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The Ice-and-Snow Tourism in Harbin Met Its Waterloo: Analysis of the Causes of the Warm Winter with Reduced Snowfall in 2018/2019

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Abstract: Harbin, located in northeast China (NEC), has obvious monsoon climate characteristics due to the influence of its geographical environment. Under the control of the polar continental air mass, winter in Harbin is exceedingly cold and long, with the frequent invasion of the cold and dry air from the north. Because of its intensely cold climate in winter, Harbin has created a local form of tourism with its own characteristics: the snow and ice landscape attracts a large number of tourists. Therefore, the anomalies of air temperature and precipitation in winter have an important impact on the livelihood of the local people and economy. In the winter of 2018/2019, the ice and snow tourism in Harbin was harshly affected by the extreme weather, and the direct cause is the anomalies of atmospheric circulation. There is a center of strong positive geopotential height anomalies over east China, which favors the movement of warm air northwards to the NEC, resulting in warmer-than-normal air temperature. Anomalous precipitation is largely controlled by the anomalies of local water vapor and air temperature. The aim of this study was to determine whether the warmer-than-normal temperature, which made the atmosphere more resistant to saturation, was the primary cause of the reduced snowfall. The relative importance of water vapor and air temperature anomalies to the anomalous precipitation was compared. The results suggest that the warmer-than-normal temperature affected all levels, but its impact on the near-surface level was greater. At the middle and upper levels (above 850 hPa), in addition to the warmer-than-normal temperature, the amount of water vapor was less than normal. These conditions both reduced the amount of snow; however, by comparison, the dryness of the air contributed more significantly.

Keywords: northeast China; warm winter; snowfall; circulation anomalies; water vapor supply

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1. Introduction

The northeast China (NEC) is the most northern region of China, which includes Heilongjiang, Jilin, Liaoning, and the eastern part of Inner Mongolia Province. Its natural resources are very rich, especially agriculture and animal husbandry, which occupy a very important position in China. The main phase of winter precipitation over NEC in winter is snowfall, and the change in snow cover plays an important role in the climate system, which has a significant impact on agricultural production and the ecological environment, as well as the tourist industry [1–9].

Harbin is the capital of Heilongjiang, located in the south-central area of the province. Under the influence of the temperate monsoon, this region has four distinct seasons, but its winters are much longer than in the southern regions [10,11]. Meanwhile, Harbin is affected by cold and dry air from the Arctic and high-latitude regions relatively easily; thus, the winters there are not only longer, but much colder [12–15]. Although the cold climate causes many inconveniences to local people, these disadvantages are transformed into competitiveness in the form of tourist attractions. Every winter, there are a large number of ice-and-snow sports and cultural activities take place in Harbin, the most famous of which is the Harbin Ice and Snow World.

In the winter of 2018/2019, the temperature in Harbin was abnormally high, reaching the second-highest level since 1961. The snowfall was extremely low, 57 percent less than in the same period in previous years, making it the eighth lowest snowfall since 1961. Due to the warmer-than-normal temperature in Harbin in the winter of 2018/2019, the ice and snow melted earlier than usual, and the lack of snowfall led to a reduction in the number of tourists visiting for views of the snow. The 20th Harbin Ice and Snow World was open from 23 December 2018 to 17 February 2019 and only lasted 57 days, which was the shortest opening time in its history. It is estimated that the income from tickets alone decreased by about 66.47 million RMB, and the income from catering, lodging, and other forms of consumption caused by the reduction in tourists was also greatly reduced.

The abnormal temperature and precipitation in Harbin in winter can affect not only tourism, but all aspects of agriculture, industry, forestry, environmental protection, transportation, municipal administration, electricity, and health [1–11]. Affected by the Siberian (Mongolian) high or the warm air transport form the south, temperature inversion often occurs over Harbin in winter, which is not conducive to the diffusion of pollutants [16–19]. Meanwhile, the lack of snowfall also makes it difficult to remove pollutants from the atmosphere. Harbin mainly relies on coal burning to provide central heating in winter; therefore, the deterioration in atmospheric diffusion conditions greatly reduces the air quality. Consequently, it is necessary to study the causes of the anomalous temperatures and reduced snow in winter in Harbin, so as to find a prediction method and provide forecasts for the relevant departments as a scientific reference for advanced deployment.

The extreme weather event can be attributed to anomalies in the large-scale atmospheric circulation; the sea-surface temperature could have been a key external factor [20–28]. Whatever circulation system was affected, it was ultimately reflected in local air temperature and water vapor anomalies. This extreme event may have been the result of unusually high temperatures, which would have made the atmosphere more resistant to saturation. However, the lack of water vapor supply was also important to the formation of the event. In this study, an analysis tool is utilized to compare the effects of the warmer-than-normal air temperature and the anomalies in the water vapor supply. This tool has been used to investigate the severe droughts and floods that occurred in recent years in China [29–31], and has also been adopted to verify the causes of anomalous precipitation in the interannual variation in precipitation [32,33].

The data sets used for the calculation process in this paper and the methods used are presented in Section 2. The severity of this extreme event in the 2018/2019 winter in Harbin is briefly described in Section 3. In Section 4, the abnormalities in the atmospheric circulation, especially the impact of airflow surges from the Arctic and high-latitude regions, are discussed. Meanwhile, an analysis tool is used to compare the contributions of the anomalous air temperature and water vapor over the study region to the reduced snowfall. A summary and discussion are given in Section 5.

2. Data and Methods

2.1. Data

The observed monthly mean precipitation and temperature data of 160 stations in China were provided by the National Climate Center of China, and the datasets began in 1951. The National Centers for Environmental Prediction/National Center for Atmospheric

Research (NCEP/NCAR) Reanalysis I dataset [34] was used for pressure-level examinations, including the monthly geopotential height, wind components, air temperature, and relative humidity. The reanalysis dataset covered the period from 1979 to 2019, featured 17 pressure levels, and were in a horizontal resolution of $2.5° \times 2.5°$. The Arctic oscillation (AO) index was derived from the NOAA Climate Prediction Center, and the dataset started from 1950. The climatic means in this paper were all calculated over the 30 years from 1981 to 2010.

2.2. Methods

Empirical orthogonal function (EOF) analysis was employed to extract the local air temperature leading mode in NEC. In addition, regression and correlation were used to analyze the link between air temperature and the Arctic oscillation (AO), and the significance check was based on the Student's t test. These methods are widely used in climate diagnosis, and a method to separate the effects of air temperature and water vapor on precipitation that we proposed previously is introduced below.

With large spatial samples, Lu and Takle [35] revealed that on an interannual timescale, precipitation and relative humidity possess a very tight positive relationship, which is much stronger than the precipitation–moisture relation. Thus, the lower-than-normal precipitation ($P_{dry} < P_{nor}$) event can be represented as $r_{dry} < r_{nor}$. Relative humidity (r) is expressed in terms of vapor pressure (e) and saturated vapor pressure (e_s) at a temperature (T) as $r = e/e_s(T)$. The variation in relative humidity is denoted as $C_r \equiv r_{dry}/r_{nor}$, and can be written as

$$C_r = C_q/C_T < 1 \tag{1}$$

where

$$C_q \equiv e_{dry}/e_{nor} \tag{2}$$

and

$$C_T \equiv e_s(T_{dry})/e_s(T_{nor}) \tag{3}$$

When the unit of pressure (p) and vapor pressure (e) is hPa and the unit of specific humidity (q) is g/g, according to the definition of specific humidity (q)and gas state equation, q can be approximately derived as $q = 0.622 * e/p$, and specific humidity (q) is proportional to vapor pressure (e). Therefore, C_q can also be expressed as a change in specific humidity ($C_q = q_{dry}/q_{nor}$), that is, it represents the change in water vapor.

For ease of comparison, take the logarithm of C_q and C_T, then (1) can be transformed into

$$I_r = I_q + I_t < 0 \tag{4}$$

where

$$I_q = \ln(C_q) \tag{5}$$

and

$$I_t = -\ln(C_t) \tag{6}$$

Among them, I_q and I_t are used to reflect the anomalies of water vapor and temperature, respectively, in this event. When $I_q < 0$, the water vapor is less than normal, and when $I_t < 0$, the temperature is warmer than normal. That is, if the value of either is below zero, this represents a negative contribution to the formation of precipitation.

3. The Warm Winter with Less Snowfall in 2018/2019 over NEC

Meteorological records suggest that in the winter of 2018/2019, the temperature over NEC was generally warmer than normal, especially in Heilongjiang Province. Meanwhile, the abnormally temperature of Harbin in the winter of 2018/2019 ranked second in the historical period since 1951, and was only lower than the same period in 2006/2007. The abnormal temperatures persisted throughout the winter. However, January and February, which have a greater impact on ice and snow tourism, were selected as the study period (Figure 1a,b). In January 2019, the temperature in the western part of Heilongjiang was more than 5 °C higher than normal, and more than 4 °C warmer than normal in Harbin (marked as the study domain by a black rectangle, while the black triangle marks the location of Harbin Ice and Snow World), as presented in Figure 1a. Figure 1b shows the anomalous temperatures of February 2019. Although not as severe as the temperature anomaly in January, since the temperature is warmer and closer to zero in mid-to-late February, this had a greater impact on the ice-and-snow landscape.

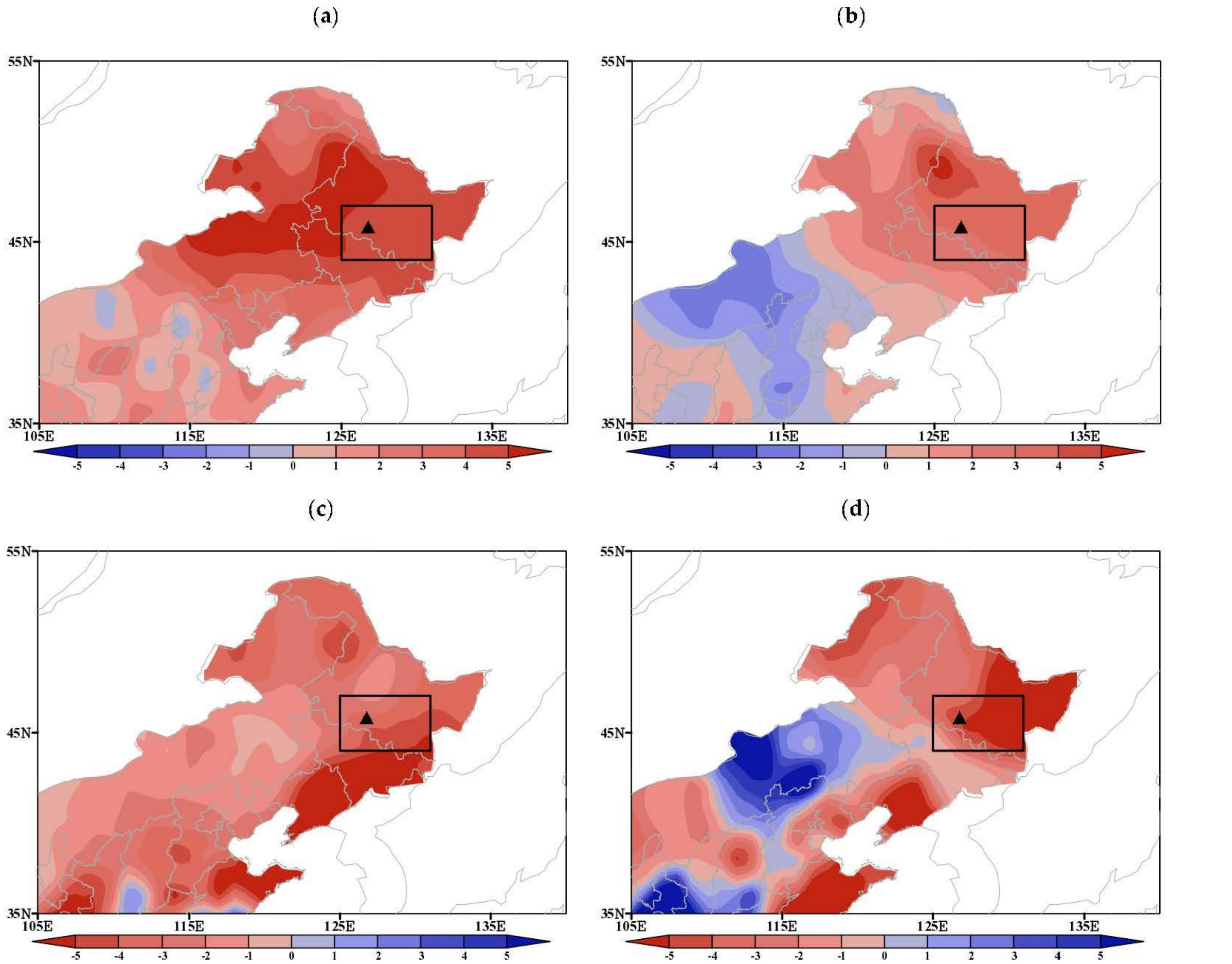

Figure 1. The temperature anomalies in (**a**) January and (**b**) February of 2019 (units: C), and the anomalies in precipitation in (**c**) January and (**d**) February of 2019 (units: mm). The climatic mean is for the 30 years of 1981–2010. The domain (125–131° E, 44–47° N) around Harbin is marked in black, and black triangle marks the location of Harbin Ice and Snow World.

During this extreme event, precipitation was abnormally low in most parts of NEC. In January, all the NEC regions experienced less precipitation than normal (Figure 1c). The negative anomalous center of precipitation was in the middle and east of Heilongjiang Province in February (Figure 1d), and the degree of reduced snow in Harbin ranked eighth in the same period. There was virtually no snow cover throughout the winter of 2018/2019 in Harbin, which significantly affected the region's ice-and-snow tourism.

4. Causes of Temperature and Precipitation Anomalies in Winter of 2018/2019

4.1. The Anomalies in Atmospheric Circulation

Changes in atmospheric circulation have a crucial impact on regional air-temperature and precipitation anomalies. In addition to the Qinghai-Tibet Plateau, which is the most obvious cold air source in China in winter, the Siberian high, located in central and western Mongolia and southern Siberia, is an other important source of dry and cold air transport to NEC in winter. Figure 2a shows the anomalies of 500 hPa geopotential height in January–February 2019 relative to the climatic mean, as well as the winds. The distribution at 1000 hPa is presented in Figure 2b. It can be seen from these two plots that the position of the East Asian Trough is slightly eastward because of the strong positive center over east China. When the trough is in its normal position (in winter, it is generally stable at 120–130° E), the NEC is affected by a strong northwest airflow, which brings dry and cold air. However, during this extreme event, the airflow is relatively flat, and the anomalous northwest winds mainly affect the region to the east of Harbin.

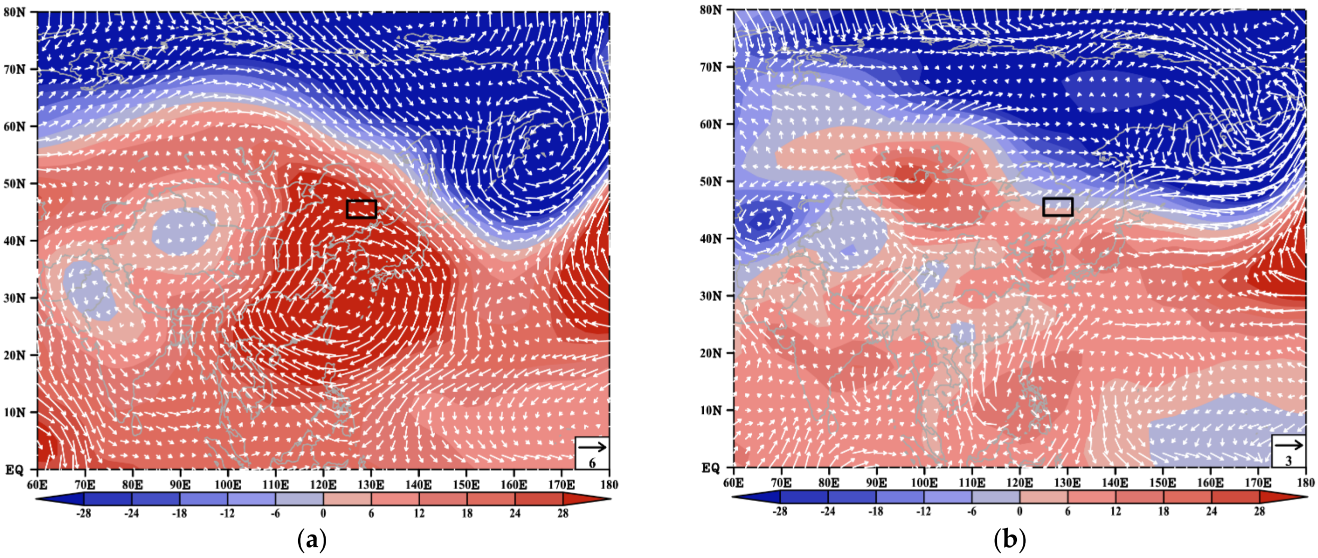

Figure 2. The anomalies in geopotential height (unit: 10 gpm, shaded) and wind (unit: m s^{-1}, vector) for January–February 2019 at (**a**) 500 hPa and (**b**) 1000 hPa, relative to the climatic mean for 1981–2010. The domain (125–131° E, 44–47° N) around Harbin is marked by black rectangle.

The strong positive anomalous center of geopotential height at 500 hPa caused the warm air from the south to easily reach NEC. By comparison, at the lower level (at 1000 hPa), Harbin is essentially in the area of negative height anomalies. This vertical distribution caused the geopotential thickness of the middle troposphere (e.g., 600, 700 and 850 hPa) over Harbin to thicken, which indicates that the air at these levels was warmer than normal.

The Aleutian low is abnormally strong. Consequently, its anomalous east airflow weakens the intensity of the East Asian winter monsoon at lower levels, and reduces the cold air transports to NEC. As shown in Figure 2b, NEC is mainly affected by abnormal southwesterly winds, with bringing warm and moist air northwards to the region.

4.2. Effects of Circulation Systems in Polar and High Latitudes

Atmospheric circulation anomalies at high latitudes also have a certain impact on winter air temperature and precipitation in NEC. There is a significant correlation between winter air temperature over NEC and the Arctic oscillation (AO) index [36–39], which is due to the change in circulation pattern affecting the local air temperature. Previous studies have shown that the AO index has a good negative correlation with the intensity of the East Asian trough, while the intensity of the East Asian trough has a good positive correlation with the Asian winter monsoon [12–14,35–38]. When the AO is strong, the East

Asian trough weakens and moves eastward, and the cold air transported by the northwest airflow behind the trough is weaker, which makes the air temperature in the northern part of China higher. Conversely, when the AO is negative, the East Asian trough is strong, its location is westward, and the winter monsoon flow is stronger, which favors the transport of cold air to NEC and makes the air temperature lower than normal. The AO index for January 2019 was slightly negative, which favored the occasional invasion of NEC by cold air from high latitudes. Nonetheless, the AO in February was significantly positive, and the cold air southwards to NEC was weak, resulting in an overall warmer-than-normal air temperature in winter.

Figure 3a shows the spatial map of the first EOF mode of the winter air temperature anomalies, and the percentage of the variance explained by the first mode is 68.54%. This clearly reflects the distribution and chronological variation of the winter temperature in NEC. The EOF mode shows clearly a positive anomaly pattern across the NEC. The related first principal component (PC1) given in Figure 3b indicates that there was a transition of the winter temperature from a negative phase to a positive phase in the mid-1980s, leading to a significant upward trend in the past 30 years. The air temperature in winter 2018/19 has a large projection onto this mode. The black line in the figure shows the AO index in winter from 1951 to 2018. The overall change trend is similar to the temperature change, and the correlation coefficient is 0.48. Figure 3c further shows the distribution of the correlation coefficient between the AO and winter temperature in NEC, and the correlation coefficients in most areas are above 0.4, which are significant at the 95% confidence level. Figure 3d is the regression distribution of the geopotential height anomalies at 500 hPa against PC1, and the dots denote the shading passing the confidence level of 95%. The figure indicates significant anomalous low pressure in the Arctic and anomalous high pressure in the mid-latitude regions, which is similar to the spatial distribution of a positive phase of the AO. In general, based on the very significant correlation between the two, the AO index can be used as a predictor of winter temperature in NEC.

4.3. The Anomalies in Air Temperature and Water Vapor Supply

The surface air temperature over NEC was significantly warmer than normal during the winter of 2018/2019 (as shown in Figure 1a,b), but was there any change between the different vertical levels? Furthermore, although the anomalies in the air temperature were obviously an important cause of this extreme event, the lack of water vapor supply also led to a reduction in snowfall. Therefore, the warmer-than-normal air temperature and the less-than-normal water vapor were both important in the reduction in precipitation.

Figure 4 shows the anomalies of specific humidity and its flux, the anomaly of air temperature, and the anomaly of relative humidity at different levels. As shown in the first column of the figure, the air temperature in NEC had positive anomalies at all four levels, but the anomalies were more obvious in the near-surface layer (1000 hPa). This may have been due to the weaker-than-normal cold air surge, as analyzed above. Simultaneously, it may also be attributed to the stronger-than-normal warm air transported from the southern regions; this is further illustrated by the distribution of the water vapor across the levels in the second column of Figure 4. Except for the higher-than-normal levels of water vapor at the near-surface level (1000 hPa), the other levels are lower than normal. From the perspective of atmospheric circulation changes, it can be concluded that the warm and moist air from the south invaded NEC from the near-surface levels, and the cold and dry air from the north penetrated at the upper levels.

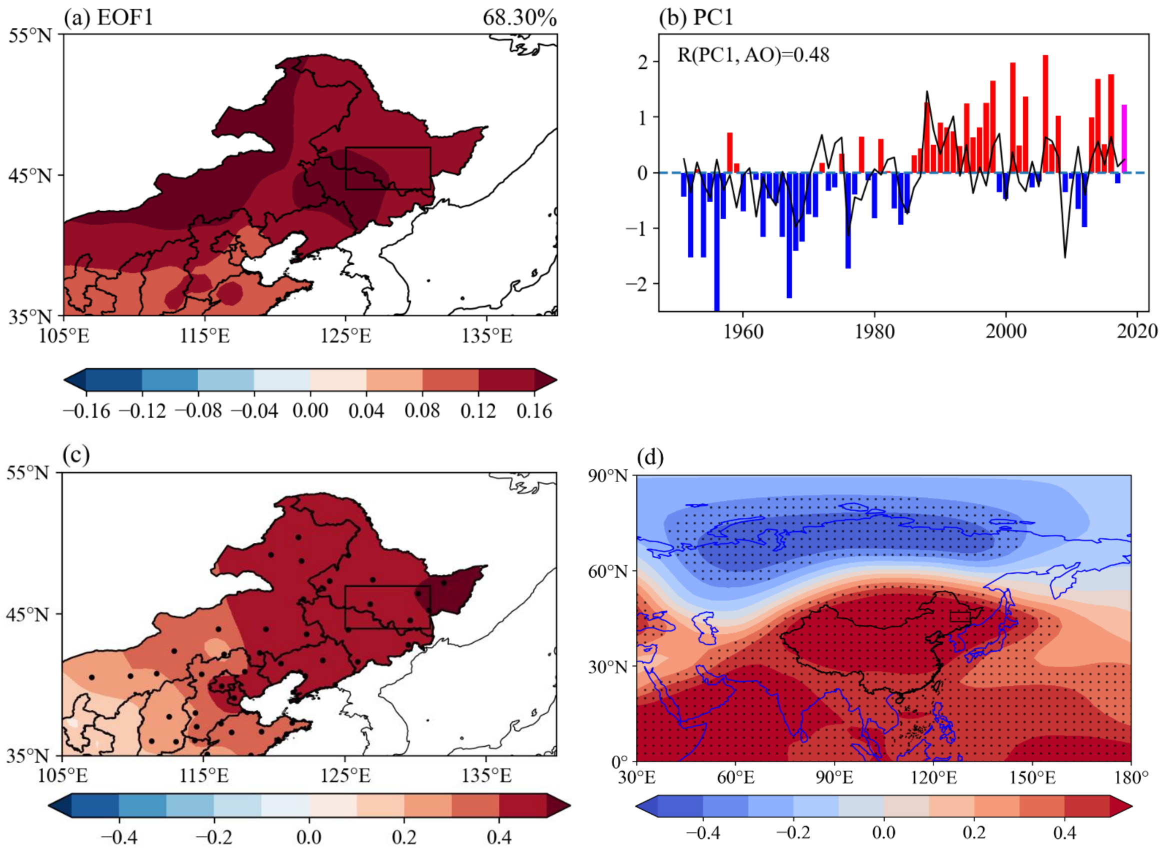

Figure 3. (**a**) The first leading mode of the EOF for air-temperature anomalies in the winter of 2018/2019 over NEC and (**b**) its related first principal component (PC1). (**c**) The distribution of the correlation coefficient between AO and winter temperature in NEC. (**d**) The regression distribution of geopotential height anomalies at 500 hPa with regard to PC1. In (**b**), the bars represent PC1 (the extreme year is highlighted by pink), and the black line is AO. In (**c**,**d**), the dotted regions indicate the correlation and regression coefficients are significant at the 95% confidence level. Samples used in calculations were from 1951–2020.

To prove this conjecture, the vertical distribution of the meridional wind over Harbin (127.5° E, 45° N) during this event of January–February 2019 is shown in Figure 5. The area was mostly affected by northern winds in early-to-mid-January, but the intensity was weak and did not last for a long time. It was then affected by strong southern winds until the end of February. As in the analysis of the AO in Section 4.2, the negative AO index in January indicates that cold and dry air easily invaded from the Arctic to the south, and the positive value in February represents a weakening of the cold air transport. It can be further seen from the period when the north wind turned into a south wind in late January (marked with black dotted lines in Figure 5), the warm and moist air transported from the south first invaded from the lower levels. The atmospheric circulation constantly changed; accordingly, the local water vapor and air temperature changed. However, since the formation of precipitation requires air saturation, the change in precipitation can be linked to the synergic variations of moisture and temperature, as has been emphasized in previous studies [40,41]. With large spatial samples, Lu and Takle [35] revealed that there is a very tight positive relationship between precipitation and relative humidity, and, accordingly, a method to estimate and compare the effects of the changes in water vapor and temperature on changes in precipitation was proposed. It is shown in the last column of Figure 4 that the relative humidity in NEC was negatively anomalous at all levels, corresponding to the reduced-precipitation event. In the middle and upper troposphere, the warmer-than-normal air temperature and lower-than-normal water vapor both reduced the relative humidity. Furthermore, at near-surface level, the negative effect of the warmer-than-normal temperature on the relative humidity counteracted the weak positive effect of the greater-than-normal water vapor.

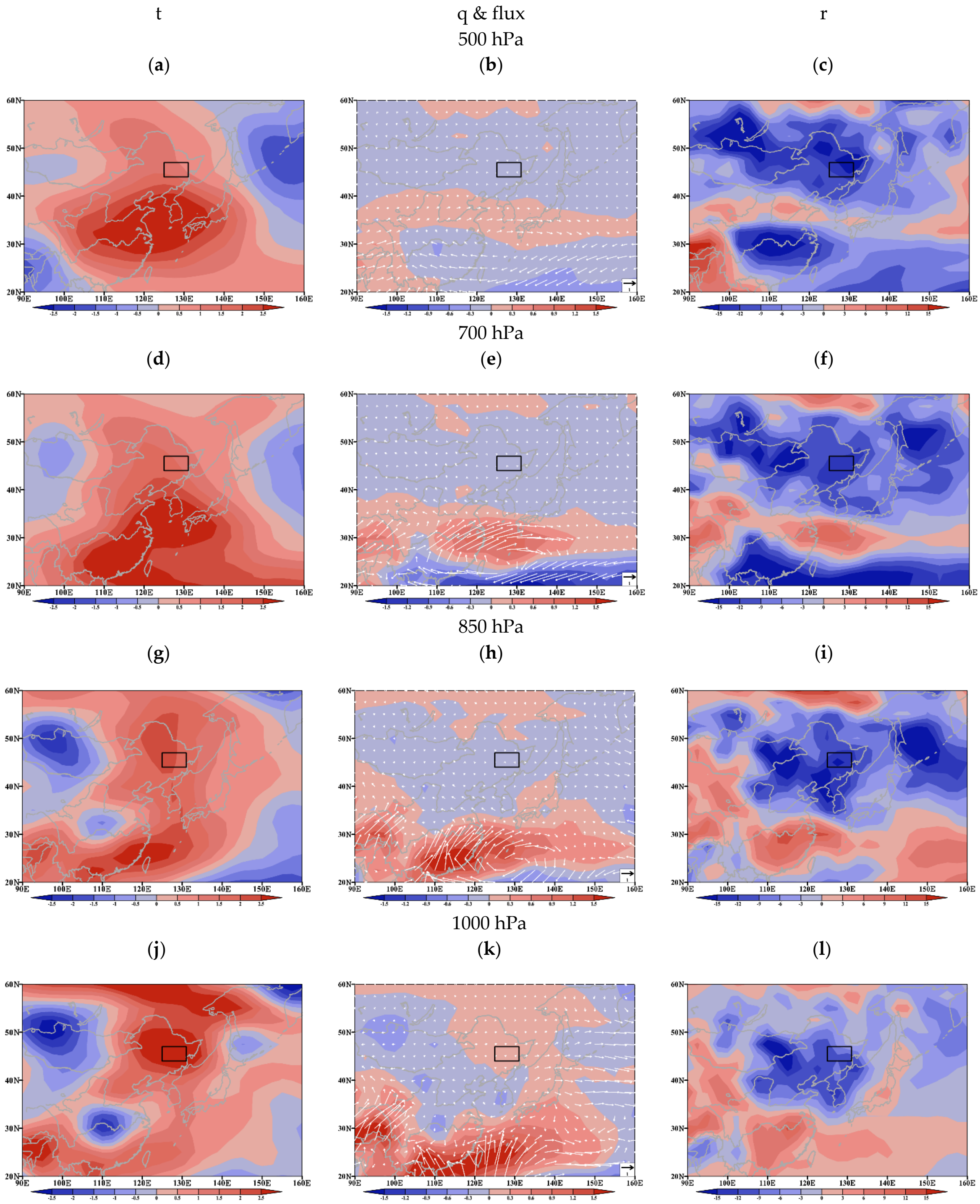

Figure 4. The anomalies in temperature (unit: °C), specific humidity (unit: g kg^{-1}; shaded) and water vapor flux (unit: g kg^{-1} m s^{-1}; vector), and relative humidity (unit: %) at (**a**–**c**) 500 hPa, (**d**–**f**) 700 hPa, (**g**–**i**) 850 hPa, and (**j**–**l**) 1000 hPa for January–February 2019 relative to the 30-year climatic mean (1981–2010). The domain (125–131° E, 44–47° N) around Harbin is marked by a black rectangle.

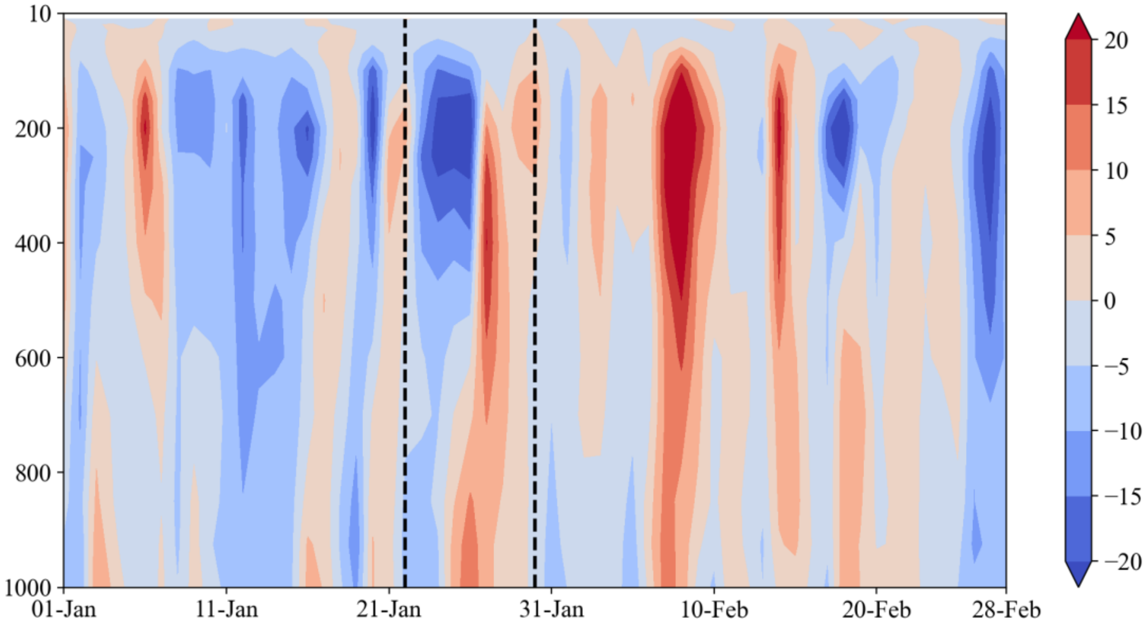

Figure 5. Vertical distribution of the meridional wind over Harbin (127.5° E, 45° N) during January–February 2019. The black dotted lines are the period of significant north–south wind shift.

Water vapor and air temperature are different quantities, and cannot be compared directly. In the next section, the physical method introduced in Section 2 is used to compare the contributions of air temperature and water vapor in the formation of this reduced-snowfall event.

4.4. The Contributions of Air Temperature and Water Vapor to the Reduced Snowfall

The method of separating the effects of water vapor and air temperature is based on the tight interannual relationship between precipitation and relative humidity. The contributions of air temperature and water vapor are quantitatively calculated with the physical method, and thus compared in the vertical direction.

Figure 6 shows the three measures that were used to calculate with specific humidity and air temperature averaged over the study domain. IAs can be intuitively seen from the vertical profile, the I_r, representing the relative humidity anomalies, is always below zero, which means that the relative humidity was lower than normal at all levels, as we discussed above; this is the most direct reason for the lower-than-normal precipitation. The I_t, representing the air-temperature anomalies, is negative in the vertical direction at all the layers, and the I_q, which has a positive and negative transformation at the lower levels, represents the contribution of the water vapor to precipitation changes in the vertical direction. At the middle and high levels, the anomalies in both the air temperature and the water vapor contributed positively to the lower-than-normal precipitation. By comparing the magnitude of I_q and I_t, clearly, the magnitude of I_q is greater than I_t, suggesting that the less-than-normal water vapor made a greater contribution to the reduced precipitation. At the near-surface level, although I_q is positive, since the value is small, the magnitude of I_t is large enough for I_r to still be negative. This means that although the moist air favors precipitation, there was not too much water vapor, with the excessively warmer-than-normal air temperature offsetting the negative contribution of the moist air to the reduced precipitation.

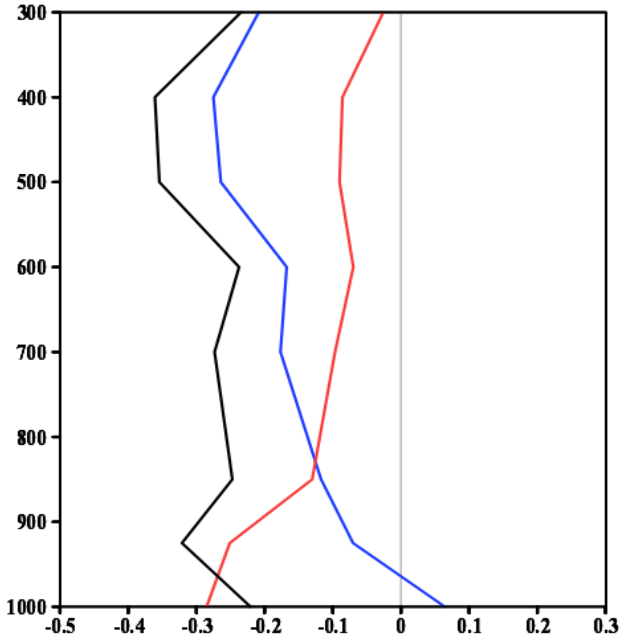

Figure 6. The vertical profiles of the I_q (blue), I_t (red), and I_r (black) from 1000 hPa to 300 hPa. The three measures were calculated with the specific humidity and temperature averaged over the domain (125–131° E, 44–47° N) of January–February 2019 relative to the 30-year climatic mean (1981–2010).

I_r is always negative, which also shows that the total contribution of I_q and I_t to the precipitation formation was negative, but the reasons for this less snow event were different between the levels. At about 850 hPa or lower levels, I_t made a greater contribution, while in the middle and upper levels, the major contribution was from I_q. A very obvious positive contribution of the warmer-than-normal air temperature in the lower levels was brought by the south wind, which also brought water vapor, but its contribution to the reduced precipitation was relatively small. Due to the weakening of the East Asian trough, the dry and cold northern winds entering the NEC weakened. The middle and upper levels were cooled by the north wind, which was not as serious as the higher temperature in the lower levels. However, the north wind was very dry, which reduced the relative humidity.

In mid-latitude of the winter, the atmospheric condensation level was slightly lower than that of the summer, at about 700 hPa. According to the comparison of the contributions of the water vapor and air temperature in Figure 6, the lower-than-normal relative humidity at 700 hPa was mainly due to the lower-than-normal levels of water vapor ($|I_q| > |I_t|$). The reduced-snow event was, to a great extent affected by the lower-than-normal levels of water vapor at the condensation level. The moist air at the lower level could not alter the tendency toward reduced precipitation, and the warm and moist south wind mainly caused the local warming.

5. Summary and Discussion

In winter, the East Asian trough located on the east coast of Eurasia, and at the upper levels over Harbin, it is generally under the control of high-altitude northwesterly airflows. Cold air from Siberia and the Arctic is transported to the southeast along the northwest airflow and affects NEC. Against climatic background, Harbin has developed a unique ice-and-snow tourism culture.

During the winter of 2018/2019, the temperature was much warmer than normal and the precipitation was less than normal in Harbin, which had a significant impact on the ice and snow tourism. In particular, the warmer-than-normal temperatures in late February were above 0 °C for dozens of hours. This may have caused the ice and snow to melt, which not only reduced the aesthetic value, but even posed a safety hazard. According to the analysis in Section 4, this event in Harbin was caused by the anomalous south wind and positive AO, indicating that the cold air affecting NEC was weaker.

The formation of the severe reduction in precipitation can be attributed to the anomalies in the large-scale atmospheric circulation. Whatever circulation system was affected, it was ultimately reflected in local water vapor and temperature anomalies. Although the warmer-than-normal temperature was apparently an important reason for the less-than-normal precipitation during this event, the decisive factor was the atmospheric saturation (especially at saturation level); thus, the effect of water vapor should also be taken into account.

The method we previously designed, based on the tight precipitation–relative humidity relation, can be used to compare the contributions of moisture anomalies and temperature anomalies to drought and flood events directly. The defined I_t and I_q were used to compare the effects of the warmer-than-normal temperature and lower-than-normal levels of water vapor on the reduction in snow. The calculation of this method shows that, I_r ($I_t + I_q$) is negative at all levels, which means the relative humility (the synergic effects of water vapor and temperature) was lower than normal. At lower levels (at about 850 hPa and less), the magnitude of I_t was greater than I_q, and it reversed in the middle and upper levels. That is to say, the warm and moist air from the south invading NEC mainly affected the near-surface levels. Furthermore, the severely warmer-than-normal temperature, which played a positive role in this reduced-snow event, offset the negative effect of the higher-than-normal levels of water vapor. By comparison, in the middle and upper levels, including the saturation level (at about 700 hPa), the air temperature is warmer than normal and the water vapor level was lower than normal, both of which made positive contributions to the reduction in precipitation. However, the contribution of the air temperature was greater than that of the water vapor.

From the perspective of meteorological services, this study discusses the causes and mechanisms of snowfall and temperature anomalies in winter, which are conducive to improving the accuracy of meteorological forecasting. An important meteorological service in winter in Harbin is the analysis of the meteorological conditions affecting ice and snow, which are sensitive to temperature changes. This is especially true of the severe warming and strong wind from the beginning of February, which cause the melting of the ice and snow and have a significant impact on ice-and-snow tourism. Moreover, the abnormal snowfall had a direct impact on the construction of the snow-and-ice landscape. Not only do lower-than-normal levels of snowfall seriously affect the snow-and-ice landscape and entertainment facilities, but different abnormal conditions of water vapor and temperature also form different types of snow. The result of increased moisture and weaker cold air is dense wet snow, which is small in size, large in water content, and relatively voluminous in precipitation. By contrast, if the cold air is stronger and the water vapor is reduced, the resultant snowflakes are fluffy because of the low water content, and although these snowflakes appear large and the snow cover is thick, the actual precipitation is not large. According to statistics, when the temperature is -18 °C to -12 °C, large and fluffy snowflakes are most likely to form. Therefore, if the discussion on the relative importance of water vapor and air temperature to snowfall formation in this study is added to the winter precipitation prediction process, precipitation and snow-cover thickness can be predicted more effectively. In the future research, based on current theoretical research, we will propose further methods for forecasting winter temperature and precipitation in NEC, and provide a complete operational forecasting scheme for meteorological services for ice-and-snow tourism.

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Data Availability Statement: The reanalysis data used in this study were provided by the National Centers for Environmental Prediction (NCEP) and Department of Energy (DOE), and are available at https://psl.noaa.gov/data/gridded/data.ncep.reanalysis2.html (accessed on 14 August 2021). The observed daily precipitation data were provided by the National Climate Center of China, and are available at http://cmdp.ncc-cma.net/cn/download.htm (accessed on 14 August 2021).

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