Analysis on the Mechanism of the Heavy Snow Process in the Northeast of Tarim Basin, Xinjiang, in 2018

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Abstract: An analysis was made on the routine data of meteorological stations, high-resolution satellite cloud images and the NCEP/NCA R 1°×1° reanalysis data during one instance of heavy snow precipitation that took place in northern Bazhou, Xinjiang on October 18, 2018, followed by a diagnostic analysis of physical quantities, including the large-scale circulation anomalies, upper and lower-level circulation conditions and water vapor transport. The following are the results: (1) the heavy snow precipitation process in northern Bazhou, Xinjiang is a heavy precipitation process largely caused by a convergence of severely cold air carried from Siberia by an upper vortex, and a strong, warm and humid air current from southwest China. During this weather process, the upper layer was dry and cold, while the lower layer was warm and humid; an obvious wind shear and convergence center appeared at 700hPa, 850hPa in the lower layer over northern Bazhou; the heavy precipitation area was located in the front of the trough bottom at 500hPa, on the left side of the lower-level shear line. 2) The secondary circulation formed on the right side of the upper-level jet stream entrance area at 200hpa and 300hpa enlarged the ascending motion of the heavy snowfall area, while the low-level easterly jet stream played a critical role in transporting and accumulating water vapor at 850hpa. 3) The variations of temperature at 850hpa and on the ground layer were of certain indicative significance to the forecast of the precipitation phase state, and the temperature field at 850hpa well-indicated the change from rain to snow. When the air temperature fell to 0.5°C or so, and the ground temperature fell below 0°C given T700hpa<-10°C and T850hpa<-2°C, it could be used as a criterion for the judgment of rain changing to snow. 4) The vapor condition, lifting force condition and unstable stratification condition in the numerically-forecasted physical quantity field, all had a good guiding effect on the heavy precipitation process that took place in the Yanqi Reclamation Area.

1. Introduction

Many scholars have done a lot of research on the detection and prediction of the snowstorm formation mechanism. Zhang Jiabao et al. [1] conducted a comprehensive research on the formation mechanism of snowstorm.
mechanism of intensive precipitation processes in Xinjiang, and concluded that the snowfall in Xinjiang is extremely uneven due to the combined effects of various factors like special geographical environment and underlying surface in the context of Xinjiang's arid climate. Some scholars have analyzed the variation characteristics of precipitation time in the northwest region and Xinjiang area[22], and the results show that the precipitations of the north region and Tianshan mountains of Xinjiang have an obvious increasing tendency, and the annual precipitations of different areas in Xinjiang show a significant increase to different degrees. Where, South Xinjiang shows a more obvious wetting tendency, and its annual precipitation is presents a weak consistent increasing tendency [3-4]. At the same time, many meteorologists have also conducted in-depth research on the discrimination of the precipitation phase and the formation mechanism of snowstorm weather in Xinjiang [5-11].

Yanqi Reclamation Area of the second division of Xinjiang Corps is located in the northern part of Bazhou, Xinjiang, on the northeastern side of the Tarim Basin, and it is a Mesozoic fault basin between the main mountain of Tianshan Mountains and its branches, inclining from the northwest to the southeast, with an altitude of about 1200 meters at the edge. The precipitation in this area is concentrated and unevenly distributed, with the annual average of 89.6mm. At present, most of the researches mainly focus on the north region of Xinjiang, but few of them involve the heavy snowfall in South Xinjiang. Therefore, this paper attempts to reveal the causes of the heavy snow process occurring in the northeast of the Tarim Basin in Xinjiang on October 18, 2018, in terms of large-scale circulation anomaly, upper- and lower-level circulation models, and water vapor transport, to provide the technical support for the accuracy of the heavy snowfall forecasting and warning as well as the services in disaster prevention and mitigation of this region.

2. Weather Conditions, Data and Methods

2.1 Weather Conditions

Affected by the strong cold air of West Siberia and the warm and humid airflow in the southwest, each reclamation area of the second division of Xinjiang Corps experienced strong wind, temperature reduction, and precipitation weather processes during the period from October 17 to 18, 2018. Of such reclamation areas, Yanqi Reclamation Area experienced the process of moderate rain to heavy snow (17.5 to 19.6mm) (Fig.1); Korla Reclamation Area experienced moderate rain, and hail in some areas; Tarim Reclamation Area and Qieruo Reclamation Area in the south experienced the above-mentioned weather accompanied by sand blowing or sandstorm (with the maximum wind speed 16.0m/s). The high wind and snowfall this time adversely affected the agricultural and livestock production, crop drying, and transportation in the second division, causing the trees on the roadsides were torn off and broken, and some grape racks and greenhouses collapsed under pressure. The earliest first snow since the second division had the historical records occurred on October 19, 1995 (2.5mm) and this first snow has refreshed the latest history. Since the air temperature of Yanqi Reclamation Area was maintained at 1 to 1°C in the daytime on October 18, there was obvious snow on the ground, with the maximum depth of 13cm, which was the maximum snow depth in the same period in October.
2.2 Materials and Methods

Based on the conventional meteorological data from the surface weather station and the NCEP / NCAR 1°×1° reanalysis data, using the weather dynamics method and the satellite meteorology method, and in combination with the physical quantity diagnostic analysis, this paper attempts to analyze and discuss this weather process in terms of large-scale circulation anomaly, upper- and lower-level circulation models, in order to provide an effective reference for improving the accuracy of the heavy snowfall forecasting and warning as well as the services in disaster prevention and mitigation of this region.

3. Evolution of the Circulation Situation as well as Upper-and Lower-level Jet Stream

3.1 Evolution of the Circulation Situation

According to the 500hpa upper level chart (figure omitted here), the high-pressure ridge of the Mediterranean Sea and the Black Sea developed vigorously at 20 o'clock on October 16. The area from the Aral Sea to the Balkhash Lake was a polar vortex area, where the meridional degree of the circulation was large, and the main body of the polar vortex was located northward 40°N, forming a cut-off vortex to the north of Balkhash Lake, with a cold center of -32 °C matching with it.

At 8 o’clock on October 17 (figure omitted here), the high-pressure ridges of the Mediterranean and the Black Sea continued to extend northward to the north of 70°N. Guided by the strong northerly airflow in front of the ridges, the cold air continuously went southward, and the low trough of West Siberia was connected to the low trough of Central Asia. The southern section of the low trough gradually entered the northwest of Xinjiang. With the eastward movement of the system, the frontal area of the mid-latitude area continued to increase. At 20 o’clock on October 17 (Fig.2a), the southeast movement of the high-pressure ridges of the Mediterranean and the Black Sea ridges gradually declined, driving the southern section of the low trough to go southward rapidly, while the low trough of West Siberia was continuously strengthened and cut into low vortices which continuously divided short waves, supplementing the cold air in the low trough of Central Asia entering South Xinjiang. After the trough formed at 2 o’clock on October 18, the northerly wind was gradually strengthened, and the wind speed increased to 30m/s at 8 o’clock on October 18 (Fig.2b). The southerly airflow in front of the trough was strengthened to 28m/s, while the westerly wind in the middle of the South Xinjiang basin increased to 40m/s; Bazhou was under the control of the strong southwest airflow in
front of the trough, and the temperature field clearly lagged behind the height field (figure omitted), and the frontal zone was further strengthened in the process of moving to the north of Bazhou.

According to the 700hpa upper level chart (figure omitted here), the most area of South Xinjiang was under the control of the southwest airflow in front of the trough at 20 o'clock on October 17, and the cold center was -28°C; the southwest jet stream (14m/s) appeared in the east of the South Xinjiang basin. Yanji Reclamation Area of the Second Division was located in the forward windward convergence area of the low-level jet stream; the water vapor was rapidly converged in this area due to the special topography of the basin.

For the 850hpa ground flow field, there was a clear wind speed convergence center in the middle of the South Xinjiang basin at 20 o'clock on October 17 (Fig.2c); at 8 o’clock on October 18 (Fig.2d), guided by the low-level easterly airflow, the warm and humid air flow from the southern Bengal Bay was transported to the north of Bazhou via the east of the Qinghai-Tibet Plateau.

3.2 Ground Situation Field

According to the ground situation field at 11 o’clock on October 17, the ground cold high pressure generated near the Balkhash Lake increased to 1042.5hpa during the eastward moving and southward sloping, and the cold front leading edge was basically sloped to North Xinjiang along the Tianshan Mountains (figure omitted). From 20 o’clock of October 17 to 8 o’clock of October 18, the north of Bazhou was in the strong frontal zone. Before the occurrence of precipitation, a regional easterly wind appeared in the area from Korla City of Bazhou to Tiegan Rick in Yuli County at 20 o'clock on October 17.
It can be seen from Fig. 3 that at 17 o'clock on October 17, the pressure drop and temperature occurred in Yanqi Reclamation Area of the Second Division, and reached the extreme values, which provided the preconditions for the release of unstable energy in the region on October 18. As the system moved eastward, the snowfall gradually ended at 19 o’clock on October 18.

**Fig.3** Temperature, Dew Point Temperature and Pressure Change of the Ground Station of the 21st regiment of the Second Division of Xinjiang Corps

### 3.3 Upper-and Lower- level Jet Streams

During the heavy snowfall, the southwest airflow appeared at 200hpa from 20 o’clock of October 17 to 8 o’clock of October 18, and continued to increase. At 5 o’clock on October 18, the maximum wind speed of at the center of the jet stream core reached 44m/s, and the reclamation areas of the Second Division were located on the right side of upper-level southwest jet stream exit area. The pumping action caused by the strong upper-level divergence was conducive to the continuous increase of the lower-level ascending motion in the area. At 300hpa, it changed from the southwest jet stream at 23 o’clock on October 17 to the southerly jet stream at 2 o’clock on October 18; at 500hpa, the southerly jet stream appeared, and the maximum wind speed of the jet stream axis reached 30m/s; with the continuous increase of the southwest airflow at 500hpa, a strong pumping action was formed, promoting the increase of the dynamic convergence uplift in the area, thus triggering the heavy precipitation.

From 20 o’clock of October 17 to 23 o’clock of October 23, the easterly jet stream appeared at the lower-level 700hpa in the east of the reclamation areas of the Second Division, the westerly airflow appeared in the middle west of the South Xinjiang basin, and the obvious wind shear and convergence center appeared in the north of Bazhou. After 8 o’clock of October 18, the easterly jet stream changed to the southwest airflow in the snowfall area.

From 20 o’clock of October 17 (Fig.2a) to 5 o’clock of October 18, the easterly jet stream was firstly established at 850hpa in the east of the South Xinjiang Basin, and the maximum wind speed of the jet stream core area was 22 m/s. The westerly airflow in the middle of the southern basin gradually increased, and the maximum wind speed was up to 24 m/s; and Yanqi Reclamation Area was located on the left front side of the intense convergence center. The easterly jet stream entered the South Xinjiang Basin and fully played a role as air cushion, which is essential for the enhancement of the lower-level convergence uplift in the north of Bavaria.
4. Dynamic Conditions and Water Vapor Conditions

4.1 Vertical Circulation Characteristics

The heavy precipitation area was mainly concentrated in the reclamation areas of the Second Division (85 to 87°E, 41 to 43°N). By making a divergence profile (Fig. 4a) along the 21st regiment (86°E, 42°N) of the Second Division, it can be seen that: the lower-level convergence began to increase from 2 o’clock of October 18, and the increase was more obvious from 6 o’clock on October 18 (at this time, rain began in the 21st regiment area at the front); from 08 o’clock of to 17 o’clock on October 18, a strong convergence center was formed between 850 to 700 haps, and a strong divergence center appeared between 600 and 400 haps correspondingly; the corresponding vertical negative velocity region was strengthened (Fig.4b), and the parts below 300 hPa were all strong ascending motion areas; the strong ascending movement was conducive to the condensation of water vapor, which corresponded to the period with the strongest precipitation in this area; the upper- and lower-level models with the upper-level divergence and lower-level convergence provided a favorable dynamic condition for the heavy precipitation weather process. After 17 o’clock of October 18, the lower-level convergence ascending motion gradually declined, the upper-level divergence center also declined, then the snowfall in this region gradually declined.

![Fig.4: Evolution of (a) divergence on (unit: 10^{-5}s^{-1}), and (b) vertical velocity (w \times 100, unit: m\cdot s^{-1}) along the vertical profile of the 21st Regiment (86°E, 42°N) of the Second Division from 8 o’clock of October 17, to 20 o’clock of October 18](image)

4.2 Analysis of Water Vapor Conditions

Abundant water vapor transport is one of the necessary conditions for the formation of strong precipitation. According to Fig.5a, there was an obvious southwest airflow at the 850hPa level in the middle of the Bazhou plain during the heavy snowfall in Yanqi Reclamation Area of the Second Division in October 18, 2018 and there was an easterly airflow in the north of Bazhou. The two lower-level jet streams make The water vapor was obviously converged and the ascending movement was enhanced, so that the water vapor in the Bay of Bengal could be transported by relay to the Yanqi Basin in the north of Bazhou. With the continuous enhancement of the low-level southwest jet stream, the region had a continuous supply of water vapor, and the water vapor was concentrated, which was one of the important factors that caused this heavy snowfall.

From the humidity-time profile (Fig. 5b), it can be seen that the relative humidity of the lower level (700hpa, 850hpa) in the region was above 80% from 8 o’clock to 14 o’clock on October 18, and 90% of which reached 500hPa; The wet layer in the area was thicker and had a distinct high-humidity area, indicating that the water vapor in the area has become saturated, providing favorable conditions for the occurrence of heavy precipitation. With the beginning of precipitation in the reclamation area, after the rain turned snow, the snow on the ground was ablated, and the saturation of water vapor in the area was intensified. After the effective energy of the area was fully released, the precipitation intensity obviously declined.
5. Precipitation Phase Evolution as well as Formation Temperature and 0 °C Layer Height Changes

Rainfall began at 6 o’clock on October 18, 2018 in Yanqi Reclamation Area, the rain turned to snow at 21:20 in the 21st regiment of the Second Division (Fig. 6) and the rain in other regiments of the area also turned to snow at around 11:13, (22, 223, 24 and 27 regiments). Changes in near-formation temperature field: At 20 o’clock on October 17, the T850hap level in the reclamation area was 0~4°C, and the ground temperature was 10~13°C. At 8 o’clock on October 18, as the northerly airflow moved eastward and sloped southward of the 500hpa level at mid-high latitudes, and gradually strengthened, the 500hpa cold center (-28°C) continued to extend to the reclamation area of the Second Division, and the temperature in this area decreased rapidly; at 700hpa, the temperature was reduced from -4 °C at 20 o'clock of October 17 to -8 °C at 8 o’clock of October 18. The 850hpa temperature dropped to -1 to -2 °C (that of the 21st regiment was -1.1 °C), and the height of the 0 °C layer was reduced from 3.4 km at 8 o’clock of October 17 to 1.6km at 8 o’clock of October 18, and the ground temperature dropped to -1 to -4 °C. It is concluded that the temperature and formation changes at 850hpa have a direct influence on the transition of precipitation phase, and have certain indication significance for the prediction of precipitation phase. The temperature field at 850hpa has a good indication effect on rain and snow. When T700hpa<-10°C, T850hpa<-2°C, the temperature drops to about 0.5°C, and the ground temperature drops below 0°C, it can be used as the criterion for the judgement of rain turning to snow in this area.

**Fig. 5** Vertical profiles of (a) water vapor energy divergence (b) humidity of the 21st regiment of the Second Division (86°E, 42°N) from October 17 to October 18, 2018

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**Fig. 6** Variation of ground temperature with time before and after rain turned snow from the 21st and 22nd regiment meteorological stations of the Second Division

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- • indicates the time when rain turned to snow of the 21st regiment of the Second Division;
- - - - indicates the time when rain turned to snow of the 22nd regiment of the Second Division;
6. Conclusions

1) The heavy snowfall weather that occurred in the north of the Tarim Basin in Xinjiang was a strong precipitation weather process mainly caused by a upper-level low-vortex trough carrying caused by the intersection of strong cold air from western Siberia and strong southwest warm and humid airflow. During the weather, the upper-level was dry and cold (the temperature of the strong cooling center reached -32 °C), while the lower-level was warm and wet; at the low-level 700hPa and 850hPa, the obvious wind shear and convergence center appeared in the north of Bazhou, plus the influence of special topography of the basin where Qiyun Reclamation Area is located, contributed to the obvious water vapor collection in the area; the strong precipitation area was located at the front of the 500hPa trough bottom, and on the left of the 700hPa shear line. This upper- and lower-level models were conducive for the formation of heavy snowfall in this area.

2) The southwest airflow at 500hpa was continuously enhanced, and the strong pumping effect promoted the dynamic convergence of the region. The 700hPa water vapor transport could better reflect the water vapor transport status of the modified area; the 850hpa low-level eastward jet stream played a key role in the water vapor transport and accumulation during the snowfall, providing water and gas replenishment for the reclamation area while strengthening the ascending movement.

3) The changes in the temperature at 700hpa and 850hpa as well as the temperature of the ground formation had a direct influence on the transition of precipitation phase, and have certain indication significance for the prediction of precipitation phase. When T700hpa<-10°C, T850hpa<-2°C, the temperature dropped to about 0.5°C, and when the ground temperature dropped below 0°C, it can be used as the judgement criterion for rain and snow in this area. This study only involves the analysis of an individual case, it still needs to be revised later.

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