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THE FEATURES OF EAST ASIAN JET STREAM IN PERSISTENT SNOWSTORM AND FREEZING RAIN PROCESSES OVER SOUTHERN CHINA IN EARLY 2008

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Abstract: Based on the National Centers for Environmental Prediction and National Center for Atmospheric Research (NCEP/NCAR) daily reanalysis data and the upper-level objective analysis data provided by the Meteorological Information Comprehensive Analysis and Process System (MICAPS), the feature of the spatio-temporal variation of the East Asian jet stream (EAJS) in persistent snowstorm and freezing rain processes over southern China in January 2008 have been investigated. Each of the storm events was closely linked with the extraordinarily abnormal variations of East Asian subtropical jet (EASJ) and East Asian polar front jet (EAPJ) at that time. The stronger EASJ with abnormally northward position of the jet axis corresponded to the more intense storm event with broader ranges and longer duration time. The heavy freezing-rain-and-snow event occurred over the region where a strong southerly wind of EASJ prevailed. Meanwhile, the westerly and northerly winds of the EAPJ were significantly intensified, which were also closely related to the beginning, enhancement, and ending of the heavy snowfall. The meridional component of the EAPJ was dominated by the northerly wind during the snowstorm. Thus, the intensification of the snowstorm was attributed to both the strengthening of the meridional wind of EAPJ and the southerly wind of EASJ. Further analysis indicated that wind speed and the zonal wind of the two jets exhibited precursory signals about half a month prior to this extreme event, and the precursory signals were found in the meridional components of the two jets about 20 days preceding the event. The sudden weakening of the meridional component of EASJ and the zonal component of EAPJ signified the ending of this persistent snowstorm.

Key words: chilly freezing-rain-and-snow events; East Asian subtropical jet; East Asian polar front jet; precursory signals

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1 INTRODUCTION

The variation of the upper-level circulation is highly organized and precursory and the westerly jet stream and the Hadley circulation are two important circulation systems which directly affect the variation of the mid- and lower-atmospheric circulation as well as the temperature and precipitation in China (Ren et al.[1]). Understanding the variation feature and activity mechanism of the East Asian jet stream (EAJS), such as its position and intensity changes, has important scientific significance and application values to the weather/climate simulation and prediction over East Asia (Cressman[2]). Previous studies mainly focus on the impact of the EAJS on the regional precipitation anomalies and torrential rain in summer. Recent progresses prove that the EAJS also has significant impact on the variation of the East Asian winter monsoon. For example, Kuang et al.[3] and Mao et al.[4] pointed out that the position and intensity changes of the EAJS were closely linked with the climate variation in China. Zhu and Shou[5] investigated a snowstorm that happened over the lower reaches of Yangtze River in winter and found that the upper- and lower-level jet streams provided abundant amount of water vapor and favorable thermal and dynamic conditions to the snowstorm area in the form of mesoscale disturbance. Through a quantitative diagnostic analysis, Zhou et al.[6] and Wu et al.[7] investigated a rare snowstorm that occurred in early 2008 over southern China and indicated that the region was located in an upper-level divergence area (i.e., near the right side of the entrance of a jet core)

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and was dominated by an intensely upward motion that transported the water vapor to the upper-level, resulting in the freezing rain. Gao et al.[8] further stressed that the confluence of the warm and cold air was an important dynamical and thermal cause for the formation and maintenance of a stationary front over southern China, causing this persistent snowstorm.

However, less attention has been paid to the relationship between the upper-level jet stream and the persistent chilly freezing-rain-and-snow events in the winter. It is well known that in January and early February 2008, an extraordinarily long-lasting snowstorm occurred in central and southern China, leading to excessive snow amount, low temperatures and severe icing conditions in the region. This extreme event broke the record of 100 years in the history of the number of days with sustained minimum temperatures, snow amount and the number of freezing days, causing extensive social and economic damages in China (Wang et al.[9]). Previous studies (Wang et al.[10]; Wang[11]; Ding et al.[12]; Gao et al.[13]; Wen et al.[14]; He et al.[15]) reported that the snowstorm was closely linked to the obvious change in the Middle East jet stream, which intensified and shifted southeastward. Unfortunately, few works paid close attention to the impact of the intensity and location anomalies of the EAJS on this extreme event, especially with focus on the variation of the East Asian polar front jet (EAPJ). Besides, the research on the East Asian subtropical jet (EASJ) was often limited to the zonal wind, with less focus on its meridional wind features. As two important parts of the EAJS system, there exists a concurrent variation relationship between the EAPJ and the EASJ (Zhang et al.[16]). Thus, it is necessary to consider the combined impacts of the two jets on the severe storm event.

The objective of this study is to examine the spatio-temporal features of the EAPJ and EASJ during the snowstorm and investigate into their relationships with the formation and development of the snowstorm. Since the EAPJ is most notable on 300 hPa (Duan et al.[17]), the wind data on that level are used to analyze the variation features of the EAPJ and EASJ prior to the snowstorm and the development and ending of the snowstorm. We attempt to seek the precursory signals for the extreme event and provide some possible extended-range forecast for the persistent chilly freezing-rain-and-snow disasters in the near future.

2 DATA AND METHODS

The data used in this study include the following two sources. (1) The National Centers for Environmental Prediction/National Center for the Atmospheric Research (NCEP/NCAR) reanalysis data, with a longitude-latitude resolution of 2.5°×2.5°, 17 vertical levels. The daily values are from 1948 to 2008, totally 61 years. (2) The upper-level objective analysis data provided by the Comprehensive Analysis of Meteorological Information Processing System (MICPAS) from December 2007 to February 2008, with a longitude-latitude resolution of 4.0°×4.0° and 11 vertical levels.

The persistent snowstorm that happened in early 2008 can be divided into 5 processes (Duan and Tao[17]). We focus on the first four processes with strong intensity: 10–15 January, 18–22 January, 25–28 January, and 31 January–2 February. The NCEP/NCAR reanalysis data are used to investigate the general climatological feature of the EAJS during the snowstorm and the variation feature of the EAJS in each storm event. The MICAPS data are used to examine in detail the diurnal fluctuation feature of the wind velocity as well as the longitudinal (latitudinal) component of the two upper-level jets for each storm event. Finally, the spatio-temporal variation features of the two jets before and after the snowstorm are further investigated.

3 SPATIO-TEMPORAL VARIATION FEATURE OF THE EAJS

3.1 *Experiment design*

Figure 1 describes the distributions of the averaged wind velocity, the zonal and meridional components of the wind speed and the wind anomalies at 300 hPa in each storm event. It is shown that a wind zone with velocity exceeding 30 m/s existed between 20°N and 45°N, corresponding to the location of the EASJ. The span of the wind zone was larger than normal (Zhang et al. [16]), about 3° to 4° larger west of 110°E and 1° to 2° larger east of 110°E. Its southern boundary was close to the climatological position in winter but the northern boundary shifted about 2° to 4° of latitude northward. Two notable wind centers were located in the east and west of the wind zone respectively. However, compared to the situation in the snowstorm, only an eastern center appeared in the climatological winter. The velocity of the western center exceeded 60 m/s, about twice as much as that of the climatology. Besides, there existed an upper-level ridge between 60°N and 80°N west of 130°E, corresponding to the location of the EAPJ. A long and narrow wind center appeared around 70°N in the snowstorm. Compared with the climatological situation, no closed wind center was observed in this area, which indicated that the EAPJ shifted further northward than normal with stronger intensity during the snowstorm. The features of the zonal wind and the eastern and western anomaly centers were similar with that of the wind speed. The negative anomalies of the zonal wind of EASJ were located over the central and southern China, where the intensity of the snowfall and freezing rain were much stronger than normal. Meanwhile, the southerly wind of EASJ was stronger than normal in these areas. The maximum southerly wind was about 2.5 m/s (Wang et al. [18]) in boreal winter, but it reached 12 m/s in early 2008. The EAPJ regions north of 60°N and west of 70°E were dominated by the westerly and southerly wind while the area east of 70°E was occupied by the northerly wind. Large negative anomalies of the meridional wind appeared east of 110°E, indicating that the northerly wind intensified during the snowstorm.

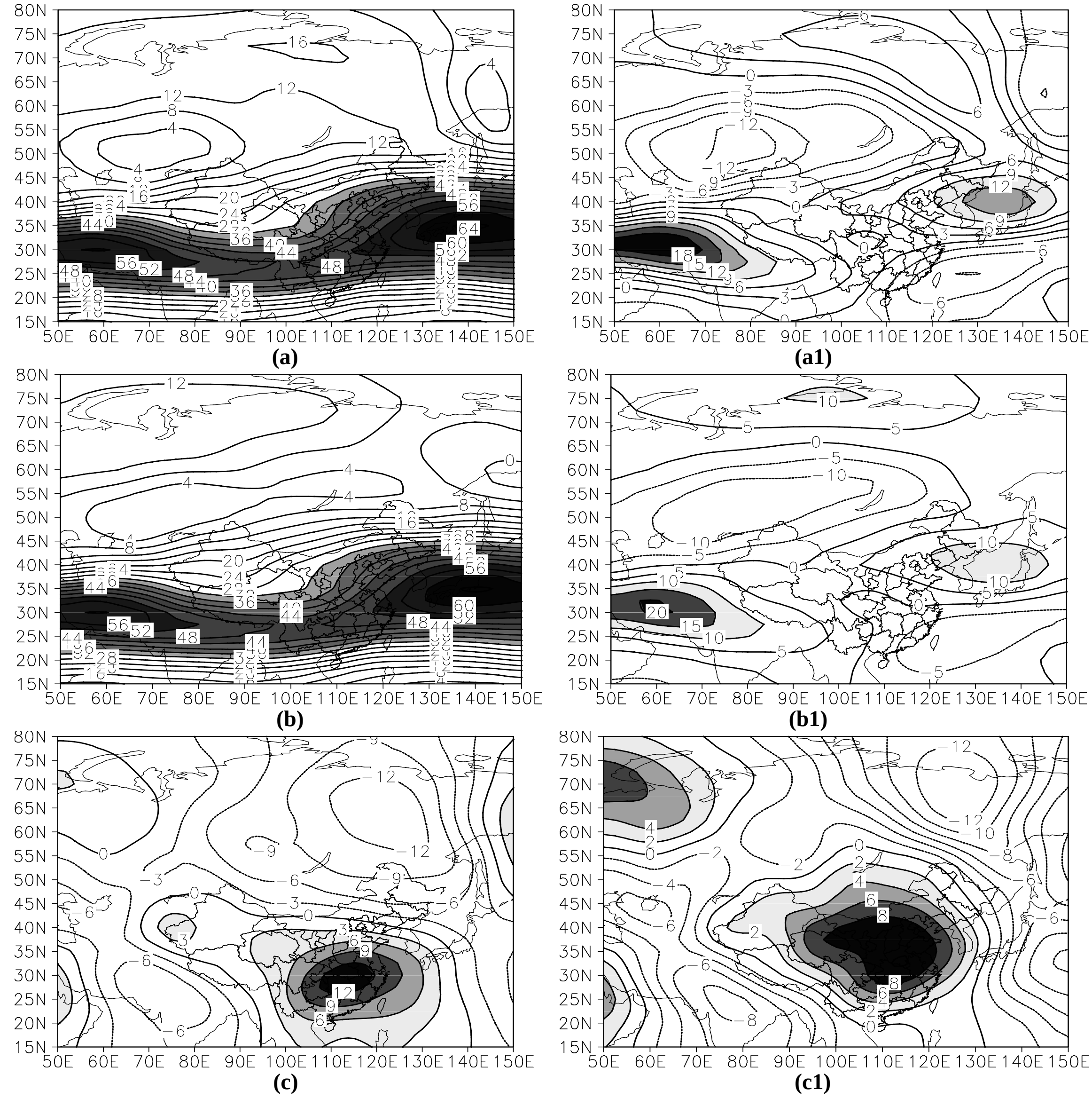


Figure 1. (a) The distribution of the wind speed on 300 hPa in early 2008 (from 10 January to 2 February), (a1) wind anomalies, (b) zonal component of the wind speed, (b1) zonal wind anomalies, (c) meridional component of the wind speed, and (c1) meridional wind anomalies. Wind velocity equal to and greater than 30 m/s is shaded in (a) and (b), the shaded areas in (c) indicate the southerly wind and the shaded areas in (a1), (b1), and (c1) denote the positive anomalies.

3.2 *The synoptic-scale variation feature of the EAJS*

The spatio-temporal evolution of the wind velocity of EAJS in the four storm events is shown in Fig. 2. The north-south span of the EASJ gradually narrowed during the snowstorm and heavy snowfall was observed in Anhui, Jiangsu and Zhejiang provinces before 21 January. Accompanied with the southward shifting of the EASJ, snowfall and freezing rain were mainly concentrated in the central and southern part of the Yangtze River basin (Zhu and Shou[5]; Ding et al.[12]) and the duration of the four events was getting shorter and shorter during the snowstorm. Thus, the region and the duration of each event may be related to the north-south span of the EASJ. The intensity of the western wind center was 55, 60, 65, and 60 m/s respectively in the four events, all enhancing first and then weakening. Previous research (Wang et al.[9]) reported that the largest snowfall occurred in the second and third episodes and the maximum range of the freezing rain was observed over 283 stations on 25 January. The intensity and range of the freezing rain may be positively correlated with the intensity of the EASJ. Compared with the EASJ, the intensity of the EAPJ was below the standard of an upper-level jet during the snowstorm. However, a closed wind center appeared over the EAPJ region in the last three storm events, except for the first episode. The magnitude and the range of the wind center intensified more and more and the maximum wind areas were located over the latitudinal bands of 65° to 70°N, 55° to 65°N, and 60° to 70°N, respectively in the last three storm events. Two wind centers emerged in the third storm event, with the wind velocity exceeding 25 m/s in the eastern wind center.

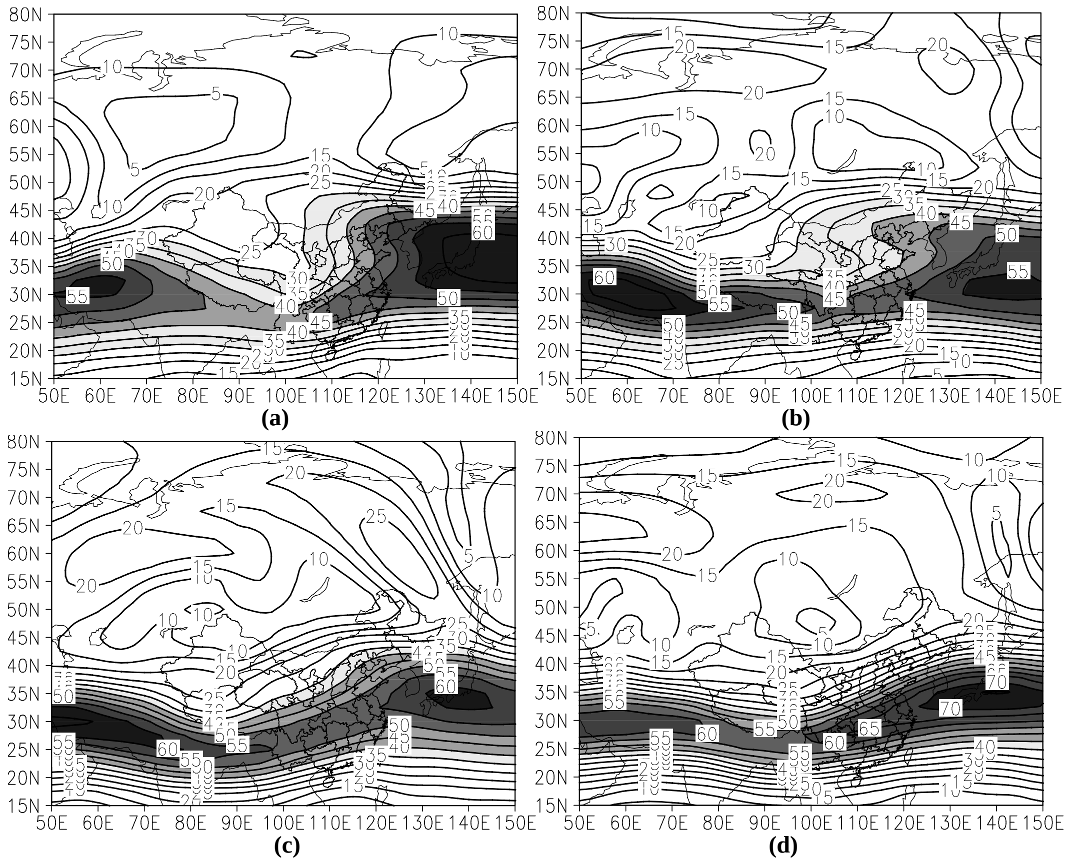


Figure 2. The distribution of the wind speed on 300 hPa during the (a) first, (b) second, (c) third, and (d) fourth episode of the snowstorm in early 2008 (from 10 January to 2 February). Wind velocity exceeding 30 m/s is shaded.

The distribution of the zonal component of the EASJ was similar to that of the wind speed. The difference was that the intensity of the zonal wind around the wind center varied little, except for its east-extending range. This can be explained by the splitting and eastward propagation of the western wind center of the EASJ, resulting in the intensification of the EASJ over the central and southern China. The zonal component of the EAPJ was also consistent with the feature of the wind speed. Besides the first storm event, a closed wind center was apparently observed in the second and fourth episodes, with wind velocity exceeding 20 m/s. The range of the zonal wind center was smaller than that of the wind speed in the third episode, which can be explained by the strengthening of the meridional component of the EAPJ in this storm event.

Figure 3 portrays the variation feature of the meridional component of the EAJS in the four storm events. In the first storm event, the southwestern flank of the Tibetan Plateau and Lake Baikal were dominated by the northerly wind while the lower reaches of the Yangtze River was occupied by the southerly wind. The heavy snowfall was mainly attributed by the southward outbreak of strong cold air activity and the range of the freezing rain was relatively small (including central Guizhou, southern Hunan and eastern Yunnan provinces). In the second episode, the northerly wind zone over Lake Baikal and the southerly wind zone over the central and southern China were east-west distributed, with the range and intensity apparently increased, and correspondingly, the range of the freezing rain were enlarged as well, almost covering the whole provinces of Guizhou and Hunan. The range and intensity of the wind zone were persistently enhanced and the scopes of the freezing rain were largest in the third storm event. Accompanied with the eastward retreat of the western boundary of the southerly wind, the northerly wind center was located further eastward than in the second episode, corresponding to the southeastward expansion of the freezing rain area. The southerly wind was still strong, with notably eastward retreat of the western boundary in the last storm event. The intensity of the northerly wind was reduced, much weaker than the southerly wind. Besides, the ranges of the freezing rain decreased rapidly, extending to eastern Yunnan province. From the analysis above, we can infer that the zonal wind of the EASJ was gradually intensified during the snowstorm, while the northerly wind of the EAPJ was intensified in turn in the first three storm episodes, but weakened in the last storm event. Heavy snowfall appeared in the second and third episodes, with the largest freezing rain areas being observed. Thus, when the southerly wind of the EASJ and northerly wind of the EAPJ were both strong, the snowfall and freezing rain were broad in range and strong in intensity.

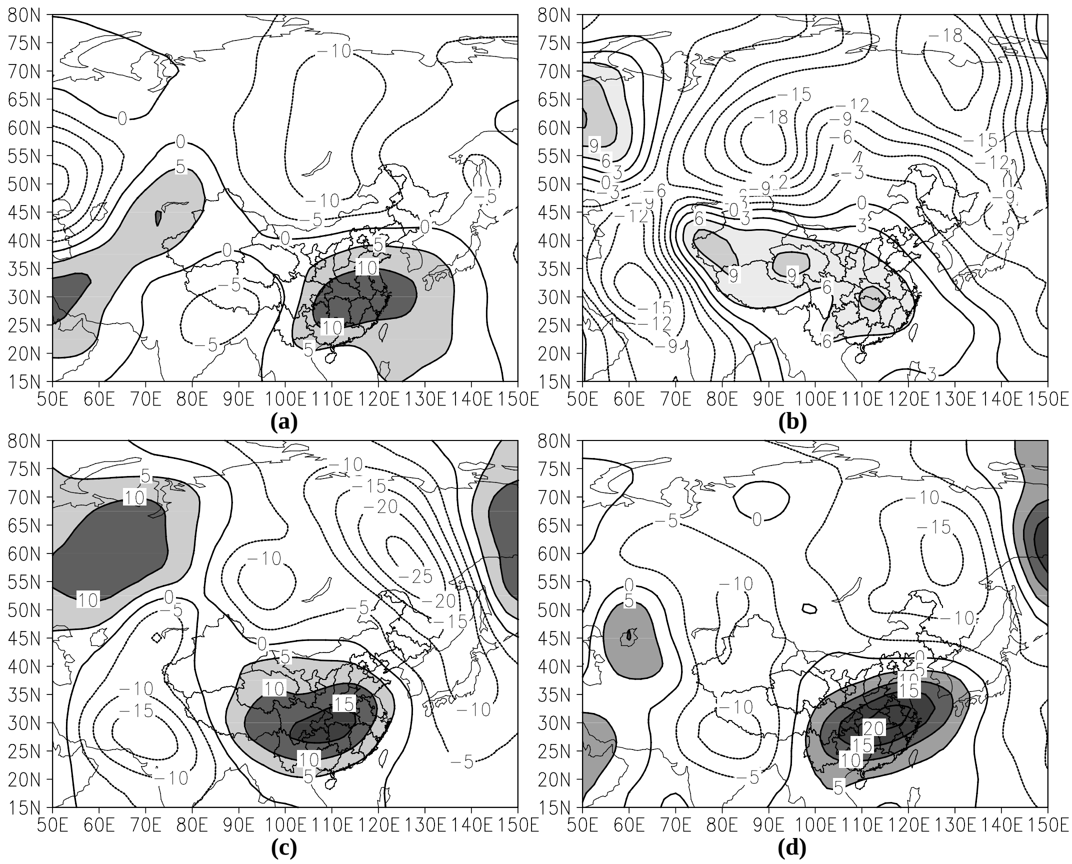


Figure 3. The distribution of the meridional wind speed on 300 hPa during the (a) first, (b) second, (c) third, and (d) fourth episode of the snowstorm in early 2008. Wind velocity exceeding 5 m/s is shaded.

3.3 *The diurnal variation feature of the EAJS*

To examine the diurnal variation features of the two jets in detail, we first chose the wind anomalies centers over the EAPJ and EASJ areas as the key regions. The regional-averaged wind speed, zonal wind, and meridional wind anomalies in these key regions represent the overall intensity, the zonal intensity and meridional intensity of the EAPJ and EASJ, respectively during the snowstorm. The regional-averaged wind anomalies over the region 25° to 35°N, 50° to 80°E (70° to 80°N, 90° to 130°E) are defined as the overall intensity of EASJ (EAPJ). The regional-averaged meridional wind anomalies over the region 25° to 40°N, 100° to 120°E (60° to 80°N, 100° to 140°E) are defined as the meridional intensity of EASJ (EAPJ). Besides, the regional-averaged zonal wind anomalies over the region 25° to 35°N, 50° to 70°E (70° to 80°N, 70° to 110°E) are defined as the zonal intensity of EASJ (EAPJ).

Figure 4 shows the temporal evolution of the overall intensity, zonal intensity and meridional intensity of the EAPJ during the snowstorm. We can clearly distinguish the beginning of each storm event in Fig. 4a. The overall intensity increased at the beginning of each storm event (except for the first episode), maintained large magnitude in the development of the event and weakened at the end of the event. The intensity of the EAPJ was relatively weak in the first storm event, strengthened in the last three episodes, with moderate and strongest intensity in the second and third storm event respectively. The result is consistent with the previous qualitative analysis. The zonal intensity variation feature of the EAPJ shown in Fig. 4b is similar to that of the overall intensity. A notable interval was observed between the first storm event and the last three storm events, but the interval was not that apparent among the last three storm episodes. Fig. 4c indicates that a northerly wind prevailed over the eastern region of the EAPJ, similar to the overall intensity variation feature, which was in agreement with the four storm episodes. The meridional wind was weakest in the last storm event, corresponding to the end of the persistent snowstorm.

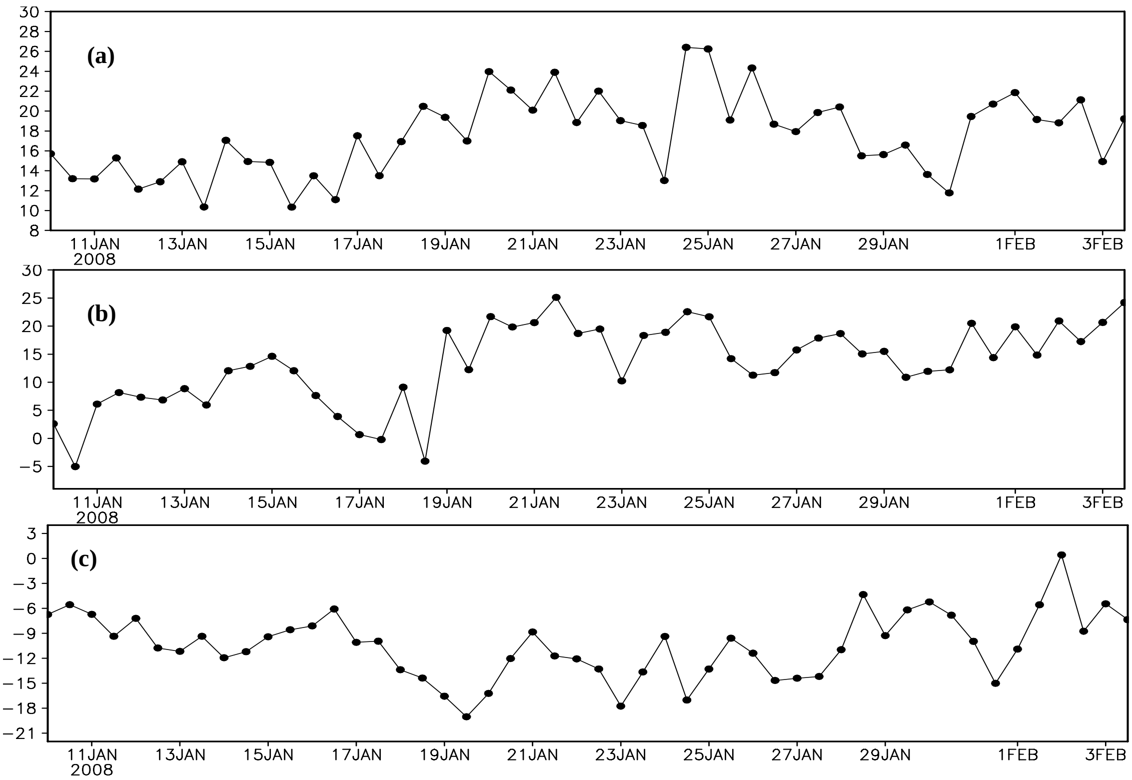


Figure 4. The temporal evolution of the (a) overall intensity, (b) zonal intensity, and (c) meridional intensity of EAPJ in early 2008 (from 10 January to 2 February).

Figure 5 displays the temporal evolution of the overall intensity, zonal intensity and meridional intensity of the EASJ during the snowstorm. The overall intensity of the EASJ was strongest in the first storm event while being relatively weak in the last three episodes with wind speed below 20 m/s. This may be related to the southward spreading of the strong clod air activity in the first storm event and the intensified warm air activity in the last three storm episodes. The variation trend of the zonal intensity was consistent with that of the overall intensity. Significant meridional intensity anomalies of the EASJ were observed over the central and southern China which were dominated by a strong southerly wind (except on 17 to 18 January). The intensity of the meridional wind was much stronger in the last three storm episodes than in the first storm event, with maximum wind velocity close to 20 m/s, exhibiting remarkable difference from the climatology in winter. The meridional wind weakened to about 0 m/s on 3 February, the central and southern China were occupied by the westerly wind, indicating the adjustment of the upper-level atmospheric circulation, and the persistent snowstorm basically came to an end. Thus, the exceptional strong southerly wind over the central and southern China may be an important factor that led to this persistent extreme event.

Figure 6 shows the comparison of the meridional intensity variation between the two jets. During the snowstorm, the meridional component of the EAPJ was dominated by the northerly wind over the northern China, while that of the EASJ was occupied by the strong southerly wind over the southern China. When the wind direction was opposite between the two jets with great absolute value of the wind speed, heavy snowfall was observed (in the third storm event). The difference of the meridional wind speed between the two jets was almost above 10 m/s (except on 10 and 17 January), maintaining a relatively large value between 15 and 25 m/s in most of the time during the snowstorm. The difference weakened to small magnitude on 3 February, corresponding to the end of the persistent snowstorm.

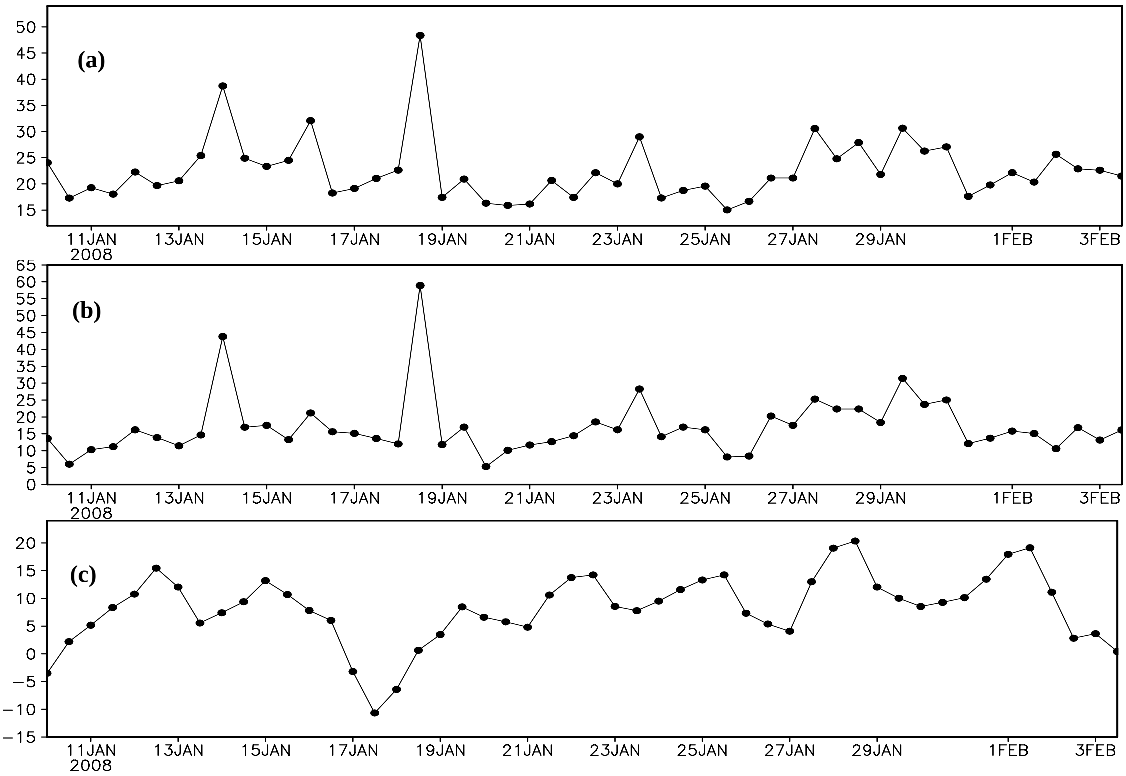


Figure 5. Same as Fig. 4 but for the EASJ.

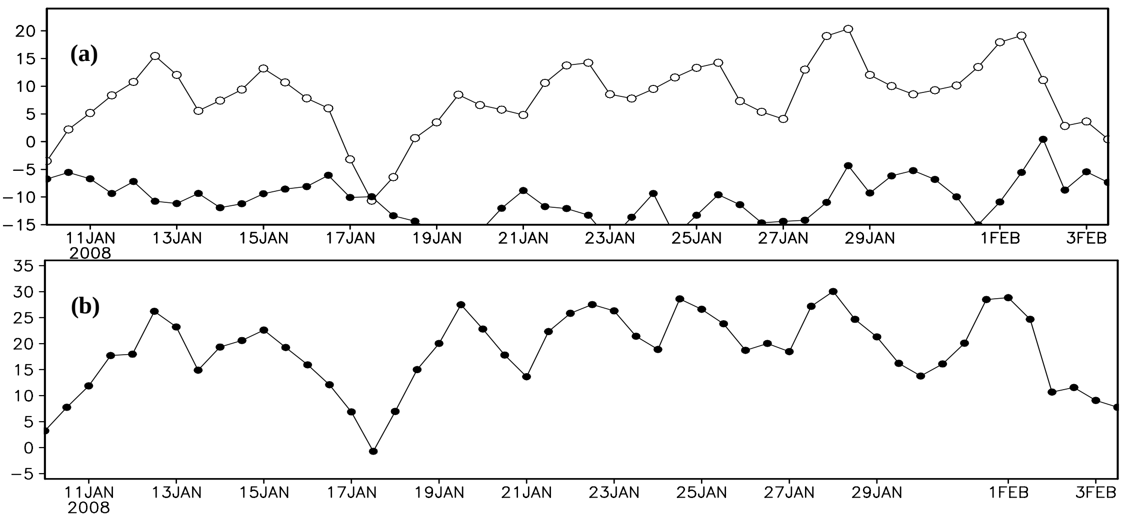
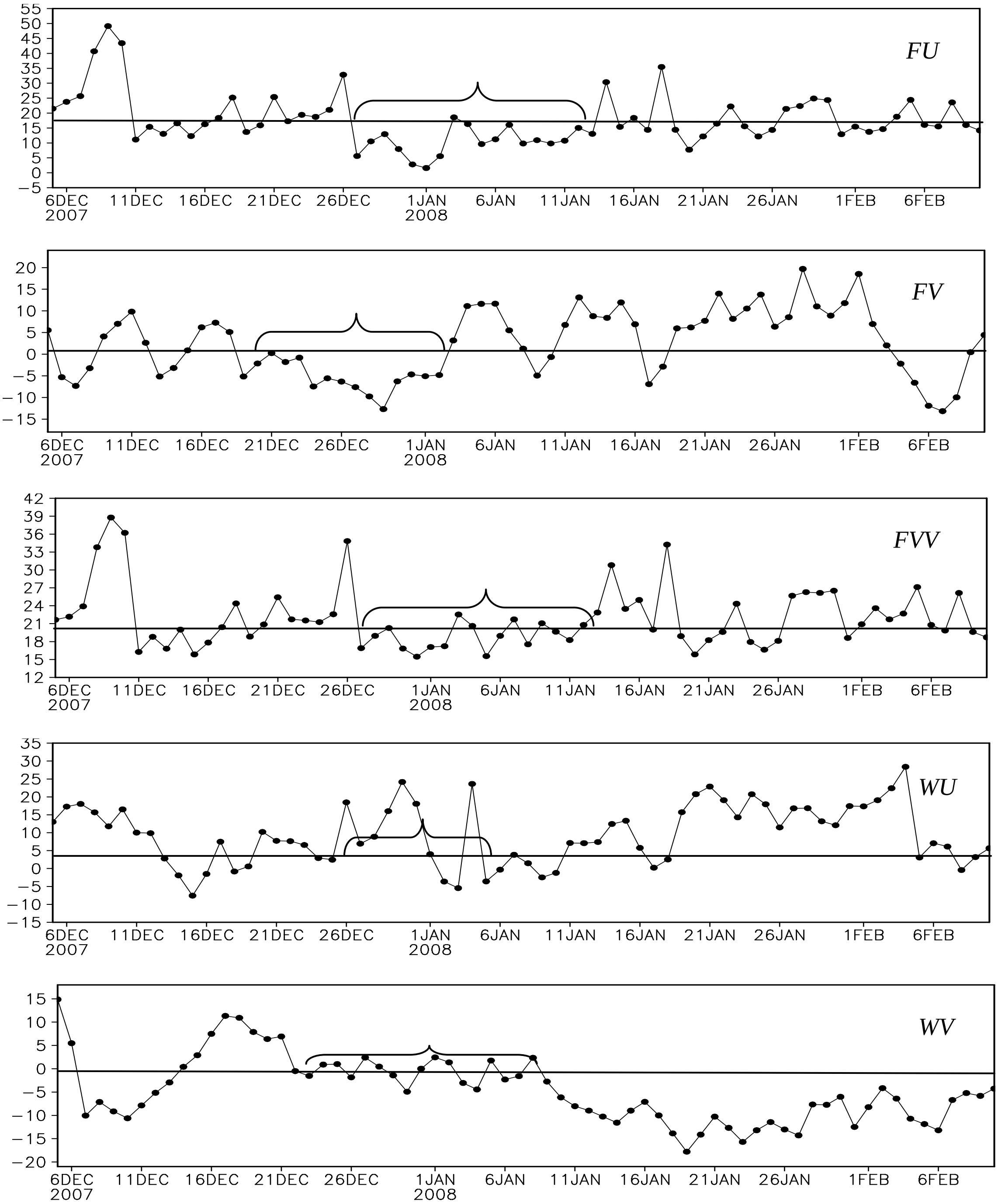


Figure 6. (a) The temporal evolution of the meridional intensity of EASJ (open circle) and EAPJ (closed circle) and (b) the difference between the EASJ and EAPJ.

4 PRECURSORY SIGNALS OF EAJS IN THE PERSISTENT SNOWSTORM

The variation features of the EASJ and EAPJ on 300 hPa over a period of 37 days before the snowstorm and 7 days after the snowstorm (i.e., from 21 December 2007 to 12 February 2008) is shown in Fig. 7. It reveals that the wind speed of the EASJ as well as its zonal component kept small from 27 December to 13 January, lasted about half a month, and increased during the snowstorm. The meridional component of the EASJ was dominated by the northerly wind for about half a month from 18 December to 2 February, by strong southerly wind from 3 January to early February, weakened and replaced by the northerly wind again at the end of the persistent snowstorm event. The wind speed of the EAPJ and its zonal component were notably strengthened from 27 December to 5 January, with large-magnitude oscillations lasting about 10 days. Besides, the velocity kept relatively large in the following period. The meridional component of the EAPJ remained small (closing to 0 m/s) for 18 days from 22 December to 9 January, intensified from 10 January with strong northerly wind, and weakened after 6 February. Generally, the wind speed of the

EASJ as well as its zonal component remained small for about half a month two weeks before the snowstorm, while the meridional component of the EASJ maintained small values for about half a month 20 days before the snowstorm till early January. Comparatively, the wind speed of the EAPJ as well as its zonal component preserved small values for about 10 days half a month prior to the snowstorm with large-magnitude oscillation, while the meridional wind of the EAPJ kept small in magnitude 20 days before the snowstorm, lasting about 20 days. All these variations were the precursory signals of the anomalous features of the two jets during the persistent snowstorm.



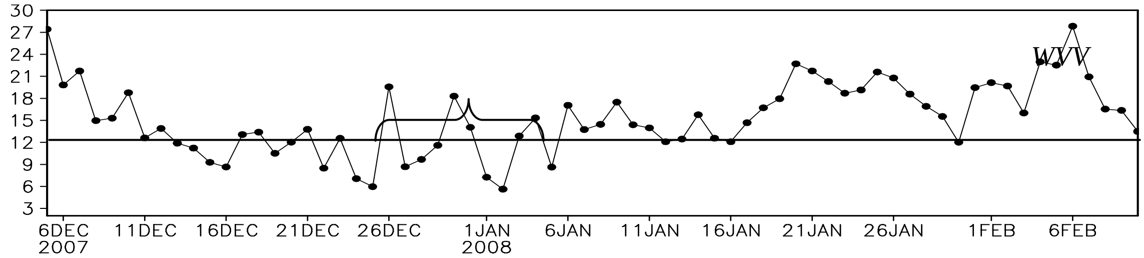
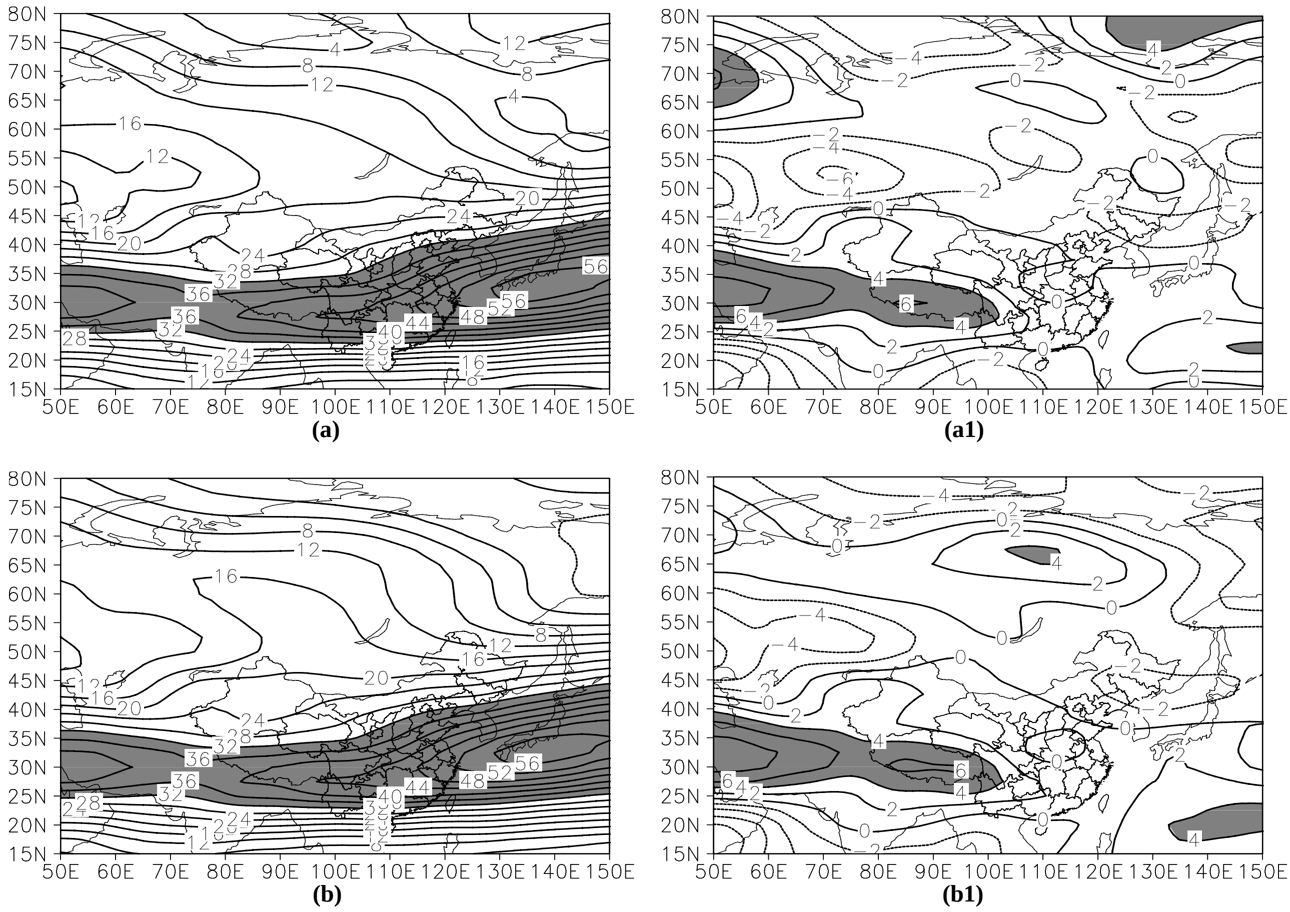
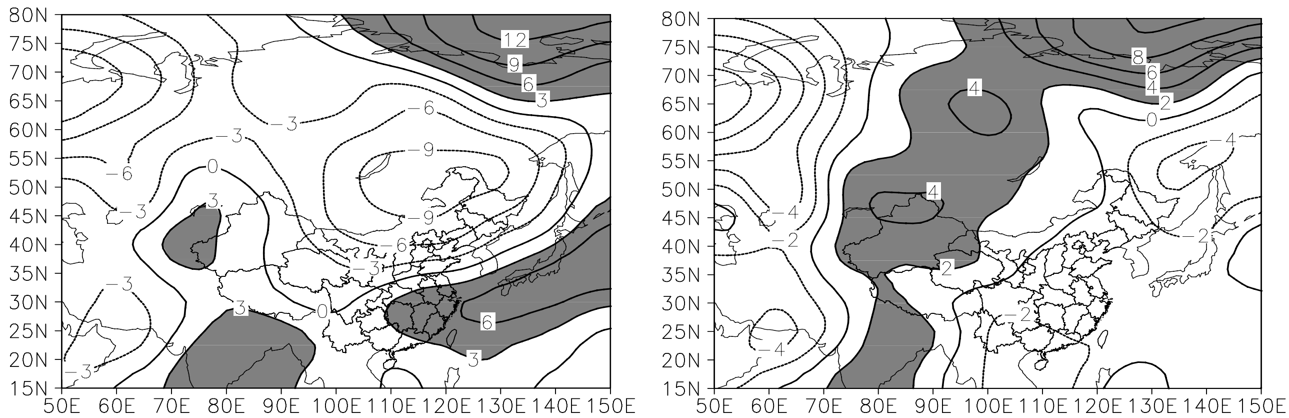


Figure 7. The variations of the zonal wind (*FU*), meridional wind (*FV*), and the wind speed (*FVV*) of EASJ, as well as that of the zonal wind (*WU*), meridional wind (*WV*), and the wind speed (*WVV*) of EAPJ from 21 December 2007 to 12 February 2008.

Figure 8 reveals the wind and wind anomalies distributions of the two jets before reaching the peak (i.e., from 1 to 25 December 2007). Compared with Fig. 1, the wind velocities of the two jets as well as their zonal components before 26 December 2007 were much weaker than in the snowstorm. Furthermore, the positive meridional component of the EASJ was weak and the northern boundary was situated further southward. The negative meridional component of the EAPJ was weak as well, with the southern boundary located further southward. Similar results were obtained from the wind anomalies distributions of the two jets, which further indicated that the intensities of the EASJ and EAPJ were much stronger than normal during the snowstorm and there existed closely concurrent variation relationship between the two jets.





(c) (c1)

Figure 8. Same as Fig. 1 but for the period from 1 to 25 December 2007.

5 CONCLUSIONS AND DISCUSSION

In this paper, we investigate the spatio-temporal variation features of the EASJ and EAPJ during a severe, persistent snowstorm over southern China from the middle of January to early February in 2008. We further examine the precursory signals of the East Asian jet stream in this extreme event. The main results are as follows:

(1) Compared with the climatology, the East Asian jet stream exhibited remarkable anomaly during the snowstorm: The EASJ was much stronger and located further northward than normal, the meridional component of EASJ was dominated by the strong southerly wind and maintained for a long time. The zonal westerly wind and meridional northerly wind of the EAPJ were significantly strengthened, with the northerly wind lasting for a long time during the snowstorm.

(2) The variation of the East Asian jet stream was closely linked with the occurrence and development of the four storm episodes. When the south-north span of the EASJ was broader, the duration of the storm event was longer. When the center intensity of the EASJ was stronger, the strengths of the snowfall and freezing rain were heavier with wider ranges. Large positive anomalous regions of the meridional component of the EASJ corresponded to the heavy snowfall and freezing rain areas. The overall and meridional intensity variations of the EASJ were in accord with the beginning and breaking of the four storm events. When the meridional southerly wind of the EASJ and the meridional northerly wind of the EAPJ were both strong, the intensities of the snowfall and freezing rain were strong as well.

(3) The precursory signals were found in the East Asian jet stream before the occurrence of the chilly freezing-rain-and-snow disasters. The wind speed of the EASJ as well as its zonal component kept small for about half a month 15 days before the persistent snowstorm, the wind and zonal component of the EAPJ intensified with oscillation half a month before the snowstorm, and both the meridional components of the two jets remained low for about half a month 20 days prior to the snowstorm, indicating the precursory signals of the anomalous jet steams for the occurrence and development of the snowstorm. These precursory signals exhibited on the East Asian jet stream may provide some possible extended-range forecasts for persistent freezing-rain-and-snow events in the future. The sudden weakening of the meridional component of the EASJ and the zonal component of the EAPJ were a prominent indication for the breaking of this extreme event.

The anomalous variation features of the East Asian jet stream in the chilly freezing-rain-and-snow event in 2008 are investigated in this paper with some useful conclusions. The jet stream exhibited precursory signals before this persistent abnormal event and made it possible to predict the extreme weather/climate events 7 to 15 days in advance. However, due to the complexity of the climate system and rarity of the extreme weather/climate event, the results obtained in our study only provide preliminary and qualitative relationship between the East Asian jet stream and the persistent chilly freezing-rain-and-snow event. As pointed out by Zhu et al.[19], the combination of various anomalous circulation systems is the primary cause of the blizzard event. Thus, the relationships between the East Asian jet stream and various synoptic systems deserve to be further examined. In addition, the extreme event in 2008 is not independent and seems to be associated with the abnormal feature of the upstream circulation system (e.g., West Asian jet streams), which needs to be further studied. Since the results obtained in our study are only based on a case study, more chilly freezing-rain-and-snow events, more robust results about the relationship between the variation of the EAJS and these extreme events from the climatological perspective over East Asian in winter, and the relationships between the EAJS and the other abnormal weather/climate events, such as the extreme high temperature, drought and the persistent rainy events, will be further examined in our following study.

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