The Severe Cold Air which Affected Qingdao during the 2022 National Holiday of China

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Abstract. Under the background of global warming and climate change, the number of extreme weather is increasing, not only the extremely hot weather in summer but also record-breaking cold events. This paper uses synoptic maps and sounding graphs to analyze an unusual weather process of severe convection and sudden drop in temperature that happened in Qingdao between 2nd October 2022 and 4th October 2022. The weather process could be roughly divided into two parts. Before the cold front reached Qingdao, the precedent cold air came across with the strong west Pacific subtropical high and created severe convection like heavy rain, thunder, and lightning as well as strong wind, especially gusts, the characteristics resemble a typical summer severe convection. After the dusk of 3rd October 2022, the temperature began to fall rapidly, with the winds shifting to the north, this process is like a cold wave surging Qingdao in winter. The purpose of this paper is to study the impact of climate change on extreme weather using this weather event as an example. This study will help those concerned to better understand the evolution of weather events so that the necessary precautions can be taken to mitigate the damage they may cause to people, property and infrastructure.

Keywords: Erect turn of across trough, west Pacific subtropical high, synoptic map, sounding graph.

1. Introduction

The global warming has become a worldwide challenge. Global warming leads to more frequent extreme weather, such as rainstorms and cold waves, which has a profound impact on human society [1]. Rainstorms can lead to soil degradation, and economic losses, as well as claiming countless lives [2]. It also has an impact on the water ecology system hidden behind the surface of water[3]. Similarly, the cold wave can cause disaster as well, and influence human society's production and activity. The sudden drop in temperature can directly destroy crops, especially the tropical fruit grown in south China. On the other hand, the cold wave-induced frost hurts crop growth [4]. Therefore, extreme weather can lead to great financial loss. Statistics show that the economic loss caused by meteorological disasters comprises 70% of the total economic loss from natural disasters. Take China for example. In the first half year of 2023, floods and cold waves caused a direct economic loss of ￥21,040,000,000 and ￥4,370,000,000 respectively in China [5].

Global warming does not mean the temperature is rising everywhere around the world. On the other hand, the rate of warming is not the same in different parts. For instance, the polar area tends to warm faster than the lower attitude area, which is known as Arctic amplification (AA). On 18th September 2022, the area covered by Arctic sea ice reached its minimum throughout the year, 4,670,000 km2, reaching the least one of that figure within the past 3 decades. The AA, along with the thermal effect of warming, can cause greater uncertainty in forecasting extreme cold weather, especially extreme cold waves[6].

According to the definition provided by the China Meteorological Center (CMA), temperature dropping by more than 10 ℃ while the daily minimum temperature dropping to less than 5 ℃ is categorized as a cold wave [7]. According to the ERA5 reanalysis, the latest climate reanalysis produced by the European Centre for Medium-Range Weather Forecast (ECMWF), the majority of Qingdao reached the standard of torrential rain in the autumn of 2022. Although the daily minimum temperature did not meet the standard of a cold wave, the impact of the drop in temperature cannot

be neglected. What drove the rainstorm was severe convection, which normally happens in hot summer. However, it is unique for severe convection to take place in the middle autumn period. The intense thunderstorm resulting from severe convection had even caused damage to the Shilaoren rock formation, a prominent feature of the Laoshan scenic area in Qingdao. The substantial rainfall and abrupt temperature decrease, both outcomes of extreme weather conditions, should not be underestimated.

Therefore, this paper is going to analyze this weathering process by digging into the synoptic maps, as well as using numerical models to better illustrate its features, explain why the weathering process has characteristics of both summer and winter, and try to summarize the key to forecast it. To illustrate some influences of climate change like AA on extreme weather.

2. Weather Review

From 7:00 a.m. Beijing time on October 1st to 6:00 a.m. Beijing time on October 4th, the total average precipitation in Qingdao was 96.1 mm. The highest recorded precipitation was in Datian, Pingdu district, with a total of 175.5 mm. The average precipitation for each district, listed in descending order, is as follows: Pingdu with a total of 129.4 mm, Laixi with a total of 117.8 mm, Jiaozhou with a total of 90.8 mm, Chengyang with a total of 89.5 mm, Jimo a total of 81.0 mm, Laoshan with a total of 79.1 mm downtown area (including Shinan district, Shibei district and Licang district) with a total of 67.0 mm, and Huangdao with a total of 57.0 mm. As of 4th October 2022, the average precipitation in Qingdao had reached 968.8 mm, marking an increase of 213.7 mm compared to the same period last year (2021), and a significant 352.2 mm higher than the historical average. Meanwhile, the maximum air temperature on 4th October experienced a notable decrease of 10℃ compared to the previous day. Before 3rd October, the temperature in Qingdao maintained more than 20℃, it even peaked at 24℃ in the afternoon of 3rd October. However, After the invasion of cold air at dusk of 3rd October, the temperature dropped 7.3℃ in just 2 hours, and all along to the bottom, the dawn of 4th October, when the temperature was only 12℃ [1]. The slump in temperature makes people experience a sudden shift from mid-Acumn to early winter in just 12 hours. This meteorological pattern exhibited a blend of characteristics associated with both winter cold waves and summer rainstorms. The subsequent analysis provides a succinct examination of this particular weather phenomenon.

2.1. The torrential rain

Based on the observed data, most observation stations in Qingdao met the standard of “torrential rain”. Analyzing the synoptic maps (Figure 1), it becomes apparent that the area affected by the rainstorm is situated south of a shear line at a low altitude, while the subtropical high was located just to the south of Qingdao, providing energy and moisture. Typically, rainstorms are prevalent during the summer, specifically from July to September. Remarkably, by 19 September of that year, Qingdao had already transitioned into autumn, and the commencement of October marked the middle of the autumn season. Therefore, this weather pattern is not common in the same period.

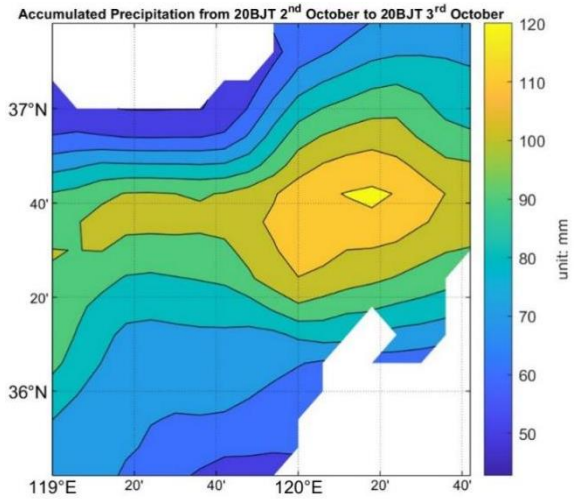

Figure 1. The Accumulated Precipitation from 8 p.m. 2nd October to 8 p.m. 3rd October (Photo/Picture credit : Original)

By using the ERA5 reanalysis, it can be figured out that the distribution of the precipitation at that time. The result shows that precipitation in most areas exceeded 50 mm, there were even some areas in the middle of the Shandong peninsula whose precipitation exceeded 100 mm. Such huge precipitation reflects an extreme weather process that day.

2.2. The cold wave

The observation showed that the weathering process did not attain the threshold of a cold wave warning. However, it affected people's lives, as the slump of temperature can alter the daily dressing of citizens there. The CMA has an industrial standard for the meteorological index of clothing launched on October 30, 2017. The temperature at dusk of 3rd October 2022, exceeded 20℃, which belonged to level 4 (wearing clothes like a jacket is recommended) of a meteorological index of clothing, while the temperature dropped to less than 15℃ at dawn of 4th October, making the index to level 6 (wearing clothes like cotton-padded clothes is recommended). However, since each person has a different constitution and values weather changes differently, causing these people to ignore such changes. As a result, they are more likely to catch a cold. When exposed to cold environments, people who suffer from asthma and lack cold protection are especially vulnerable to cold air and cold[8].

The reason why the temperature in Qingdao dropped so quickly was due to the strong cold air mass behind it, forming a typical winterly cold-air outbreak. Normally, there are three types of a cold wave affecting China, which is development of small trough, east movement of low trough and erect turn of across trough [9]. That process was the last one, which will be analyzed in the next section.

3. Result

3.1. Circulation analysis

Figure 2 is about the evolution of the trough line from 30th September 2022 to 3rd October 2022. As shown in the figure, there was an area with lower geopotential height, while the upper trough was relatively wide. However, when it came to 1st October, the upper trough significantly became narrower, and the isoline of geopotential height on the east of the upper trough became more intensive, which caused the geostrophic wind to become stronger. However, the isoline of geopotential height turned sparse on the west. The trough also turned into stretching northeast-southwest in early October instead of stretching northeast-southwest in late September, which is known as an erect turn of across trough. The cold wave process can be roughly divided into two phases, before 30th September was the ferment of the cold wave, and after 1st October was the outbreak of the cold wave. The little component of the wind in the east and west direction in the trough area after the formation of the

across trough caused the trough to move slowly, which led to the gathering of cold air behind the across trough, and pushing the tail of the trough moving slowly. and northerly winds ahead of the Ural high increases the gradient of the geopotential height, moving the cold air southward, as well as stretching the trough. Therefore, the trough began to tilt to the southeast [10]. When the cross trough was turning erect, the guided airflow became more beneficial for the trough to move, as a result, the process was accelerating, which is obvious in Figure 2.

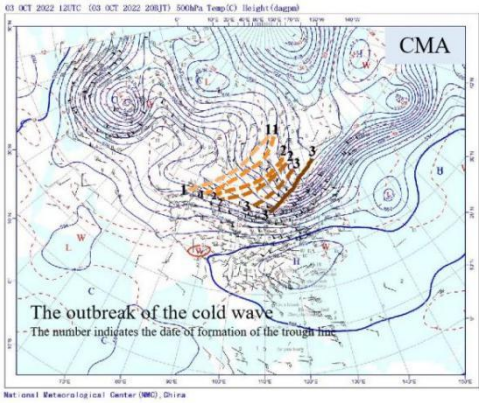

Figure 2. The Evolution of the Trough Line Based on The Synoptic Map of Eurasia at 500 hPa at 8 a.m. 3rd October 2022[11]

Remarkably, a so-called "inversed Ω" pattern of the geopotential height contour distribution was formed on 3rd October 2022, according to the synoptic map of Eurasia at 500 hPa at 8 a.m. on 30th September 2022 (Figure 3). The trough was restricted by the ridges on the west and east. The west one is located near the Ural mountains——the boundary of Asia and Europe, which is known as "Ural high" or "Ural blocking high". This phenomenon usually happens in cold winter, especially December and January, regarded as the precursor of a strong cold wave that will influence China within a few days. The process in late September and early October of 2022 is quite familiar with the winter style, although the center of the trough is not as strong as the winter ones. However, in this case, the cold air had some unique points. First, the Ural blocking high did not collapse, or to be specific, it still maintained its shape on the synoptic maps, while its strength was weakened during the process.

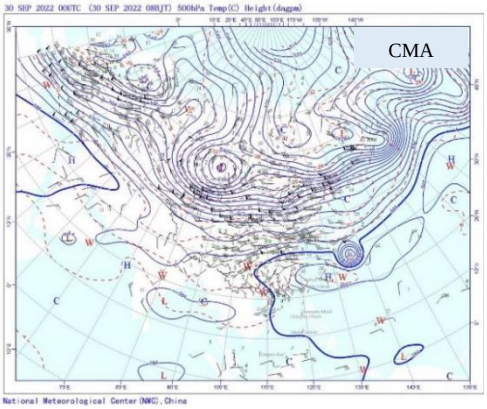

Figure 3. The Synoptic Map of Eurasia at 500 hPa at 8 a.m. 30th September 2022[11]

3.2. The process and analysis of the drop in the temperature

According to Figure 2, there was a low center of geopotential height over the west Siberian plain, with northerly wind on its west. The northerly wind had little component in the east-west direction, causing the guided airflow can only slowly push the system forward. However, its geopotential height increased when it came to 1st October, making the trough narrower, and became gradually narrow from the high latitude to the low latitude, which made the shape of the weather system resemble a trough. The wind direction at the end of the trough also from northerly wind turned into northwesterly

wind, contributing to more components of the wind in the east-west direction of the guided airflow, which could push the trough faster.

With the guided airflow, the across trough began to turn erect. Behind the high-altitude trough, cold air on the ground tends to move southeast. The process of occurrence of a cold wave can be described based on the change in the area where a 5℃ drop in temperature occurs during the 24 hours from 8 a.m. of the previous day to 8 a.m. of the following day (Figure 4). Firstly, the cold wave affected Xinjiang, in the northwest of China, then outer Mongolia, and finally the northeast of China and the north of China. The cooling center continued to move eastward and southward, which reflects the systematic process of the erect turn across troughs. However, its cooling effect continued to weaken while moving south, because the west Pacific subtropical high was still strong at that time and prevented the cold air from penetrating south.

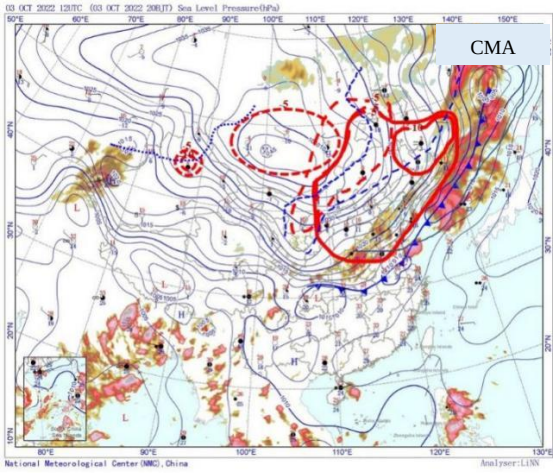

Figure 4. The Synoptic Map of China at the ground at 8 a.m. 3rd October 2022, with cooling center and cloud[11]

Such a strong Ural blocking high is very likely to be linked with the AA. Since the Arctic region is warmed faster than the mid-latitude and tropical areas, the meridional gradient of temperature decreases. Having a new influence on the circulation of the atmosphere both dynamically and thermally. On the dynamical dimension, the AA creates more waves with larger amplitudes among the circulation in the midlatitude area [6]. Therefore, ridges that pierce into high-latitude areas can be formed more easily. Meanwhile, Siberian high on the surface in north Asia tends to be stronger, and more apt to intrude East Asia, especially China, and create extreme cold waves, since the blocking high of great strength can push it southward and eastward [6]. On the thermal dimension, the change of meridional gradient of temperature can weaken the thermal wind, then slow down the polar jet driven thermally [12]. Thus, the atmospheric long waves tend to move slower and have larger amplitude, forming stronger Ural blocking high as well as Siberian high.

On the other hand, the Arctic oscillation (AO) can also have an impact on the Ural high and cold waves in East Asia. According to recent studies, the AO index has a negative correlation with the cold extremes in East Asia [11]. The positive value of AO indicates the air pressure in the Arctic region is higher than normal, which can cause a stronger polar vortex over the frigid zone, and hold the cold air tight within the polar area, preventing it from moving southward. In this case, the East Asia region tends to be warmer than usual while being less likely to experience extreme cold waves, and vice versa [13]. The AO index of September 2022 was -0.63, which is in favor of cold waves in late September and early October 2022 [14].

3.3. The analysis of the condition of the precipitation

3.3.1 The overview of precipitation

According to the sounding graph of Qingdao (54857) on 8 a.m. 2nd October (Figure 5), the Convective available potential energy (CAPE) is relatively high, while the Convective inhibition (CIN) is relatively low, which means the air mass had plenty energy to rise with less restriction.

Therefore, in this situation, severe convection is highly possible to take place. On the noon of 2nd October, the downtown area of Qingdao experienced heavy precipitation in just an hour from the west to the east. By the evening, the CAPE of Qingdao was still high according to the sounding graph (Figure 6). As a result, strong convective took place again in Qingdao, with thunder and lightning. On the morning of 3rd October, there was also some rainfall in the downtown area of Qingdao. Later in the afternoon, the wind turned to northerly wind with scattered rain, and the precipitation process ended on 4th October.

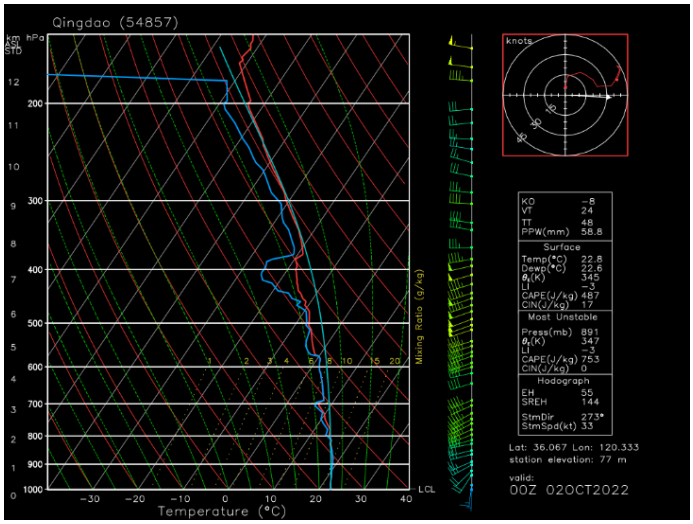

Figure 5. The Sounding Graph of Qingdao at 8 a.m. 2nd October 2022[15]

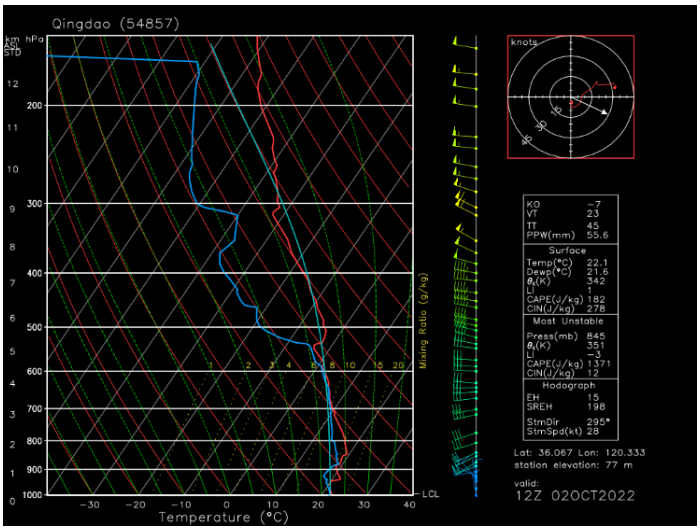

Figure 6. The Sounding Graph of Qingdao at 8 p.m. 2nd October 2022[15]

3.3.2 General analysis of the precipitation

During late September and early October of 2022, the west Pacific subtropical high was still strong, the '588' line on the 500 hPa synoptic map, which indicates the sphere of influence of the west Pacific subtropical high, even reached the south of Qingdao on 30th September according to Figure 2. The west Pacific subtropical high drove the trough away and changed the direction of the wind. According to the synoptic map of China at 850 hPa at 8 a.m. on 1st October 2022 (Figure 1), there were three types of air mass, forming a situation like the occluded front. Specifically, there was a cold front and a warm front over the Baikal region, in the north, those two different fronts connected. According to the ground synoptic map, the cold air tended to enter the inverted trough. If the cold air comes across the warm air with enough water vapor, it is likely to produce precipitation and drop in temperature. There was also a sudden change in the ground pressure, causing wind shear.

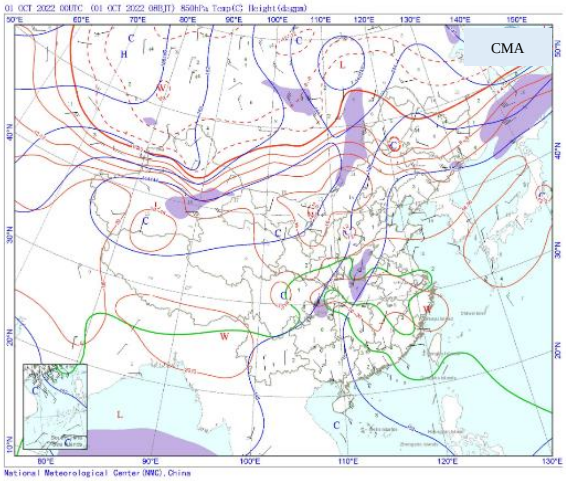

Figure 7. The Synoptic Map of China at 850 hPa at 8 a.m. 1st October, 2022[11]

4. The analysis of the Reason why the Weather Process Lasted for a Long Time

The precipitation process began in the morning of 2nd October 2022 and ended in the evening of 3rd October 2022, the span was relatively long. According to the synoptic map on the ground on 2 p.m. 1st October (Figure 8), there was a cold high-pressure system in west Siberia that day, and it tended to move southeast. Meanwhile, the west Pacific subtropical high was just to the south of Qingdao (Figure 9), which pushed the specific humidity at the ground in Qingdao to more than 15g/kg (the shaded area). During the 2nd October and 3rd October, the cold front moved slowly to the southeast, creating steady and long-period precipitation in Qingdao.

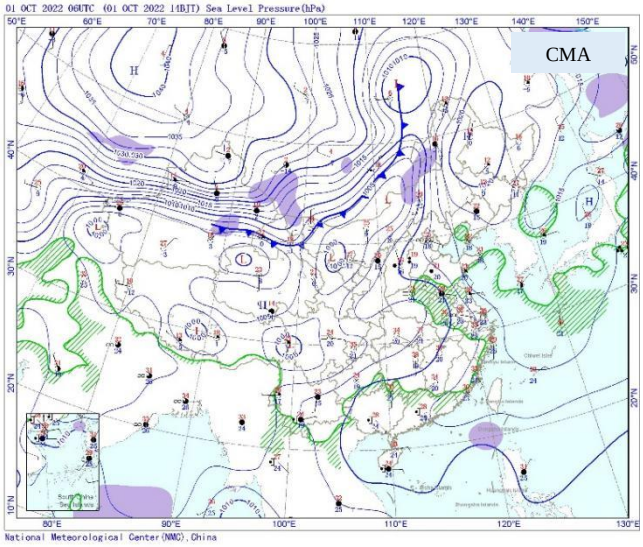

Figure 8. The Synoptic Map of China at Ground at 2 p.m. 1st October 2022[11]

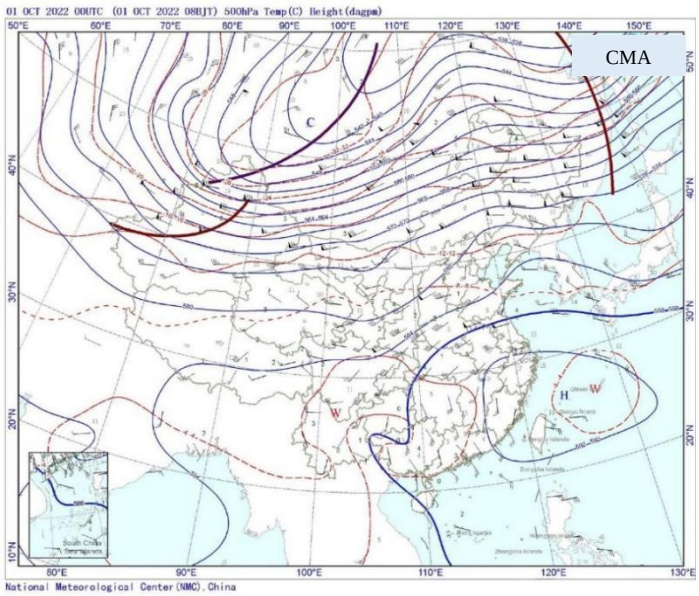

Figure 9 The Synoptic Map of China at 500 hPa at 8 a.m. 1st October, 2022[11]

5. Conclusions

This paper analyzes a weather process of rainstorms and temperature drops that affected Qingdao during 2nd October and 4th October. By using synoptic maps and sounding graphs, the cause of the rainstorm and cold air is figured out, which involves the strong Ural blocking high, the erect turn of across trough, and the strong west Pacific subtropical high. The strong Ural blocking high prevented the trough from moving quickly at first, which stored cold air behind it. When the Ural blocking high collapsed, with the help of guided airflow, the across trough began to turn erect, leading the cold air to move southeast and creating cold waves in the north of China. When the cold air came across the west Pacific subtropical high, severe convection was triggered at first, after the cold air took over Qingdao, the temperature slumped.

However, there are some minor flaws in this research. First, this passage only focused on the qualitative analysis, there was not enough quantitative analysis of the dynamics of the severe convection. Next, the research did not include a Doppler radar map, which lacks the specific process of the moment of severe convection. Last, the plotting scale of the 500 hPa synoptic maps is too small to focus on Qingdao's specific process during the cold air influencing Qingdao.

By analyzing this unusual weather process, some impacts of global warming can be revealed. Global warming does not simply mean the rising average temperature, but a chain of impacts behind it. For non-researchers, it is hard to believe that there are also severe cold surges and record-breaking low temperatures. Climate change puts forward higher requirements to the weather forecast system and the climate predicting system. The earlier, the more accurate the weather or climate tendency is predicted, the less people will be affected.

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