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Analysis of a Snowfall Process in North China during February 12-13, 2022

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Abstract

This research analyzed a snowfall process in north China during February 12-13, 2022. By using synoptic and numerical analysis, it is concluded that this snowfall process was mainly caused by trough, low-level vortex, shear line and Siberian High. Meanwhile, an easterly wind that transports water vapor from the Bohai to North China, was the water resource of the snowfall process. Relative humidity in the low atmosphere was above 80%, providing an excellent humidity condition for snowfall. Positive vorticity and convergence induced upward motion, which offered conditions for snowfall. Numerical reconstruction is also used to show the range and the intensity of the snowfall process.

Keywords

Vortex, Trough, Snowfall, Numerical Reconstruction

1. Introduction

A large-scale snowfall stroke the North China on February 12, 2022, accompanied by strong precipitation in certain areas. Light snow appeared in parts of central Inner Mongolia, northern Shanxi, northern Hebei, Beijing, and southern Tianjin. Moderate snow occurred in southern Tianjin, central Hebei, and other places. The snowfall continued in the Beijing-Tianjin-Hebei region, Shanxi, Inner Mongolia, and other areas on February 13. Some areas reached heavy snow level. And the range of snowfall also spread eastward to Liaoning, Jilin, and other places. The whole snowfall process was significantly weakened on February 14. The 2022 Beijing Winter Olympic Games were also affected by the snowfall. The Zhangjiakou competition region encountered the snowfall on February 13. The viscosity of the track surface was affected due to the heavy snow. Low visibility was also a major problem. The women's slalom skiing qualifiers were postponed to February 14.

Many scientists have done the research on the snowfall process. Xia et al. (2013) discovered that to improve the forecasting of the nature of winter precipitation, close attention should be paid to the simulated characteristics of temperature stratification in the lower troposphere. Lin et al. (2007) found that the southward strong and cold air on the high-latitude and the vapor transportation on the low-latitude is a reason for the snowfall event. Zhao et al. (2002) pointed out that to fully predict the shallow snowfall process, the higher time and space resolution data is needed. Zhou & Zhao (2021) indicated that the snowfall process can be divided into four types: westerly trough eastward moving type, North vortex South trough type, transverse trough type and reflux type. Louka et al. (2010) showed that the main factor causing the snowfall event was the entrainment of arctic air masses from North-Eastern Europe.

All the research mentioned are relatively old. And none of them analyzed a large-scale range of snowfall event. In this research, extensive snowfall process in the North China in 2022 will be illustrated in many parts in detail.

2. Data and Methods

2.1. The Data Samples

In the research, two major kinds of data are involved. The NCEP reanalysis, the second-generation product of monthly dynamic extended ensemble prediction (DERF2.0) and the Japan's Meteorological Agency (JMA) data

a) The NCEP data is used for plotting diagnostic analysis. The start date is February 12, 2022, and the end date is February 15, 2022. The NECP analysis can be obtained from its official website (https://psl.noaa.gov/data/histdata/). Its accuracy counts for a major reason for choosing.

b) The FNL (Final Operational Global Analysis) Data is applied to numerical reconstruction. The start date is at 00:00, February 12, 2022, and lasts for 2 days.

2.2. Methodology

a) This study applies synoptic methods to analyze the circulation situation in multiple levels. These include diagnosis of relative humidity, precipitable water, low and middle level circulation, and vorticity in low levels (Kai et al., 2021).

b) The research uses numerical method to reconstruct the snowfall process. The numerical model that involved is the Weather Research and Forecasting Model (WRF). The WRF system contains two dynamical solvers, referred to as the ARW (Advanced Research WRF) core and the NMM (Nonhydrostatic Mesoscale Model) core. The version used is 4.2, and the core involved is ARW core.

WRF model is currently the most widely used mesoscale regional model for atmospheric research and operational forecasting, and is suitable for various meteorological applications ranging from tens of meters to thousands of kilometers. WRF is a new generation of weather and climate simulation system, which is more and more widely used in meteorology and related fields (meteorological services, agriculture and forestry, new energy, etc.) due to its high accuracy, novel scheme and inclusion of multiple Earth system processes (Kumar et al., 2015; Zoljoodi, 2017).

3. Research and Analysis

3.1. Analysis of Atmospheric Circulation and Decade Precipitation

From the 500 hPa average geopotential height field in mid-February 2022 (**Figure 1**), the atmospheric circulation situation in the middle and high latitudes of Asia and Europe was of the "two troughs and one ridge" type. The average East Asian trough was above the Middle and East China. The North China was above the trough line. Another trough was located near the Black Sea. The average ridge was above the central Asia and extended to the right of the Ural Mountains. The blocking high can be spotted in the Arctic areas, near the 135E. A cold vortex was above the North China.

From the 500 hPa geopotential height at 08:00on February 13, 2022 (**Figure 2**), in comparison of the climatic mean field, the variation of the ridge position barely changed, but the variation of ridge intensity is obvious. The ridge was stronger compared to the mean field, closed contour line and a high-pressure center formed near the central Russia. A deep low trough appeared near the Black Sea. The southern branch trough was located on the east coast of the South Asian subcontinent with great intensity.

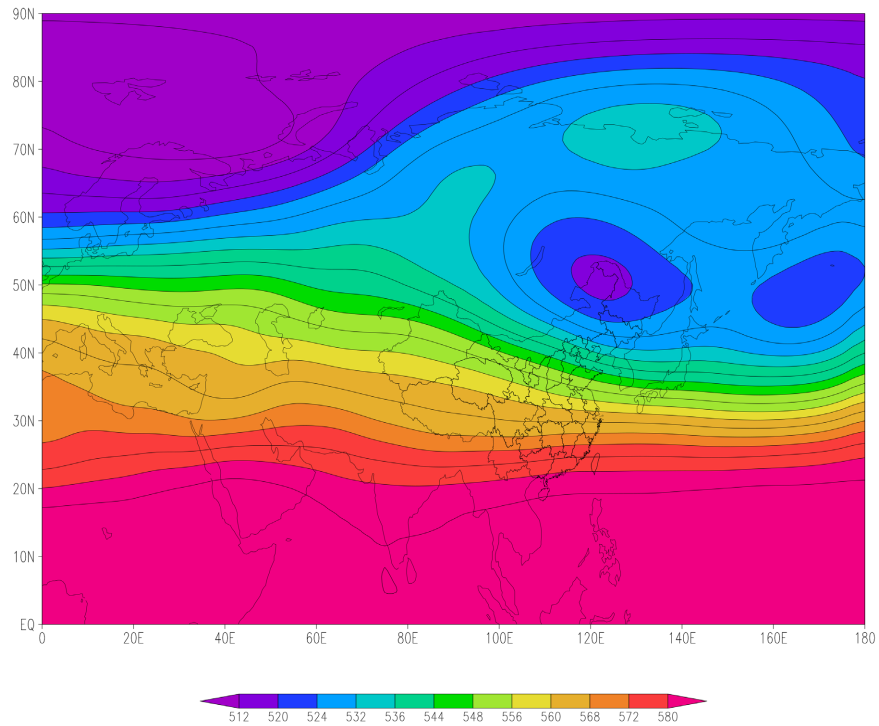

Figure 1. The 500 hPa average geopotential height in the middle February 2022 (Unit: dagpm, the same below).

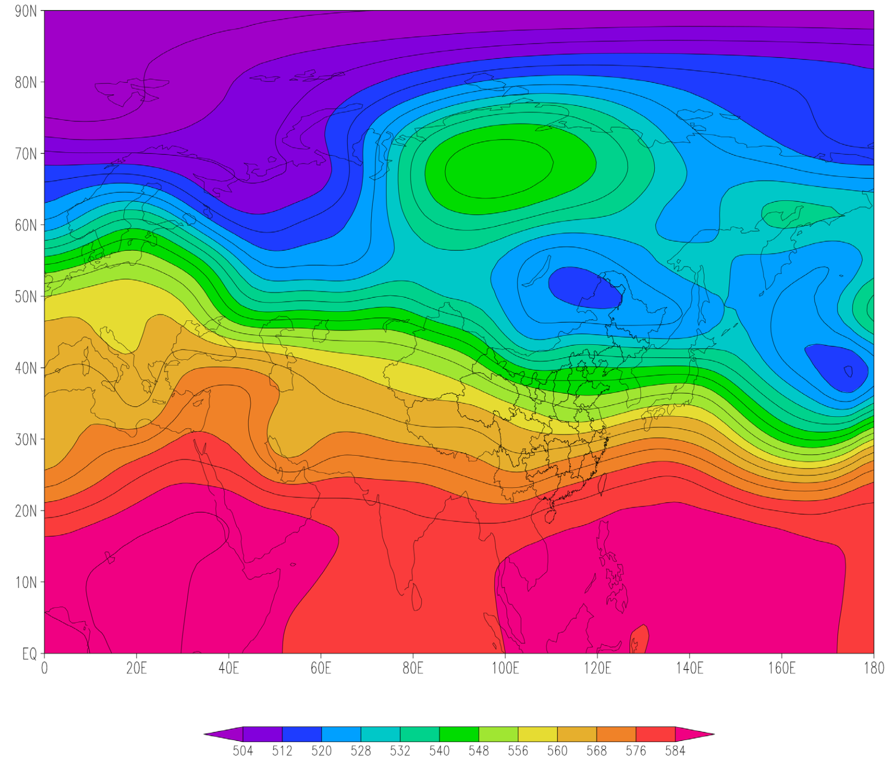

Figure 2. The 500 hPa geopotential height at 08:00 on February 13, 2022. (Beijing time, the same below.)

The whole situation did not change much at 20:00 (**Figure 3**) on the same day .The intensity of the cold vortex above slightly declined. The rest remained almost the same.

From the Precipitation Anomaly Percentage field in mid-February 2022 (**Figure 4**), the precipitation in China in mid-February was mainly distributed in the North China and South China. In early to middle February, due to the influence of the horizontal trough over Mongolia turning vertically and heading south, there was cold wave process in the northern North China and Northeast China Region. The eastern Northeast China Region, the central and northern parts of North China and other places generally experienced significant temperature drop. The North China and other places appeared moderate to heavy snow weather, with blizzards in certain areas. In mid-to-late February, moderate to heavy rains occurred in eastern Southwest China, Jiangnan, South China and other places, Heavy rains or severe heavy rains occurred in local areas. Rain turned to snow or sleet in northern Hunan, eastern Hubei, southern Anhui, northern Zhejiang, and other places.

3.2. Weather Process Situation Analysis

From the 500 hPa geopotential height at 08:00 on February 13 (**Figure 5**), there is a low vortex center over the eastern part of Mongolia and the northern part of Heilongjiang. A short-wave trough appeared at the bottom of the vortex, the

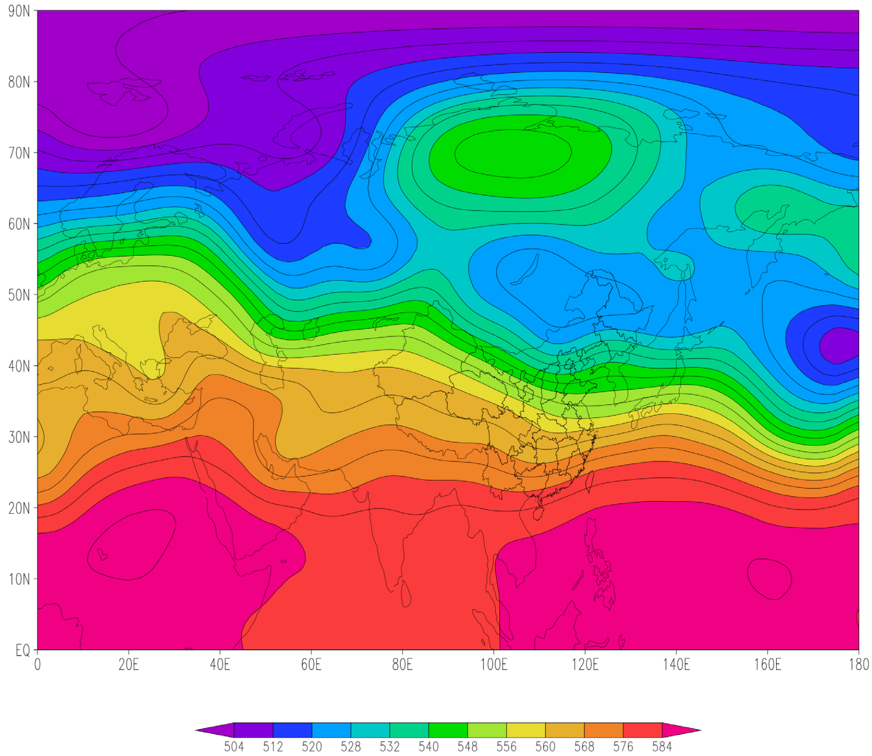

Figure 3. 500 hPa geopotential height at 20:00 on February 13, 2022.

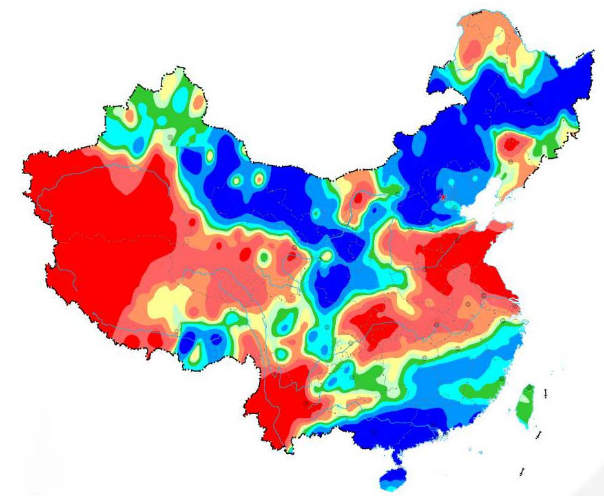

Figure 4. Precipitation anomaly percentage field in middle February, 2022 (Unit: %).

trough moved to Hetao region and gradually deepened as it moved. This though was important because it provided an opportunity for the cold wave to break out. It was deepened due to the following two reasons:

The system received cold air from the vortex and the blocking high. The cold air was moving from the north to the south near the Lake Baikal, which is exactly where the trough was. Such cold air would cause the trough to deepen.

Figure 5 and Figure 6 show the growth process of the ridge in West China. Figure 5 is at 08:00 on February 13, 2022, and Figure 6 is at 20:00 of the same

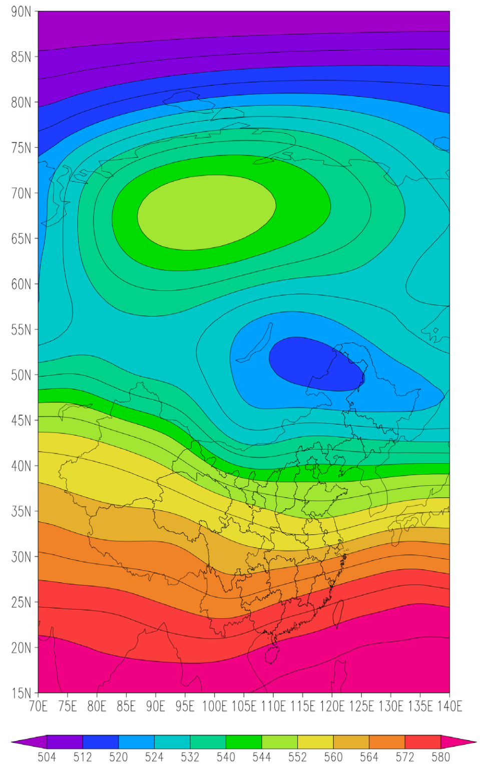

Figure 5. Regional 500 hPa geopotential height at 08:00 on February 13, 2022.

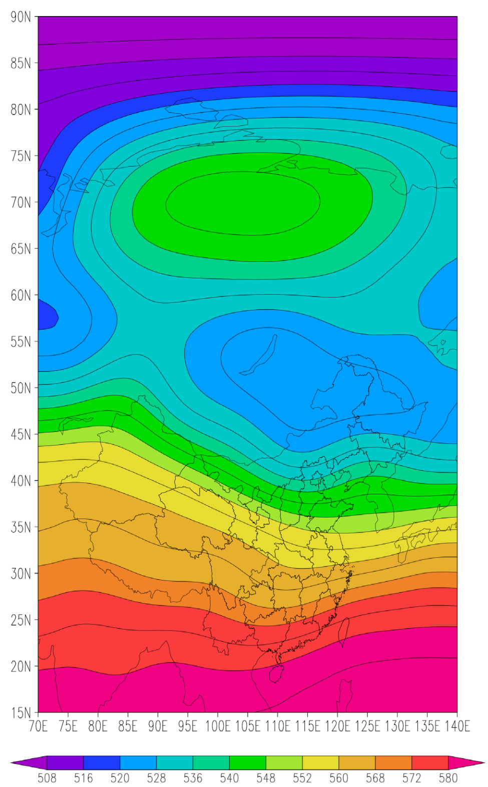

Figure 6. Regional 500 hPa geopotential height at 20:00 on February 13, 2022.

date. Due to the growth of the ridge, it forces the trough to the right to move away from the ridge.

In Figure 5, the trough was in the middle-to-north Inner Mongolia and could not affect the North China and Beijing. The cold air mass was led from higher latitude to its position, and then move parallel to the isallohypse. This should cause the invasion of the cold wave and provide an excellent environment for snowfall in North China.

In Figure 6, the trough was in the North China region, it received the cold air from the vortex above, causing the snowfall progress in such areas.

Due to the movement of the trough, at 20:00, it already affected the North China and Beijing. Meanwhile, the cold vortex began to diffuse, forcing the blocking high to move northward to bring even more cold air.

Overall, at 500 hPa, with the corporation of the blocking high, the vortex, and the trough, it created a circulation that was beneficial for snowfall.

At 850 hPa (Figure 7), the blocking high was clearly illustrated above the Lake Baikal. In the North China, closed contour line was spotted. A vortex formed due to the reason that shears line in the northwest gradually moved eastward. The

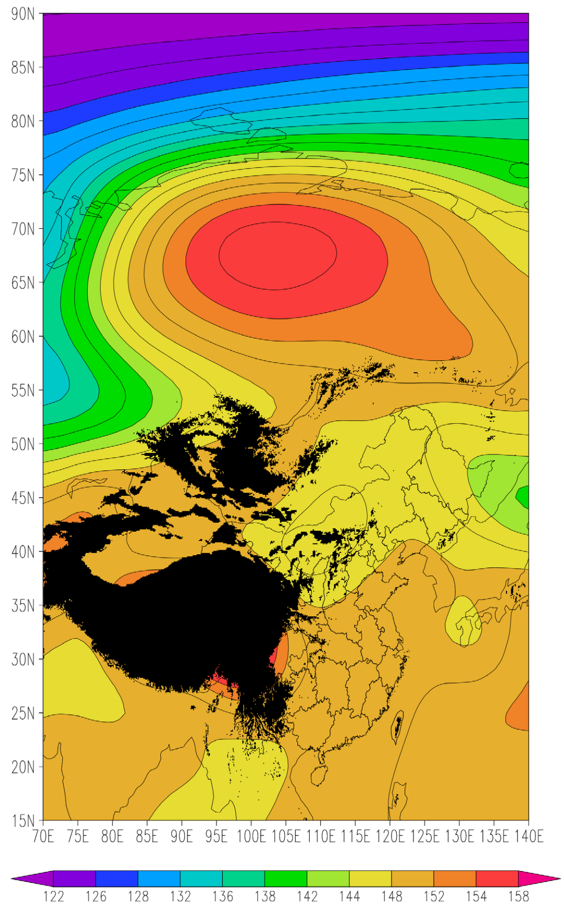

Figure 7. Regional 850 hPa geopotential height at 08:00 on February 13, 2022a. (Black shaded areas represent Tibet Plateau and other high terrains, the same below.)

cold air mass near the Lake Baikal was led to the south because of the existence of the vortex. With the help of the vortex, cold air can be guided to turn southeast instead of southwest, so that North China may be influenced. Since the cold air mass was able to contact the vortex, it would push the whole vortex moving eastward.

Figure 8 shows their location and strength after 12 hours. The vortex began to move eastward, affecting the North China Region, providing an ideal situation for snowfall.

In general, the low-level vortex and the blocking high are the two main reasons for the snowfall process in the lower atmosphere.

Figure 9 shows the sea level pressure at 14:00. The giant Siberian High with cold air formed above the north of Lake Baikal. This system reached the North China, constantly transporting cold air to China. The Siberian High continued to expand and strength at 20:00. (Figure 10) Under such circulation, cold air could be delivered to China successively and snowfall was more likely to occur.

3.3. Lifting Conditions Analysis

This research also analyzes the lifting conditions.

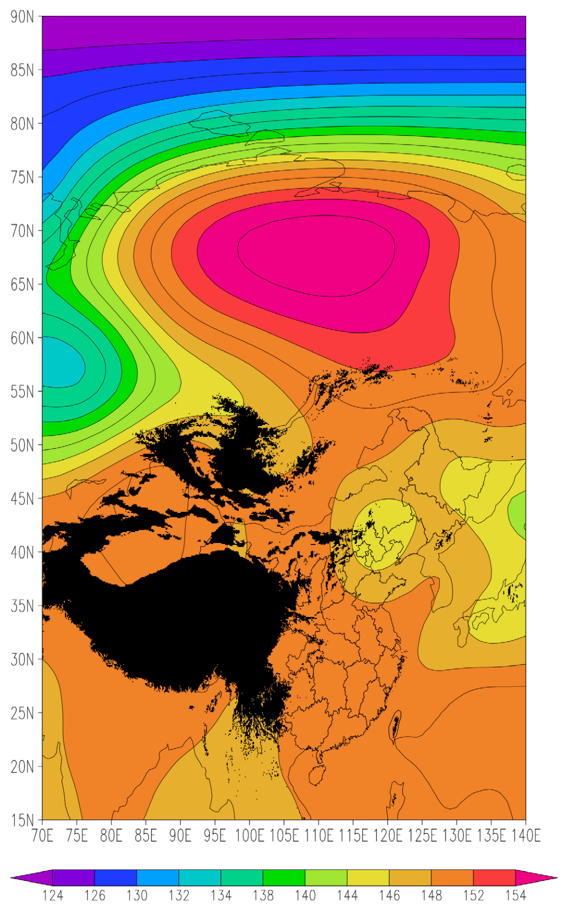

Figure 8. Regional 850 hPa geopotential height at 08:00 on February 13, 2022.

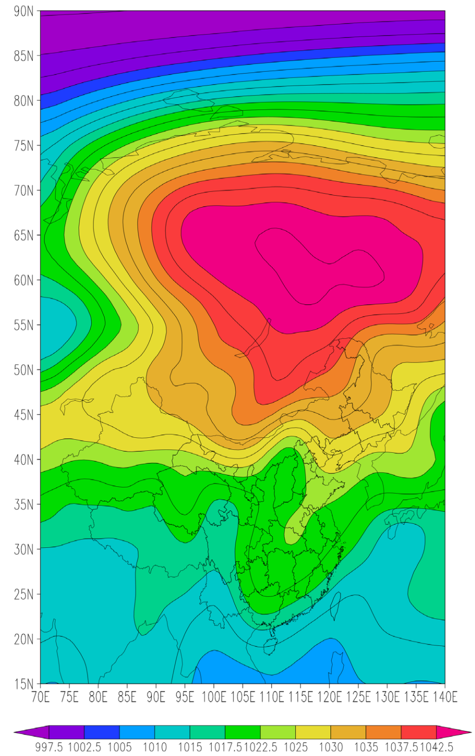

Figure 9. Regional Sea Level Pressure at 14:00 on February 13, 2022.

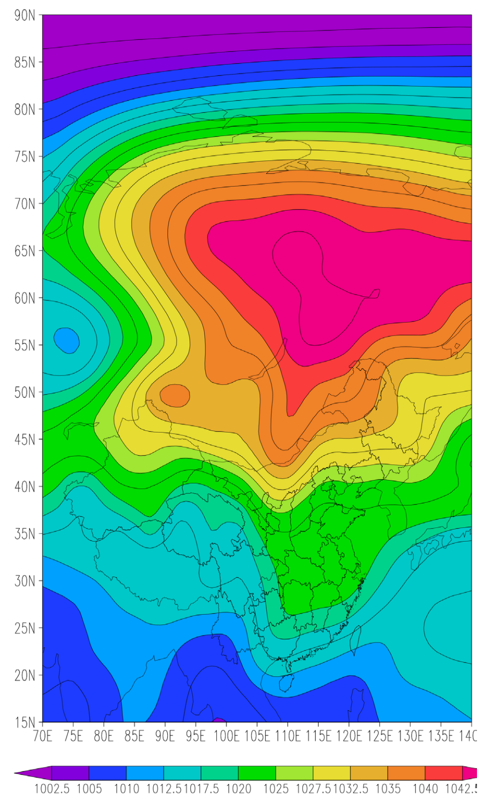

Figure 10. Regional Sea Level Pressure at 20:00 on February 13, 2022.

Figure 11 shows the omega on 850 hPa at 08:00. It can clearly illustrate that the upward motion happens near Beijing-Tianjin-Hebei region, Shanxi, Inner Mongolia. The central upward motion was in the middle of the Shanxi Province. These areas were corresponded to the areas that the snow stroke.

Figure 12 shows the omega at 20:00. The upward motion center moved east, hovering above the north Hebei Province. The upward motion areas covered the whole Beijing-Tianjin-Hebei region and were extended to the northern Inner Mongolia as well as the central Henan Province. This provided an excellent condition for snow.

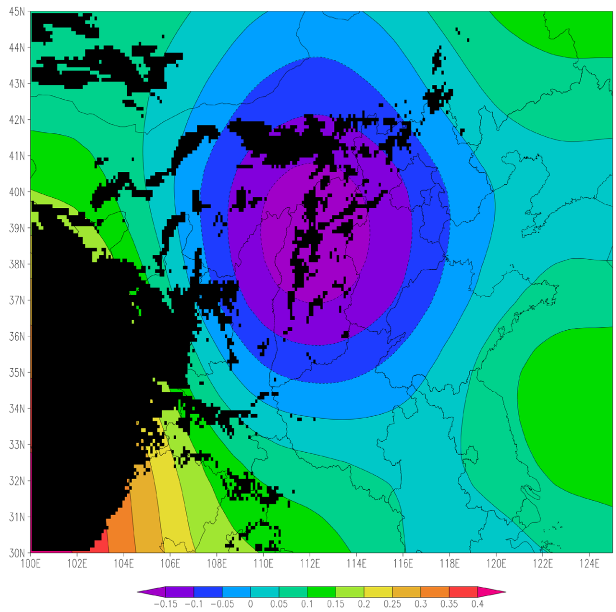

Figure 11. Omega at 08:00 on February 13, 2022 (Units: Pa/s).

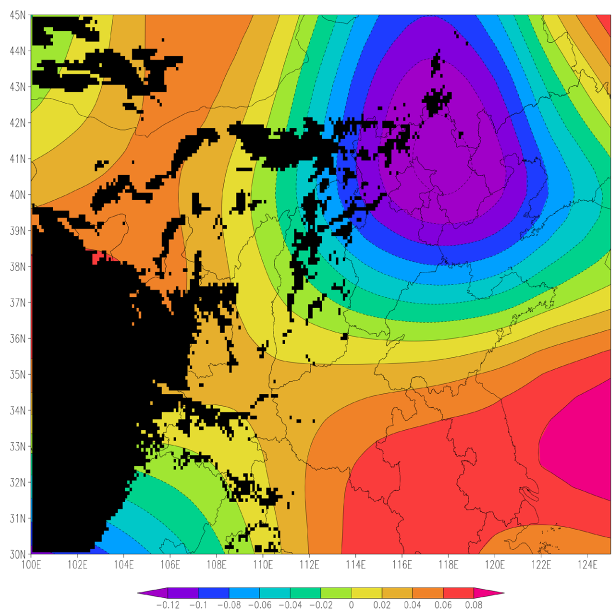

Figure 12. Omega at 20:00 on February 13, 2022.

3.4. Water Supply Analysis

Figure 13 demonstrates the Relative Humidity in 850 hPa. The low-level relative humidity in North China generally exceeded 80% at 08:00. In northern Shanxi, southern Inner Mongolia, central Hebei, the relative humidity was above 84%. The relative humidity continued to rise and formed a center in the middle of the Hebei (Figure 14). The central humidity reached above 87%. The snowfall areas were well corresponded to the places that have high relative humidity.

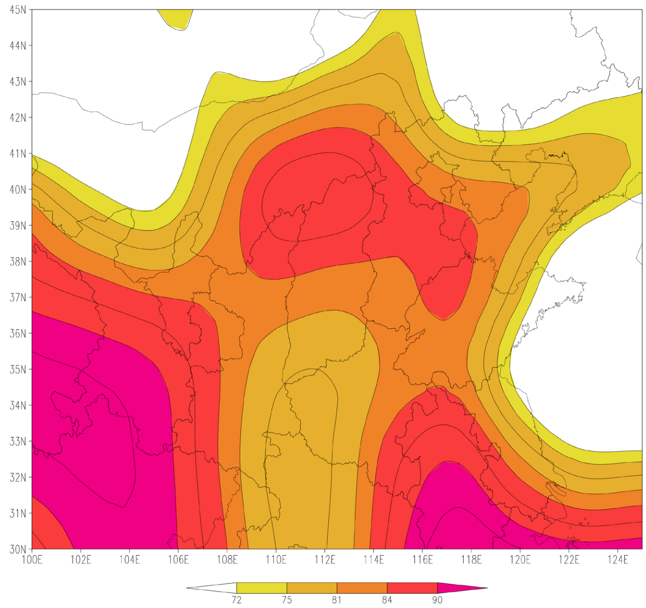

Figure 13. 850 hPa relative humidity on February 13, 2022, at 08:00 (Unit: percentage).

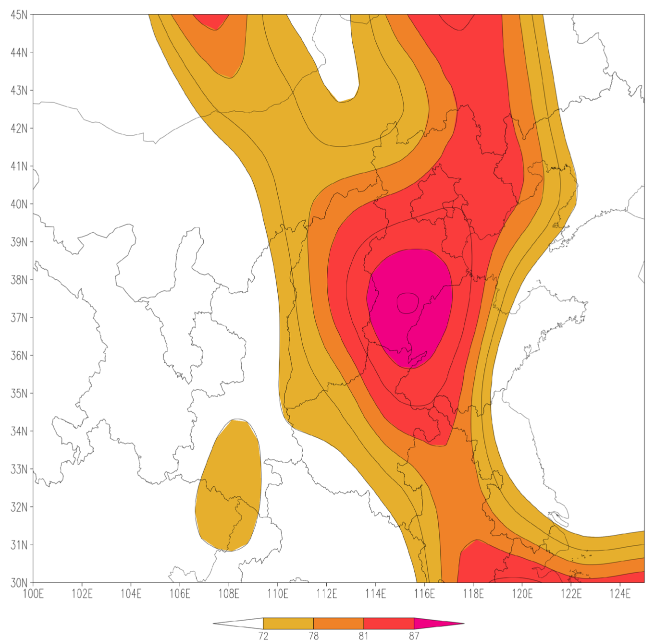

Figure 14. 850 hPa relative humidity on February 13, 2022, at 20:00.

The 08:00 total precipitable water can be obtained from **Figure 15**. The total precipitable water of the whole atmosphere in the south of Beijing-Tianjin-Hebei region, central and northern Hebei, and Shanxi, were generally above 6 mm. The 6 mm and 8 mm isopleths continued to expand at 20:00 (**Figure 16**). Southern Hebei, southern Shanxi is all inside the 8 mm isopleth, providing a good condition for snowfall process.

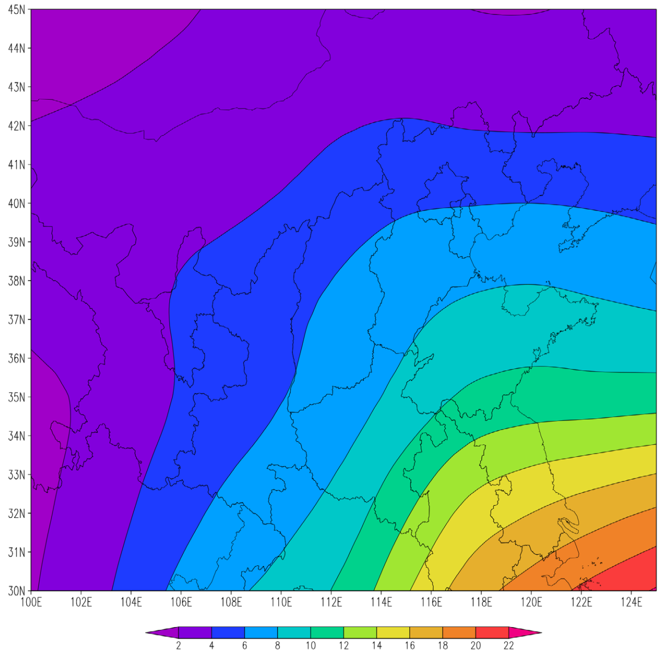

Figure 15. The Total Precipitable Water at 08:00 on February 13, 2022 (Unit: mm, the same below).

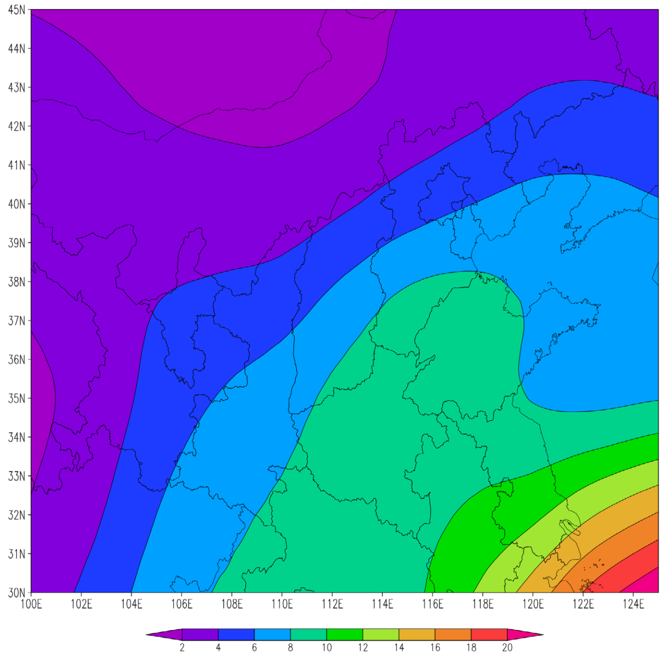

Figure 16. The Total Precipitable Water on February 13, 2022, at 20:00.

The source of water vapor mainly came from the Bohai and travelling through the wind to the vortex (**Figure 17**). Meanwhile, a week vapor transportation can be seen from the South Sea, passing through the south China to reach the vortex.

3.5. Divergence and Vorticity Analysis

Vorticity at 08:00 at 850 hPa (**Figure 18**) shows the central positive regions are in the central Inner Mongolia. The border between the positive and negative was near central Shanxi and extended from the northeast to southwest. The main positive vorticity regions slowly turned east at 14:00 (**Figure 19**). The positive center moved to the northeastern Inner Mongolia. Beijing-Tianjin-Hebei region, middle and north Hebei, and the whole Shanxi were all under the control of the positive vorticity. The positive center continued to move and reached northern Hebei at 20:00 (**Figure 20**). The whole Beijing-Tianjin-Hebei region, western Liaoning, and Hebei were all under control by the positive vorticity region, the whole Beijing and Northern Tianjin were at the center.

Such vorticity evolution would provide cyclonic circulation in the low-level atmosphere, creating a condition for the upward motion in the low level, which provided an advantage for the snowfall process.

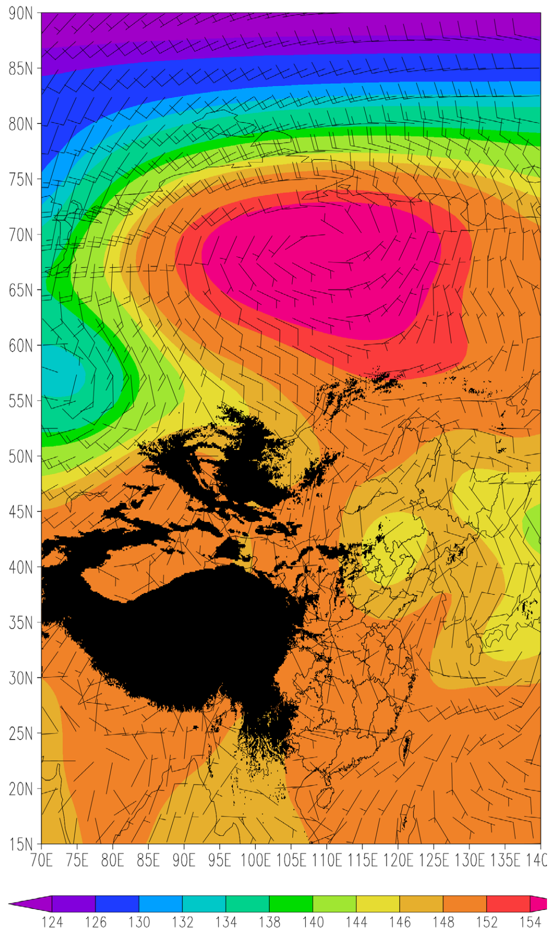

Figure 17. The regional 850 hPa with barb (Units: dagpm).

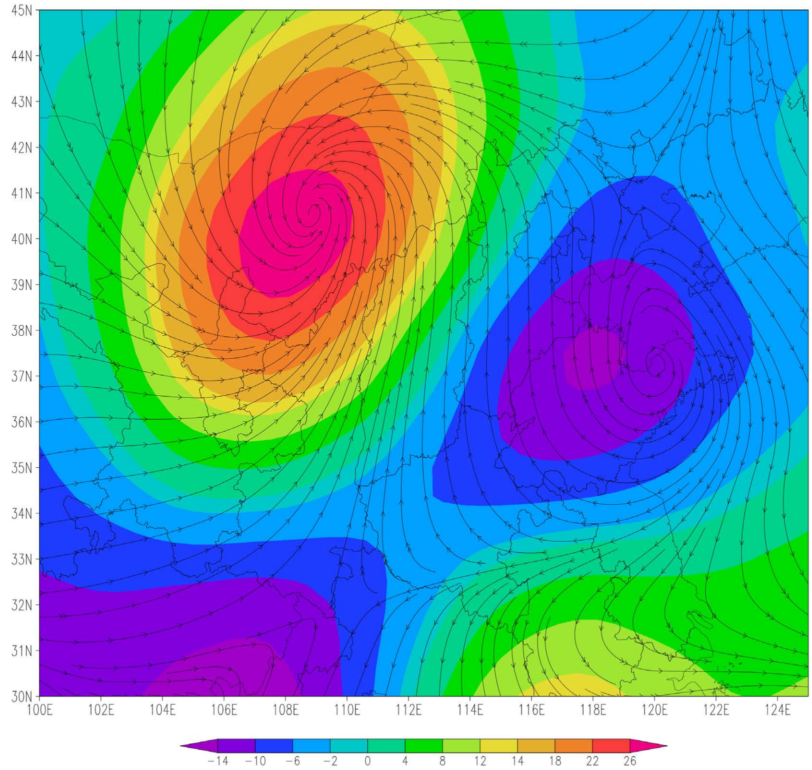

Figure 18. The vorticity with stream at 850 hPa at 08:00 in February 2022 (Unit: s^{-1}).

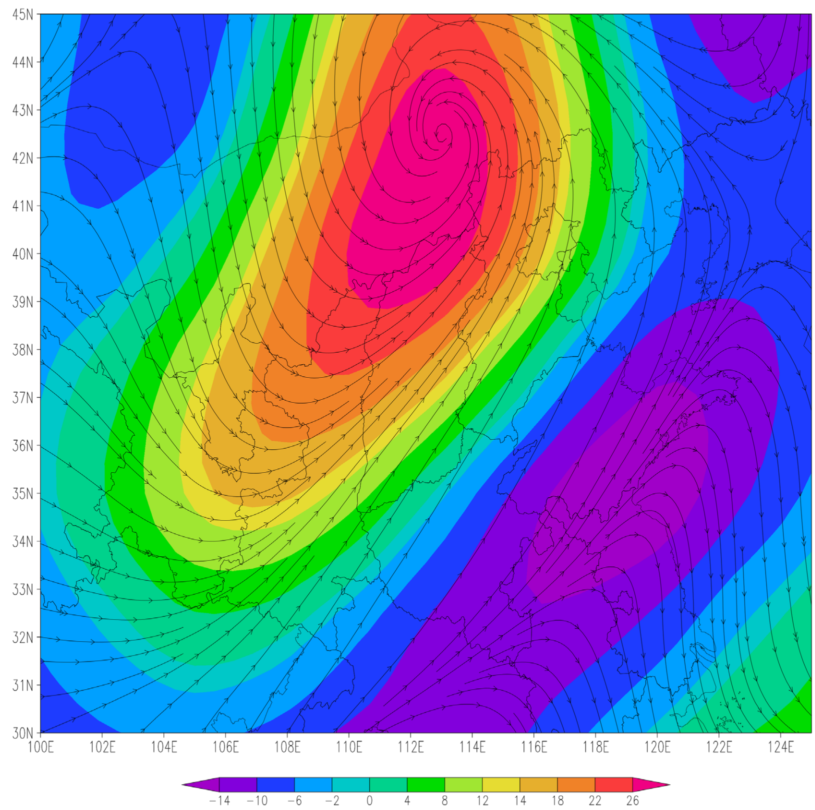

Figure 19. The vorticity with stream at 850 hPa at 14:00 in February 2022.

The convergence areas corresponded well to the vorticity in the lower atmosphere. Here this research only gives the low-level divergence at 20:00 (**Figure 21**). The negative convergence combined with the positive vorticity to create an advantage for the upward motion. The upward motion has been analyzed in 3.3 Lifting Conditions Analysis.

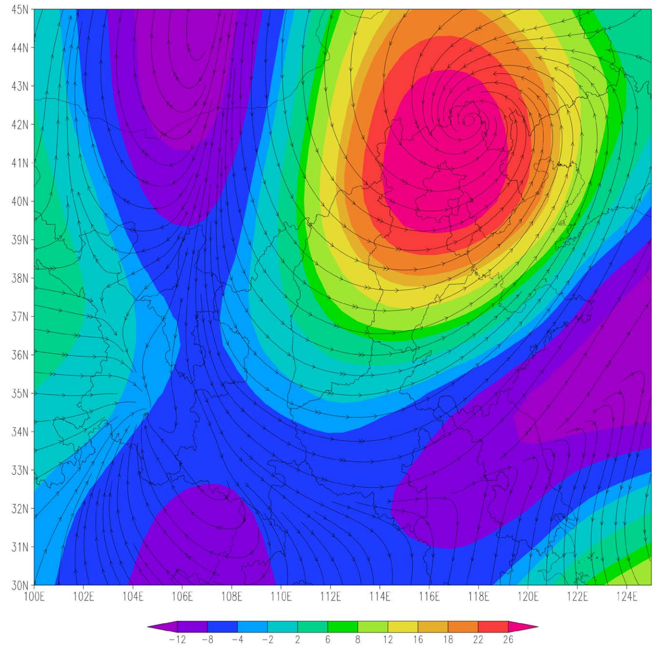

Figure 20. The vorticity with stream at 850 hPa at 08:00 in February 2022.

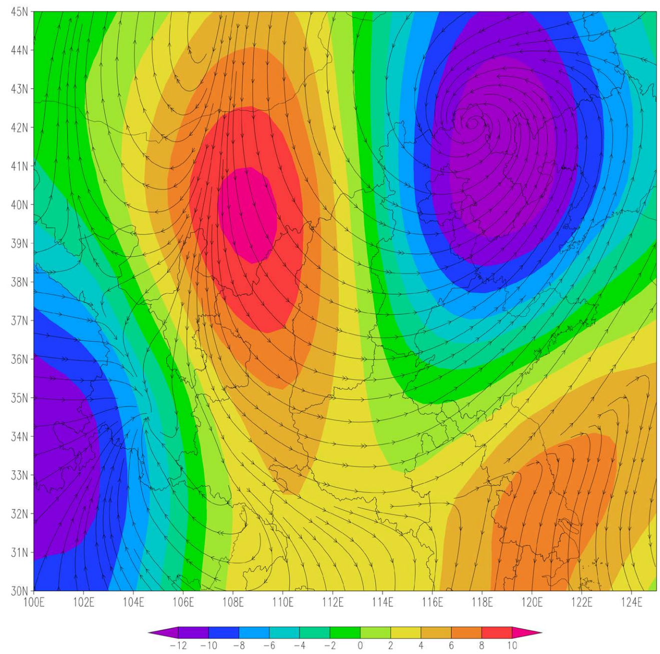

Figure 21. The divergence with stream at 850 hPa at 20:00 in February 2022 (Unit: s^{-1}).

3.6. Numerical Analysis

This study uses numerical ways to reconstruct the snowfall process by WRF Model. The WRF contains many physics parameterization schemes. For the simulation of the snow, this research chose the following schemes and model settings Li (2019) (**Table 1** and **Table 2**).

The simulation areas are illustrated in **Figure 22**.

Table 1. Physical Settings of the WRF Model.

Physical Settings	Methods
Micro Physics	Thompson Scheme
Shortwave Options	Dudhia Shortwave Scheme
Longwave Options	RRTM Longwave Scheme
Planetary Boundary Layer Physics	Yonsei University Scheme
Land Surface Options	Unified Noah Land Surface Model
Cumulus Parameterization Options	Kain-Fritsch Scheme

Table 2. Model settings of the WRF Model.

Model Settings	Methods
Time	February, 13 2022
Grid numbers	100 * 100
History intervals	240 s
Time Resolution	6 h
Space Resolution	10 km
Vertical Layers	34

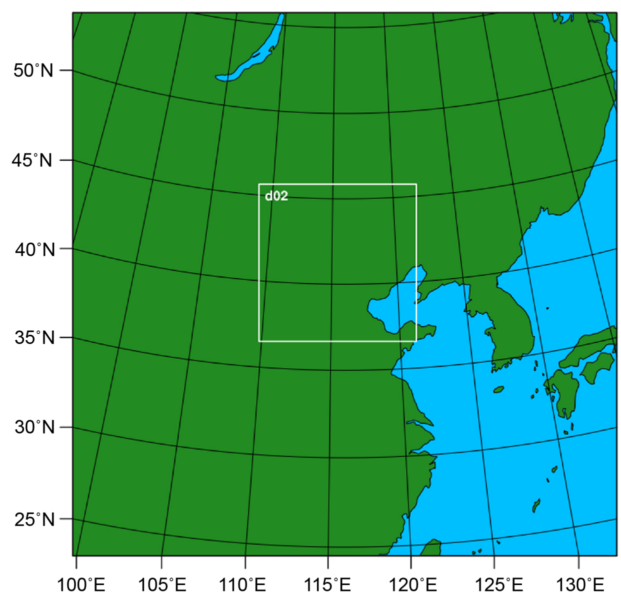

Figure 22. WPS domain configuration.

The simulation result (**Figure 23**) shows the range and the intensity of the snow. The snowfall center lied at 114E, 38N, which was the southeast of Hebei Province. The whole Beijing-Tianjin-Hebei region and Hebei Province, eastern Liaoning and northern Shanxi were all covered with snow. Southern Tianjin, southern Hebei and western Shanxi suffered heavy snow, with the total snowfall over 10 mm.

4. Conclusion

There were three main reasons for the formation of an obvious snowfall process in North China on February 13, 2022.

1. In the middle of February, the atmospheric circulation situation in the middle and high latitudes of Asia and Europe was "two troughs and one ridge". The snowfall weather process was mainly caused by the high-level trough, the low-level vortex. Meanwhile, the snowfall regions were in the south of the Siberia high, which could transport cold air and caused a snowfall process.

2. The relative humidity was above 80% in the snowfall regions. There was a strong easterly wind that transports water vapor from the Yellow Sea and the Bohai to the North China Region. At the same time, the southerly relatively weak air flew in front of the 850 hPa low vortex transported water vapor from

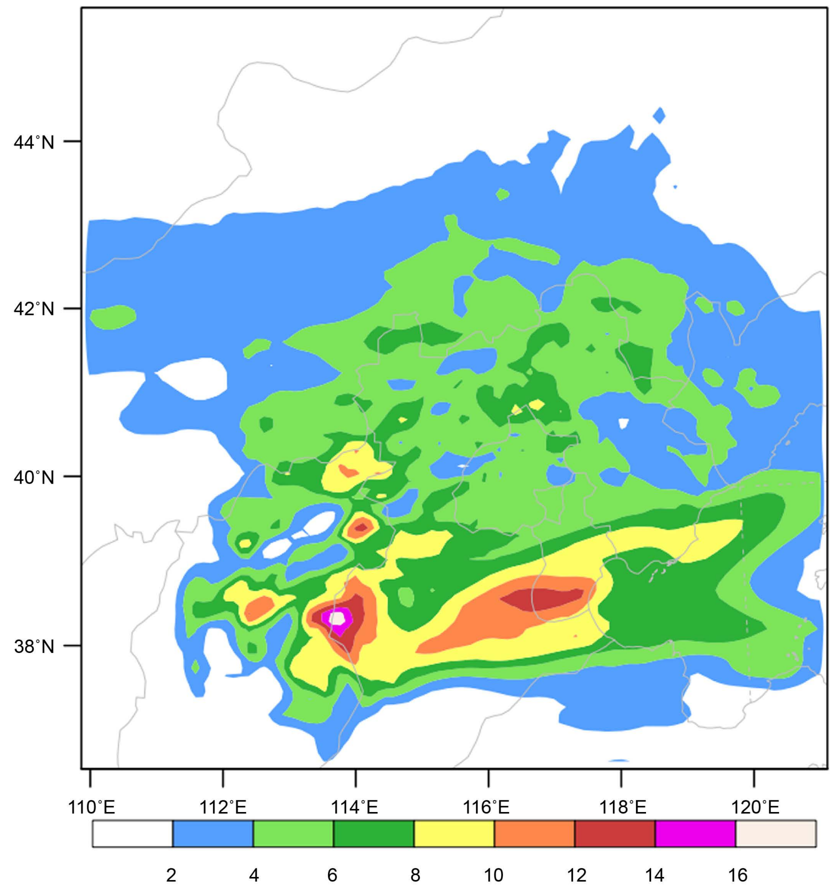

Figure 23. The simulation result at 20:00.

the South China region to the North China region. Meanwhile, the total precipitable water all reached above 5 mm in the snowfall areas, giving conditions for snowfall.

3. The vorticity, divergence and lifting situation were corresponding. In the low-level atmosphere, convergence and positive vorticity could be analyzed in Hebei, Shanxi, Beijing, and Tianjin, where were the main places to encountered snowfall. The positive vorticity with convergence would form upward motion, thus resulted in snowfall.

4. Numerical reconstruction reveals the main field of the snowfall range and the intensity. The center lied at 114E, 38N. Light to moderate snow occurred in central Inner Mongolia, Beijing, Tianjin, Hebei, northern Shanxi, northern Shandong, Liaoning, and southeastern Jilin, and heavy snow occurred in Southern Hebei.

Conflicts of Interest

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

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