Analysis on the Influence of Topography on a Short-Time Local Heavy Rainfall Forecast in Western Xinjiang

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Abstract. Based on the prediction results of RmAPs-CAV1.0, a short time heavy rainfall in western Xinjiang was simulated and analyzed. By comparing the forecast results with the actual precipitation, it is found that RMAPS-CAV1.0 can accurately reflect the important forecast parameters of the short-time heavy precipitation system, such as precipitation level and starting time. Contrast observation and prediction results found that the terrain has forced effect to the surface wind field, the precipitation process in Yili valley special opening of the west mountain terrain, the center is located in Kazakhstan in central Asia low vortex cause lower for the westerly Yili river valley, the center is located in the Tarim Basin of central Asia for Piandongfeng middle low vortex makes the Yili river valley, cause the Yili river valley and the lower levels of vertical wind shear reinforcement; In the Yili River Valley, the combination of topography and the central Asian vortex circulation in Kazakhstan forms a low-altitude convergence line. The low-level westerly winds transport water vapor into the valley, and the northerly airflow in the valley and the northern margin of the Taklamakan Desert converge near the windward slope, and the enhanced upward movement results in the uplift of the water vapor accumulated in the valley. The result analysis of RMAPS-CAV1.0 shows that the warm and cold airflow and water vapor under the action of topography have important contributions to the generation of this precipitation.

Keywords: Short-term heavy precipitation; Terrain; High resolution; Disaster prevention and mitigation

1. Introduction

In Yili Prefecture in western Xinjiang, short-term rainstorms, floods and other meteorological disasters often occur in summer and the consequent geological disasters cause adverse effects and heavy losses to local people's lives and property, agricultural and animal husbandry production, transportation and infrastructure. Yang Lianmei, et al. analyzed the precipitation characteristics in Xinjiang from the perspectives of climate and water vapor sources [1-3]. More research (Zhang, 1987 [4]; Yang Jinhu, et al., 2007 [5]; Han Yunhuan, et al., 2014 [6]; Wang Shaoping, et al., 2014 [7]; Dai Xingang, et al., 2007 [8]; Shi Ya-feng, et al., 2003) also showed that in recent years, precipitation in arid and semi-arid areas in northwest China increased and extreme precipitation occurred frequently (Zeng Jia, et al., 2014 [10,11]; Huang Jianping, et al., 2014 [12]; Chen Chunyan, et al., 2015 [13];). The characteristics of rainstorm and precipitation in Xinjiang are quite different from those in eastern and southern China, showing stronger local characteristics. Moreover, its topography and underlying surface are obviously different from other regions, and the source of water vapor is also very different from the eastern
monsoon region, so it is very difficult to forecast. Therefore, the rainstorm in Xinjiang needs to be studied more specifically.

Xie Zeming pointed out that the heavy rain occurred often need to unstable stratification, the formation of the thermal instability associated with vertical profile distribution of the temperature and humidity, and the dynamic instability and discontinuity density, horizontal wind shear and vertical wind shear, therefore, the terrain by influencing the thermal instability and dynamic instability, in turn, affects the occurrence of strong convection weather development is also a way of terrain effect on precipitation is very important [14]. Among them, thermal instability is also called static instability, stratification instability, potential instability or convective instability; Dynamic instability, also known as shear instability, includes inertial instability, symmetric instability and conditional symmetric instability. Sun Jisong and Tao Zuyu (2012) emphasized that thermal instability is a rapid release that only affects the initial intensity of convection and cannot affect the development and persistence of convection, while dynamic instability is a key factor for the development and maintenance of convection [16]. In addition, there are many researches on the influence of thermal instability on the occurrence and development of convection (Tao Shiyian, et al., 1979 [17]; Ding Yihui, 1989 [18]; Gao Kun, et al., 1994 [19]; Gao Shouting, et al., 1994 [20]; He Lifu, et al., 2007 [21]; Huang Yan, et al., 2008 [22]; Jiang Yuanan, etc., 2010 [23], Karen KF. biological basis for, etc., 1989), but the research on thermal instability causes is relatively small, etc. (2018) by quite a bit around the tendency of vertical temperature gradient equation, it is concluded after analysis potential divergence can comprehensive characterization of vertical wind shear over the precipitation area, wet atmospheric baroclinicity, horizontal convergence divergence and atmospheric potential stability of changed circumstances, is the main force of the change of the local potential stability [24-26]. Therefore, the use of potential divergence can be thermal instability and dynamic process, diagnosis of thermal stratification distribution and reasons of the change, and the study of strong convective precipitation is important, Huang Xin (2020) to the Yili river valley, such as a rainstorm process environment and unstable condition has carried on the diagnosis and analysis, points out that the potential divergence divergence of part can strengthen the small terrain leeward slope in the valley of the convective instability, shows that the precipitation in the process of evolution, the mutual interaction of dynamic thermal factors affect the precipitation intensity and the drop zone [28]. It can be seen from the existing studies that there have been some statistical analyses and case studies on the synoptic scale system and topography affecting Xinjiang, but it is not clear how the topography of the Yili Valley and the central Asian low vortex cooperate to cause the dynamic and thermal instability, and how the dynamic and thermal instability conditions are related to the occurrence and development of heavy precipitation. On May 10, 2010, a local heavy precipitation occurred in Yili area (reaching the magnitude of Xinjiang's torrential rain), among which the Ma Industrial Park station reached over 70mm, which was the place with the largest rainfall in the whole Xinjiang during the heavy weather. The rainfall exceeded the local historical extreme value and was an obvious extreme precipitation process. This article selects the rainstorm process, this paper discusses favorable circulation background of storm rainfall and Yili valley terrain influence, using high-resolution numerical simulation data analysis how dynamic thermal instability affect thermal stratification distribution which affect precipitation, in order to deepen the understanding of the mechanism affecting the Yili river valleys, the strong rainfall and provide a meaningful reference for local precipitation forecast.

2. Observation
On May 9, as the high pressure ridge centered in the Ural Mountains moved eastward, it pushed the central Asian low vortex eastward. At 10:00 on October 10, the Central Asian low vortex is located in the central Asian region between the Aral Sea and The Balkhash Lake, and the rainstorm area is located in the southwest airflow control area in front of the low vortex. At this time, the mid-latitude shows the circulation situation of "two ridges and two troughs", and the Central Asian low vortex is between the Ural ridge and the Xinjiang Weak ridge. The local rainstorm occurred under the background of “two ridges and two channels” circulation. The rainstorm area was located to the left of
the southwest jet outlet area at 200 h Pa, near the southward airflow at 500 h Pa and the shear line at 700 h Pa. As shown in figure 1, precipitation above 48 mm occurs in 2 stations; 24-48 mm precipitation occurred in 0 stations; 12-24 mm precipitation occurred in 8 stations; 6-12 mm precipitation occurred in 12 stations; Precipitation of 0.1-6 mm occurred in 85 stations; Maindustrial Area of Zhaosu County. As shown in Table 1 the maximum precipitation center is 71.8 mm.

![Figure 1. Precipitation area and magnitude.](image)

| Station     | Location | Precipitation (mm/12hour) |
|-------------|----------|---------------------------|
| Machanyequ  | Zhaosu   | 71.8                      |
| Zhonghahezuo| Horgos   | 59.6                      |
| Akedala     | Zhaosu   | 21.1                      |

The precipitation maxima were concentrated in Zhaosu and Horgos counties (Table 1).

3. Model Prediction
As shown in figure 2, RMAPS-CAv1.0, a regional numerical forecast system based on WRFv3.8.1 forecast model, is a new generation of regional numerical forecast operation system of Xinjiang Meteorological Bureau. The system adopts double nesting. The resolution of the outer zone is 9 km, covering the central Asian region, and the resolution of the middle zone is 3 km, covering the whole Xinjiang, western Gansu and Qinghai regions. The number of regional grids is 752X532 and 832X652, respectively. The boundary layer parameterization scheme was ACM2, SW: RRTMG, LW: RRTMG, LSM: NOAH, MP: WSM6. The GFS 6 h forecast field is used as the background field, and the outer zone one-way feedback is used for 24 h integral forecast.
According to the forecast results, for the small-scale local heavy precipitation, the model has a good grasp of whether there is precipitation and the starting time of precipitation. In Zhaosu County in Yili, both forecasts and observations showed precipitation starting at 10 a.m. There is a certain deviation in the precipitation level and the core of the falling area. The forecast precipitation is one order smaller than the observed precipitation. According to the spherical distance formula, the forecast core falling area is 20.4 km north of the actual situation. As shown in figure 3, on the whole, the forecast of precipitation is relatively successful.

4. Terrain Analysis

4.1. Topographic Features
Zhaosu County, where the precipitation center is located, is the main vein of Tianshan Mountain in the south, which is the natural barrier to hold back the dry and hot wind of the southern Xinjiang desert.
Wusunshan in the north, east-west, the mountain is shorter; the western part of the basin is separated by The Shaltou Mountain and the Chadaner Mountain in Kazakhstan, forming a basin with high south, west and north sides and slightly lower east. The ratio of mountain, hill and plain is 4:1. Located on the border line between China and Kazakhstan in the southwest, Han Tengger Peak, known as the "father of Tianshan Mountain", with an altitude of 6,995 meters, is the second highest peak in The Tianshan Mountain range, with a snow-covered area of more than 100 square kilometers all year round. Such topography is conducive to the convergence and uplift of warm and cold airflow in front of the mountain and the formation of short-time heavy precipitation process.

The force of terrain on the wind field

As shown in figure 4 (a, b) shows the simulation and forecast of the precipitation process by RMAPS-CAV1.0. As shown in figure 5, it can be seen that from 00:00 on October 10 (UTC) to 0:00 on October 10 (UTC), the westerly wind guided by the central Asian low trough met the northerly cold airflow pouring east into the northern margin of the Taklamakan Desert, forming the topographic wind shear. For the precipitation process to improve the water vapor uplift conditions.

Figure 4. (a, b) Intersection and uplift of the Middle and western airflow in front of the mountain during the precipitation process (as shown by the red arrow).

Figure 5. Forcing effect of terrain on wind field.

4.2. The Transport of Water Vapor by Wind Field

As shown in figure 6, before the precipitation, the westerly wind of the lower trough in Central Asia transported moisture from the west of Lake Baikal to the Yili River Valley continuously, providing moisture conditions for the heavy precipitation process. Atmospheric water vapor content is also
known as atmospheric precipitation, that is, the liquid water vapor amount that can be obtained when water vapor in the entire air column condenses is calculated as follows:

\[ W(y, \theta, t) = \frac{1}{\rho_r} \int_{p_s}^{p_r} Q dp \]  

(1)

Where, \( W \) is the total moisture content of a layer above a unit area, \( Q \) is the specific humidity, and \( p_r \) is the atmospheric pressure at a certain height and on the ground, \( p_s \).

According to formula (1) and as shown in figure 7, 9km per unit length =500hpa can be taken to calculate the water vapor content and flux in Zhaosu region within 10 hours during the precipitation process (figure7 and figure 8). It can be seen that after the moisture transported to Zhaosu area increased continuously, as shown in figure 8, the extreme value appeared at 2 o’clock on 10th, reaching 1.7*10^7 kg, and then gradually decreased.

5. Conclusion and Prospect

(1) As a means to study mesoscale weather processes, high-resolution numerical simulation will play an increasingly important role in the development of meteorological forecast in the future.

(2) The local precipitation process sex strong, short-term rainfall intensity big, precipitation occurred corresponding high latitudes in the middle troposphere, "a ridge of the two slot" the circulation situation, two special low vortex and the Yili river valley to the west open terrain matching formed a circle in the lower level strong vertical wind shear resulting is advantageous to the Yili river valley upward movement of produce and strengthening, is advantageous to the Yili river valley to form dynamic unstable conditions.

(3) Under the control system of low-level west wind brought by central Asian vortex in Kazakhstan and Middle East risk brought by central Asian low vortex in Tarim Basin, water vapor humidity
accompanied by low-level west wind provided sufficient precipitation for the short-term heavy precipitation.

This article though to the Xinjiang Zhaosu area a short-time rainstorm process in the high-resolution simulation modeling and analysis, and some preliminary conclusions are obtained, but there are still some problems need further research and analysis, as this article is not involved in using high-resolution simulation data to directly trigger instability energy release of the mesoscale weather system and how it influence the evolution process of the precipitation, it will continue in-depth discussions in the subsequent work.

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