Analysis of Causes of a Widespread Strong Cold Wave Process

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Abstract Based on the high-altitude and ground observation data, as well as physical quantity field data, a cold wave weather process in Northeast China, North China and Inner Mongolia during January 1 -6, 2010 was comprehensively analyzed from the aspects of circulation background, circulation situation, influence system, dynamic conditions, water vapor conditions, *etc.* The results show that the cold wave weather process appeared during the transition of circulation pattern from zonal to meridional type in middle and high latitudes in the northern Hemisphere. Due to the development of the European trough, the strong warm advection was transported to the Ural Ridge, making it strongly developed. The strong northerly wind belt in front of the ridge moved southwards. The warm advection at the rear of the transverse trough and the cold advection in the southeast in front of the transverse trough on the northwest side of Lake Baikal caused the transverse trough to turn upright and moved southwards, and the longitude of the circulation increased continuously to guide cold air to move southwards, resulting in this strong cold air process. The large ground pressure gradient caused by strong cold air and the frontogenesis of strong surface cyclone led to the gale in North China.

Key words Cold wave; Influence system; Circulation pattern; Physical quantity field; Cold advection

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Cold wave, a large-scale weather process, often causes a variety of serious meteorological disasters. On the one hand, it affects the normal life of people and livestock; on the other hand, it can also maintain ecological balance, such as freezing some pests. From January 1 to 6, 2010, the north was hit by a strong cold wave process, and the extreme minimum temperature in most of northeastern China and northeastern Inner Mongolia ranged from -30 to -40 ℃, and was below -40 ℃ in some areas. On January 1, the lowest temperature in Manzhouli, Inner Mongolia reached -43. 8 ℃, breaking the historical extreme. The lowest temperature in Beijing on January 6 reached -16. 7 ℃, breaking the record of the lowest temperature in early January since 1971. The cold wave weather event was selected as one of the top ten weather and climate events in China in 2010.

There have been many studies on cold wave at home and abroad. As early as the 1930s, Li Xianzhi[1] studied "cold wave in China". Tao Shiyan[2] made an incisive analysis of the source and path of cold wave in China. Xu Aihua *et al.*[3] analyzed a cold wave process in March 2005, and pointed out that the atmospheric temperature below 925 hPa was the key to the phase change of precipitation in southern China. He Chengcheng *et al.*[4] analyzed a spring cold wave rainstorm and snow weather process, and pointed out that the abnormal rise of near-surface temperature in spring was a good precursor of cold wave weather. Zhang Shanqing *et al.*[5] analyzed a national cold wave blizzard process, and concluded that the low-level jet stream and warm moist air were one of the factors that caused the blizzard and drastic cooling during the cold wave. In this paper, the formation and development of the cold wave weather process from January 1 to 6, 2010 were analyzed to further understand the formation mechanism of northern cold wave weather, expand forecast ideas, and provide reference for the future forecast of this kind of cold wave.

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1 Actual situation of weather

From January 1 to 6, 2010, China experienced a national cold wave weather process. The strong cold air caused heavy snowfall, gale, freezing, and especially the temperature broke through the record of the lowest temperature in early January since 1971, seriously affecting the normal production and life of people in northern China.

The strong cold air mainly has four characteristics. Firstly, the temperature dropped obviously. For instance, the minimum temperature in northern Xinjiang, eastern Northwest China, North China, Northeast China, Huanghuai and other areas declined by more than 10 ℃. At 08:00 on January 3, the 24-hour drop in temperature in Qinghe and Buerjin of Xinjiang was 19 and 16 ℃, respectively. At 08:00 on January 4, the temperature in parts of northern Shanxi and central Inner Mongolia dropped by more than 20 ℃ during 24 h. Secondly, there were more extreme low-temperature events. After the temperature plummeted, the temperature in most of North China continued to be low. On January 5, the minimum temperature was generally between -16 and -18 ℃ in Beijing and Tianjin, and ranged from -20 to -36 ℃ in northern Hebei and central Inner Mongolia. The daily minimum temperature in 35 meteorological observation stations in Inner Mongolia, Liaoning, Hebei, Beijing, Tianjin and other provinces (autonomous regions and municipalities) met the standard for extreme low-temperature events. The daily minimum temperature in 15 meteorological observation stations in Inner Mongolia and Hebei Province exceeded the historical extreme. Thirdly, the range of strong winds was large. There were force 4 – 6 northerly winds in the middle and lower reaches of the Yangtze River and areas to the north, and force 7 – 9 gales in the eastern sea area. In the afternoon of January 3, instantaneous gales of force 8 – 10 appeared in Hetao and some parts of central Inner Mongolia, and were accompanied by sand weather. According to the cold wave standard of the Central Meteorological Observatory, this process was classified as a regional cold wave weather process in the north.

2 Analysis of circulation situation

2.1 Circulation situation at 500 hPa In the cold wave process, there were two ridges and one trough (inverted Ω flow type) in middle and high latitudes over Eurasia, and there was a high ridge near the Ural Mountains, which extended from northeast to southwest. In Alaska area, a ridge gradually developed westwards near the Sea of Okhotsk.

Since 20:00 on December 28, 2009 (Beijing time, the same below), there were three main polar vortexes in northern Asia, western Europe and North America. Among them, the polar vortex in northern Asia was stable, so that the temperature in parts of Inner Mongolia, northeastern and North China remained low. At 20:00 on December 29, a trough developed strongly over Europe and formed a cut-off vortex. The temperature trough lagged behind the altitude trough. The ridge near the Ural Mountains developed northwards. In front of the ridge, northerly air carried cold air from the polar regions southwards to Siberia, forming a wide low-value area here. At the same time, there was the blocking effect of high-pressure ridge in Okhotsk Sea region. As a result, powerful cold air was trapped in Siberia, and gradually became stronger. By December 30, the cold air accumulated in Siberia became relatively strong, and the vortex center was 5 100 gpm, –45 ℃.

At 08:00 on January 1, 2010, there were two ridges and one trough in middle and high latitudes in Asia, and the east of the Aral Sea and the south of the Sea of Okhotsk were controlled long wave ridges, while there was a broad low-value area in the north of Asia. The polar vortex split in the north of Asia moved eastwards, and under its influence, there was obvious cooling weather in most parts of northeast China and eastern Inner Mongolia. There was a transverse trough on the west side of Lake Baikal. At 08:00 on January 2, there were obvious small fluctuations spreading eastwards over the Black Sea and Caspian Sea; the eastern ridge of the Ural Mountains strengthened and moved eastward, and the northeast air flow in front of the ridge led the cold air to the south into the transverse trough of Siberia, so that northern China was still controlled by the cold air. The transverse trough in Siberia gradually moved southwards to the north of Xinjiang, and cold air accumulated. The isotherms in the north of Xinjiang were relatively dense, so there was an obvious upper front area. By 20:00 on January 2, the transverse trough in Siberia began to gradually turn vertical, and the northerly air flow after the trough transported cold air to the south. Meanwhile, the south branch trough of the Bay of Bengal cooperated, so that strong cooling and gale weather appeared in the center of Inner Mongolia, North China and most parts of northeastern China. At 20:00 on January 3, the cold vortex in northern Asia weakened, moved eastwards and split into a low vortex on the eastern side of the sea, while there was a shallow trough in East Asia. At 20:00 on January 5, the large trough in East Asia gradually weakened and moved to the east, and the broad low-value area in northern Asia also gradually weakened. Since then, the cold wave slowly weakened and died out.

2.2 Ground situation Seen from the evolution of the surface system, the cold wave process was caused by the frontogenesis of surface cyclone in the west of Inner Mongolia and its nearby areas, leading to a large range of cooling and gale weather in the north of China.

At 20:00 on January 2, there was a low-pressure area in northern Gansu and western Inner Mongolia. At 23:00 on January 2, the surface cyclone developed, and the sea level pressure at the center of the cyclone was 1 007.1 hPa. At 02:00 on January 3, the surface cyclone moved eastwards to the center of Inner Mongolia, and the sea level pressure in the center of the cyclone reached 995 hPa. The cyclone continued to develop and significantly deepened, and the influence area expanded. At 08:00 on January 3, the surface cyclone continued to move eastwards, and was still located in the center of Inner Mongolia. The central pressure continued to drop to 980 hPa, resulting in the formation of a strong baroclinic area over the cyclone, and there was strong temperature advection and cyclone front, and the force of cold air intensified dramatically. At 14:00 on January 3, the frontal cyclone continued to develop, and the influence area increased greatly; the cold air force continued to strengthen. Due to thermal reasons, the front of the cyclone was decompressed, and the rear was pressurized. The gale weather appeared in the entire Hetao area. At 20:00 on January 3, the cyclone moved eastwards into the sea, and the gale weather weakened significantly in most parts of central and eastern Inner Mongolia, North China and northeastern China.

3 Analysis of physical quantity fields

3.1 Dynamic conditions Vertical motion causes vertical transport of heat, water vapor, vorticity, momentum, *etc.*, thus achieving energy conversion in the atmosphere. The main condition of water vapor cooling and condensation is the lifting effect of ascending motion. At 20:00 on January 1 at 500 hPa, the central value reached -40×10^{-3} hPa/s in the east – west rising area of northeastern Inner Mongolia and Heilongjiang through the northern part of the Sea of Japan to the northwest of the Pacific. At 08:00 on January 2, a rising area appeared in central Inner Mongolia, northern Gansu and eastern Qinghai, with a central value of -20×10^{-3} hPa/s. At 20:00 on January 2, the rising area moved to the east, and the central position of the rising area had a good correspondence with the heavy snowfall area. Due to the invasion of cold air from the north, the rising speed had an obvious feature, that is, the central position was higher in the north, and there was a slight inclination from the bottom to the top. At 08:00 on January 3, vertical velocity was obviously strengthened, and the upward movement at 500 hPa was the strongest; the negative-value center continued to move eastwards to the middle of Inner Mongolia, and the central value reached -40×10^{-3} hPa/s. At 20:00 on January 3, an upward zone appeared in the Bohai Bay area, with a central value of -20×10^{-3} hPa/s. At 08:00 on January 4, the center of the rising area moved eastwards to the Korean Peninsula, and the scope expanded, but the intensity remained unchanged. Most of the northeast of China was still controlled by the rising movement. At 08:00 on January 5, subsidence movement areas appeared in most parts of northern China, and the cold wave snowfall process gradually ended.

The rising movement of the whole layer accelerated the convergence near the ground, was very favorable to the development of surface cyclones, and promoted the transport of water vapor to the convergence area, which provided sufficient power and water vapor conditions for the occurrence of precipitation.

3.2 Moisture conditions At 08:00 on January 1, there was a wide range of high specific humidity from the Tanggula Mountain to the middle and lower reaches of the Yangtze River and then to the coastal areas of South China and its south areas. At 08:00 on January at 850 hPa, the area with high specific humidity moved slightly to the north; a wet tongue extended to the northeast, and the head reached the north of Shanxi and Shaanxi. There was a center with high specific humidity along the southern coast of China, and the area was large. Along with the southwest wind jet, a large amount of water vapor was transported to the north of China. A small specific humidity center appeared in the northwest of Inner Mongolia. At 20:00 on January 2, the wet tongue split into a specific humidity center in central Inner Mongolia and northern Shanxi and Shaanxi, indicating that water vapor had been transported from China's southeast coast to the north. At 08:00 on January 3, the large high specific humidity area in the south once again extended a wet tongue to the north, and the head reached the central region of Inner Mongolia. At 20:00 on January 3, the wet tongue subsided to the southeast, and moved eastwards into the sea. At 08:00 on January 5, the cold dry air at the lower level invaded downwards, and the relatively dry area gradually appeared in the northern region. The large-scale snowfall came to an end.

4 Conclusions

Based on the data from the end of December 2009 to the beginning of January 2010, the strong cold wave process that occurred in most parts of north China from January 1 to 6, 2010 was analyzed, and some conclusions were drawn as follows.

(1) The cold wave weather process happened during the transition of circulation pattern from zonal to meridional type in middle and high latitudes in the northern Hemisphere. The high ridge in the north of Lake Balkhash developed strongly, and the strong northerly wind belt in front of the ridge moved southwards. The warm advection at the rear of the transverse trough and the cold advection in the southeast in front of the transverse trough on the northwest side of Lake Baikal caused the transverse trough to turn upright and moved southwards, and the longitude of the circulation increased continuously to guide cold air to move southwards, resulting in this strong cold air process.

(2) In this cold wave process, strong cold advection was the main reason for the large drop in temperature in northern China. The polar vortex in the early stage was stable in Siberia. Cold vorticity constantly split out, and moved eastwards. As a result, the temperature in the eastern part of China continued to be low. Under the influence of this cold wave, extreme low temperature appeared in parts of the east.

(3) In this cold wave process, the strong cold air behind the front caused a large pressure gradient, which strengthened the atmospheric baroclinicity in the frontal zone. Strong warm advection developed in front of the frontal zone, leading to strong frontogenesis of surface cyclone, rising of warm air, sinking of cold air, formation of continuous snowfall, and increase of surface wind speed.

References

[1] LI XZ. The flow of the atmosphere[J]. Acta Meteorologica Sinica, 1935 (5): 213-216.

[2] TAO SY. A cold wave process in East Asia during the period of blockage and destruction[J]. Acta Meteorologica Sinica, 1957, 28(1): 63-74.

[3] XU AH, QIAO L, ZHAN XF, *et al.* Diagnosis of a cold wave weather event in March 2005[J]. Meteorological Monthly, 2006, 32(3): 49-55.

[4] HE CC, JIN Q. Diagnosis and analysis of a cold wave rainstorm weather process in spring[J]. Meteorology Journal of Hubei, 2006(3): 18-21.

[5] ZHANG SQ, TIAN HP. Analysis of a nationally cold wave and heavy snow[J]. Bimonthly of Xinjiang Meteorology, 2005, 28(4): 7-8.