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Analysis of a Cold Wave Weather Process of China from December 23rd to 26th, 2021

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Abstract

Cold wave weather process is a large-scale strong cold air activity process, will bring drastic cooling and wind, as well as rain and snow weather. This research mainly studies the evolution and cause of a cold wave weather process of China from December 23rd to 26th, 2021. The weather map from the National Climate Center and the geopotential height and sea level pressure reanalysis data from December 23rd to 26th, 2021 provided by National Centers for Environmental Prediction of United States are analyzed by the comparative analysis method and the high altitude situation forecast equation. As a result, this research found that this cold wave was considered a nationwide process. Besides, this cold wave process was mainly caused by the invasion of cold air from Siberia. In addition, under the joint action of the warm high pressure ridge in the Ural Mountains, the polar vortex split and presented a multi-polar distribution. One of them was located near West Siberia, which was conducive to the accumulation of cold air here. With the rotation of the transverse trough, cold air moved southward, and cold wave broke out.

Keywords

Cold Wave, Atmospheric Circulation, Polar Vortex

1. Introduction

From December 23rd to 26th, 2021, the sixth cold wave of the winter of 2021 was in full force, heading southward to Hainan. And the temperature in many places was the lowest since the beginning of the winter of 2021. This is the last cold wave in 2021, and the range of temperature dropping of this cold wave is not as wide as that of November. However, due to the superimposed effect of the cold wave and the approaching midwinter season, the intensity of the cold air itself is strong. And the basic temperature is relatively low, especially in southern

China. The temperature drop is obvious, so this cold wave makes people feel extremely cold. In the south, the temperature drops by more than 10°C in many places. In addition, the strong wind would produce obvious wind-chill effect, and the body would feel very cold. The rain and snow weather would also make the wet and cold feeling more obvious, and there would be the largest snowfall since this winter.

Many scientists have done a lot of research on cold wave. Dong et al. (2017) based on daily minimum temperature data during 1979-2013, the frequency of occurrence, the beginning date and ending date and other characteristic values of cold waves at all levels are processed. Then, by using the method of Mann-Kendall method, correlation analysis, empirical orthogonal function and Morlet wavelet analysis, the spatiotemporal distribution and inter-annual variation and other characteristics of cold wave, strong cold wave and ultra-strong cold wave of Shandong Province are analyzed. Zhang et al. (2022b) pointed out that an unprecedented cold wave intruded into East Asia in early January 2021 and led to record-breaking or historical extreme low temperatures over vast regions. This study shows that a major stratospheric sudden warming (SSW) event at the beginning of January 2021 exerted an important influence on this cold wave. Radinović & Ćurić (2012) showed clearly that many areas of society are susceptible to the effects of extreme temperatures. Without an adequate definition of what constitutes heat and cold waves, it is impossible to assess either their changes in the past or their possible consequences for the future. Gu et al. (2021) based on the circulation situation and ground observation data, carried out a synographic analysis of the cold wave gale weather process at Anqing Airport on November 17, 2019, and found that the 3-hour variable pressure is a good indicator to predict the strong wind in this cold wave. Li et al. (2021) indicated that from January 4 to 8 in 2021, a strong cold wave in Lesser Cold quickly spread across China. Using EC visualization products on the windy website, wind field in Huang Bohai area and the process of snowfall in single station has been carried on the forecast, and validation and analysis indicate that the regional forecast should consider the color range, duration, maximum gust, wind change time of visual average wind and gust products, and then the comprehensive forecast conclusion can be drawn.

More previous studies (Zhang & Shang, 2022; Zhang et al., 2022a; Li & Yuan, 2019) are very comprehensive and diverse, but the weather situation is constantly changing. So, it is necessary to study and analyze the recent cold wave. This research focuses on the cold wave process in December 2021. Based on the meteorological observation data, the occurrence and development of this cold wave were analyzed. It provides reference for the influence of cold wave on weather in the future.

2. Data and Methods

2.1. Data

The data in this research comes from two ways:

1) The weather map from National Climate Center, the second-generation product of monthly dynamic extended ensemble prediction (DERF2.0) and the second-generation seasonal prediction air-sea coupled model (BCC-CSM) data.

2) This research also uses the geopotential height and sea level pressure reanalysis data from December 23rd to 26th, 2021 provided by National Centers for Environmental Prediction of United States.

2.2. Methodology

1) Comparative analysis

Comparisons were made day by day, using weather maps obtained from the websites. First and foremost, the trough and ridge changes in the upper 500 hPa of East Asia were analyzed, especially for the Ural high pressure ridge analysis, focusing on its changes between December 23ed and 26th, 2021. It is also necessary to compare and analyze weather maps obtained from multiple sources in order to get more accurate results. Besides, by means of Isotherm analysis in the 500 hPa and 850 hPa from December 23rd to 26th, 2021 could determine the location of the heating and cooling center. And we can know the extent to which cold wave affect temperature.

2) Synoptic method

High altitude situation forecast equation (Zhu et al., 2007):

$$\frac{\overline{\partial \xi}}{\partial t} = -\overline{V}_g \cdot \left(f + \overline{\xi}_g \right) - 0.6\overline{V}_T \cdot \nabla \xi_T$$

Firstly, the development and movement of trough and ridge can be analyzed more accurately by qualitative analysis of absolute vorticity advection term in 500 hPa. In this part, the density of contour lines was analyzed to judge the development and movement of trough and ridges, and so on. Secondly, through advection of thermal wind vorticity, we could study effect of temperature on trough and ridge.

The above two research methods can help us to study the cold wave from a better point.

3. Results and Analysis

3.1. Analysis of Atmospheric Circulation and Precipitation

From **Figure 1**, we could know that the contour of east and north Asia is mostly positive anomaly, the central part is negative anomaly, and the northern part is almost positive anomaly. Among them, there is a strong center of negative anomaly in western and southeast Asia, reaching −16 dagpm. Meanwhile, eastern Asia and northern Asia positive anomaly recorded 16 dagpm.

It can be seen in **Figure 2** that from December 21, 2021, the cumulative precipitation in southern China reached 10 to 50 millimeters, and the central region reached 0.1 to 10 millimeters. Northwest China is relatively dry and has no precipitation. Precipitation in northeast China has accumulated from 10 to 50 millimeters, except for some areas with no precipitation.

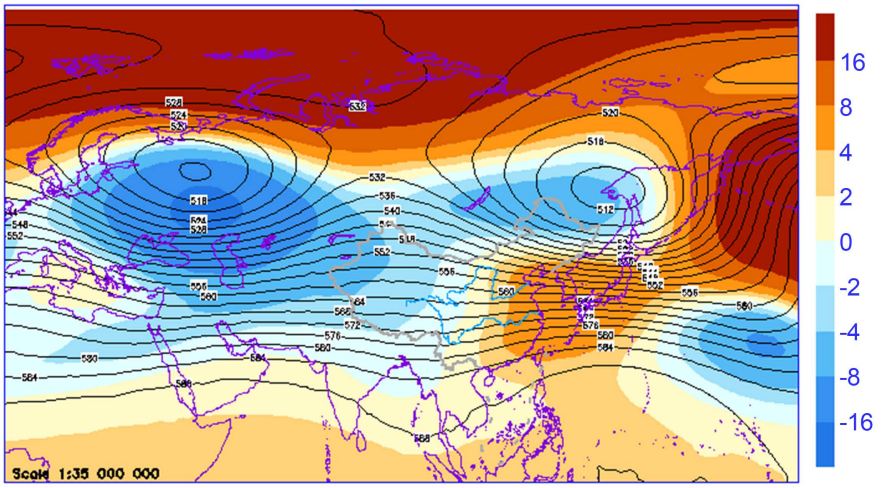

Figure 1. Average geopotential height field at 500 hPa in late December 2021.

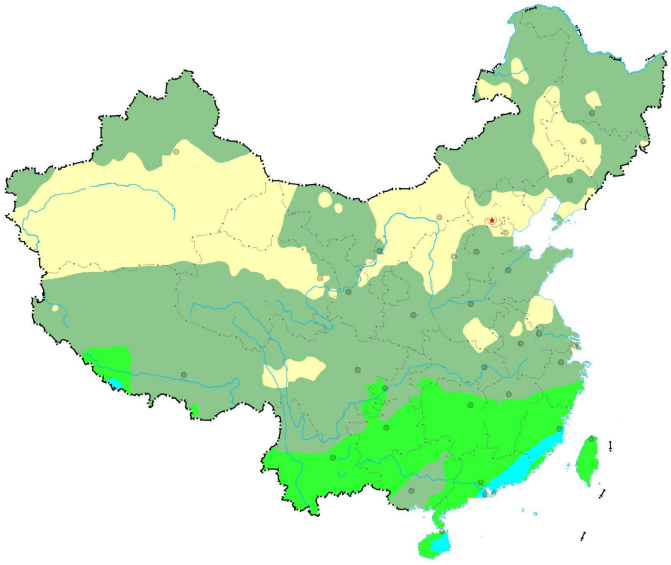

Figure 2. Precipitation accumulation map of China mainland in late December 2021.

According to the circulation pattern map of mid-high latitude in Eurasia in late December 2021, the meridional dimension of the mid-high latitude circulation in eastern Asia increased. And the surface cold air frequently invaded the northern China from eastern Siberia to the southeast with a strong force, resulting in a nationwide cold wave process in late December. From December 23rd to 26th, 2021, the temperature in northern China dropped significantly, with the temperature in most areas reaching the lowest since the beginning of the winter of 2021. There was rain and snow in most parts of central and eastern China.

3.2. Analysis of Cold Wave Weather Process from December 23rd to 26th, 2021

From December 23 to 26, 2021, China experienced a cold wave from northwest to southeast. The cold wave process was transversal trough to vertical. The cen-

tral and eastern regions showed obvious wind cooling and severe cooling. The minimum temperature in most regions reached the lowest value since the beginning of winter. Besides, the temperature in southern regions continued to be significantly low. Affected by the cold wave, snow or sleet fell in northwest China, North China, Huanghuai, Jianghuai and Jiangnan regions. The low temperature rain and snow weather has a certain adverse impact on the living conditions, agricultural production, transportation, and energy supply of the above areas.

From Dec 23rd to 26th, 2021 average 500 hPa geopotential height field and sea level pressure field (compare Figure 3 and Figures 5-8), we can clearly see that the high pressure ridge near the Atlantic Ocean and Ural Mountains developed poleward strongly, resulting in the polar vortex splitting and multi-polar distribution. One of them is located near West Siberia, which is conducive to the accumulation of cold air here. With the rotation of the transverse trough, cold air moves southward, and cold waves break out.

3.3. Specific Analysis of Cold Wave Process on December 23, 2021

At 08:00 on December 23 (Beijing time, the same below), the northern region was affected by a strong cold vortex, and the main cold air was located near Lake Baikal. The North China region was affected by a cold trough and weak shear line in the upper air. Weak southerly water vapor was transported in front of the trough, and warm and cold air converged here, bringing rain and snow to North China. See Figures 3-5 for details.

3.4. Specific Analysis of Cold Wave Process on December 24, 2021

At 08:00 on December 24, 500 hPa transverse trough swung and moved to the eastern part of North China. The northerly air flow behind the trough constantly guided the cold air southward, and the surface cold high pressure moved southward. At the same time, the main body moved to Mongolia, with the central intensity of 1055 hPa, bringing gale cooling weather to the central and eastern parts of China. And light snow or sleet occurred in the eastern parts of Shanxi, southern parts of Hebei, Shandong, and other places. Contrast is shown in Figure 6 and Figure 7.

3.5. Specific Analysis of Cold Wave Process on December 25, 2021

At 08:00 on February 25, the main position of the cold high pressure moved to the east of Inner Mongolia, China, with the swing of the transverse trough behind the cold vortex. The cold front reached the northern part of South China and continued to affect the southern part of China. In addition, the strength of the south branch trough was strong. And the southern region was in the convergence zone before the trough, which provided favorable water vapor and dynamic conditions for heavy snowfall, and most parts of China experienced snowfall. Contrast is shown in Figure 8.

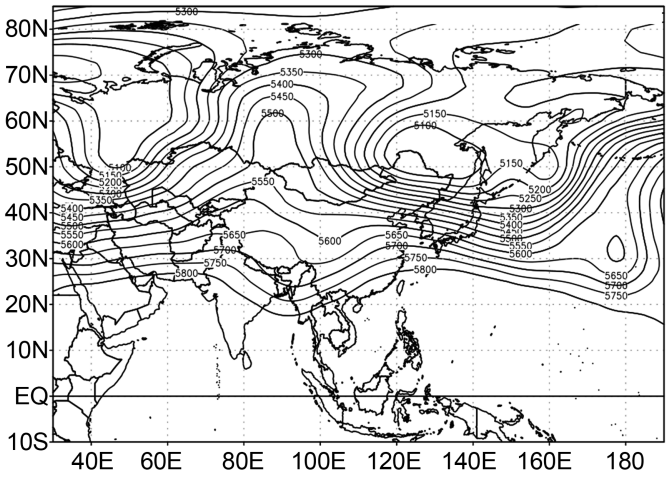

Figure 3. The 500 hPa geopotential height field at 08:00 on December 23, 2021 (Beijing time, the same below).

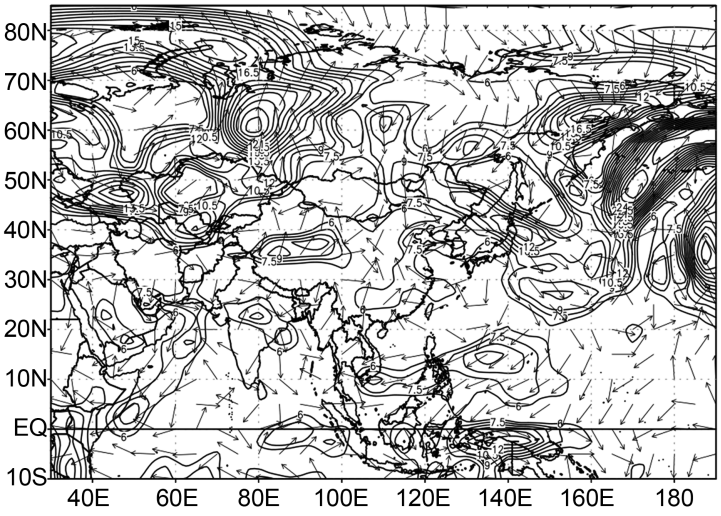

Figure 4. The 850 hPa wind field at 08:00 on December 23, 2021.

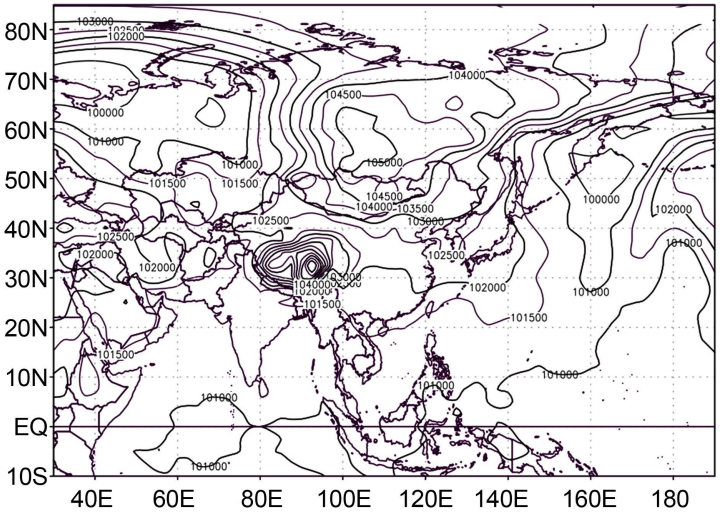

Figure 5. Sea level pressure field at 08:00 on December 23, 2021.

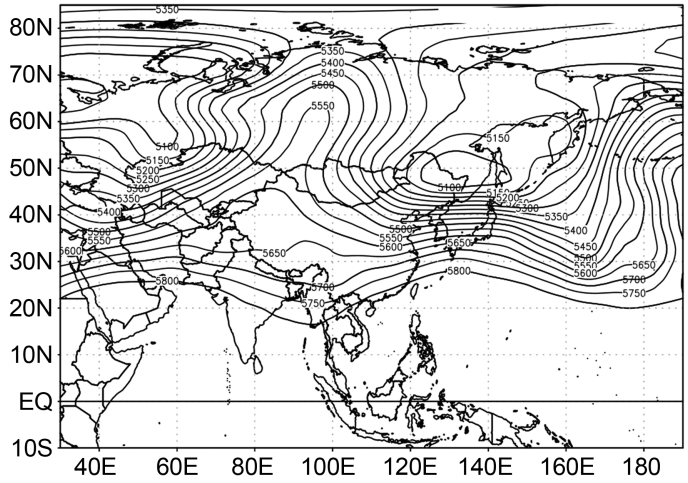

Figure 6. The 500 hPa geopotential height field at 08:00 on December 24, 2021.

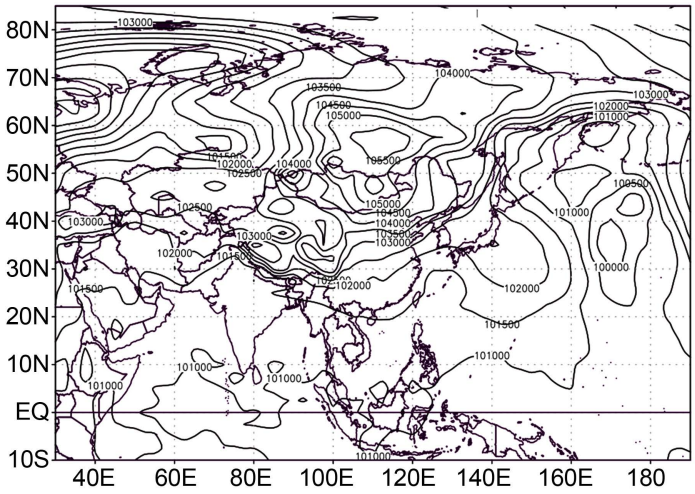

Figure 7. Sea level pressure field at 08:00 on December 24, 2021.

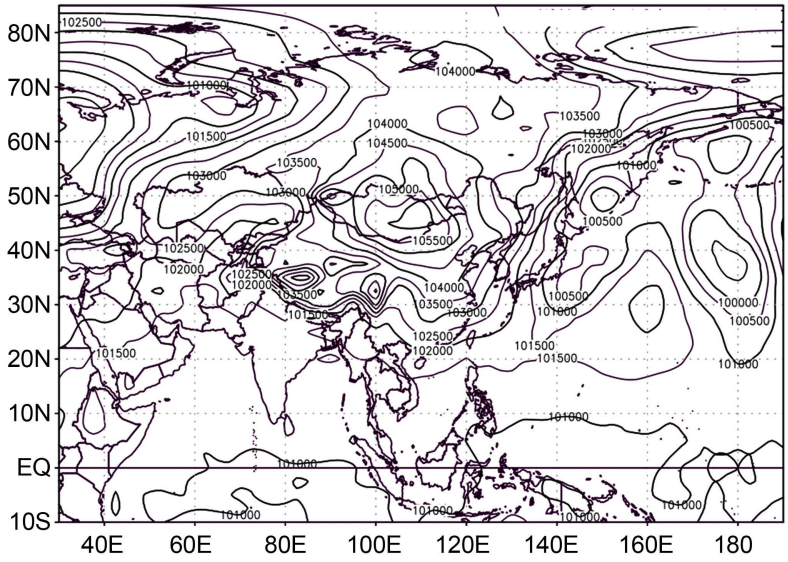

Figure 8. Sea level pressure field at 08:00 on December 25, 2021.

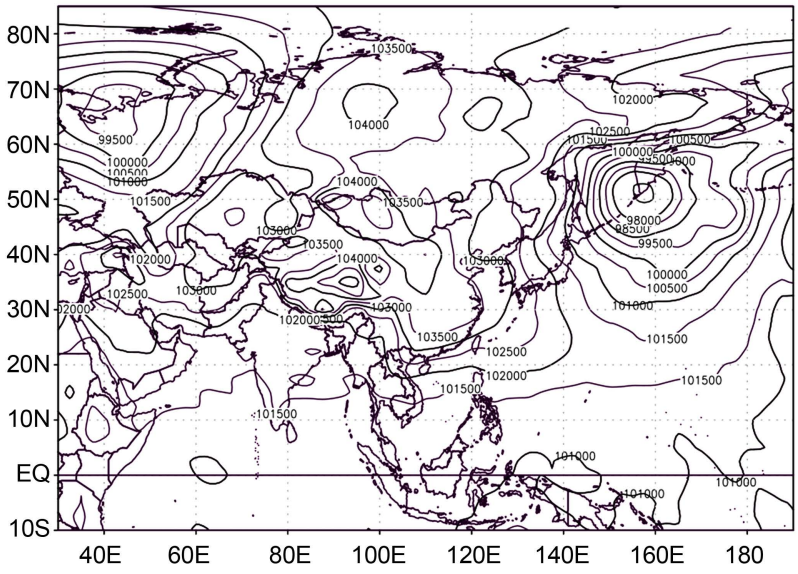

Figure 9. Sea level pressure field at 08:00 on December 27, 2021.

3.6. The End of the Cold Snap in December 2021

At 8 o'clock on December 27, as the cold air gradually moved eastward into the sea. At the same time, the dense band of isobars gradually moves from the Asian continent to the Pacific Ocean. The East Asian Grand Trough underwent a renewal when the transverse trough turned vertical to replace the old East Asian Grand trough. Besides, the position of the long wave was repositioned. The cold wave weather process tended to end. See **Figure 9** for details.

4. Conclusion

In this research, a cold wave weather process of China from December 23rd to 26th, 2021 was analyzed by using geopotential height and sea level pressure reanalysis data provided by National Centers for Environmental Prediction of United States and the weather map from National Climate Center. We get the following main conclusions:

1) By analysis of the circulation pattern map of mid-high latitude in Eurasia in late December 2021, this cold wave had a large impact area and a large cooling range, which was considered a nationwide cold wave. And it caused widespread rain and snow.

2) The cold wave process was mainly caused by the invasion of cold air from Siberia.

3) By comparing and analyzing the average geopotential height field and sea level pressure field at different levels, it was concluded that the cold wave process was transverse trough to vertical.

4) The key to this cold wave forecast is the warm ridge of Ural high pressure.

5) By analyzing the development of high-pressure ridges over the Atlantic Ocean and near the Ural Mountains at 500 hPa, the polar vortex split and showed a multi-polar distribution caused by warm ridge of Ural high pressure. One was

located near West Siberia, which was conducive to the accumulation of cold air and provided an indispensable condition for the outbreak of cold wave.

The above conclusions affect and restrict each other, and the change of one will affect the other parts.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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