The Unprecedented Freezing Disaster in January 2008 in Southern China and Its Possible Association with the Global Warming*

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ABSTRACT

The unprecedented disaster of low temperature and persistent rain, snow, and ice storms, causing widespread freezing in the Yangtze River Basin and southern China in January 2008, is not a local or regional event, but a part of the chain events of large-scale low temperature and snow storms in the same period in Asia. The severity and impacts of the southern China 2008 freezing disaster were the most significant among others. This disastrous event was characterized by three major features: (1) snowfall, freezing rain, and rainfall, the three forms of precipitation, coexisted with freezing rain being the dominant producer responsible for the disaster; (2) low temperature, rain and snow, and freezing rain exhibited extremely great intensity, with record-breaking measurements observed for eight meteorological variables based on the statistics made by China National Climate Center and the provincial meteorological services in the Yangtze River Basin and southern China; (3) the disastrous weathers persisted for an exceptionally long time period, unrecorded before in the meteorological observation history of China.

The southern China 2008 freezing disaster may be resulted from multiple different factors that superimpose on and interlink with one another at the right time and place. Among them, the La Niña situation is a climate background that provided conducive conditions for the intrusions of cold air into southern China; the persistent anomaly of the atmospheric circulation in Eurasia is the direct cause for a succession of cold air incursions into southern China; and the northward transport of warm and moist airflows from the Bay of Bengal and South China Sea finally warranted the formation of the freezing rain and snow storms and their prolonged dominance in the southern areas of China.

A preliminary discussion of a possible association of this disastrous event with the global warming is presented. This event may be viewed as a short-term regional perturbation to the global warming. There is not any possibility for this event to divert the long-term trend and the overall pattern of the global warming.

Key words: low temperature, freezing rain, rain and snow storms, global warming, the southern China 2008 freezing disaster

1. Introduction

An unprecedented low temperature, rain and snow, and ice freezing disaster happened in southern China during January 10 to February 5, 2008. Owing to its unusual persistence and intensity, this disaster caused great losses in the national economy, especially in almost countrywide transportation, energy supply, electric power transmission, communication facilities, agricultural and ecological systems, and people's life. Great attention to this event was paid by foreign and Chinese governments, institutions of disaster prevention and public preparedness, and scientific communities. Some scientific problems are raised, e.g., why did the unprecedented low temperature, rain and snow and ice freezing disaster occur when the global climate is getting warmer? What are the characters of this disaster? Will this disaster change the warming pattern of the climate in China and even the whole world? Can this kind of severe disasters be predicted and prevented?

Some studies have been conducted to address the scientific issues related to the low temperature, rain and snow and ice freezing disaster in January 2008 from the following angles: (1) the climate background of the disaster (Wang Donghai et al., 2008; Wang,

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2008; Wen et al., 2008; Gao et al., 2008), with an emphasis on the importance of the La Niña event as well as the anomalous activity of the Atlantic Oscillation (AO) and the corresponding strengthening and eastward propagating of the upper-level jet stream over the Middle East; (2) characters revealed by comparisons with the historical records of similar disasters (Wang Ling et al., 2008; Wang Zunya et al., 2008; Zheng, 2008); (3) the general circulation and the synoptic processes dominating this disaster (Wang Donghai et al., 2008; Yang, 2008; Zheng et al., 2008), as indicated by a succession of cold air intrusions, anomalous development of the western Pacific subtropical high impacts the trough in the southern branch of the westerlies over the Bay of Bengal, the enhanced water vapor transport, and the converging of cold air from the west and warm air from the south over the Yangtze River Valley and South China under the stable large-scale circulation pattern over Eurasia; (4) thermodynamical and micro-physical conditions for the formation of the snow storm and freezing rain (Wang Donghai et al., 2008; Yang, 2008; Zhang et al., 1996), such as the inversion layer and the persistent ascending of the southwesterly airflows along the cold fronts; (5) impacts of this disaster on the electric power facilities and supply, traffic, agriculture, and ecology (CMA, 2008)[‡]; (6) the medium and long-range forecasts and the early warnings of the severe disaster. Forecast verification and assessment show that the short-range forecast (1-5 days) of this disaster was relatively accurate, while the medium- and long-range forecast (15-30 days) was short of skills, and the early warnings were not issued in a timely manner due to the limitation of the medium-range forecast predictability (about 2 weeks). Further studies are needed in order to establish a subseasonal forecast and disaster prevention system.

Considerable results have been obtained from the above studies. However, several problems remain, including: (1) La Niña events generally cause cold and dry winters in China. In contrast, this disaster occurred with much precipitation. Then how was this disaster affected by the La Niña climatic background? (2) Why did the Ural blocking and the splitting of airflows over Eurasia persist so long during this disaster? What caused the continuous eastward shifts and southward incursions of cold air? (3) How did the warm and wet airflows form? And why can they converge with cold air over the Yangtze River Valley? (4) Why did this severe disaster happen under a warming climate background? What relationship does it have with the global warming? Will this disaster change the global or regional climate warming pattern? In this paper, questions (1), (3) and (4) will be mainly discussed.

Datasets used in this paper include: (1) daily observations of 740 stations in China from 1951 to 2008; (2) NCEP/NCAR reanalysis; (3) Monthly Highlights on Climate System from January to April 2008 compiled by Japan Meteorological Agency; (4) Climate Monitoring Bulletin from January to April 2008 edited by National Climate Center, CMA. For brevity, the low temperature, rain and snow, and ice freezing disaster in southern China from January 10 to February 5, 2008 is called the southern China 2008 freezing disaster in the following discussions.

2. Characters of the southern China 2008 freezing disaster

Four major characters of the Southern China 2008 freezing disaster have been identified and are reviewed herein, besides its extensive and profound impacts.

2.1 The most important part of the eastward propagating chain events of large-scale low temperature and snow storms in the same period in Asia

Several countries were hit by cold waves from the west to the east in West, Central and South Asia in January 2008. Temperature 2°C lower than normal appeared in most of Asia, and 6°C lower than normal showed in some parts of Central Asia. Unprecedented snow storms occurred in a belt from the eastern costal

[‡]China Meteorological Administration, 2008: Forum on the low temperature, rain and snow and ice freezing disaster in 2008 January. Beijing.

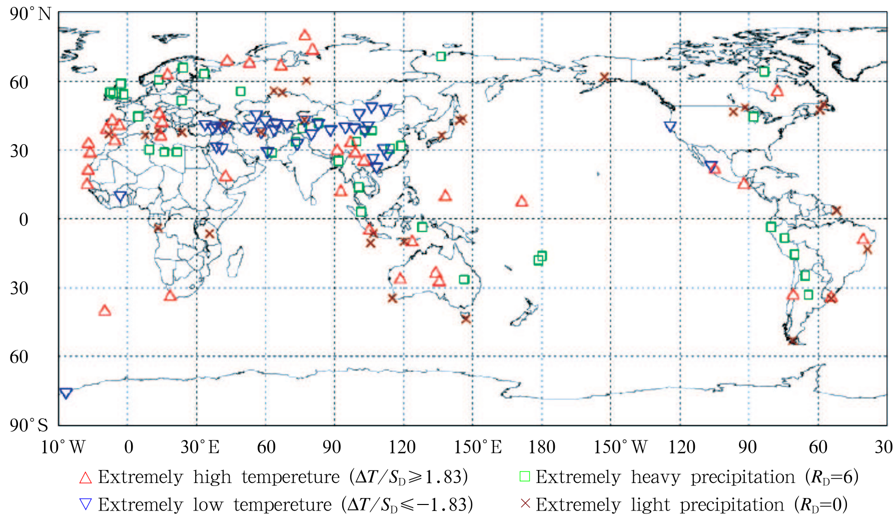

Fig.1. Global distribution of extreme events in January 2008. Triangles denote the extreme low temperature events ($\Delta T/S_D \geqslant 1.83$), squares denote the rain/snow storm events (R_d=6), and crosses denote the light rain events (from Japan Meteorological Agency, 2008).

of the Mediterranean Sea to the capital of Iraq and Iran, with the snow depth of 55 cm in the northern and central Iran and the record-breaking snowfalls for the first time in the recent century in Iraq. Snow storms resulted in traffic disruption, temporary close of some government institutes and schools, 21 deaths and 88 injuries in Teheran. Kyrgyzstan and Tajikistan suffered in succession from unusual cold weathers. Continuous snowfalls covered the whole Afghanistan and even avalanches happened, causing over 60 deaths in total. And, northwestern Bangladesh was affected by strong cold waves and the temperature dropped significantly. Figure 1 shows the global distribution of extreme climate events in Asia in January 2008. The abnormal low temperature events and snow storms were observed in a belt from West Asia, via South Asia, to East Asia. In the chain events of cold weathers and snow storms in Asia, the disastrous weather propagated from West Asia to China, via Central Asia and South Asia, and ended in Japan lastly.

As seen from Fig.2, the abnormally low temperature appeared in central-western Asia to the west of Black Sea in early November 2007, while it was warmer than normal in the extensive region to the east of Black Sea (figure omitted). Until December 2007, the major abnormal low temperature center had moved to Central Asia (Fig.2a). And in January 2008, it moved further to East Asia and an obvious cold tongue stretched southward to southern China (Fig.2b). Until February 2008, the abnormally low temperature covered the whole region to the south of 40°N in Asia (Fig.2c), while it was warmer than normal to the north. However, the drop of temperature began to weaken. Temperature anomalies, being warm in the north and cold in the south, in Europe and Asia during this period showed an opposite pattern as compared with the climatic pattern as well as that in the early period of 2008. According to the above analyses, the ice and snow disaster in January 2008 is not a local event, but a part of large-scale climate anomalies in Asia in winter 2007/2008, as well as the result of continuous eastward propagation of low temperature and snow storms from West and Central Asia.

2.2 Co-existence of snowfall, freezing rain and rainfall with persistent freezing rain being the dominant factor responsible for the severe damage in southern China

Disastrous weathers were mainly snowfalls in such provinces of eastern China as Anhui, Jiangsu, Zhejiang, and so on, rainfalls in South China, and freezing rains or sleet in between the two regions.

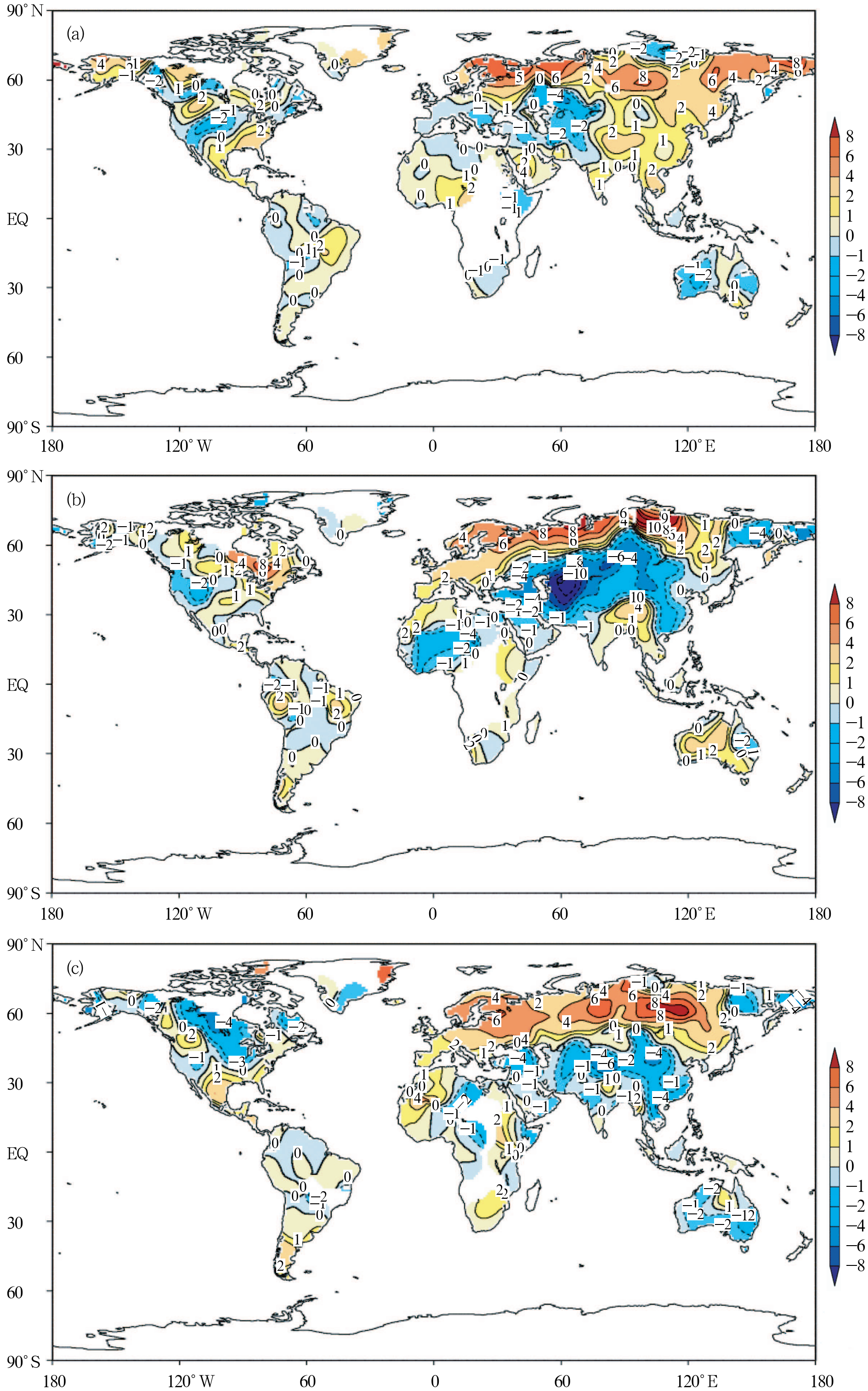

Fig.2. Monthly mean temperature anomalies in (a) December 2007, (b) January 2008, and (c) February 2008. The blue color denotes the negative value and the red color denotes the positive value (unit: °C; National Climate Center, CMA, 2008).

The distinction of the precipitation features in different regions depends on factors such as temperature, terrain, circulation, cloud and rain micro-physical processes, and so on (Fig.3). Freezing rains occurred mainly in Jiangxi, Hunan, Hubei, and Guizhou where the freezing rainy days exceeded the historic maximum and disasters were the most severe. Usually, freezing rains occur in Guizhou every year, with freezing rainy days being less than 3 days in 30 counties at most (Zhang and Lin, 1985). But in January 2008, freezing rains happened in 79 counties, and the freezing rainy days, the impacted range and the thickness of the icing on the electrical wires exceeded the historic records of those in the 76 counties in 1984. The thickness of the icing on the electrical wires ranged from 30 mm to more than 60 mm in some parts of central Guizhou, reaching 83 mm in Wanshan and breaking the historic record of 53 mm (1961) in Weining. Ice freezing weathers lasted 20 days or so in some parts of Guizhou. Additionally, ice freezing weathers maintained so long in Jiangxi, being 11 days in more than 60 counties of the whole province, the longest since meteorological observations were firstly made there. Actually, freezing rains are not unique in China, but happen frequently in winter in the central-eastern North America (USA and Canada). A severe freezing rain, accompanying the great gale, occurred in this region in 1998 and caused interruptions of traffic, electric power, and communication in extensive areas. The second most serious ice freezing disaster in this region happened in winter 1942 (the so-called ice storm). Scientists over there have been studying freezing rains for years. According to their experience, an ice storm lasting over 6 days can cause severe disasters, which happens once every 25 years. Thus, the freezing rains in southern China in 2008, which persisted more than 20 days, are extremely rare in the whole world and resulted in the unprecedented damage.

2.3 Extremely great intensity with a number of record-breaking observations

Based on the statistics in the Yangtze River Basin and southern China, the event showed obvious temperature drops, abnormally low daily maximum temperature and significant precipitation. It was 2–4°C warmer than normal in the Yangtze River Valley in the first ten days of January 2008, with the mean temperature ranging from 5°C to 10°C. Afterwards, the temperature decreased sharply in most portions of southern China as a result of frequent cold air intrusions. The temperature drop ranged from 10°C to 20°C in most parts to the south of the Yangtze River

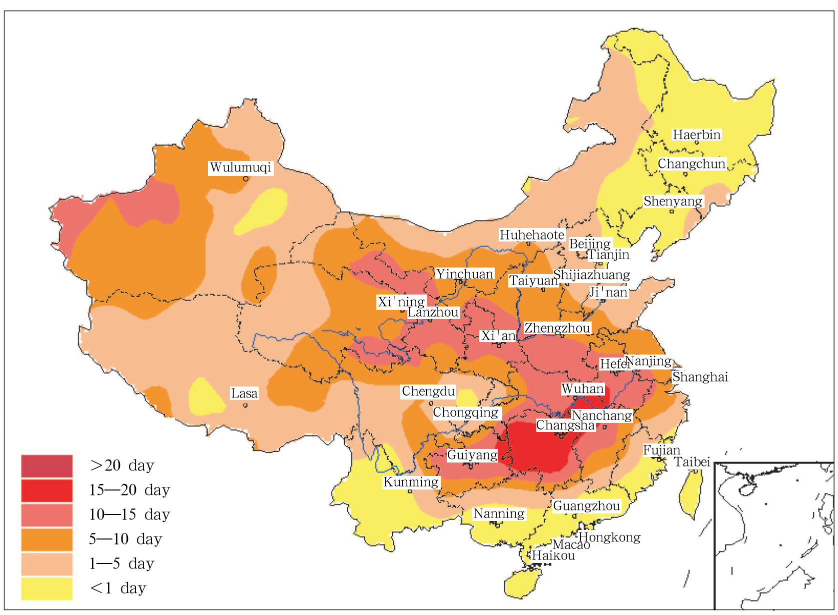

Fig.3. Ice freezing days in China from January 11 to February 3, 2008 (from National Climate Center, China).

(Fig.4). It seemed to begin in Xinjiang, then propagated eastward and southward, and finally stretched along the northern and eastern edges of the Tibetan Plateau in the form of an arch. The temperature decreased the most in Hubei, Guizhou, and Guangxi. Both the daily minimum and maximum temperatures were much lower than normal in the mid and lower reaches of the Yangtze River Valley, with the former decreasing to −6–0°C. The daily minimum temperature was 2–4°C lower than normal, while the daily maximum temperature 5–9°C lower than normal in Hubei, Guizhou, and Guangxi. According to the statistics (Wang Ling et al., 2008), the eight meteorological variables breaking historic records are as follows: (1) Mean daily maximum temperature, being the lowest during the same period of the history. It was especially low, much lower than that of 1976/77, and estimated to happen once every century in the mid and lower reaches of the Yangtze River and Guizhou. As the daily maximum temperature affects greatly the snow melting, its persistently low values are disadvantageous to the melting of snow and freezing ice in the daytime, and then intensifies the impacts of the disaster; (2) significant precipitation, with the accumulative amount reaching the maximum for the same period since 1951; (3) ice freezing days in the mid and lower reaches of the Yangtze River Valley and Guizhou exceeding the maximum in history; (4) persistence of ice freezing weathers in Hubei and Hunan being the longest since 1955; (5) persistence of freezing rains in 43 counties of Guizhou breaking the historic records; (6) ice freezing disasters in Jiangxi being the most serious since 1959; (7) persistence of snowfalls in Anhui being the longest since records start; (8) persistence, thickness and impacts of snow storms in Jiangsu all being the maximum in historical records. Until January 29, the cumulative thickness of snow was up to 30 cm in 18 cities or counties of Jiangsu, and even reaching 40 cm in some parts.

2.4 Incredible persistence of disastrous weathers with record-breaking durations

The freezing weather in some parts of the southern China lasted nearly a month. A cold day is defined as a day when the daily temperature is equal to or lower than 1°C. It is found that, the maximum persistent cold days in winter of 2007/2008 was 18.7 days, being the longest in the history, and 2 days more than that in the winter of 1954/1955 in the mid and lower reaches of the Yangtze River Valley (Fig.5). And in this region, the maximum persistent ice freezing days was 9.9 days, being the longest in the history, and

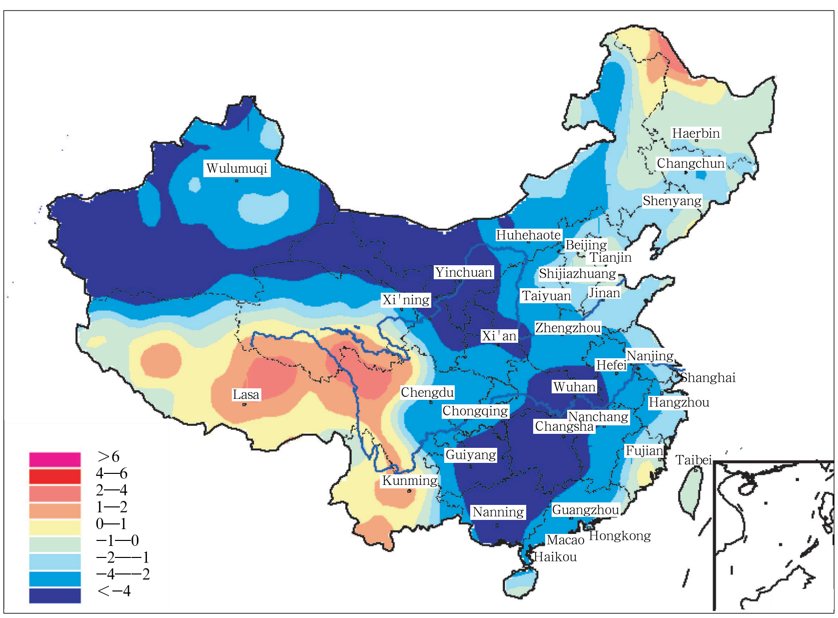

Fig.4. Temperature anomalies in China from January 11 to February 3, 2008 (from National Climate Center, China).

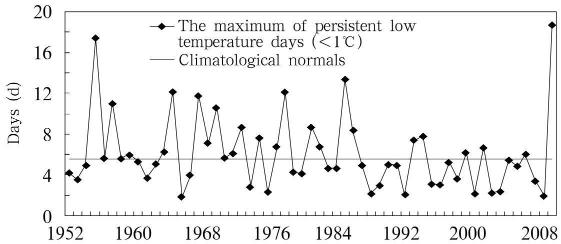

Fig.5. Time series of consecutively persistent low daily mean temperature days (<1°C) in winter in the mid and lower reaches of the Yangtze River from 1951 to 2008.

exceeded that in the winter of 1954/1955, too.

The intensity and persistence of the ice freezing weathers broke the historic records in some provinces. In Guizhou, the intensity, the impacted areas and the thickness of the icing on electrical wires all broke the historic records. The persistent ice freezing days reached the maximum of historic records in 56 counties (cities). In Hunan, the range, the number of stations where the ice freezing weather was observed, and the damage of the ice freezing disaster all reached the maximum of the historic records, and the persistence ranked the third in the historic records, following that in 1982/83 and 1954/55. In Hubei, this low temperature and rain and snow process was the most intense since 1954/55, in which the persistent cold days reached 16-18 days in most parts, being the longest since 1954/55, and the consecutive rainy and snowy days reached 15-18 days, being the maximum in the historic record. In Jiangxi, freezing rains occurred in more than 60 counties and the persistent rain and snow and ice freezing was the most intense since 1959. In Jiangsu, unprecedented snow storms happened, with the persistence, thickness of snow and the impact all breaking the historic records. In Anhui, the persistent snowy days became the longest in historic records, exceeding those in 1954/55 and 1968/69.

The long persistence of this rain and snow and ice freezing disaster is mainly caused by the unusually stable general circulation over Eurasia, which was favorable for cold air to break out successively southward to the mid and lower reaches of the Yangtze River along a similar path. The continuous impact of the disastrous synoptic system on the same region is a key factor causing serious disasters there. This is true for both the heavy rain case in summer (e.g., the extreme floods in the Yangtze River Valley in 1998) and the ice and snow disaster in January 2008.

3. Causes for the Southern China 2008 freezing disaster

Many studies have discussed causes for the ice and snow disaster in January 2008. On the basis of our study, three factors are of primary importance: Firstly, the impact of the La Niña event. Though some studies have stressed on it, the concrete impacting mechanism is still uncovered; secondly, the abnormal development of the blocking pattern over Eurasia and the stability of the general circulation; finally, the persistent northward transport of warm and wet airs from the Bay of Bengal and the South China Sea. In general, the disaster in January 2008 is caused by multiple factors, which intensively interact with and superimpose on each other over the same region during the same period. As this situation is unprecedented and rare, the specially persistent and strong snow and ice freezing disaster in January 2008 has a very low probability to happen, being defined as an extreme weather-climate event and estimated to occur once every 50 years.

3.1 The strong La Niña since August 2007 causing global weather and climate anomalies including the abnormal freezing disaster in China in January 2008

The La Niña event is an oceanic phenomenon, marked by the persistent abnormally low sea surface temperature (SST) in the tropical central-eastern Pacific Ocean. On the contrary, The El Niño event is the phenomenon of abnormally high SST in the same region. Generally speaking, when the SSTA (SST anomaly) of this region persists to be or lower than −0.5°C for at least six months, La Niña is formed. The La Niña event since August 2007 is stronger than normal, with the areal averaged SSTA reaching −2°C or so in January 2008 (Fig.6). Moreover, this La Niña event developed in the rapidest manner ever seen since 1951 and its mean intensity for the first six months was the greatest, with the areal mean SSTA reaching −1.2°C. Both the La Niña event and the El Niño event have great impacts on global weather and climate.

Before and during the disaster in southern China in January 2008, frequent abnormal weathers have happened in many other regions including South America, North America, Europe, and so on. For example, from late November to early December 2007, the cold wave breaking out southward from northwestern North America met with warm and wet air from the subtropics to cause a heavy snow storm. Many airports were thus forced to close, highways were blocked, electrical supply was affected badly, and 75 people were dead in the central-western and northeastern U.S. and eastern Canada, with the thickness of snow cover reaching 51 cm in Maine. In South America, the persistent rain storm caused great floods in Bolivia in the last 10 days of January, in which 32 people were dead. In Asia, rain storms attacked Southeast Asia in December 2007 and January 2008 and resulted in floods and mud slides in southern Thailand, Malaysia, and Indonesia, causing 21 deaths in Malaysia and 131 deaths in Indonesia. All the above disasters accord with the statistical consequences of impacts of La Niña events on global weather and climate in autumn and winter.

Precipitation is more than normal in northern China, while it is less than normal in southern China in the autumn when a La Niña event happens (He, 2007). As for the impacts of the La Niña event on the winter monsoon and the winter weather and climate, many studies (Mu and Li, 1999; Chen, 2002; Zhang et al., 1996) have revealed that the winter monsoon is stronger than normal when the La Niña event reaches a climax. According to the analysis of He et al. (2007, 2008) on the winter general circulation and corresponding weather and climate based on 8 strong and 12 weak La Niña events, some meaningful results are obtained: (1) extensive positive geopotential height regions are located in the high latitudes of Eurasia (to the north of 60°N) at 500 hPa, with the center near Novaya Zemlya exceeding the confidence level of 95%. This situation shows that, the ridge of high pressure or the blocking high develops and extends northward. However, the negative geopotential height regions are over West to Central Asia, representing the obvious development of the trough or low vortex there and constituting the dipole mode blocking pattern with the positive geopotential height regions to its north; (2) negative geopotential height regions are located along the coastal areas of East Asia, showing that the East Asian trough is stronger than normal. Then, the anomalous northerly controls the southeastern coastal areas of China and the South China Sea and cold air is stronger than normal; (3) negative geopotential height regions are situated over the Philippine Sea, and southern South China Sea, and an anomalous cyclonic circulation is found over 10°–15°N at 850 hPa, indicating the stronger and farther east subtropical high; (4) the trough in the southern branch of westerlies over the Bay of Bengal is weaker than normal; and (5) the temperature is lower and rainfalls are less than normal in southern China under the above circulation pattern.

These studies demonstrate that the meridional development of the general circulation over the mid latitude Asia was intensive in winter when the La Niña event is strong. The ridge of high pressure, consisting of warm air, stretches poleward and leads to the southward outbreak of extreme cold air there to China, resulting in the fact that the temperature is lower than normal in northern and eastern China, and rainfalls are more than normal to the north of the Yangtze River while lower than normal in the south. Actually, rainfalls in China during the autumn to early winter of 2007 bore this feature. An extensive and persistent drought happened in southern China in the autumn of 2007, showing obvious impacts of the La Niña event then. In the winter of 2007/2008, the anomalous distribution of rainfalls in China was similar to that in the years when strong La Niña events occur. That is, rains and snows are more than normal and the temperature is lower than normal in most portions of China, especially in northern China. And strong cold air forced the rainy belt to shift southward to the south of the Nanling Mountain. Between the snowy belt in the north and the rainy belt in the south, in the regions from Hunan and Hubei to Guizhou, the sleet or the freezing rain was dominant. Actually, the precipitation amount in the middle region was close to and

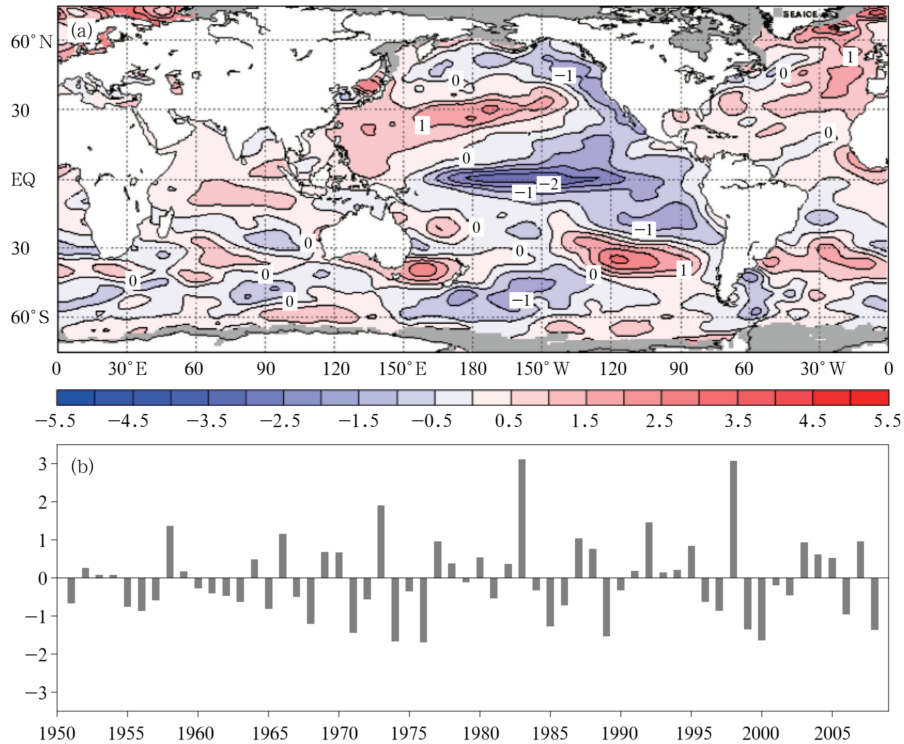

Fig.6. (a) Sea surface temperature anomalies (SSTA) in January 2008. The blue color denotes negative anomalies and red positive anomalies (from Japan Meteorological Agency, 2008). (b) Time series of SSTA (°C) of the NINO3 region in January of 1950–2008.

even less than normal in Guizhou and Hunan. Then, why is the disaster the most serious there? It was mainly due to the freezing rain. And this problem will be discussed further later.

Through the above analysis, the La Niña event was the climate background for the ice and snow disaster in January 2008, providing the advantageous conditions for the rain and snow and ice freezing weathers. However, it should be pointed out that the general circulation in January 2008 resembled that in La Niña winters in high latitudes of Eurasia, but it was different in the subtropics and tropics since the western Pacific subtropical high was farther north and west, rather than farther east and weaker than normal, and the trough in the southern branch of the westerlies over the Bay of Bengal was stronger than normal. According to He et al. (2008), these features resemble those in El Niño winters. Therefore, it was rainy but not dry in southern China in January 2008. The reason for these special features needs to be examined further.

3.2 The persistent anomaly of the general circulation over Eurasia

The anomalous circulation over Eurasia in January 2008 lies in that the strong high-level westerly over the North Atlantic Ocean split abruptly over Europe, with the northern branch over the Ural Mountains stretching northward intensively to the polar region, and then turning back southward and leading the cold air to flow eastward via Central Asia and arrive in China along the western route. This blocking pattern reached more northern latitudes than normal and persisted over 20 days, being 3 times of the climatic value and the longest since 1951 (Fig.7). Under this circulation pattern, cold air flew continuously from the northern parts of Siberia to Central Asia and invaded China along the eastern Hexi Corridor, providing advantageous conditions for the extensive low temperature, rain and snow, and ice freezing weathers in China. It can be seen that cold air from the trough of Balkhash Lake moved eastward via the northern

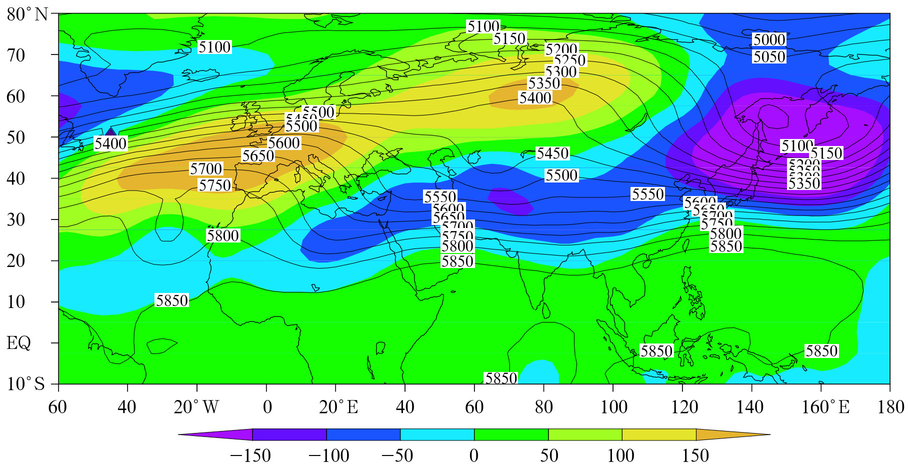

Fig.7. Mean circulation pattern at 500 hPa from January 11 to February 3, 2008. The shaded areas denote height anomalies (unit: gpm).

Tibetan Plateau, then southward along the eastern Tibetan Plateau to affect China.

Continuous intrusions of cold air from Central Asia along the western path is the most important circulation and synoptic character of China's ice freezing disaster in early 2008. Under the stable dipole mode blocking pattern over the Ural Mountains, at least four batches of cold air incursions affected China from Xinjiang in succession. Figure 4 shows the temperature drop caused by the cold air intrusions. Cold air in Central Asia was spilled from the cold trough or low vortex there and surged eastward. The cold trough or low vortex in Central Asia was caused by the splitting of the westerlies induced by the intensive development of the Ural blocking. The formation and persistent maintenance of the Central Asian trough or vortex not only resulted in the continuous intrusions of cold air into China along the western route, but also helped to intensify the trough in the southern branch of the westerlies over the Bay of Bengal by forcing cold air to flow into Iran, India, and Pakistan. As mentioned earlier, the intensive development of the trough over the Bay of Bengal is a key factor causing the freezing rain. Figure 8 shows the variation of 500-hPa geopotential height of the Ural blocking high, the low trough of Central Asia, and the trough of the Bay of Bengal from January 1 to February 8, 2008. It can be seen that the correlation coefficient of the geopotential height between the Ural high and the low trough of Central Asia is −0.41, while the low trough of Central Asia has a significant positive correlation with the trough of the Bay of Bengal with the coefficient of 0.73. Moreover, the Ural high changes out of phase with the trough of the Bay of Bengal, with the correlation coefficient of −0.24. These relations suggest that the formation of the low trough or vortex of Central Asia depended on the development and maintenance of the Ural blocking pattern, and its development and maintenance in turn affected the downstream development of the trough over the Bay of Bengal. Therefore, the Central Asian low trough was a key player for this ice

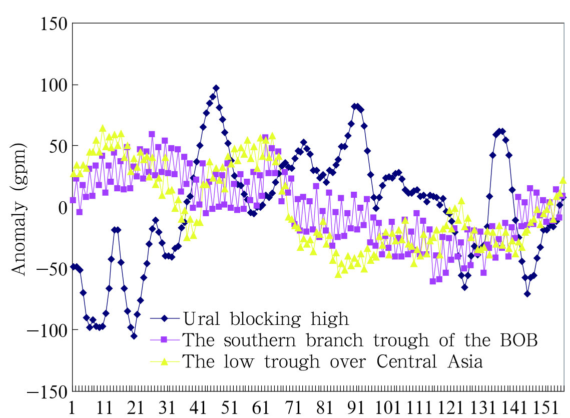

Fig.8. Evolution of the geopotential height of the Ural blocking high (55°–65°N,70°–90°E), the low trough over Central Asia (30°–40°N,65°–75°E), and the trough of the Bay of Bengal (15°–25°N,85°–95°E) from January 1 to Feburary 8, 2008 (unit: gpm).

freezing disaster. Additionally, it is noted that the East Asian major trough was relatively stronger than normal during the disaster (the negative anomalies along the coastal areas of East Asia in Fig.7), promoting the transport of cold air to China along the northwestern or the eastern routes.

On the other hand, the ridge line of the western Pacific subtropical high in January 2008 was at 17°N, farther north than normal (13°N). Please see extensive positive anomalies over the central-western Pacific Ocean in Fig.7, which reached to the northern most latitude since 1951. Meanwhile, the southerly airflows along the western edge of the subtropical high helped to transport warm and wet air northward to meet cold air from the mid and high latitudes over the mid and lower reaches of the Yangtze River and caused the snow storm in Anhui, Jiangsu, and Zhejiang Provinces at the early stage (before 21 January 2008). After that, the subtropical high shifted southward and weakened, with the converging belt of warm and cold air moving southward too, and the low temperature, rain and snow, and ice freezing weathers concentrating in the middle reaches of the Yangtze River and the regions to the south. Just in this period, the freezing rain became much heavier. It has been shown that the subtropical high was stronger and farther north than normal in the winter of 2007/2008, different from the anomalous winter circulation when La Niña events develop. The reason for this is still unknown.

3.3 Intensified water vapor transport by the trough in the southern branch of the westerlies over the Bay of Bengal

The warm and moist southwesterlies from West Asia going around the Tibetan Plateau and the southerlies from the Indo-China Peninsula and the South China Sea met with cold air from the mid and high latitudes over southern China to produce abundant precipitation. More importantly, the warm and moist airflows constituted a warm-moist layer between 1000 and 3000 m that is helpful for the formation of the freezing rain. Were there no intensive transport of warm and moist air from the Bay of Bengal, there should not be persistent freezing rains in southern China in early 2008. Instead, the precipitation distribution would be similar to the climatic situation, with snowfalls in the north of the Yangtze River while rainfalls in the south, and freezing rains for a few days in Southwest China. Then, why was there so intensive transport of warm and moist air from the Bay of Bengal? As discussed above, it was related to the development of the active southwesterlies, originating from the strong westerlies splitting over Europe. This branch of the westerlies was blocked by the Tibetan Plateau and then diverted southward to flow in the trough over the Bay of Bengal. Since mid-January 2008, the trough became active and intense, which has been unusual in recent decades (Fig.9). Seen from Fig.9, the trough of the Bay of Bengal was significant in the 700-hPa streamline field and the anomalous geopotential field. The southwesterlies ahead of the trough met the northwesterlies from the north over the Jianghuai region. The stable strong trough over the Bay of Bengal was favorable for the transport of warm and moist air from the Indian Ocean and the Bay of Bengal to the Yunnan-Guizhou Plateau.

The formation of the trough in the southern branch of the westerlies over the Bay of Bengal has a close relationship with upstream circulation systems, which propagate eastward along the southern branch of the westerlies (Fig.10). On one hand, the intensity of the trough has an obvious negative correlation with the intensity of the high pressure system over West Asia–Mediterranean Sea–North Africa, while it has a positive correlation with the intensity of the upstream pressure field over the northern North Atlantic Ocean. On the other hand, the intensity of the trough has a significant negative correlation with the downstream pressure field over the Pacific Ocean north of the subtropical high. Overall, an obvious wave train can be observed from northern North Atlantic Ocean to West Pacific Ocean, via West, South and East Asia along the southern branch of the westerlies. The positive correlation region (Fig.10), centering the trough of the Bay of Bengal, is much extensive, extending northward to Central Asia and eastward to Southwest China, most of South China and the Indo-China

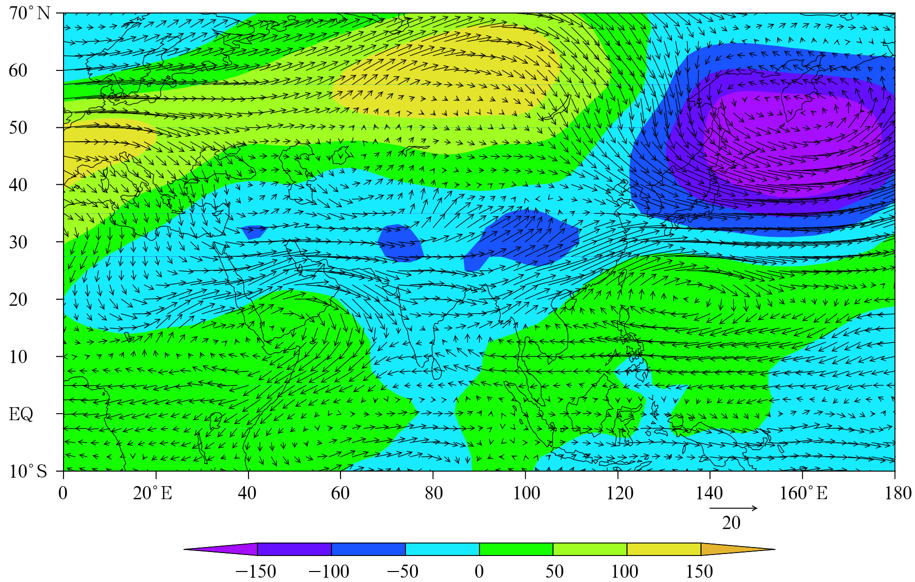

Fig.9. Streamline field at 700 hPa from January 10 to February 3, 2008. The shaded areas denote height anomalies (unit: gpm).

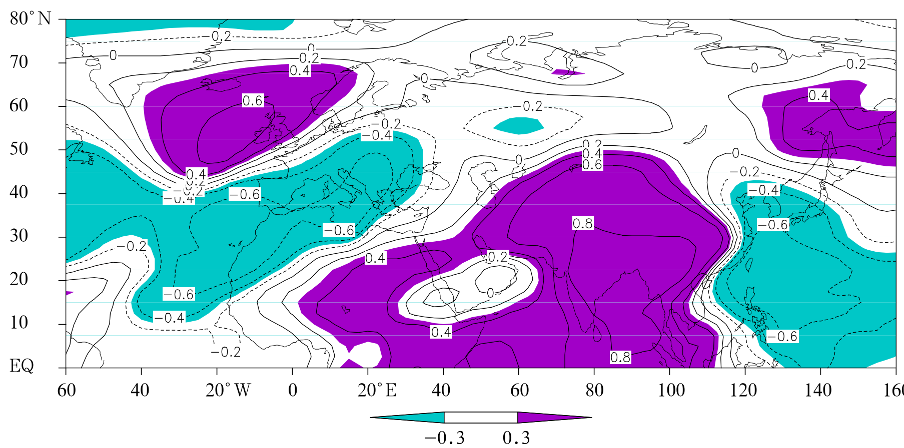

Fig.10. Simultaneous correlation coefficients of the geopotential height at 700 hPa between the southern branch trough of the Bay of Bengal (20°–27.5°N, 85°–95°E) and the whole Asia, with shaded areas exceeding the 95% confidence level.

Peninsula.

Figure 11 presents the longitude-time section of the geopotential height at 700 hPa along 25°N. It can be seen that there were two eastward propagating low troughs (negatively anomalous regions) from January 10 to February 2, 2008. One was from North Africa to southern Central Asia, via West China (20°W–70°E), corresponding to the low temperature and snow storm weathers in West-Central Asia (Fig.1), and the other corresponded to the eastward propagation of the trough of the Bay of Bengal since January 21 to 120°E in early February, matching the period of freezing rains in southern China. These two waves propagating eastward along the southern branch of the westerlies are major synoptic disturbances causing the extensive snow and ice freezing disasters from West Asia to East Asia. It should be noted that this systematic propagation was not observed before January 10.

Convergence of three airflows over Southwest China and the region to the south of the Yangtze River can be observed in the 850-hPa streamline field. The southerlies from the western edge of the subtropical

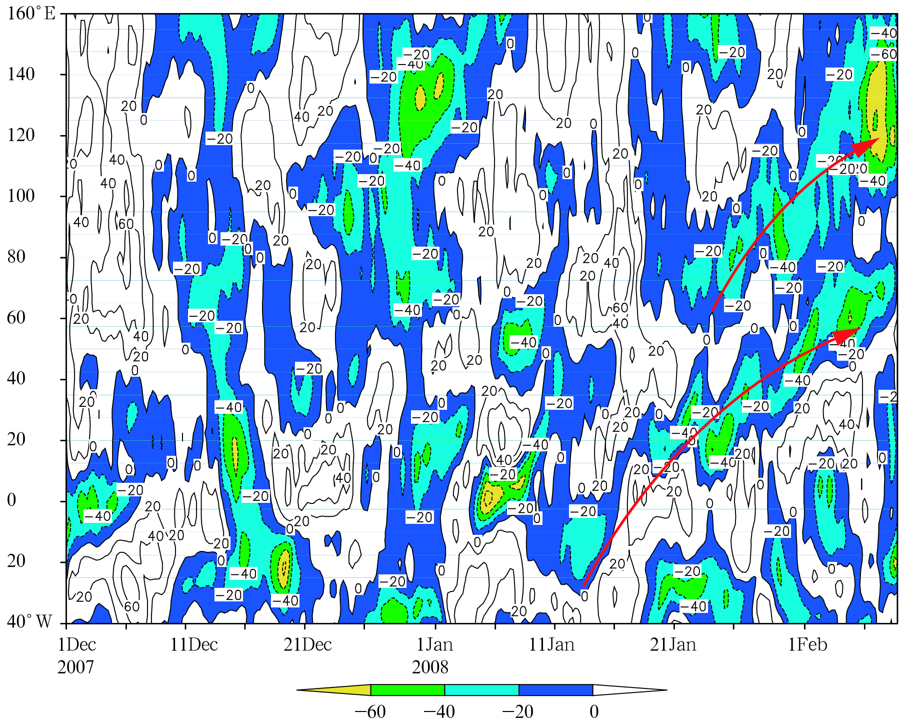

Fig.11. Longitude-time section of the geopotential height at 700 hPa along 25°N averaged from December 1, 2007 to February 6, 2008 (unit: gpm). Shaded areas denote negative anomalies.

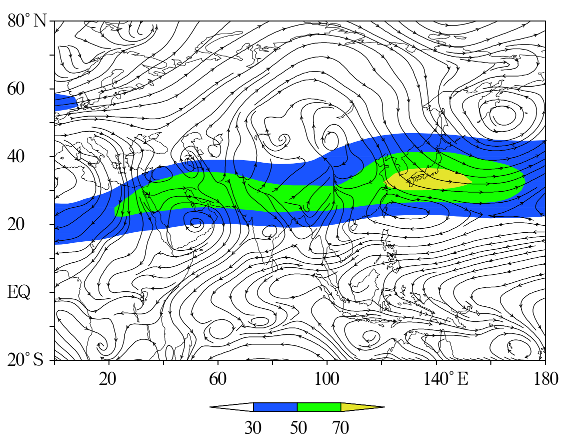

Fig.12. Streamline field at 850 hPa averaged from January 25 to Feburary 3, 2008, with the subtropical jet axis of 200-hPa shaded (unit: m s^{-1}).

high met with cold air from the north and constituted an east-west oriented convergence line along the mid to lower reaches of the Yangtze River. Furthermore, the above two airflows converged again with the airflow from the Bay of Bengal and formed another south-north oriented convergence line over Southwest China, approximately corresponding to the Yunnan-Guizhou quasi-stationary front. This circulation pattern was in favor of snowfalls in the lower reaches of the Yangtze River and sleet (freezing rains) in Southwest China. Additionally, the southwesterly jet at 200 hPa was observed between 25°N and 30°N, along which the wave train in the southern branch of the westerlies propagated eastward. The snow and ice freezing belt in southern China was located in the ascending region on the right sector of the entrance zone of the upper-level jet over southern Japan (Fig.13), with the descending region in the north of the jet. A positive circulation cell was then formed around the entrance zone of the jet.

A large amount of water vapor was transported by the trough over the northern Bay of Bengal to southern China and converged intensively there (Figs.14a,b). It is seen from Fig.14a that, the major water vapor transport channel was from the northern Bay of Bengal to southern China by the southwesterlies ahead of the trough. An obvious convergence belt of water vapor can be observed in Southwest China from Fig.14b, which was located to the east of the

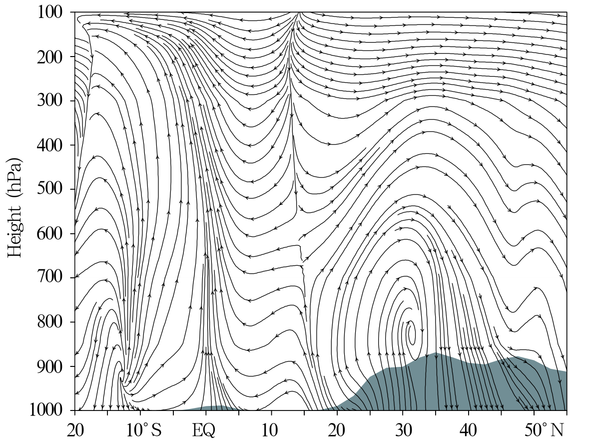

Fig.13. Latitude-altitude section of the streamline field in the entrance region of the upper-level jet averaged from January 25 to February 3, 2008 along 110°–120°E.

Hengduan Mountains due to the orographic effect, also in accordance with the convergence line in the streamline field at 850 hPa in Fig.12. Relevant calculations indicated that the water vapor transport from the trough of the Bay of Bengal (western boundary) was larger than that through the southern boundary (from the South China Sea and the Indo-China Peninsula) since 22 January, when the freezing rain reached its peak period (Fig.15).

3.4 The freezing rain effect

Freezing rain is a form of supercooled liquid precipitation, also called glaze. When it falls onto subjects with temperature lower than 0°C, it forms substantial, transparent or semitransparent ice. Formation of the freezing rain has a close relationship with the existence of low-level cold air. Cold air from the north breaks out southward via Northwest China, North China, and the Yangtze River Valley, and spreads out in the region south of the Yangtze River in a fan-shaped manner. When the southwestern part of the fan-shaped cold air mass reaches the Hengduan Mountain range, it stagnates and accumulates in the extensive area to the east of the mountain range due to the blocking effect. Then a cold layer, called the "cold cushion", is formed below 1500 m over Yunnan, Guizhou, Sichuan, Guangxi, western Hubei, and western Hunan, helping to form the freezing rain. There is a warm layer above the cold cushion, called the melting level. It is a transition level and important for the formation of freezing rains (Wang, 2008; Rafa et al., 1991; Stewart, 1992), in which there may be only sleet or sleet mixed with freezing rain and ice (ice particle and hail included). It generally produces high precipitation and can be observed in storms or extratropical cyclones in winter along the eastern coasts of continents, with the width ranging from several to hundreds of kilometers. Furthermore, it is the dividing sector between rain and snow. The transition sector includes complex interactions between multi-phase articles through the micro-physical, thermal and dynamical processes.

Figure 16 shows the longitude-height section of the temperature anomalies along 25°N in January 2008. The most prominent feature is the "sandwich"

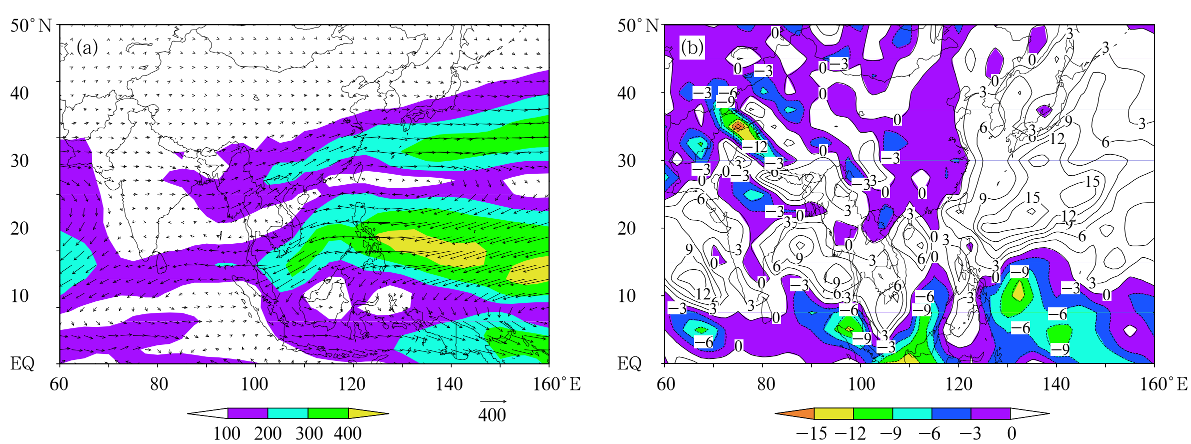

Fig.14. (a) Water vapor flux vertically integrated from surface to 300 hPa from January 10 to Feburary 3, 2008 (unit: kg m^{-1} s^{-1}). (b) Divergence of the vertically integrated water vapor flux. Shaded areas represent convergence (unit: 10^{-5} kg m^{-2} s^{-1}).

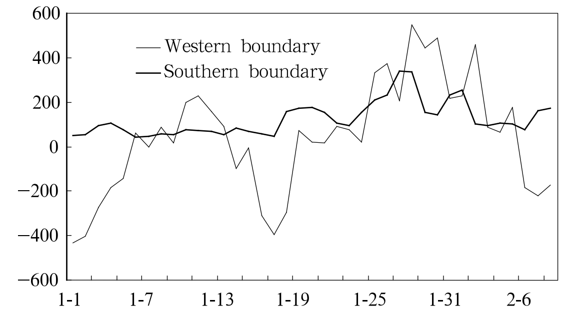

Fig.15. Time series of the water vapor flux vertically integrated from surface to 300 hPa through the western boundary (20°–27.5°N, 100°E; black squares) and the southern boundary (20°N,100°–130°E; grey squares) from January 10 to February 3, 2008 (unit: 10^6 kg s^{-1}).

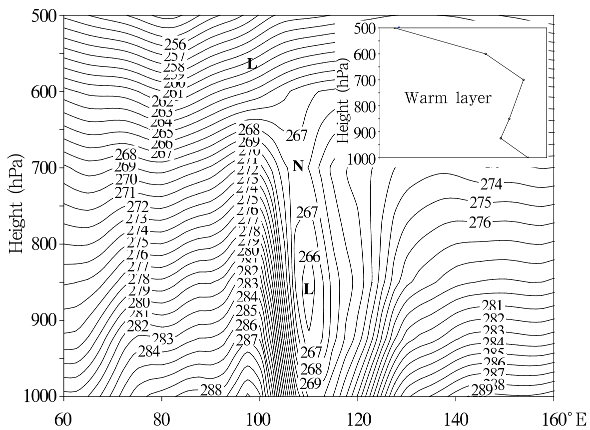

Fig.16. Longitude-altitude section of temperature anomalies along 25°N (unit: K). Small figure at top right presents the inversion layer over southern China.

structure of the temperature in the vertical direction east of the Hengduan Mountain range (100°–105°E). It was observed that there was an obvious inversion layer between 1500–3500 m over Hunan, Guizhou, and so on, since mid-January 2008, and the inversion layer strengthened gradually and maintained over 20 days. Below the inversion layer, the surface and low-level temperature persisted to be lower than 0°C, causing a thick cold underlying surface coming into being, which was in favor of freezing rains. The inversion layer is a necessary condition to form and sustain freezing rains in the extensive areas in southern China. According to the study of Wang Donghai et al. (2008), when the surface temperature is 0–3°C, the temperature difference of the inversion layer between 850 and 700 hPa will be higher than 4°C. The inversion layer to the north of 29°N is relatively weak, with snowfalls being the main type of weathers, while it is relatively strong to the south of 26°N, with rainfalls being the main type of weathers due to higher surface temperature. Thus the transition sector spanned three degrees of latitudes and was broader than that in North America and North Europe.

According to the radar reflectivity observations of Cloudsat (Wang Donghai et al., 2008), during the peak period of the snow and ice freezing disaster (for example, January 28), there were no ice particles in 26°–29°N, 112.5°E within the inversion layer (2–4 km); they were only observed near the surface. When warm and wet air over the coastal areas of South China ascended northward to mid and high levels along the low-level "cold cushion" reaching about 10 km over the Huaihe River Valley, they condensed or grew rapidly to be supercooling liquid drops or ice crystals, and the supercooling drops became big snow flakes through the Bergeron process. The big snow flakes melted into water drops in the warm layer, and the water drops condensed again on cold subjects while passing through the underlying cold layer. The ice shell was then formed with liquid water in center, and fell on the land surface, and that was the freezing rain. The low temperature at night induced the freezing rain to condense further on the ground, the roof, the exposed outside facilities, and so on. This phenomenon is called "rain freezing". The freezing rain leads to the "rain freezing", and the "rain freezing" leads to the ice. Then the massive "low temperature, rain and snow, and ice freezing" disaster occurred. Many foreign and domestic studies found another mechanism for the formation of freezing rain, the "overcooling warm rain process" as follows: since the temperature of the cloud top is relatively high, the ice crystal is hard to form; then a rain drop grows to be so big and supercooled, and falls onto subjects on the ground to condense to be the freezing rain. Big cloud drops falling from high levels (diameter greater than 40 μm) are a prerequisite for this mechanism. However, how much contribution of this mechanism to the disaster in January 2008 is still unclear.

The above analyses on the formation of the freezing rain are preliminary. In fact, a lot of researchers have discussed this subject in connection with the precipitation pattern in winter storms of Canada, eastern America, and North Europe (Rafa et al., 1991; Stewart and King, 1987; Stewart, 1992; Lin and Stewart, 1986; IPCC, 2007). They investigated the thermal and dynamic structures of the precipitation pattern and the corresponding synoptic processes, the diabatic forced mesoscale circulation and its impacts on the snow storm and the freezing rain, the destabilization process of the conditional symmetry instability, characters of the vertical bright band of radar echoes, and so on. Thus, the disaster in January 2008 in China needs to be studied further in such aspects as microphysics and the coupling and interaction of the thermal and dynamic processes.

4. Relationship between the Southern China 2008 freezing disaster and the climate change

Under the global warming, the climate variability is getting larger and the probability of occurrence of extreme events is getting higher. That is, the amplitude of the anomalies from mean climate conditions increases significantly (Tao, 2008)[§], and the frequency of small probability events also increases. Generally, the global warming is supposed to cause the increase of such extreme events as high temperature (heat wave), rain storms, and so on, and the decrease of cold extreme events. However, there are a few exceptions for some small probability local events. For example, snow storms and cold waves often occur during warm winters. The low temperature, rain and snow and ice freezing weathers in the winter of 2004/2005 and in January 2008 are both remarkable cases of small probability events under the background of 21 successive warm winters.

Climate change studies (IPCC, 2007) indicated that, under the global warming, rainfalls may increase while snowfalls may decrease, especially in regions with the surface temperature near the freezing point (about 0°C), and the intensity of rainfalls or snowfalls may increase. The ice and snow disaster in January 2008, with the freezing rain being the major precipitation type, also demonstrates this character. Though it is difficult to relate closely this character with the global warming through only one example, the impacts of the climate change are clearly reflected in the La Niña setting, the anomalies of the general circulation over Eurasia and the effects of anomalous warm and wet airflows from low latitudes. The impacts of the global warming can be obtained through a direct comparison of this disaster with those in cold periods.

The climate record shows that since 1951 the most severe cold event occurred in the winter of 1954/1955, before which there happened the most severe flood in the Yangtze River in summer. The snow and freezing ice coverage was close to that of 2008. The snow depth at many places in southern China reached 20–30 cm, with the highest record of 1 m. Most of the rivers and lakes were frozen except for the main stream of the Yangtze River. The average thickness of the lake ice was 16–25 cm, with the deepest of 1 m. The temperature of Huaihe River Valley was about $-21°$–$-18°$C, while the temperature of the areas south of the Yangtze River was $-8°$–$-5°$C, with a common temperature drop of 15°C. The winter of 1976/1977 was another cold winter, when the lakes Dongting, Boyang and Taihu were frozen for 7–10 days, which was rarely observed in history.

Although the event in 2008 was quite extreme, there was no appearance of frozen rivers and lakes, except for short-term freezing in small Honghu, East and West Lakes. The mean temperature drop during the January 2008 disaster was about 4°C in southern China. For the January 2008 disaster, the daily maximum temperature was the lowest while the daily minimum temperature did not break the historical record, because the daily minimum temperature in winter 2008 has been obviously increased by the

[§]Tao Shiyan, 2008: Reasons for the disaster in January 2008. Forum on the low temperature, rain and snow and ice freezing disaster in 2008 January. January 30, 2008. (in Chinese) impact of global warming. Thus the temperature drop during this disaster was not lower than that during the cold events of 1950s and 1970s. However, for most indices, the disaster of January 2008 is unprecedented and can be counted as "once in a century". For example, the persistence of the disastrous weathers and the widespread impacts have broken the historical record in Hunan and Hubei Provinces. Under the global warming, with 21 successive warm winters beforehand, it was exceptionally rare that southern China experienced such an extremely cold winter.

This disaster raised a question on the process and mechanism of the formation of big snow flakes and the freezing rain, a new challenge for researchers on "cloud physics". Some questions need to be addressed, such as, where did the "cloud particle" and the "ice particle" come from? Were these particles related to pollutants over the Yangtze River and southern China?

Another question is whether the extensive low temperature, rain and snow, and ice freezing disasters in Asia in 2008 will change the pattern of the global warming.

After the disaster, some researchers and policy makers who disagree on the global warming expressed their worries about the future climate change trend. They argued that the extensive cold weathers are changing the global warming trend and the earth is entering an ice age. For example, Mark Molano, an official of Environment Protection and Public Project Committee of the Republican Party in the US Senate, wrote on his blog that "The fever of the earth is gone and world is entering a little ice age". These opinions and comments misunderstood the trend of the global warming in the recent 100 years. The global warming is a centennial scale change, with short-term variations, such as the interdecadal, interannual and seasonal variations, or "noises", superimposed on it. The El Niño event can arouse the positive temperature variation, while the La Niña event, outbreak of volcanoes, emission of aerosol, extensive sand and dust storms, and anomalies of the general circulation can cause decreases of the temperature. Although the amplitude of these changes is greater than that of the global warming, they are short-term episodes. Once they are finished, the global warming will recover and the global temperature continues to increase. In January and February 2008, the global mean temperature has decreased to below the climatological normal value. After February, it increased to be near the normal value, and 0.3°C higher than normal in March.

The present global climate monitoring indicates that the global warming trend was shortly disturbed by the ice freezing weathers in Asia in January 2008, but resumed afterwards. This actually reflects the impact of the natural climate variability on the global warming. The short-term cold disturbance is also found in the cooling effect of the volcano eruptions. The global temperature usually decreases by 0.5°C or so in 1–2 yr after a volcano erupts. In the time series of the global mean temperature in the recent centuary it is found that similar cold events occurred as well in winters of 1988, 1991, 1992, and 1998. And the persistent drop of the temperature during the 1950s–1970s is believed to be caused by increases of the aerosol and pollutants in the world, which reduces the incoming sunlight and cools the surface of the earth.

As to the question whether the disaster in January 2008 will change the pattern of the global warming, the answer is clear. This event can only change the warming trend in some regions for a short period of time. The extensive snow and ice freezing disasters in Asia in January 2008 have really reversed the anomalous temperature pattern in most parts of Asia, with warm anomalies in the north and cold anomalies in the south, although it was warmer than normal over the whole Eurasia in January in the previous seven years (Fig.2). However, this change is temporary and regional. After April 2008, the temperature anomalies showed a significant warming trend again. The increase of the temperature was obvious in the extensive regions from North Africa to China, via Europe, West and Central Asia (Fig.17). All these analyses have proven that the extensive disaster in January 2008 will not change the global warming pattern and

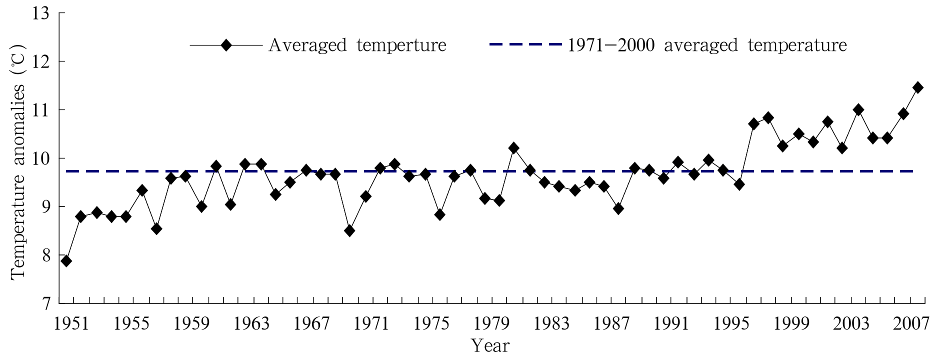

Fig.17. Temperature anomalies over China averaged from March to May during 1951 to 2008.

trend, not to mention the little ice age comment.

Even under the global warming background, the climatic system usually demonstrates all kinds of short-term and regional variations to cause severe disasters. Given the present knowledge in science and technology, it is still difficult to predict the long-term global climate change. This is a challenge that all scientists in the world are facing. Fortunately, climate models provide us a powerful tool to predict the future climate. Now, we have had the ability to predict the global and regional climate change for the next century or even longer, the abrupt change of the climate, as well as some disastrous extreme weathers and climate events. Because a climate model is a complex dynamical system, in which numerous factors interact, its accuracy is relatively low. But following the development of science and technology, climate models are expected to be pronouncedly improved. They are believed to play an increasingly important role in climate prediction and disaster prevention and preparedness.

5. Concluding remarks

Three aspects of the ice and snow disaster in January 2008 are discussed in this paper, including major characters, causes and synoptic conditions for the formation of the freezing and snow storms, as well as the relationship between the disaster and the global climate change. It is summarized that this event has the following characters:

(1) Extreme intensity and great persistence. The intensity and persistence of some variables during this disaster broke both domestic and world historical records. Especially, freezing rainy days are averaged to be 20 days, and reached 20–25 days in Jiangxi and eastern Guizhou, exceeding the historical records in the winter of 1954/1955 in China and in central and eastern North America. In these regions, the freezing rain, also called the ice storm, can cause severe disasters if lasting over 6 days. This kind of disaster occurs once almost every 25 years, and the ice storm persisting over 10 days is unprecedented. The melting layer or the transition regime of precipitation pattern of the disaster in January 2008 is over 300-km wide, while it is less than 100 km in North America and North Europe.

(2) The great disaster in January 2008 is a part of the extensive large-scale and even planetary-scale low temperature, rain and snow, and ice freezing disasters in southern Asia. However, similar kinds of weathers mostly occur with storms or extratropical cyclones in winter in central and eastern North America and North Europe. During this disaster, cold fronts and shear lines caused eastward shift and southward intrusions of cold air, but the obvious development of extratropical cyclones was not observed, while the persistently stable large-scale circulation systems were significant.

(3) Extremely stable Eurasian circulation pattern was a key large-scale condition affecting the disaster in January 2008, with the Ural blocking high and the low trough over Central Asia forming a dipole pattern.

This circulation pattern helped cold air to invade China in the western route and caused the up-stream splitting of the strong westerlies. Then the southern branch of the westerlies intensified greatly and brought cold air to West, Central and South Asia. After this strong westerly shifted eastward to south of the Tibetan Plateau along 25°–30°N, a trough in the southern branch of the westerlies over the Bay of Bengal was established due to the orographic effect of the Tibetan Plateau, with the southwesterly wind ahead of the trough flowing into China. While moving over the subtropical region, the air mass transformed gradually to be warm. At the same time, it caught abundant water vapor from the sea surface of the Bay of Bengal. Then, the airflow became the strong warm and wet southwesterly and met with cold air from the region to north of the Tibetan Plateau as well as the southerly wind from the western edge of the subtropical high over the mid- and lower reaches of the Yangtze River and South China. Thus, splitting of the airflow over Eurasia, eastward shifting of two branches of the airflow around the Tibetan Plateau and converging of them over the Yangtze River Valley are important conditions for the disaster in January 2008. It is incredible to observe that the classic circulation pattern causing rain storms in summer occurred in winter and resulted in severe snow and ice freezing storms (Tao, 2008).

As to why the westerly jet can split over Europe to the west of the Tibetan Plateau, there are two major views: 1) it is related to NAO or AO (Wang Donghai et al., 2008). During the early period of the disaster in Asia, AO maintained its positive phase, with the polar low pressure regime and the surrounding high pressure regime strengthening and the westerly in between speeding up. Then the dynamic instability induces the strong westerlies wind to split. 2) It is related to the intensifying and southeastward moving of the high-level jet over Central Asia (Wen et al., 2008). Both views indicate that the disaster in southern China in January 2008 has a close relationship with anomalies of the general circulation and the sea surface temperature over Europe and North Atlantic.

(4) The La Niña event is the climatic background of the disaster in January 2008. The La Niña event is closely related to the establishment and stability of the Eurasian blocking pattern and the strengthening of the major trough over East Asia. As pointed out in this paper, the active trough in the southern branch of the westerlies over the Bay of Bengal, the western Pacific subtropical high being farther north and west than normal and the more intensive northward transport of the warm and wet airflows are not common circulation patterns with most La Niña events, but those associated with El Niño. What caused the anomalies of circulations over West Pacific, the South China Sea, and the Bay of Bengal during this disaster is not yet clear. It is therefore difficuct for weather forecasters to predict this disastrous event.

(5) The relationship between the disaster in January 2008 and the global warming is complex. The distinction between snow and ice freezing disasters during a global warming period and those during a cold climate period is mainly analyzed. It is found that the disaster in January 2008 changed the large-scale temperature field and circulation patterns over Eurasia on monthly or seasonal scale, but it cannot change the warming trend in China and the world. This disaster can be viewed as a regional disturbance to the global warming, being similar to the cooling effect of the volcano eruption. However, it should be noted that the volcano eruption is an external forcing while the La Niña event is a coupled internal variability. The low temperature and ice freezing disaster in the winter of 2004/2005 in eastern China is also a regional disturbance to the global warming (Ding and Ma, 2007; Ma and Ding, 2008). This is an important topic to be studied further.

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