

Case Report

Analysis of the Contribution of Water Vapor from the Arabian Sea to the Local Rainstorm Process in Southern Xinjiang

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Abstract: In order to investigate the water vapor sources of summer precipitation in southern Xinjiang, especially Hotan area. Based on NCEP FNL 1°*1° analysis data and Xinjiang meteorological bureau area numerical operation prediction, a local precipitation event in southern Xinjiang on June 26 was analyzed, and the results showed that the water vapor involved in this process originated from the northwestern Gangetic Plain and was transported along the Indus River plain and over the northwestern end of the mountains. Driven by the Iranian low-pressure trough, water vapor at 500 hPa was transported across the northwestern end of the Gangdise Mountains, past Georgoli Peak, and northwest over the Kunlun Mountains to arrive in southern Xinjiang. And a zonal profile was made along the northern foothills of the Kunlun Mountains (latitude 36°N), and the width was limited to the longitude range [70°E, 80°E] and the height range [500 hPa, 300 hPa] according to the water vapor channel scope of the process. In the first 24 hours after the end of the precipitation process, the total water vapor input and transmission amount was more than 3*10⁷kg. That is, the water vapor transmitted over the preceding 24 hours far exceeded the precipitation during the precipitation event. So, under the combined influence of the Iranian vortex and equatorial vortex, moisture from the Arabian Sea at heights above 500 hPa can directly cross the Indus River plain traverse the Qinghai-Tibet Plateau and reach the southern region of Xinjiang. Therefore, the southern upper air passage is an important water vapor source in southern Xinjiang. Under appropriate conditions, it can cause short-term local heavy rainfall and lead to secondary meteorological disasters such as debris flow.

Keywords: Water Vapor, Local Rainstorm, Southern Xinjiang, Arabian Sea

1. Introduction

Due to the complexity of multiscale physical processes and the local environment, local precipitation forecasting has long been a subject of interest and difficulty in scientific research and business. The regional numerical forecast system (RMAPS-CAv1.0) localized by the Xinjiang meteorological bureau based on the WRF-ARW (Weather Research and Forecasting - Advanced Research) Version 3.8.1 model has the

advantages of high spatial and temporal resolution and plays an indispensable reference role in province-level forecasting. With the improvement of the spatial and temporal resolution of the regional numerical model, multiscale analysis of the local precipitation process has become possible. Zhang analyzed the precipitation area and intensity of two rare rainstorms in southern Xinjiang in 2013 and found that there were three main transport routes for water vapor: west, north and east [1]. Shi analyzed the climatic characteristics and areal rainfall distribution of water vapor transport in Xinjiang [2-3]. Zeng analyzed the track of

water vapor transport during a heavy rainstorm in western Xinjiang and analyzed the differences in water vapor contribution among the main channels and different sources [4-8]. Lian analyzed the role of the weather scale and geographical conditions of heavy rainfall in Xinjiang [9-12]. Wang observed and analyzed the tropospheric height and water vapor transport in summer in the Minfeng region, southern Xinjiang [13]. The results show that the water vapor over the northwestern Qinghai-Tibet Plateau is transported to the southern margin of the Tarim Basin under the influence of westerly and southwesterly winds at the base of the subtropical westerly jet stream. Other studies by previous researchers have also identified different vapor sources in southern Xinjiang [14-16]. However, the source channel of water vapor in the northwest of the Qinghai-Tibet Plateau has not been discussed. The southern part of Xinjiang is located in the leeward zone of the Qinghai-Tibet Plateau. While there is little rain year round and the average annual precipitation is less than 100 mm, the precipitation process on June 26, 2019, was characterized by a high intensity, concentrated precipitation area and other medium- and small-scale features, which are rare in southern Xinjiang. This study mainly analyzes the source of

the water vapor and the transport channel associated with this local heavy rainfall process.

2. Actual Precipitation

From 00:00 to 24:00 on June 26, 2019 (UTC), rare local heavy precipitation occurred in the southern part of Xinjiang. The total precipitation within 24 hours reached 48.8 mm (Figure 1), which corresponds to the level of heavy rain based on the precipitation level standard set by Xinjiang in 2004. This precipitation event was characterized by a high degree of localization and a high intensity. The cumulative precipitation was the second highest in the history of the meteorological station.

The circulation pattern of the 500 hPa low-pressure trough in western Siberia and the Afghan low-pressure vortex provided a favorable circulation situation for the occurrence and development of the rainstorm. In particular, the Afghan vortex provided the dynamic conditions for moisture from the Arabian Sea to cross the Qinghai-Tibet Plateau and enter the southern margin of the Tarim Basin through the Indus Plain.

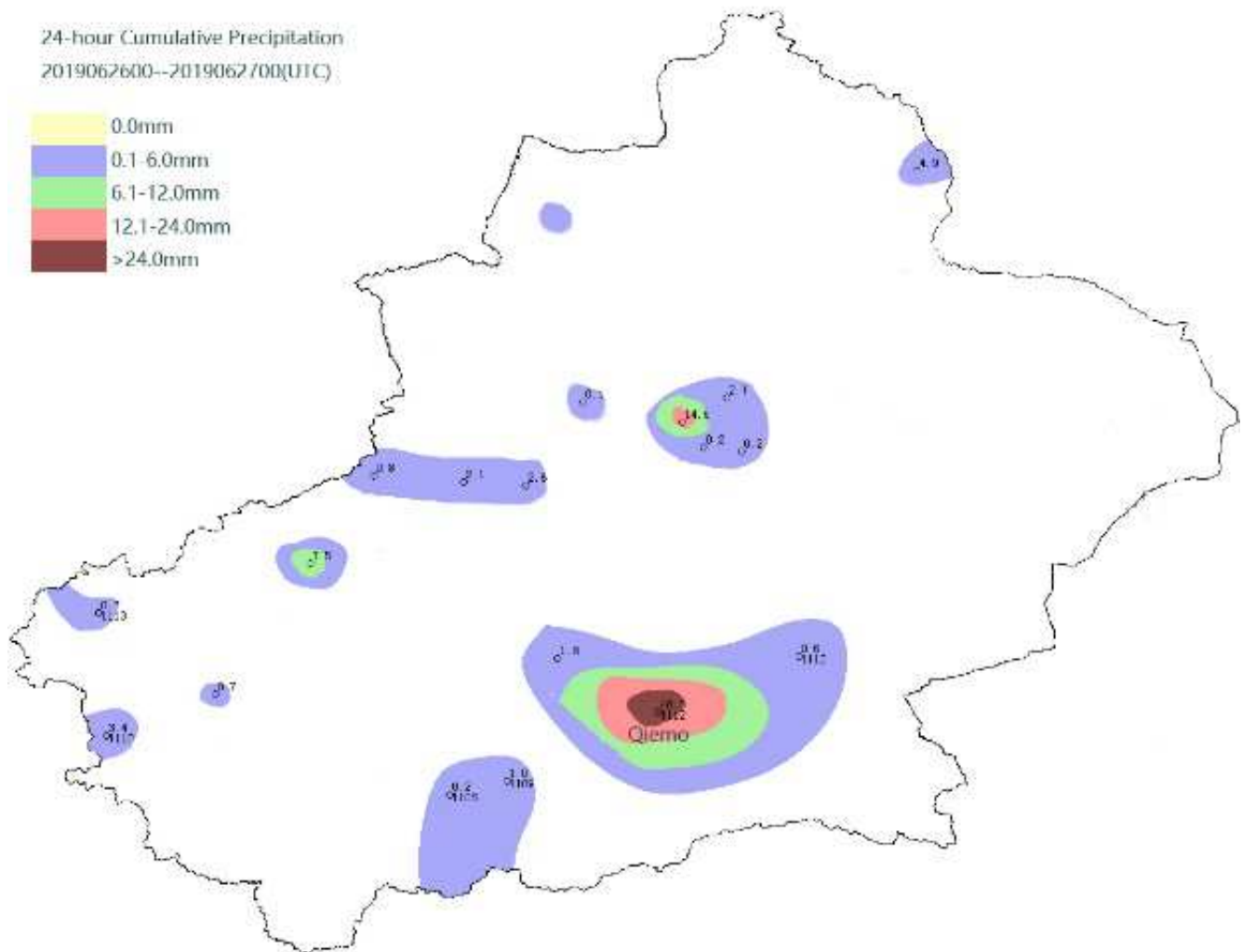


Figure 1. Twenty-four-hour cumulative precipitation observations.

3. Data

Based on FNL $1^\circ \times 1^\circ$ analysis data and RMAPS-CAv1.0 [17] prediction results, the water vapor source in the precipitation process was analyzed. RMAPS-CAv1.0 is a regional numerical prediction system based on the WRFv3.8.1 prediction model and WRFDA assimilation platform. The system is two-fold nested (Figure 2), with an outer zone with a resolution of 9 km covering central Asia, and an inner zone with a resolution of 3 km covering Xinjiang, Gansu and western Qinghai. The system adopts the Global Forecast System (GFS) prediction field at the 6th hour as the background field, the initial field in the inner region is obtained by the ndown method in the outer region, and the 48-hour prediction is carried out after the assimilation of both regions. The assimilated data include microroutine observations and local special observations, including ground observations, sounding observations, aviation reports, etc. The parameterized configuration is shown in Table 1.

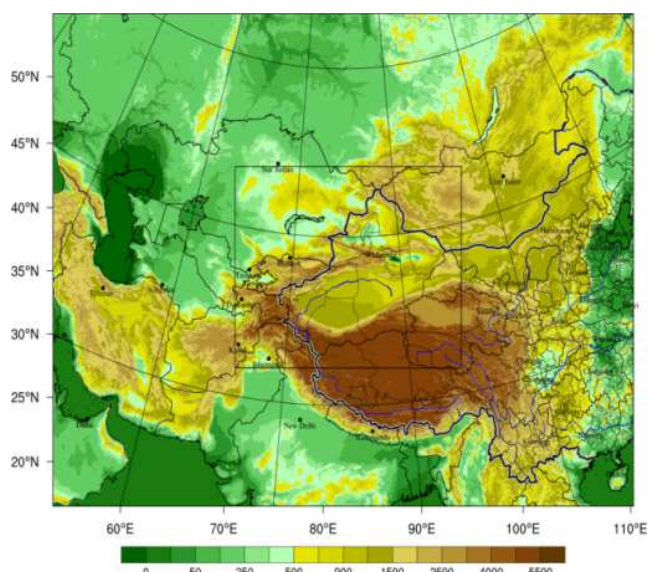


Figure 2. Two nested domains and topography.

Table 1. Model parameter configuration.

The name of the system	RMAPS-CA V1.0
Scheme version	WRFDA V4.0+WRF4.0
Model range and the resolution	9km: $712 \times 532 \times 50$ 3km: $832 \times 652 \times 50$
Run the frame work	00,12UTC adopts cold start, then hot start for 6 hours. The 9/3km cycle update forecast is performed
The background field	NCEP GFS 0.5degree forecast
Data assimilation	Three-dimensional variational assimilation including: General GTS data Xinjiang automatic station data Radial wind observation by 11 radars in Xinjiang
Physical scheme	PBL: ACM2 SW: RRTMG LW: RRTMG LSM: NOAH MP: WSM6

4. Moisture Analysis

4.1. Water Vapor Height

Since the average elevation of the Qinghai-Tibet Plateau is above 5500 meters, the distribution of water vapor only above 500 hPa is considered in this study due to the topography. As shown in Figure 3, from the height above the 0° line to the height of 10 km, there are high humidity zones with relative humidity values above 80% over a long distance. This situation provided a source of water vapor for this event.

4.2. Water Vapor Channel

In the 24 hours before the event, the combined impact of the low-pressure vortex over central Asia and cyclone over Bangladesh allowed water vapor to be transported from the Arabian Sea over the plains of the Indus River, across the mountains to the northwest and the Kunlun Mountains to the north at heights above 500 hPa. This formed a stable moisture channel from the southwest to the northeast, and large amounts of water vapor were transported to southern Xinjiang (Figure 4).

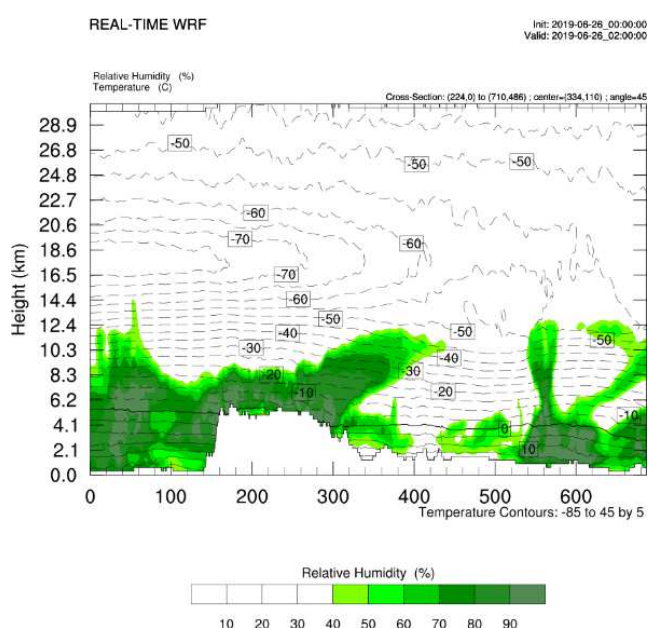


Figure 3. Profile of the humidity field.

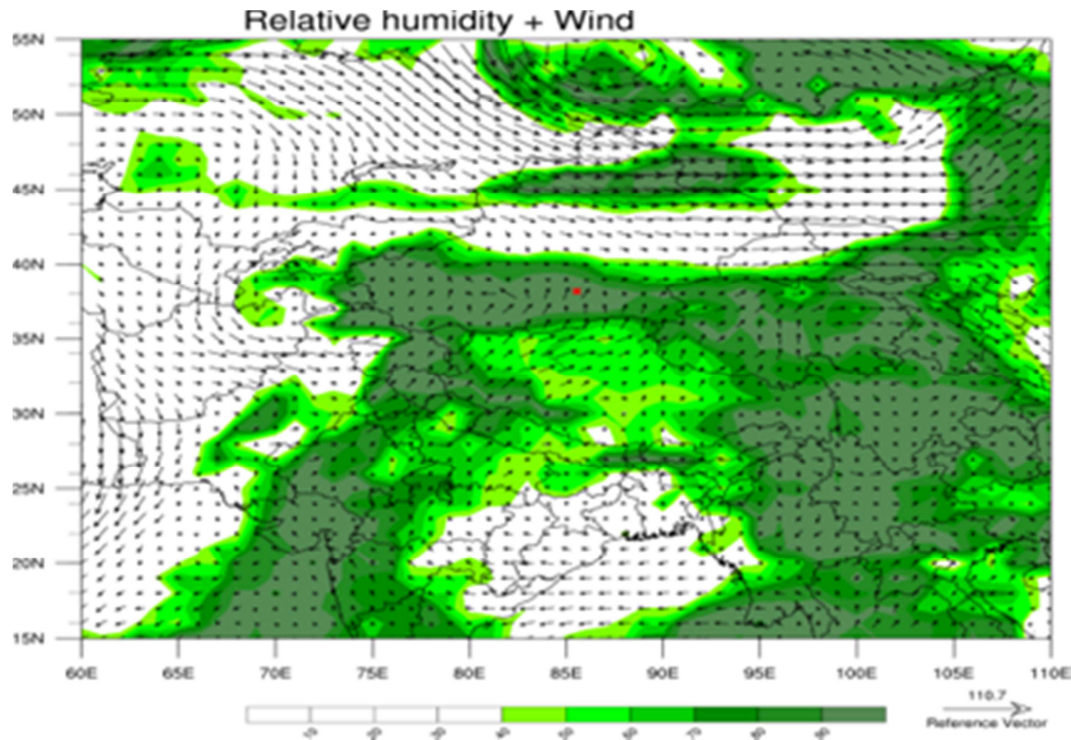


Figure 4. Wind vector field and humidity field.

4.3. Water Vapor Field

One of the necessary conditions for a rainstorm is an adequate supply of water vapor. In the 24 hours preceding the precipitation event, due to the combined effects of the northern cyclone in the Bay of Bengal and the Afghan low-pressure vortex, there was a continuous strong southwest wind along the Indus Plain from the Qinghai-Tibet Plateau to the Tarim Basin. The vertical profile showed that there was a continuous high humidity zone with relative humidity greater than 90% between altitudes of 6 km and 8 km. From the section analysis of the southern margin of the Tarim Basin, water vapor was continuously transported from south to north over time.

The formula for calculating the water vapor flux into southern Xinjiang during this process is:

$$M_v = \frac{1}{g} |V| q \Delta l |\Delta p| \quad (1)$$

The formula for calculating the amount of water vapor flowing into southern Xinjiang during this process is as follows:

$$M = \iint M_v dx dy \quad (2)$$

In the above equation, each physical quantity is as follows:

$|V|$ denotes the magnitude of the wind speed; q is the specific humidity; Δl is the unit length; and Δp is unit air column pressure. The units of these parameters are as follows:

$$g \sim \text{m} \cdot \text{s}^{-2}, |V| \sim \text{m} \cdot \text{s}^{-1}, q \sim \text{g} \cdot \text{kg}^{-1}, \Delta l \sim \text{m}, \Delta p \sim \text{hPa}$$

A zonal profile was made along the northern foothills of the Kunlun Mountains (latitude 36°N), and the width was limited

to the longitude range [70°E, 80°E] and the height range [500 hPa, 300 hPa] according to the water vapor channel scope of the process described in section 4.2. Then, formula (2) is used to calculate the quantity of water vapor reaching the southern region of Xinjiang after passing through the section, as shown in Figure 5.

In the first 24 hours after the end of the precipitation process, the total water vapor input and transmission amount was more than 3×10^7 kg. That is, the water vapor transmitted over the preceding 24 hours far exceeded the precipitation during the precipitation event.

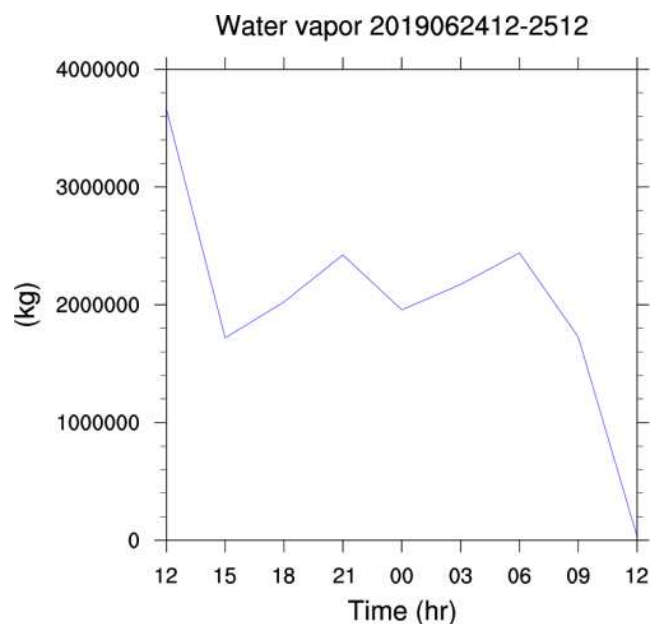


Figure 5. Curve of water vapor delivery with time.

4.4. Mesoscale Shear Lines

Based on the NCEP FNL $1^\circ \times 1^\circ$ analysis data (Figure 6) and RMAPS-CAv1.0 prediction (Figure 7), from 18:00 on June 25 to 00:00 on June 26, in the Hotan region of Xinjiang, the western air flow caused by the low-pressure vortex to the

south of Lake Baikal and the Iranian high together with the eastern air flow of the weak high in the Hetao region formed a double mesoscale vortex. The horizontal scale shows a mesoscale process on the order of a β scale.

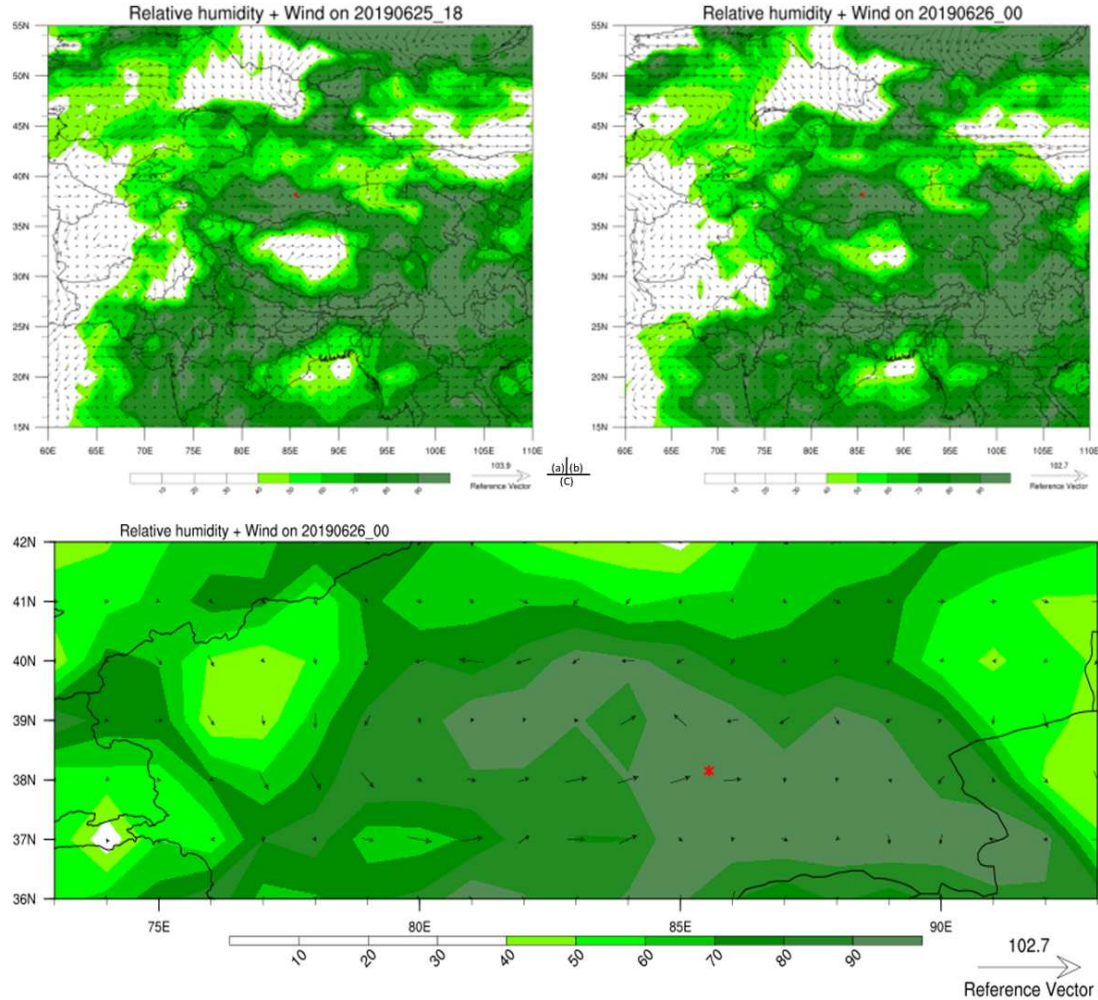


Figure 6. FNL analysis data wind vector and humidity field: a: forecast on 2019062518, b: forecast on 2019062600, c: 700 hPa wind vector and humidity field on 2019062600.

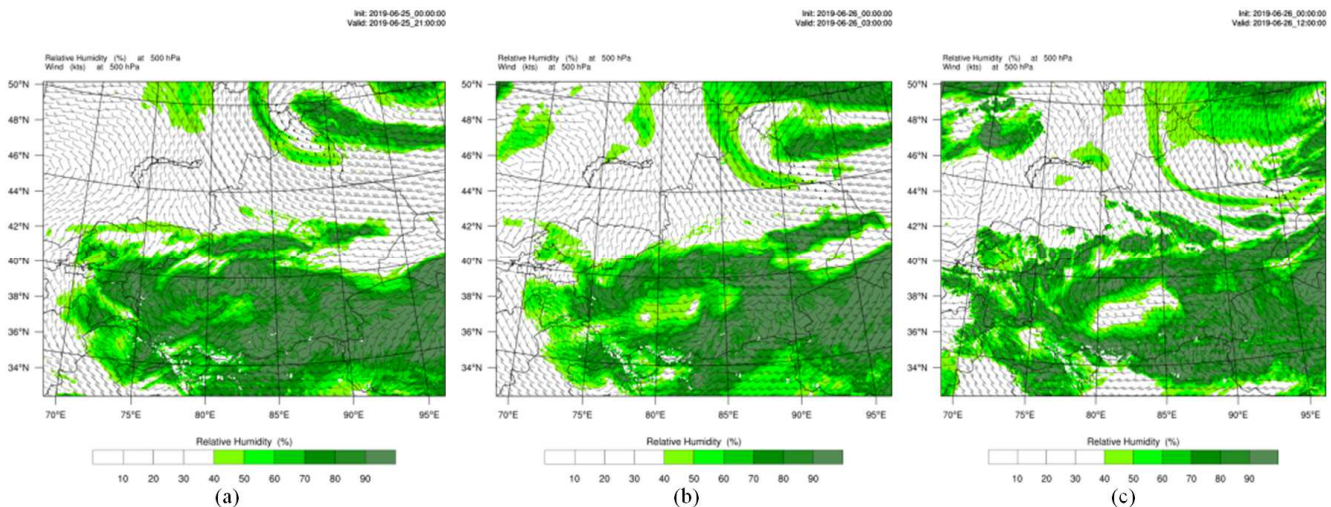


Figure 7. RMAPS-CAv1.0 wind vector and humidity forecast at 500 hPa: (a): forecast on 2019062521, (b): forecast on 2019062603, (c) forecast on 2019062612.

5. Conclusions

Under the combined influence of the Iranian vortex and equatorial vortex, moisture from the Arabian Sea at heights above 500 hPa can directly cross the Indus River plain traverse the Qinghai-Tibet Plateau and reach the southern region of Xinjiang. The southern transmission channel of water vapor is a very important source for the southern region of Xinjiang.

Under the cooperation in favorable terrain, the southward movement of the western Siberian cold vortex and the easterly flow of the Iranian high converged in southern Xinjiang to form a mesoscale vortex. This can cause local heavy rainfall and secondary mountain flood disasters.

Local abundant water vapor is a favorable condition for such extreme heavy precipitation. While southern Xinjiang is located in an arid portion of the continent, the frequency of local heavy rainfall has increased in recent years, which is worth further study.

Author Contributions

Investigation: D. B., M. E., S. F, Z. Z; writing and editing: D. B., M. E. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

All the authors do not have any possible conflicts of interest.

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