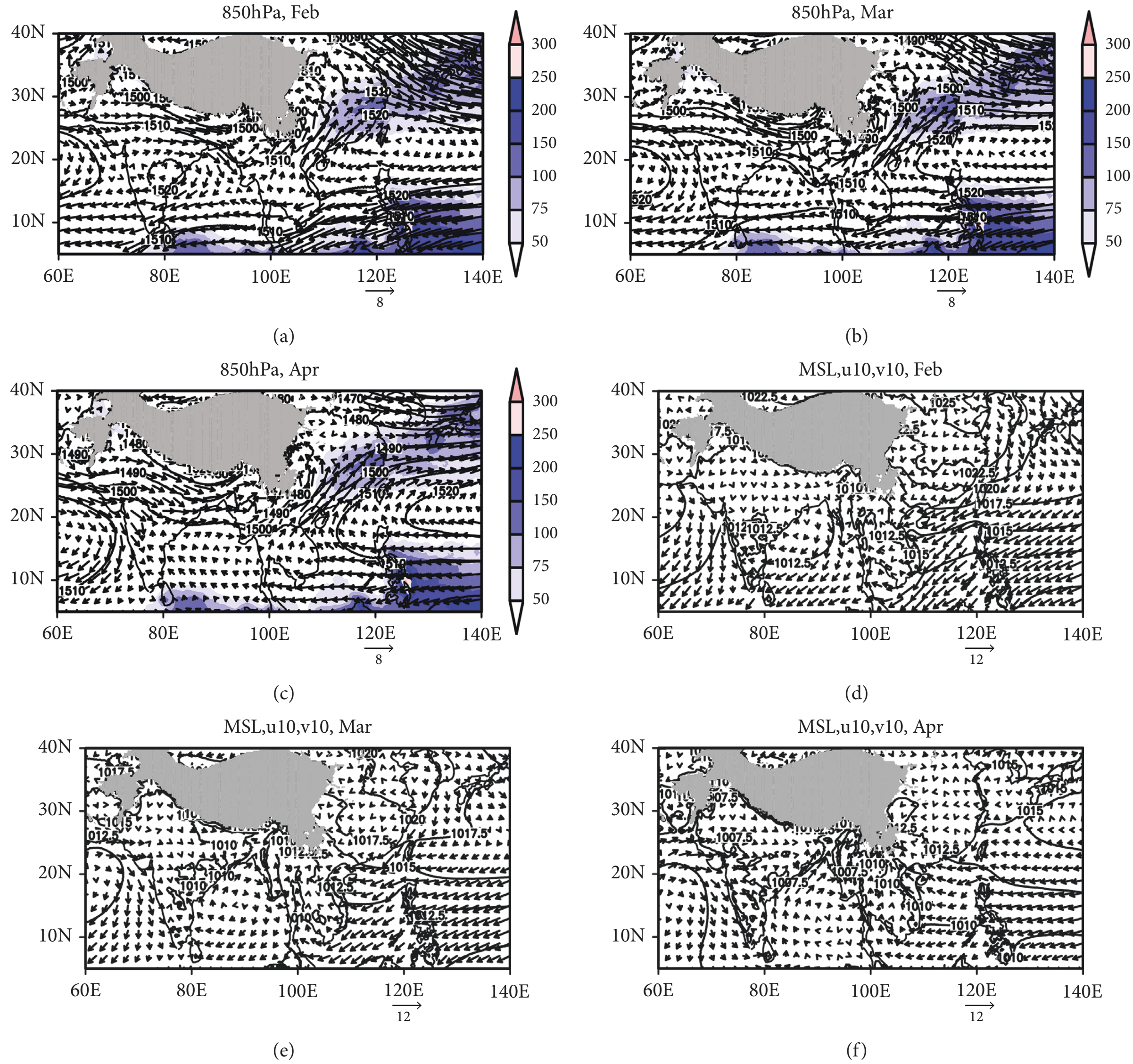

FIGURE 3: Climatology mean of rainfall (*shaded*, mm month^{-1}), 850 hPa wind (*vector*, m s^{-1}), geopotential height (*contour*, *(m)* (a–c) *and mean sea level pressure (contour, m),* and 10 m wind (*vector*, m s^{-1}) (d–f). The areas where the land elevation is higher than 1500 m are shaded gray.

4. Classification of Heavy Rainfall Patterns

4.1. Cold Surge and the Southward Movement of Low-Level Vortex. From 1983 to 2018, there were 71 heavy rainfall events in Northern Vietnam that were related to the southward movement of low-level vortex. The composite of observational rainfall during the events is displayed in Figure 4. It can be seen that light rain with the value of 6–11 mm day 1 started to occur in the northwest area on day 2, and it then gradually expanded eastward and southward on day 1. On day 0, there was a sharp increase of rainfall at almost every station with some values, which can reach over 36 mm day 1. However, the rainfall then suddenly ceased on day +1 and was only observed at three stations in the northwest subregion.

In some events, rainfall can reach extremely high values, for example, on the heavy rainfall event on 26 April 1999 (Figure 5). Some extreme values are 145 mm day^{-1} (Bac Quang), 128 mm day^{-1} (Ha Giang), 121 mm day^{-1} (Yen Bai), and 82.1 mm day^{-1} (Hoa Binh). The rainfall of greater than 50 mm day^{-1} first occurred in the northernmost area on 25 April and expanded southward on 26 April. After reaching its peak on 26 April, the rainfall decreased in the following days. On 27 April, although rainfall of greater than 20 mm day^{-1} was still observed in more than a half of the total stations, the values of greater than 50 mm day^{-1} only concentrated in the stations in Southern areas. By 28 April, rainfall was ceased in almost all the stations, marking the end of the event.

The large-scale pattern associated with the rainfall events is displayed in Figure 6. On day 3, a meso-scale vortex associated with a low is evident in the east of the Tibetan Plateau. Days later, the vortex propagated southward along the eastern side of the Tibetan Plateau, followed by heavy

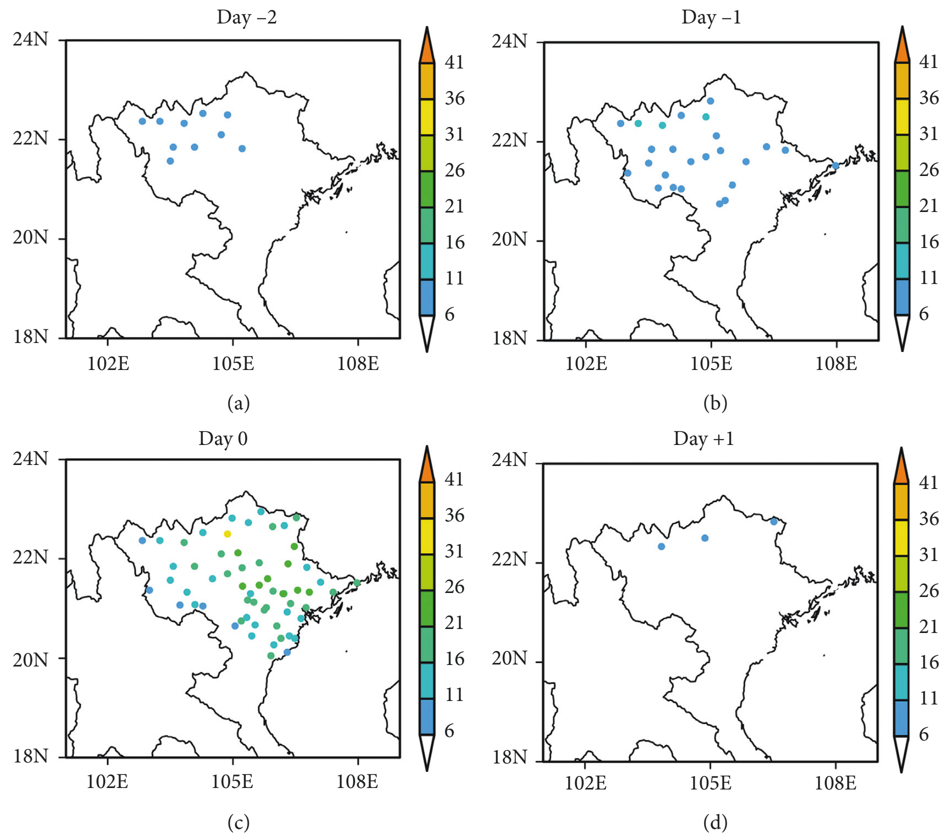

FIGURE 4: Composite of rainfall at Northern Vietnam stations (*shaded*, mm day 1) during the events associated with cold surge and low-level vortex.

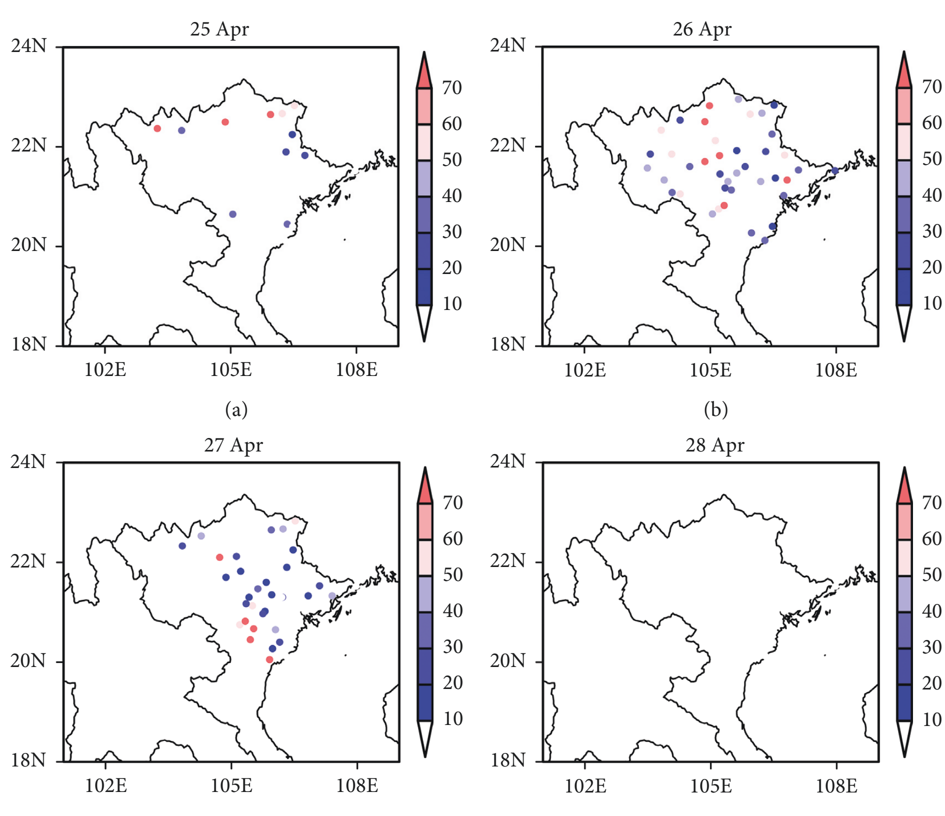

FIGURE 5: Daily rainfall at Northern Vietnam stations (*shaded*, mm day 1) from 25 to 28 April 1999.

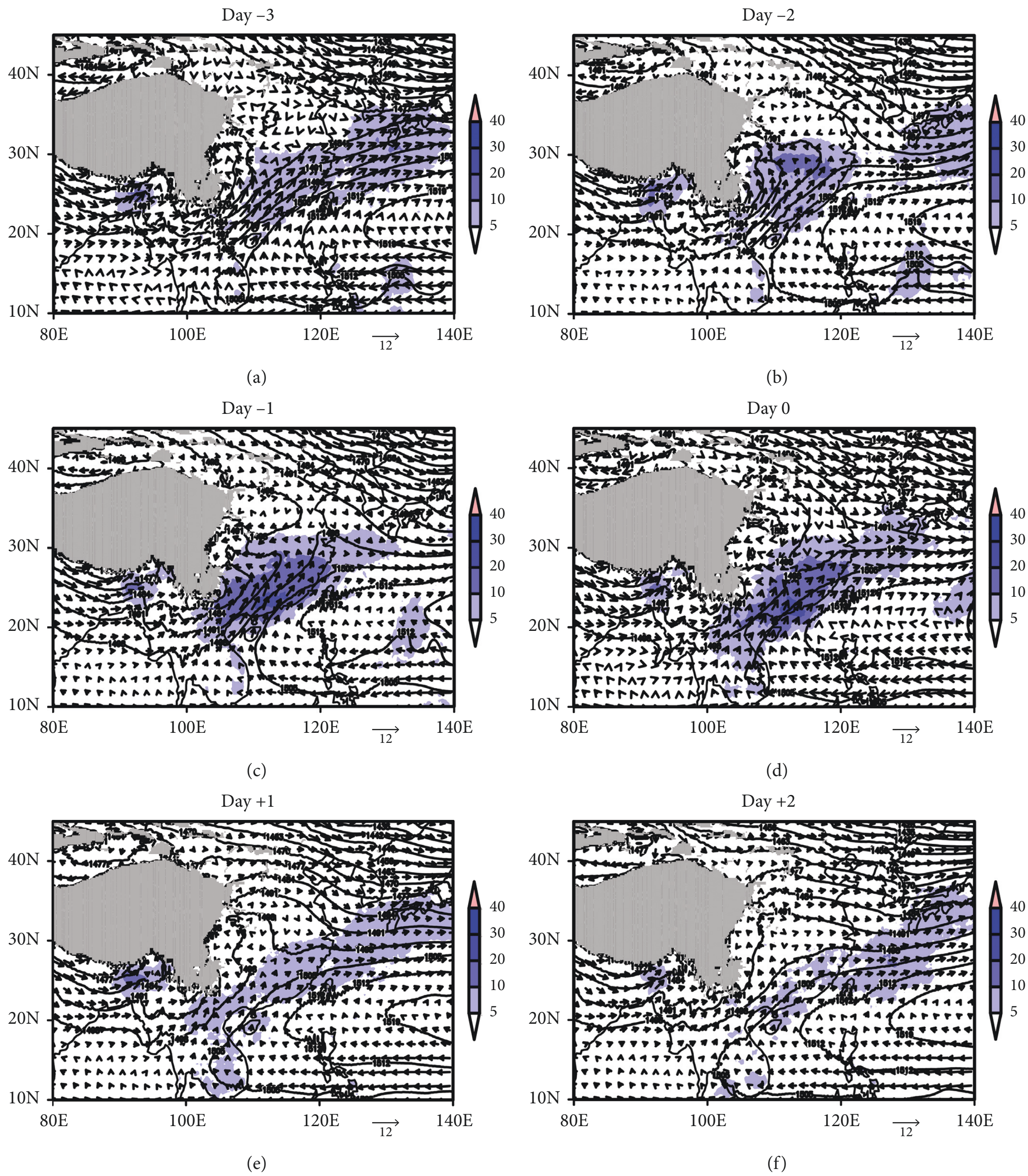

Figure 6: Composite of 850 hPa wind (*vector*, m s^{-1}), geopotential height (*contour*, m), and PERSIANN rainfall (*shaded*, mm day^{-1}) during the events associated with cold surge and low-level vortex. The areas where the land elevation is higher than 1500 m are shaded gray.

rainfall. The vortex approached Northern Vietnam on day 2, consistent with the occurrence of heavy rainfall in the mountainous region. On day 0, while the vortex lost its structure and gradually dismisses, the rainfall still maintained in Northern Vietnam. Finally, the rainfall disappeared on day +2, concurrent with the ending of rainfall in Northern Vietnam.

The formation of the vortex might relate to the lee cyclogenesis of the Tibetan Plateau. As strong wind blows from the west to the east over the Tibetan Plateau, mountain waves and downslope winds are generated. This downslope wind causes larger separation between the isentropic in the upper- and lower-level troposphere. It should be noted that this separation indicates increasing static instability and vertical stretching, thus inducing the low-level vortex. Accordingly, strong convergent wind and its associated heavy rainfall center are observed in the area to the south of the vortex.

There are other major factors contributing to the cold surge from extratropics. As displayed in Figure 7, a large high-pressure system is established over the Yellow Sea on day 3. On day 2, the high-pressure center approaches East

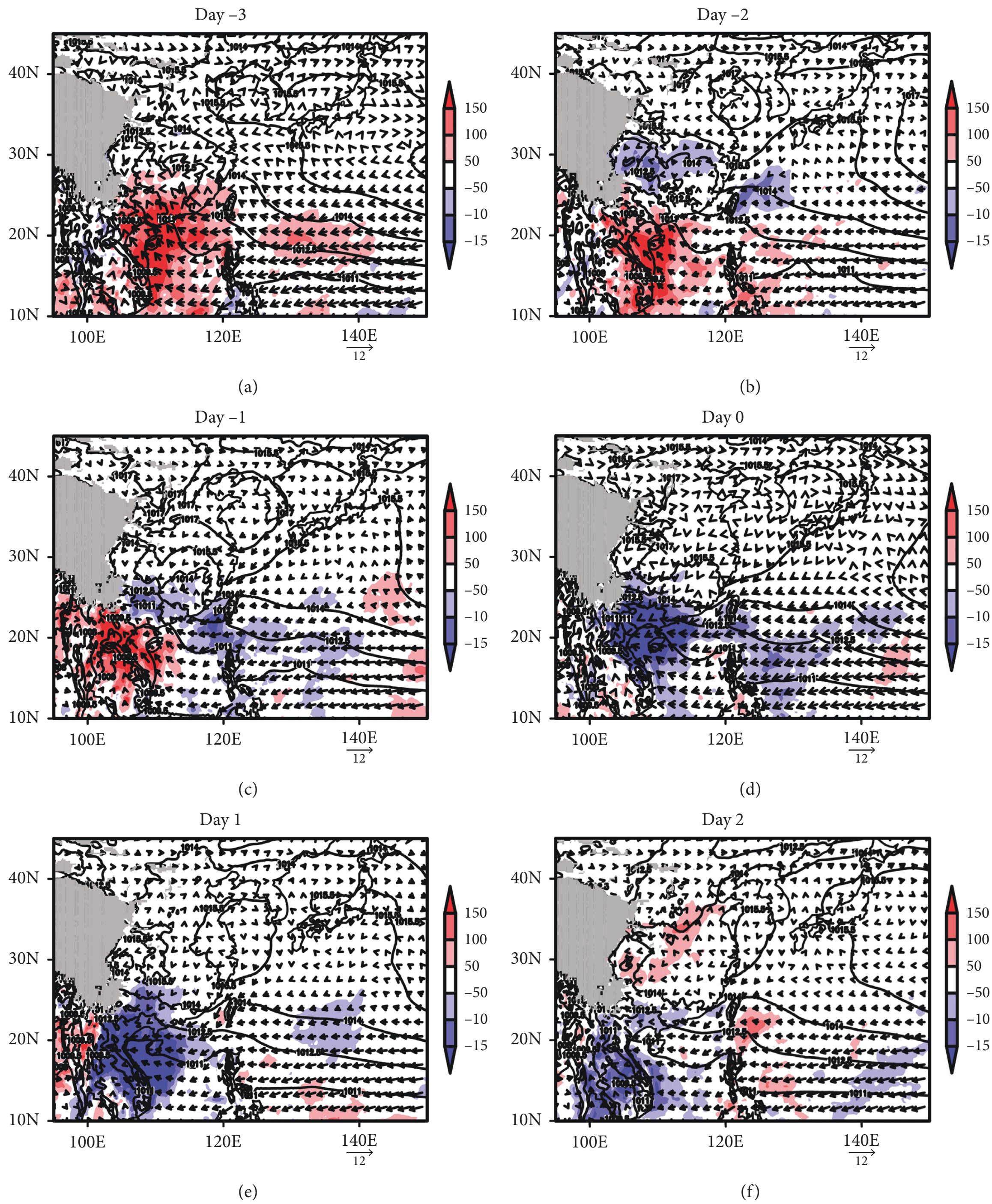

FIGURE 7: 10 m wind (*vector*, m s^{-1}), mean sea level pressure (*contour*, m), and time rate change CAPE (*shaded*, J kg^{-1}) during the events associated with cold surge and low-level vortex. The areas where the land elevation is higher than 1500 m are shaded gray.

China Sea and gradually expands to the south, leading to the formation of a northeasterly wind of the East Sea (ES). Although the high system is not very strong, its associated front evidently helps to maintain the northeasterly wind throughout the whole period. As a result, rich moisture is supplied continuously from the ES into Northern Vietnam, causing heavy rainfall. It is important to note that the high mountain ranges in the Northwest and Northeast subregions play a role as natural barriers that force the low-level wind (both easterly and westerly wind) to be upward.

Additionally, there was a substantial increase of CAPE ahead of the high system from day 3 to day 1, indicating the boost up of potential instability related to the movement of the cold air mass (Figure 7). This increment of CAPE probably helped to trigger the light rainfall in the northern areas on day 2 to day 1. However, from day 0 afterwards, the

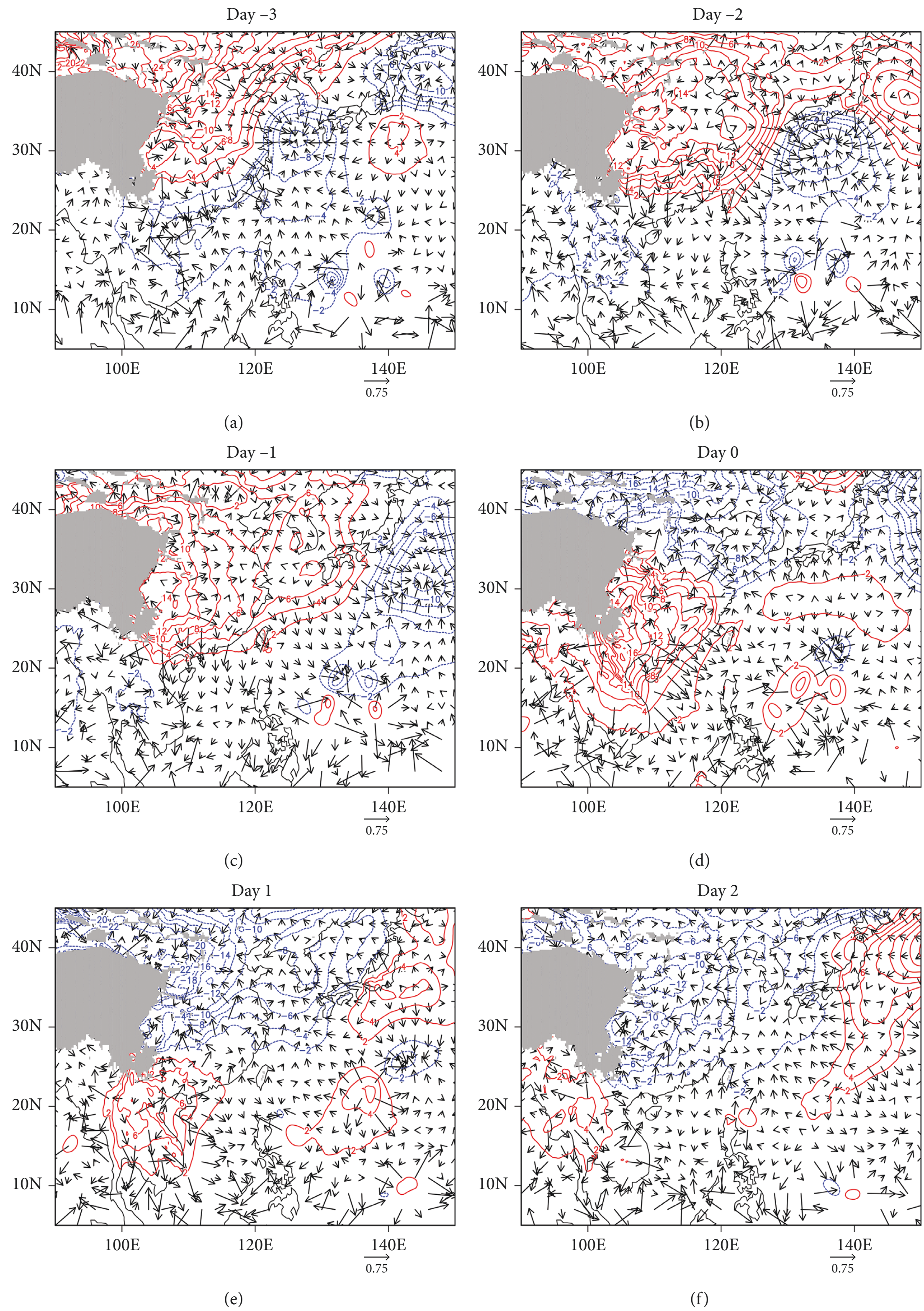

Figure 8: Composite of time rate change mean sea level pressure (*contour*, m) and isallobaric wind (*vector*, m s^{-1}) during the events associated with cold surge and low-level vortex. The areas where the land elevation is higher than 1500 m are shaded gray.

CAPE showed a sudden decrease after the domination of cold air over Northern Vietnam. Therefore, the potential instability associated with the cold surge did not contribute to the formation of the heavy rainfall on day 0. In contrast, the drop of CAPE was the main cause of the sudden cease of rainfall in the subregions on day +1.

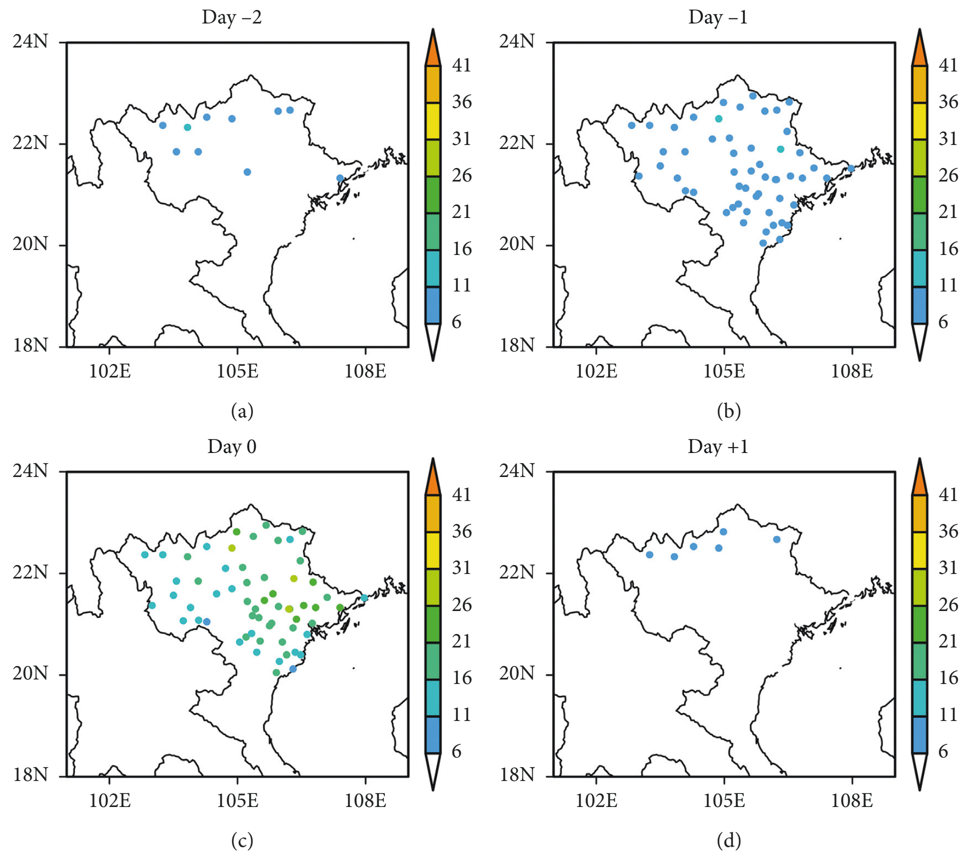

Figure 9: Same as Fig. 4, except for during the events associated with cold surge and upper-level trough.

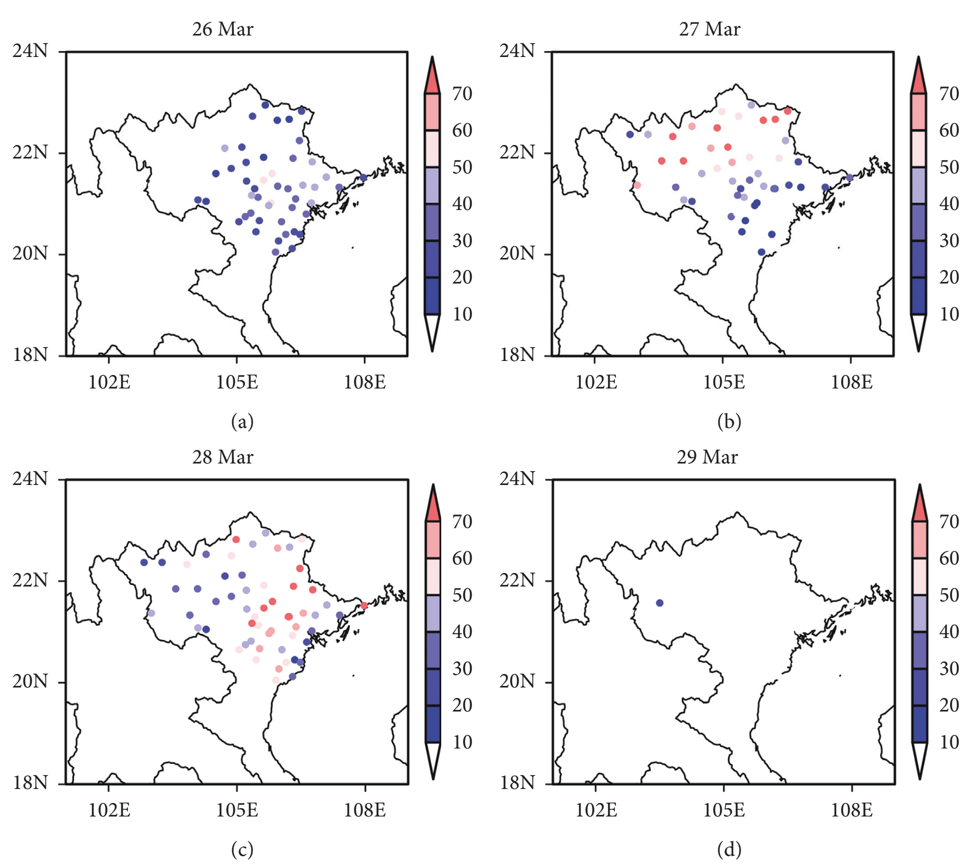

Figure 10: Same as Fig. 5, except for the period from 26 to 29 March 1999.

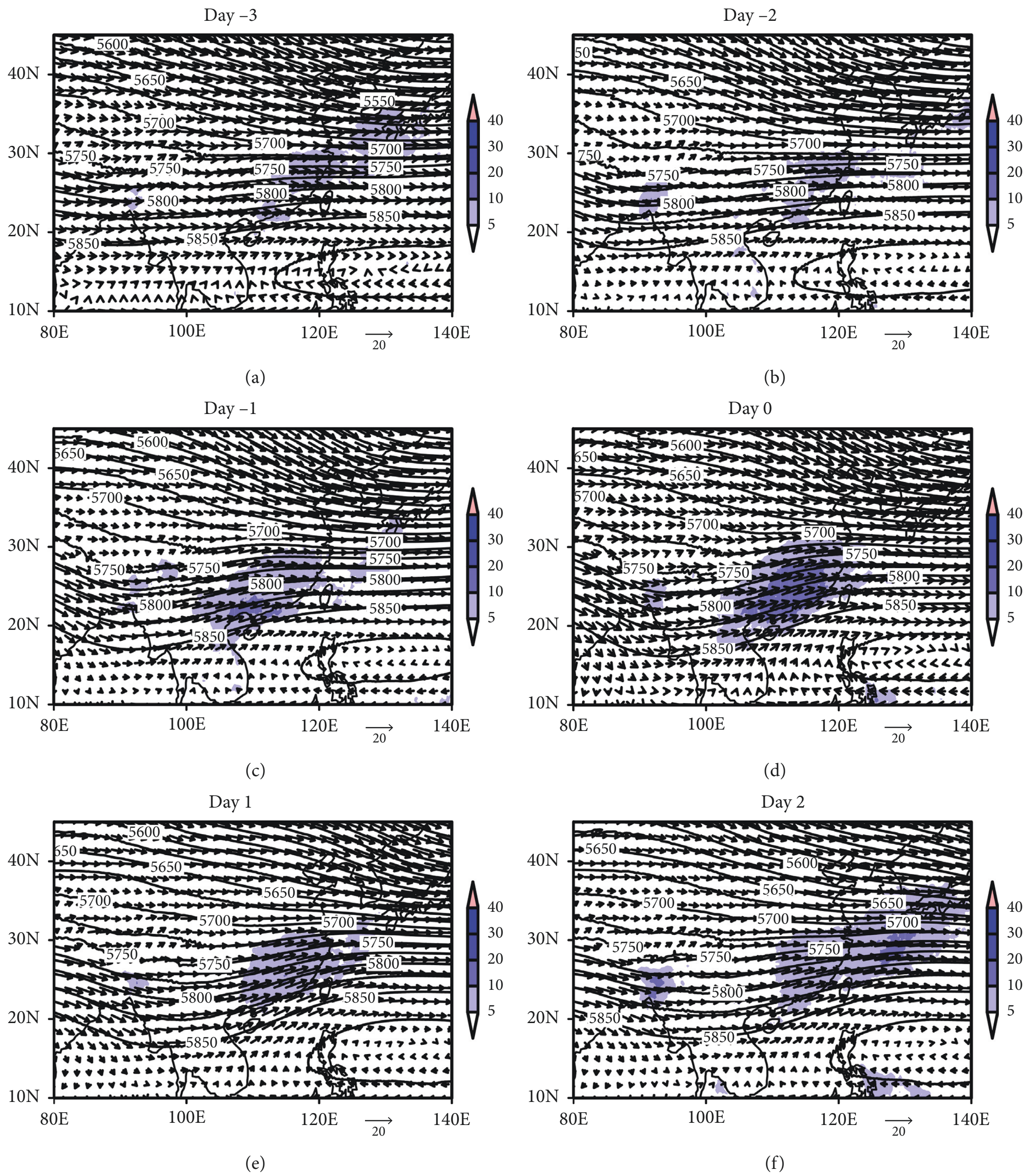

FIGURE 11: Composite of 500 hPa wind (*vector*, m s^{-1}), geopotential height (*contour*, m), and PERSIANN rainfall (*shaded*, mm day^{-1}) during the events associated with cold surge and upper-level trough.

It is worthy to note that the convergence of ageostrophic isallobaric wind was pointed out as the major cause triggering deep convection ahead of cold front [23]. Isallobaric wind is a component of ageostrophic wind that blows from regions of pressure rises to regions of pressure falls. Although the isallobaric wind is weaker than the geostrophic wind, it leads to the equatorward deflection of near-surface wind over the Northern ES and Northern Vietnam. As displayed in Figure 8, along with the southward propagation of the high system, strong isallobaric wind was directed from Southern China towards Northern Vietnam from day 3 to day 1. The convergence of isallobaric wind probably favored for the development of the light rainfall over the subregions. However, on day 0, the isallobaric wind was blown outward of Northern Vietnam due to the arrival of the high-pressure system. Therefore, the isallobaric wind also did not contribute to the formation of heavy rainfall on day 0 in the subregions.

4.2. Cold Surge and the Deepening of Upper-Level Trough (27–28 March 1996). From 1983–2018, there were 67 heavy rainfall events related to the interaction between cold surge

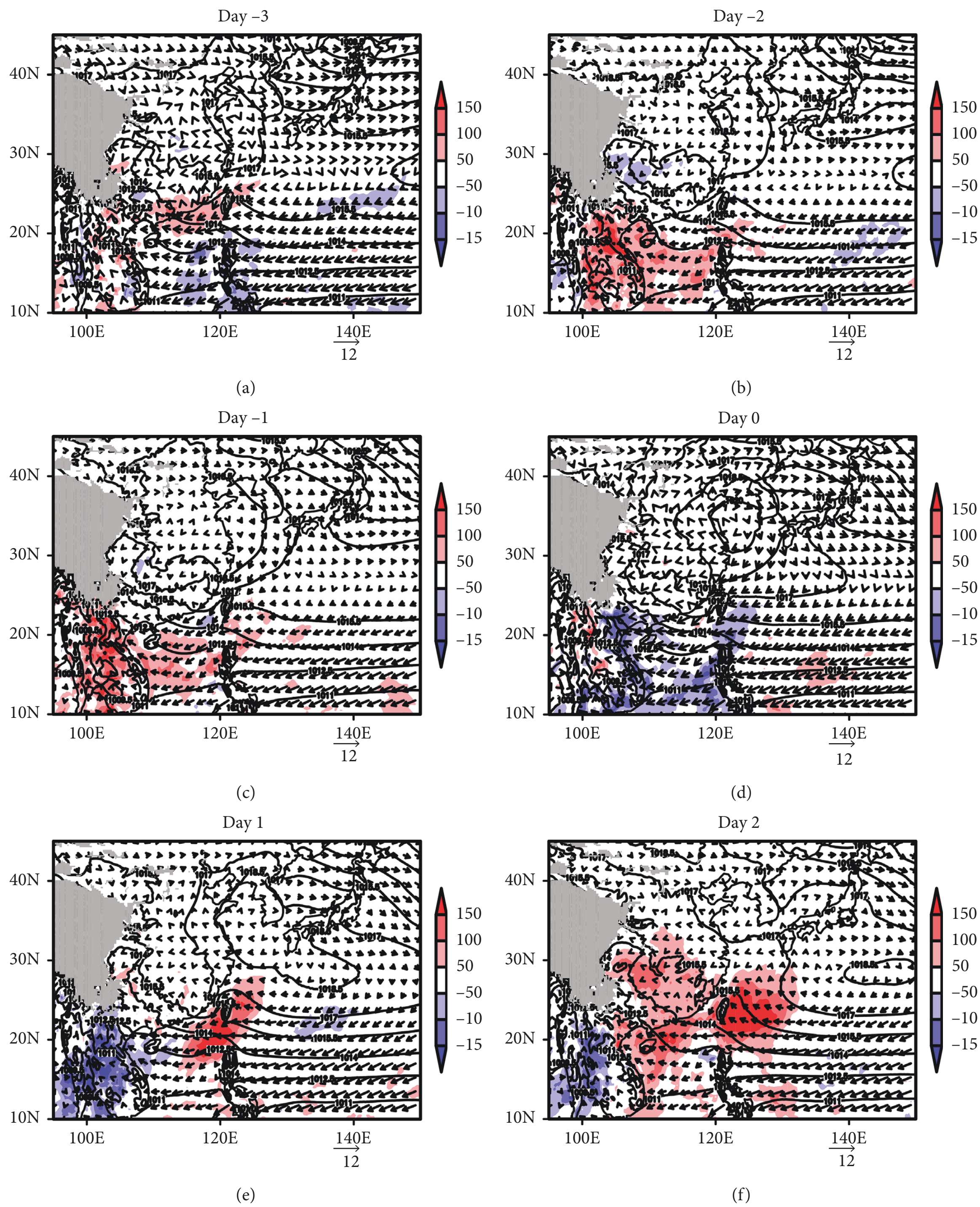

Figure 12: Same as Fig. 7, except for during the events associated with cold surge and upper-level trough.

and deepening of upper-level trough in Northern Vietnam. Especially, in the cases of 11 April 1998 and 9 April 1985, there were co-occurrences of the upper-level trough and the low-level vortex. The composite of observational rainfall during these events is displayed in Figure 9. It also can be seen that rainfall first occurred in the mountainous areas on day 2 and it then expanded rapidly southward and eastward on day 1. On day 0, heavy rainfall appeared dramatically in almost all stations. However, on day +1, rainfall also displayed a sudden drop, same as in the cases of cold surge and low-level vortex.

In some events, the collaborative effect of cold surge and upper-level trough could lead to extremely high rainfall in Northern Vietnam. For example, on 27 March 1999, there were 28 stations (nearly half of the total number of stations) whose observed rainfall values were greater than 50 mm day^{-1} (Figure 10). Some extremely high values are 130.3 mm day^{-1} in Nguyen Binh, 115 mm day^{-1} in Cao Bang on 26 March,

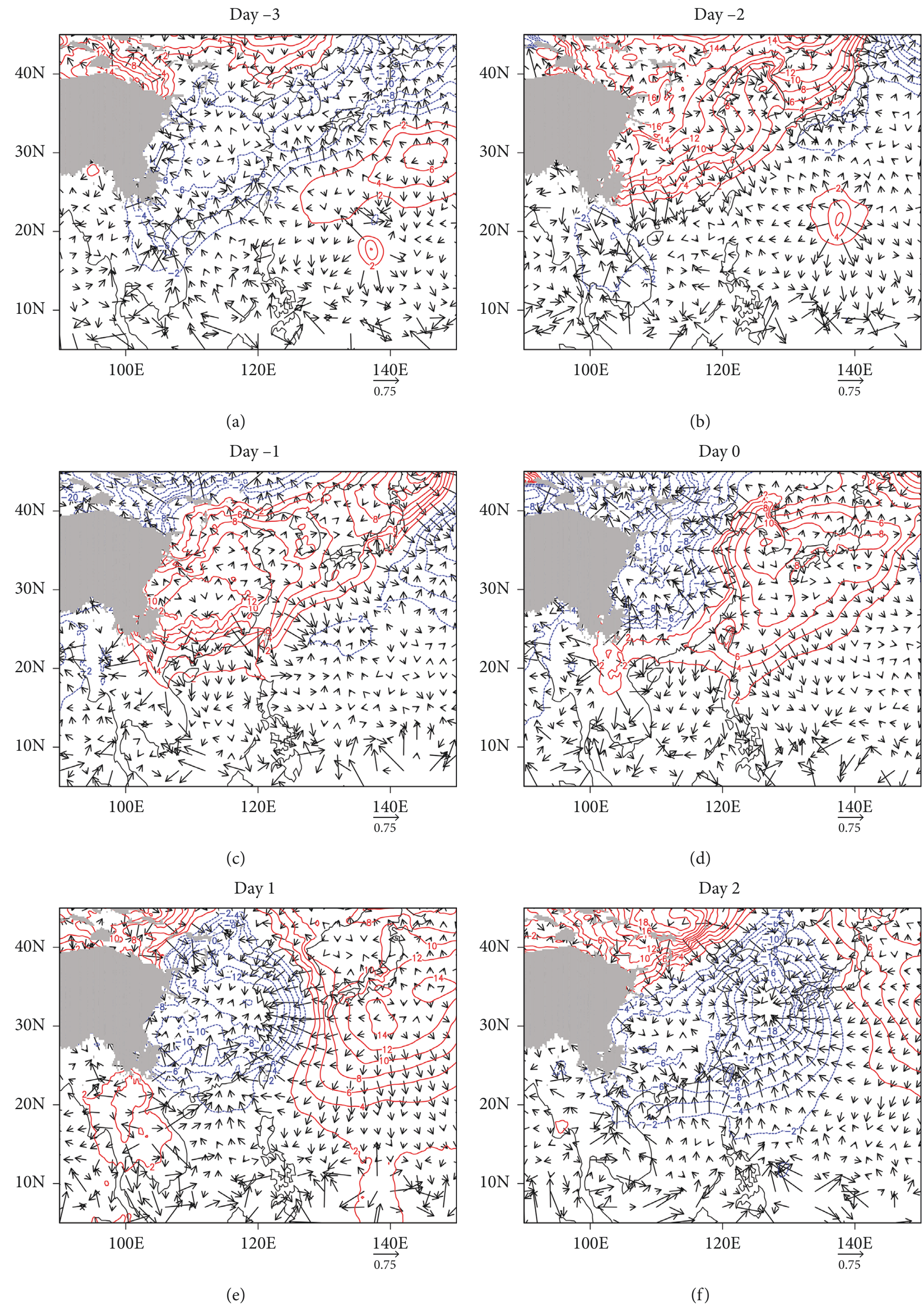

Figure 13: Same as Fig. 8, except for during the events associated with cold surge and upper-level trough.

102.6 mm day^{-1} in Lang Son, and 101.6 mm day^{-1} in Moc Chau on 27 March. In some areas, heavy rainfall was prolonged for many consecutive days, leading to many severer disasters. It should be noted that although the signal of heavy rainfall was first observed in the northwestern areas on 27 March; however, heavy rainfall mainly concentrated in the southeastern areas on later days. This signal implies the eastward movement of heavy rainfall in the period.

The large-scale pattern associated with the heavy rainfall event is displayed in Figure 11. An upper-level trough is evident over the region from Burma to Malaysia on day 2. This trough is known as India-Burma trough [24] and is one of the most important synoptic systems affecting South China in winter [25]. Regarding the formation of the trough, previous studies (e.g., [26]) found that when the westerly wind meets the Tibetan Plateau, it is split into two branches and the trough is a part of the southern branch to the south of the plateau. The trough mostly occurs from December to May and some studies believed that it plays an important role in transporting moisture from BOB to Southeast China, which triggers the onset of rainy season in the regions [27].

On day 1, the upper-level trough deepens and moves eastward, concurrent with the beginning of observed rainfall in the northwestern part of the subregion. The mechanism in which the trough induces heavy rainfall might be explained through the omega equation relationship. In the region to the east of the trough, the vorticity advection is the largest and quasi-geostrophic lifting is induced. As a result, ascending motion is generated, which is favorable for the occurrence of rainfall in the region. On day 0, the trough and its accompanied rainfall continue moving to the east, leading to the outburst of heavy rainfall in Northern Vietnam. Finally, on day +1, the trough propagated far to the east and no longer affect the subregion; thus, rainfall is completely ceased there.

In these cases, cold surge also substantially contributed to the occurrence of heavy rainfall. As displayed in Figure 12, strong northeasterly wind associated with a large area of high pressure intruded from Siberia into the southeast of China from day 3 to day 1. On day 0, the northeasterly wind prevailed over Northern East Vietnam Sea, which was concurrent with the arrival of the upper-level trough in Northern Vietnam. When the air flows were pushed up by the high mountain ranges, it was accelerated by the quasi-geostrophic lifting caused by the upper-level trough. As a result, vigorous vertical motion was induced, leading to the occurrence of heavy rainfall in Northern Vietnam, especially in the mountainous areas.

It should be noted that CAPE also displayed a substantial increment from day 3 to day 1, but it decreased dramatically from day 0 and afterwards (Figure 12). Therefore, the potential instability associated with cold surge did not contribute to the formation of the heavy rainfall in Northern Vietnam. Similarly, the isallobaric wind convergence also reversed its sign from day 1 to day 0 (Figure 13); thus, it also did not create a favorable environment for the occurrence of heavy rainfall in Northern Vietnam.

5. Concluding Remarks

This study is devoted to exploring the climatic factors associated with rainfall and especially heavy rainfall in Northern Vietnam in boreal spring. The major datasets used in this study are observed rainfall, PERSIANN satellite rainfall estimates, and ERA5 reanalysis data for the period 1983–2018. The major results are summarized below.

First, spring should not be considered a dry season, but the start of rainy season in Northern Vietnam. In that season, rainfall is caused by collaborative effects of cold surge, subtropical high, and the deepening of two low-pressures systems in the southeastern Tibetan Plateau and BOB. This first rainfall regime is distinct from the second one where rainfall is strongly modulated by summer monsoon circulation.

Second, there are two major previously unidentified synoptic patterns that induce heavy rainfall in Northern Vietnam in boreal spring. The first is the interaction of the cold surge and the southward movement of the meso-scale vortex. In this pattern, the cold surge induces strong northeasterly wind to transport moisture from ES to the study region and the meso-scale vortex significantly enhances the low-level convergence to generate heavy rainfall. The second pattern is related to the interaction of cold surge and the deepening of upper-level trough. In this pattern, quasi-geostrophic lifting induced by the upper-level trough is enhanced by the frontal lifting caused by the cold surge. Therefore, heavy rainfall is induced by this pattern seems to be more severe than that in the former pattern.

The results also pointed out that CAPE and the convergence of isallobaric wind ahead of the cold front do not contribute to the formation of the heavy rainfall in the Northern Vietnam in boreal spring. The common dynamic forcing is that low-level convergence or quasi-geostrophic lifting accompanied with orographic effects leads to the outbreak of deep convection. Because the large-scale extratropical processes are well predicted by state-of-the-art numerical models, especially at lead times of 1–2 weeks, understanding the mechanism of the heavy rainfall in Northern Vietnam might help to evaluate and extend its predictability at longer timescales. Further research on this area is absolutely needed to mitigate the impact of nature disasters in the subregions. It is also important to construct the objective indices to classify heavy rainfall events as the indicators for forecast advisory.

Data Availability

The observed rainfall data are provided by the National Center for Hydro-Meteorological Forecasting, Viet Nam Meteorological and Hydrological Administration (https://nchmf.gov.vn/KttvsiteE/en-US/2/index.html). The ear5 dataset can down loaded from the Copernicus Climate Change Service (https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5). The PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) data can be downloaded from the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California (https://chrsdata.eng.uci.edu/).

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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