Analysis on the Causes of a Hail Weather in the Eastern Tarim Basin, Xinjiang, July 2018

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Abstract. Using high altitude/ground truth data, hourly data from Regional automatic weather stations, sounding data, NEF FNL data and Doppler radar data, the paper analyzes the causes of a hail weather process occurred in the eastern Tarim Basin on July 9, 2018. The results show that: (1) The split short wave in southern Siberia is the main influence system of the local hail weather in the eastern Tarim Basin. (2) The K index is a good indication for summer thunderstorms, which can be used as a discriminative indicator of convective weather occurrence in the region when $K \geq 32^\circ C$; and the energy front and the unstable energy center of the K index provide sufficient energy and unstable conditions for the occurrence of hail weather. (3) When the convection cells moved to the Tarimu Region of Tiemenguan City, the wind direction gradually changed from the westerly wind to the east wind from the north to the south, and the wind speed convergence center near the ground layer coincided with the falling area where the hail occurred. (4) The emergence and strengthening of mesoscale ground low pressure has enhanced the convergence uplift movement of the near-surface layer to a certain extent, which provides favorable conditions for the occurrence of this hail weather. (5) Among the radar echo products, the rapid increase of VIL is a good indication for the short-term forecast of hail weather in this region.

1. Introduction
Tiemenguan City, Xinjiang Uygur Autonomous Region is located in the south of Tianshan Mountain, in the east of Tarim Basin, between the Tianshan Mountain in the north and Altun Mountain in the south. From north to south, there are Regions of Yanji, Korla, Tarim, and Qiemo/Ruoqiang. With the global warming and the frequent occurrence of meteorological disasters, the occurrence of meteorological disasters in the region has also undergone significant changes, and it has a tendency of more often and heavy. Every year, due to strong winds and dust, the meteorological disasters such as local short time heavy precipitation, hail caused a large reduction in cotton and red dates, causing certain losses to the agricultural production of Tiemenguan City and the lives of the people, seriously restricting the sustainable and healthy development of local agricultural production. The disaster prevention and mitigation has been an arduous task. Hail is a kind of severe weather caused by short time strong convective weather. The hail in spring and summer is one of the most catastrophic weathers that are harmful to agricultural production because it is often accompanied by short time fierce winds, local Short time heavy precipitation and other severe weather although its affected area is
not significant, and its duration is short. Tiemenguan City, Xinjiang Uygur Autonomous Region, an important grain and cotton production base in Xinjiang, is a floodplain-prone area. The annual hail disaster has caused different extent of economic losses to agricultural production, which seriously restricts the development of agricultural production in the region.

The analysis of hail weather has always been the focus of scholars at home and abroad. Foreign scholars have carried out research work on external field observation, hail simulation experiment, field plan, etc., and formed a fine hail prevention profile model. They have made a great of research findings in the formation and development of hail cloud and hail. [1-4]. China is one of the countries with the most hail disasters in the world. The meteorologists in China have conducted in-depth research on the mechanism of hail, analysis of hail area, and the temporal and spatial dynamics of hail disasters, and have achieved fruitful scientific achievements [5-11]. In recent years, the frequency of hailstorms in Xinjiang has been increasing. In response to the hail disaster in Xinjiang, many meteorologists in Xinjiang have carried out various analyses of hail weather in different ways and have drawn many scientific conclusions. Zhang Junlan [12] et al. conducted statistical and in-depth analysis of the climatic characteristics of hail weather in the Aksu region of Xinjiang. Zhang Lei [13] et al. studied the identification index of Aksu hail weather in southern Xinjiang, and provided scientific reference for forecasting and warning of hail weather in this area. Resuri Abra [14] et al. carried out detailed classification of the hail circulation around the Tianshan Mountains in Xinjiang and the Aksu River Basin in Xinjiang, and the selected hail forecasting factors have been applied and promoted in the most-hail-affected areas of Xinjiang. Shi Lianmei [15] analyzed the temporal and spatial distribution characteristics of the hail disaster in Xinjiang. Furthermore, Xinjiang meteorologists have conducted in-depth analysis of the typical hail weather process [16-19].

Due to the scarcity of high-altitude exploration data in the eastern Tarim Basin, the meteorologists have been faced with great challenges and difficulties in forecasting and warning of hail weather in the region. In order to better summarize the relevant forecasting experience, this paper, from a forecasting perspective, uses the datum from ground, high-altitude, automatic station, radar echo, etc. to draw the oblique temperature map with GrADS combined with the FNL data of NECP, and with comprehensive analysis of the above data, the experience of forecasting technology for hail weather is summarized in this paper with an expectation of continuously improving the capabilities of regional hail forecasting and early-warning in the future.

2. Weather and Disaster Situation

On July 9, 2018, from 18:00 to 19:00, the precipitation in the central area of the Tarimu Region of Tiemenguan City, Xinjiang (87°04'E, 40°5'N) was 5.0 mm, and the hail, the diameter being 5mm, occurred in parts of the area lasting for about 20 minutes. There was light rain (0.1 mm) around the area. In the Tarimu Region of Tiemenguan City, Xinjiang, there has been strong convective weather such as short time winds and thunderstorms from north to south. Among them, there were force 8 north winds in the central area of Tarim Region (maximum wind speed 27.1m/s, time: 18: 39), during the rapid movement of convection cellss in this area (see Figure 1), there were hailfall in the cotton fields where they passed, and the cotton fields suffered from the disasters to different extents.
Figure 1. The hail fallout area (87°04'E, 40°5'N) marked with a star

3. Backgrounds on Macroscale Circulation

Figure 2. The circulation features in 500hpa at 8:00 on Jul 9th, 2018
The synoptic character of the early hail weather: From July 7th to July 9th, the Iranian subtropical high pressure belt was extended eastward and lifted northward, and the southern Xinjiang was under the control of 584 potential contours. Most of southern Xinjiang was high temperature weather; The Korla Region, Tarimu Region, and Qiemo/Ruoqiang Region experienced a continuous hot weather above 35°C. Affected by the divided short-waves in southern Siberia, from July 8 to July 9, the convective weather, such as thunderstorms, local short time heavy rainfall, etc. occurred in the areas of Tiemenguan City, Korla Region and Tarimu Region from the afternoon to the evening.

Shown by the Figure 2, it was developed as a shallow trough at the Caspian Sea. The warm and humid southwesterly airflow in the trough was moving northeastward; there was a shallow ridges emerging between the Ural Mountains and Western Siberia, a wide low trough area between the western Siberian to Baikal, and a low vortex at the western part of Lake Baikal, and the cold center was -16°C. The Tarimuan Region of Tiemenguan City is located in the northwest downdraft of the Iranian subtropical high ridge. Due to the multi-split short-wave activity in southern Siberia, the convective weather on both sides of the Tianshan Mountains in Xinjiang occurred frequently from July 8 to July 9.

Shown by the Figure 3, the Iranian subtropical high pressure belt decayed westward, and the wide low troughs between the western Siberian to Baikal gradually strengthened. The western vortex center value was 560 dagpm and the cold center was -20°C. The low pressure in southern Siberia continues to split short-waves. Weak fluctuations were observed at 850 hPa, 700 hPa and 500 hPa at Tarim Region of Tiemenguan City, which reflected the movement of short-wave troughs, and the positive advection of vorticity before the trough produced an ascending motion. Affected by short-wave splitting, from 14:30 to 16:00, 17:50 to 19:20, local convective weather occurred in the Tarimu Region of Tiemenguan City; among them, the development of the second convection cells led to the hail occurred in the central area of Tarim Region. From July 7th to 9th, the high temperature of 37°C or above continued in Tarimu Region of Tiemenguan City. During the daytime, the solar radiation was
strong, and the underlying surface warmed up rapidly in the afternoon, meanwhile, it was affected by the split short wave in southern Siberia at high altitude, thereby, it was apt to form an unstable stratification that was cold upper and warm lower, and apt to have convective weather in the afternoon. The next day, the solar radiation was still relatively strong, which was likely to cause the re-development of the unstable stratification. This was also the reason for the frequent occurrence of thunderstorms in recent in the Regions of Yanji, Korla, and Tarim of Tiemengan City. However, such a split short wave does not cause extensive precipitation, but decentralized thunderstorms and strong convective weather such as short time heavy precipitation and hail are most likely to occur at local areas. The Tarim Basin Hail Control Team conducted operations on the first echo on July 9 (14:30 to 16:00). Microscale precipitation occurred in the area, which was conducive to the water vapor cycle in the area from noon to evening, and provided favorable water vapor conditions to the occurrence of hail.

4. Mesoscale System Analysis

4.1 Analysis of Low-level Mesoscale Systems
At 700hPa and 850hPa (the figure omitted), there are northerly winds and southwesterly wind shears in the eastern part of the southern Xinjiang basin, which is conducive to the formation of stratification instability. The temperature dew-point deficit (T-Td) at 850hPa in Tarim Region of Tiemengan City is 1 to 3 °C, and is 1 to 2 °C at 700hPa, which manifests the bottom water vapor is sufficient, while the middle and upper layers are drier, i.e. dry upper and wet lower, and wet layer is shallow.

4.2 Analysis of Ground Mesoscale Systems
At 14:00 on July 9th, there was a thermal low pressure development in the Hetian area of southern Xinjiang (low pressure center 997.5hpa). From 14:00 to 20:00, the thermal low pressure in the southern Xinjiang basin developed vigorously and expanded to the eastern part of the basin and gradually strengthened to a closed low pressure (low pressure center 995hpa). According to the data of the automatic stations in all areas of Tiemengan City from 15:00 to 17:00 on July 9, 2018, from the north to the south of the Tarim Region, the wind direction gradually changed from the westerly wind to the easterly wind; among which, strong easterly wind was observed at the Tieganlike station located at the south of the plain and the vicinity, with a maximum wind speed of 16.9m/s (16:34), while the force 8 north wind (27.1m/s,time: 18:39) was observed at 45km north of the Tieganlike station. The convergence center of the wind speed is more consistent with the falling area where the hail occurs. It is concluded that the occurrence and strengthening of the mesoscale ground low pressure enhances the convergence uplift movement of the near-surface layer to a certain extent, and the convergence of the near-surface wind speed also provides favorable conditions for the occurrence of the hail weather.

5. Analysis on Physical Quantity Analysis and Diagnosis

5.1 Analysis of Water Vapor Conditions
As shown by the vertical profile of the humidity in the central area (87°04'E, 40°5'N) of the Tarimua Region of Tiemengan City (Fig. 4), the humidity at low-level in this area was not high at 08:00 on July 9th. However, from 14:30 to 16:00, a microscale precipitation occurred during the first echo passing through this area, which was beneficial to the water vapor circulation in this area, and provided favorable water vapor conditions for the occurrence of hail weather. At 08:00 on July 9th, a clear high-humidity area occurred near 500hPa to 400hPa, while the bottom and upper stratifications had less humidity, the humid stratification was shallow, and there was a clear dry stratification between 400hPa and 300hPa, indicating that the dry and cold air intrusion occurred in this stratification.
5.2 Dynamic Conditions

With the analysis on the time profile of water vapor flux divergence (Fig. 5), from 08:00 to 14:00 on July 9th, the configuration of lower convergence and upper divergence occurred in this area, which was conducive to the upward transport of water vapor and the occurrence of local hail weather. And after 20:00, the lower stratification gradually turned into lower divergence.

5.3 Instability of Atmospheric Stratification

As a comprehensive characteristic quantity, the K index reflects the stability of the atmospheric stratification. On July 9th, the K-index of the Tarimu Region of Tiemenguan City showed an increasing trend (figure omitted), which increased from 28.0°C at 08:00 to 40.0°C at 20:00, indicating that the atmosphere in the middle and lower layers was gradually unstable.

In this area, T (850-500)=32°C, T(700-500)=20°C at 08:00 on July 9th; T (850-500)=38°C, T(700-500)=22 °C at 20:00 on July 9th. It was dry and heat at near-surface layer, and dry and cold at high-altitude, the lapse rate between the atmospheric stratifications was higher, such a vertical
distribution of temperature advection of upper-cold-and-lower-warm was conducive to the formation and occurrence of hail weather.

The potential pseudo-equivalent temperature reflects the temperature and humidity characteristics and vertical motion of the atmosphere. The potential pseudo-equivalent temperature chart is shown (figure omitted): On July 9th, the potential pseudo-equivalent temperature in the central area of Tarimu Region of Tiemenguan City increased from 60°C at 08:00 to 67°C at 20:00, and a high-energy area(≥70 °C) was occurred at Mid-Tarimu in the east part of Tarimu Region, and the energy front zone (the potential pseudo-equivalent temperature isoline concentration zone) was located at the area between the Mid-Tarimu station and the central area of Tarim Region. At 08:00 on July 9th, ΔΘse(500-850)=3.0°C, the atmospheric stratification was stable; at 20:00, ΔΘse(500-850)=-10.0°C, ΔΘse(500-850)≤0°C, ΔΘse decreased with height, which indicated that the atmospheric stratification was in a convective instability. At Near-ground layer, the convergence center of the wind speed and the front edge of the potential pseudo-equivalent temperature coincided, which was conducive to trigger the occurrence of convective weather.

As shown in the figure, at 14:00 on the 9th, the central area of Tarim Region was near 700 haps, the temperature stratification curve and the dew point stratification curve were relatively close, indicating the favorable water vapor condition of the area around 14:00 (Fig. 6), which is conducive to the occurrence of convective weather in the afternoon in the area. As shown in Table 1, the K index and the TT total index at 08:00 and 14:00 on July 9 are higher, and the CAPE at 08:00 was higher, which contributes to the occurrence of strong convective weather in the afternoon. However, not all physical parameters are contributing to the convective weather.

Figure 6. Skew/T-log P diagram of the central area of Tarimu Region, Tiemenguan City at 14:00 on July 9th, 2018
Table 1. Sounding physical parameters in the central area of Tarimuan Region, Tiemenguan City, from 20:00 July 8th to 20:00 July 9th

| Sounding physical parameters | Jul 8th | Jul 9th |
|-----------------------------|---------|---------|
|                             | 20:00   | 02:00   | 08:00   | 14:00   | 20:00   |
| K Index (°C)                | 28      | 30      | 31      | 34      | 27      |
| TT Total Index (°C)         | 48      | 48      | 46      | 52      | 48      |
| LI (°C)                     | 1       | 0       | -2      | -1      | 1       |
| CAPE wet convective available potential energy (J/kg) | 4       | 114     | 432     | 262     | 21      |
| CIN convective inhibition available potential energy (J/kg) | 434     | 524     | 344     | 249     | 371     |

6. Analysis on the Radar Data

Figure 7. Korla radar combined reflectivity factor on July 9 (unit: DBZ)

As shown by the data from Xinjiang Korla's new generation weather radar: at 16:43, the convection cells occurred again in the eastward of Yuli County, 70km from the center of Tarimuan Region, Tiemenguan City (13:23 to 15:40, the first convection cells developed, micro-rain showers occurred in
the central area of the Region through a manual operation). At 16:58, the cells began to increase gradually. The center of the strong echo was 45 DBZ (Fig. 7a), and the top of the echo was 7 km. The cells moved rapidly to the southeast, and new convection cells were continuously formed. At 17:55 (Fig. 7b), the cells moved to the central area of the Region and was elliptical-shaped. The strong echo area (>50 DBZ) gradually increased during the movement, and the echo height rose to 8-9 km at 1800 hours; at 18:26 (Fig. 7c), the strong echo center increased to 55 DBZ, the echo height rose to 11 km, and the liquid water content increased significantly. From 18:11 to 18:47 (Fig. 7d), the cells developed rapidly and moved at a high speed in the center of the Tarim Region, Tiemenguan City, and the hail disasters occurred to different extent. At 19:02, the strong echo area of >50 DBZ decreased rapidly, the echo top began to fall, the liquid water content dropped, and the hail weather in the area ended.

7. Summary
(1) The split short wave in southern Siberia was the main influence system which caused the local hail weather in the eastern Tarim Basin, Xinjiang.

(2) The K index is a good indication for summer thunderstorms, which can be used as a discriminative indicator of convective weather occurrence in the region When K≥32°C; and the energy front and the unstable energy center of the K index provide sufficient energy and unstable conditions for the occurrence of hail weather.

(3) When the convection cells moved to the Tarimu Region of Tiemenguan City, the wind direction gradually changed from the westerly wind to the east wind from the north to the south, and the wind speed convergence center near the ground layer coincided with the falling area where the hail occurred.

(4) The emergence and strengthening of mesoscale ground low pressure has enhanced the convergence uplift movement of the near-surface layer to a certain extent, which provides favorable conditions for the occurrence of this hail weather.

(5) Among the radar echo products, the rapid increase of VIL is a good indication for the short-term forecast of hail weather in this region.

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