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Research Article

Triggering Mechanism of an Extreme Rainstorm Process near the Tianshan Mountains in Xinjiang, an Arid Region in China, Based on a Numerical Simulation

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The current study investigated the triggering mechanism of a record-breaking heavy rain process in the area near the Tianshan Mountains in Xinjiang, an arid region in China, from July 31 to August 1, 2016, based on the simulation using the Weather Research and Forecasting (WRF) model. The results illustrated that the rainstorm system was generated in the middle atmosphere of the western Aksu region near the Tianshan Mountains and gradually evolved into a multicell linear echo during system evolution. The cold air transported from the Tianshan Mountains partly reached the low altitudes during the downhill process, and the warm southwest air from Aksu was lifted, forming oblique updraft airflow. The other part of the cold air converged with the southeastern warm air in the middle atmosphere, and the transportation and convergence of the water vapor related to the southwestern, southeastern, and oblique updraft airflows provided good water vapor conditions for the storm system. Meanwhile, the inclined upward air transported cloud water and ice-phase particles to high altitudes, mixing the two and generating a large amount of supercooled cloud water, which was very beneficial for the development and maintenance of the storm system. These conditions were favorable for power, heat, water vapor, and water condensate particles, which enabled the development and maintenance of the rainstorm system on the convergence line, thus triggering this rare rainstorm process during the movement to the northeast.

1. Introduction

Under the background of global warming, extreme heavy rainfall shows an increasing trend, which has an important impact on arid regions [1–3]. On the one hand, heavy rainfall can provide a large amount of water vapor for arid regions, which can improve the local ecological environment to some extent and store a certain amount of water for the local area, which is conducive to agricultural irrigation and production activities [4]. On the other hand, heavy rainfall can cause geological disasters such as flash floods, landslides, and debris flows and cause large losses to people's lives and property, especially in areas near mountains [5–9]. Mountains play an important role in the triggering and enhancing rainstorms, and heavy rainfall events near mountains often bring extreme rainstorms and floods to local areas [10–14].

Xinjiang is located in the middle of Asia and is in northwestern China. It has a vast territory and occupies approximately one-sixth of China's land area; additionally, it belongs to an arid region not directly affected by the monsoon in China [15, 16]. The Tianshan Mountains in central Xinjiang divide Xinjiang into northern and southern parts, which have significant differences in climate [17]. The large size of the Tianshan Mountains profoundly affects the weather and climate in Xinjiang. Different climatic backgrounds and unique topography determine that the torrential rain process in Xinjiang must be different from that in central and eastern China and has its own particularities [18]. The combination of high-, medium-, and low-altitude airflows in Xinjiang's heavy rain process is conducive to the occurrence of heavy rain [19–22]. The coupling effect between the strong divergence at high altitude and the convergence at low altitude not only increases the accumulation of water vapor in the middle and lower layers in the rainstorm area but also transports more humid air upward by increasing the vertical speed and increasing the atmospheric humidity of the upper and middle layers [23–25]. The terrain of the Tianshan Mountains is conducive to the occurrence of systematic strong ascent [26–28]. Research on the Xinjiang rainstorm mesoscale system shows that the convergence line of the low altitude, the rapidly generated, developing, and moving mesoscale convective cloud clusters on the cloud map, and the mesoscale convective system with obvious characteristics on the Doppler weather radar are direct systems causing heavy rain in Xinjiang [29–32].

Currently, due to the extremely complicated topography and sparse observation sites in western Xinjiang near the Tianshan Mountains, there is no clear understanding of the structural evolution characteristics and trigger mechanism of the rainstorm system related to the rainstorm process in this area. To enhance the scientific understanding of the relationship between the structural evolution of the rainstorm system and the process of heavy precipitation and the triggering mechanism of the rainstorms in this region, this paper selects the extreme torrential rain process that broke the historical record for maximum rainfall in western Xinjiang near the Tianshan Mountains from July 31 to August 1, 2016. The Weather Research and Forecasting (WRF) model is used for high-resolution numerical simulation of the heavy rain event. Zeng et al. [33] conducted preliminary studies using the same model and noted that rainstorms first occurred in the Aksu region and affected the Yili region after crossing the Tianshan Mountains. However, though the research focused on the evolution process of the rainstorm system after crossing the Tianshan Mountains and the impact on the rainstorm in the Yili area, the triggering mechanism of the rainstorm system was not involved, and the structural evolution of the rainstorm system was not explained in Aksu. These issues are key in the rainstorm process. Therefore, on the basis of ensuring that the simulation results are credible, the simulation data are used to analyze the causes of the rare heavy rain events to reveal the system evolution structural characteristics and triggering mechanism of heavy rain.

2. Study Area, Data, and Methods

2.1. Study Area. The study area is the Tianshan Mountains and the areas near the northern and southern sides, including Yili and Aksu (Figure 1). The large size of the Tianshan Mountains has a profound impact on the weather and climate of Xinjiang, and the Yili area presents a trumpet terrain opening to the west. The Tianshan Mountains are to the west and north of Aksu, with the terrain decreasing towards the east. Because the rainstorm system starts in Aksu, the trigger mechanism of the rainstorm focuses on the Aksu area.

2.2. Data. The data used for analysis and numerical simulation in this paper are based on the hourly rainfall amount

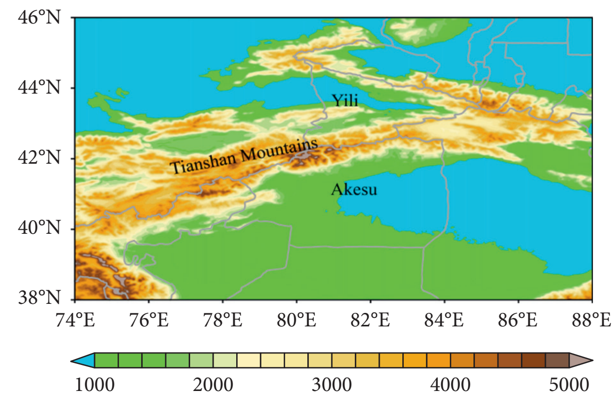


Figure 1: Study area (the shadow is the height of the terrain, unit: m).

data based on 1490 automatic weather observation stations in Xinjiang from the Xinjiang Meteorological Information Center from 12:00 on July 31 to 12:00 on August 1 2016 [24, 33] and the global final analysis (FNL) dataset produced with a horizontal resolution of 1.0° and 26 vertical levels, which are provided by the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) (https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html).

2.3. Methods. The WRF model version 3.8.1 with 50 vertical levels was used for simulation using the initial and outermost lateral boundary conditions provided by the 1.0° resolution NCEP/NCAR data at 6-hour intervals. The center point of the simulation was 42°N, 81°E, with three-layer two-way nesting; the horizontal resolution of area 1 was 27 km, and the number of horizontal grid points was 280×210; the horizontal resolution of area 2 was 9 km, and the number of grids in the horizontal direction was 535×391; the horizontal resolution of area 3 was 3 km, and the number of grids in the horizontal direction was 442×325 (Figure 2). The single-moment 6-class protocol was utilized for the microphysical processes [34], and the Kain-Fritsch protocol was used for cumulus parameterization [35] (parameterization was closed for area 3). In addition, it included Yonsei University's PBL scheme [36], Rapid Radiative Transfer Model (RRTM) longwave radiation scheme [37], and the Dudhia shortwave radiation scheme [38]. The integration time spanned from 00:00 on July 31 to 12:00 on August 1, 2016, and the spin-up time of model is from 00:00 to 12:00 on July 31, 2016. The data used for simulation analysis in this study were all obtained from the simulation outcomes from the 3 km layer.

3. Results

3.1. Rainfall Facts. Xinjiang is located in Central Asia, where it is far from the ocean and has sparse precipitation; thus, it is a typical arid climate zone. Therefore, the local meteorological and hydrological departments stipulate that torrential rain is classified as daily rainfall that exceeds 24 mm [39]. From 12:00 on July 31, 2016, to 12:00 on August 1, 2016, a

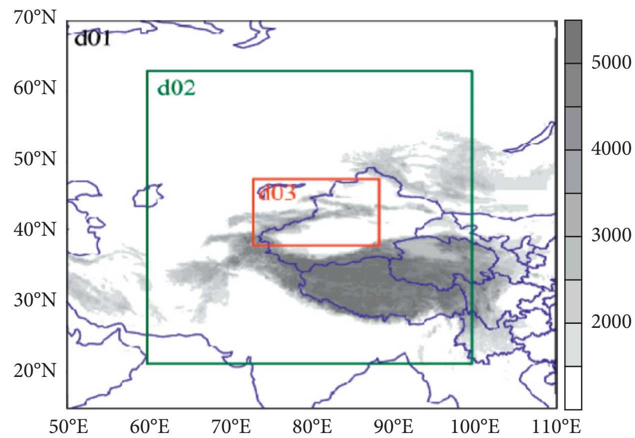


Figure 2: Model domain and terrain height (monochrome shaded, unit: m) in simulation.

rare heavy rainstorm event occurred in Xinjiang; Figure 3(a) shows the precipitation distribution obtained by interpolation of the precipitation data at the station through the objective analysis method of Gressman. The rainstorm area was located in the Yili area and on both sides, and the rain belts were distributed from the northeast to southwest. The daily rainfall of several weather stations broke their records for the largest daily rainfall in history. Strong locality, strong extremes, and large accumulated rainfall were the characteristics of this rare rainstorm.

3.2. Weather Situation. Before the rainstorm occurred, 500 hPa presented a circulation pattern of "two ridges and one trough." The Iranian subtropical high and the Ural Mountain high-pressure ridge were superimposed in the same phase, the western Pacific subtropical high stretched westwards and developed strongly, the 588 dagpm line extended to eastern Xinjiang, and the low trough area extended from Balkhash Lake to western Xinjiang. The large vertical movement in east of the trough provided very favorable background conditions for the heavy rain event. At 12:00 on July 31, 2016 (Figure 3(b)), the Iranian subtropical high and the Ural Mountain high-pressure ridge further developed, the development of the low trough of Balkhash Lake deepened, and the western Pacific subtropical high stabilized and was maintained after the northward elevation, blocking the westward shift of the low trough of Balkhash Lake and causing the trough system to stay in western Xinjiang for a long time, which provided good conditions promoting the occurrence of this heavy rain. At the same time, studies have shown that the area on the right side of the inlet area and the left side of the outlet of high altitude are conducive to the generation and strengthening of heavy rain by enhancing the divergence of the upper atmosphere [40], the 200 hPa high-altitude jet core is located in northern Xinjiang, and the rainstorm area was in the divergent and unstable area on the right side of the high-altitude jet inlet area [24, 33]; the strong divergence of the upper atmosphere enhances the vertical ascending motion and finally intensifies the rainstorm [41].

3.3. Verification of the Outcomes of Numerical Simulation. The results of the model simulation were compared with the observation data to verify the reliability of the simulation results, and the observed data used for verification included the 24 h rainfall amounts, every 6 h rainfall amount, horizontal wind profiles, and surface wind field data from the automatic stations. The comparison between the simulated daily rainfall amounts (Figure 4) and the observed daily rainfall amounts (Figure 3(a)) showed that the simulated rainfall area distribution and rainfall area range were consistent with the observations, and the intensity corresponded well with the observations. There were still some deficiencies in the details. For example, although the simulated rainstorm area and the observed rainstorm area were both distributed from the southwest to the northeast, the simulated precipitation area in Aksu was greater than the actual situation and it was located more westward. These deviations may be related to the selection of the initial moment of the simulation, the difference between the model terrain and the actual terrain, and the uneven distribution of the observation sites.

Further from the distribution and evolution of every 6 h rainfall amount, horizontal wind profile data, and surface wind field, it could be seen that the simulation results corresponded well with the observations [33].

Based on the abovementioned comparisons, although there were still some differences, the simulated outcomes were basically consistent with the actual observations and therefore can be used as the data for further analysis of the rainstorm process.

3.4. Horizontal Structure of Rainstorm System. At 12:00 on July 31, 2016, scattered echoes appeared in the western Aksu region, and the echo intensity was generally below 40 dBZ (Figure 5(a)); then, the rainstorm process began. After 4 h, the scattered echo developed into a linear strong echo zone, and the strongest echo exceeded 50 dBZ (Figure 5(b)), which was the stage of system development. With the further development of the system, the strong echo developed into a quasi-south-north linear echo zone during the northeastward movement, and the echo range above 50 dBZ further increased at 17:30 on July 31 (Figure 5(c)). At this time, the rainstorm system developed and matured. In the process of the linear echo moving northeastward, the rainstorm system crossed the Tianshan Mountains to reach the Yili area. At 22:00 on July 31, the main body of the rainstorm system reached the Yili area, and only the southern part of the echo still affected the Aksu area (Figure 5(d)). The system was in the extinction stage.

From the above analysis, it could be seen that the rainstorm system started in the west of Aksu and the east of the Tianshan Mountains and developed into a more regular linear strong echo zone during the northeastward movement. The whole process could be divided into initiation, development, maturity, and extinction stages.

In the initiation stage of system evolution, the eastern part of the Tianshan Mountains was a trough. The southwestern airflow in east of the trough and the southeastern airflow from the eastern region formed a convergence line in

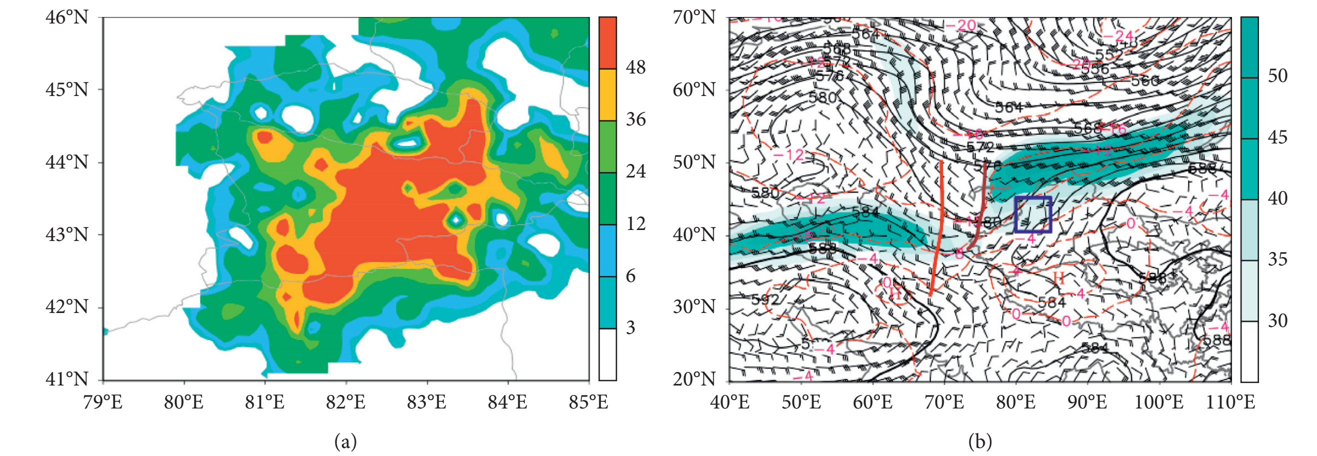


Figure 3: (a) The precipitation distribution in the Tianshan region from 12:00 on July 31 to 12:00 on August 1, 2016 (shadow, unit: mm). (b) The geopotential height of 500 hPa (solid line; unit, dagpm), wind field (wind pole; unit, m·s^{-1}), and high-altitude jet stream at 200 hPa at 12:00 on July 31, 2016 (shadow; unit, m·s^{-1}) (the blue rectangle represents the location of the rainstorm area, the brown solid line represents the groove line, and the red solid line is the temperature groove line).

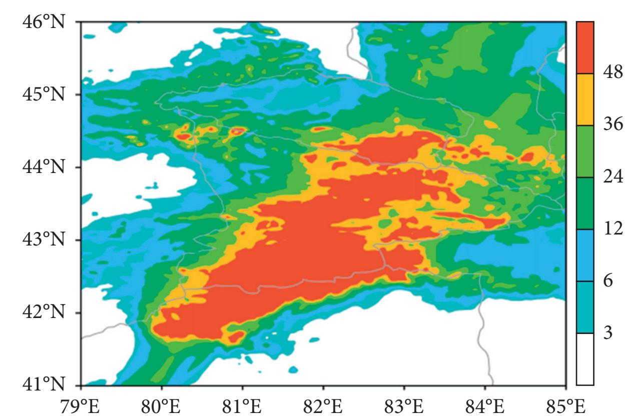


Figure 4: The total rainfall amounts simulated from 12:00 on July 31 to 12:00 on August 1, 2016 (shadow; unit, mm).

the western Aksu region (Figure 6(a)). With the development of the trough, the southwestern low-level jet in east of the low trough strengthened, pushing the convergence line eastward (Figure 6(b)). The strong echo area was located between the trough line and the convergence line, which had a good correspondence with the low-level jet. During the further eastward movement of the low trough, the northern section of the trough line evolved into a cyclonic circulation at 17:30 on July 31 (Figure 6(c)), the convergence line was quasi-south-north, and the southwestern airflow and southeastern airflow forming the convergence line pushed the system to move northward as the system moved eastward. During the northeastern movement of the system, the development of cyclonic circulation in the northern section of the trough line strengthened. At this time, the easterly wind component of the southeastern flow and the westerly wind component of the southwestern flow weakened, resulting in a marked weakening of the convergence line (Figure 6(d)); additionally, the southerly jet of the cyclonic circulation had a good correspondence with the strong echo area.

3.5. Vertical Structure of Rainstorm System. To explore the changes in the vertical structure of the rainstorm system and the convergence line during the evolution of the rainstorm system, profiles were made along the direction of the convergence line (the direction of the black solid line AB in Figure 5) and the direction perpendicular to the convergence line (the direction of the black solid line CD in Figure 5) in the four stages of system evolution. As shown in Figure 7(a), at the initiation stage of system evolution, weak echoes appeared in the mid-layer airflow towards the Tianshan Mountains, and the southwestern airflow was stronger. From 700 to 500 hPa, the airflow from the Tianshan Mountains to Aksu which sank encountered southwestern airflow near 79 °E, 40.9 °N, while the southwestern airflow rose, and the weaker echoes were mainly located near the convergence line (Figure 7(b)). In the system development stage, the airflow from the southwest to the Tianshan Mountains increased, the echo developed downward to contact the ground, and the strongest echo reached 45 dBZ, located near 550 hPa (Figure 7(c)). Near the strong echo, the northwestern airflow sank after encountering the southeastern airflow below 550 hPa, while the northwestern airflow rose above 550 hPa; at the same time, the southeastern airflow rose significantly, with a large vertical upward velocity from 700 to 500 hPa (Figure 7(d)). In the maturity stage, the linear echo presented a multiconvection system structure, the intensity of the echo was further enhanced to more than 50 dBZ, and the upward airflow was strengthened on the windward slope (Figure 7(e)). The intensity of the rainstorm system near the convergence line was further strengthened, and the inclined upward airflow was strengthened (Figure 7(f)). During the system extinction phase, the multielement linear echo structure was still clear, but the intensity was weakened (Figure 7(g)). The weakening of the northwestern and southeastern winds led to the weakening of the convergence line, and both oblique ascending airflow and oblique subsidence airflow were weakened, resulting in a weakening of the rainstorm system (Figure 7(h)).

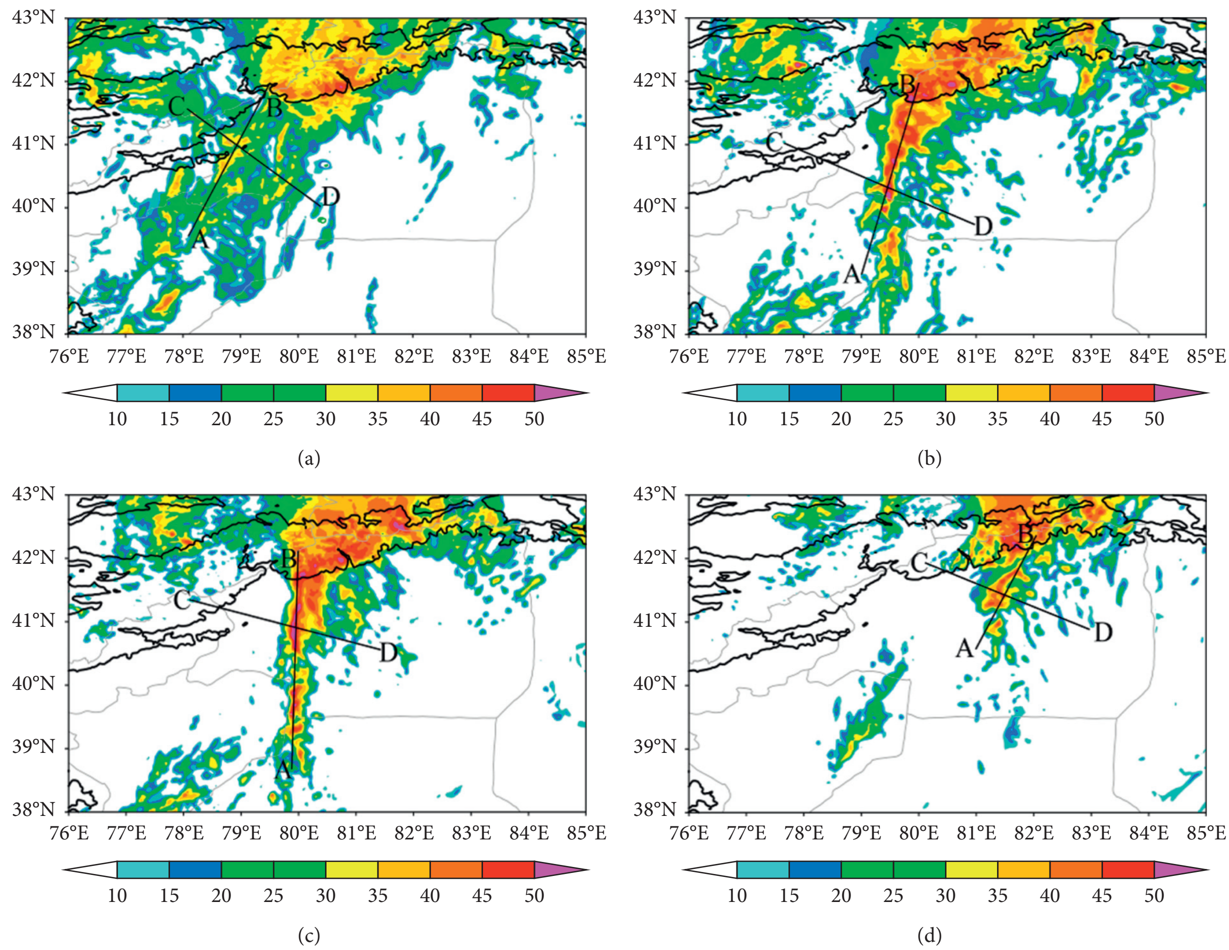
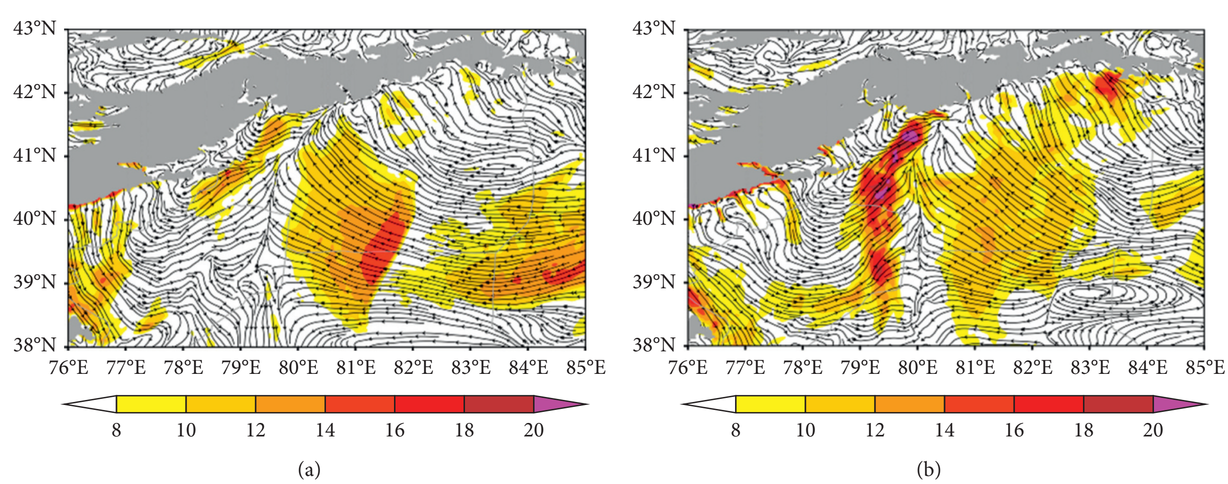


Figure 5: Simulated radar reflectivity in four stages of rainstorm system evolution (shadow; unit, dBZ; the solid black line represents the terrain of the Tianshan Mountains above 3000 m). (a) Initiation stage at 12:00 on July 31, (b) development stage at 16:00 on July 31, (c) maturity stage at 17:30 on July 31, and (d) extinction stage at 22:00 on July 31, 2016.



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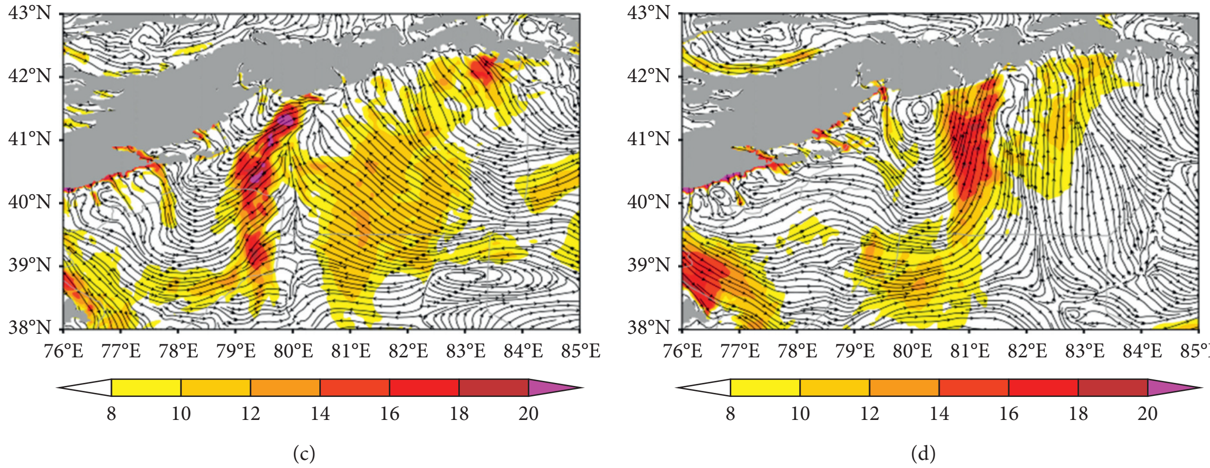
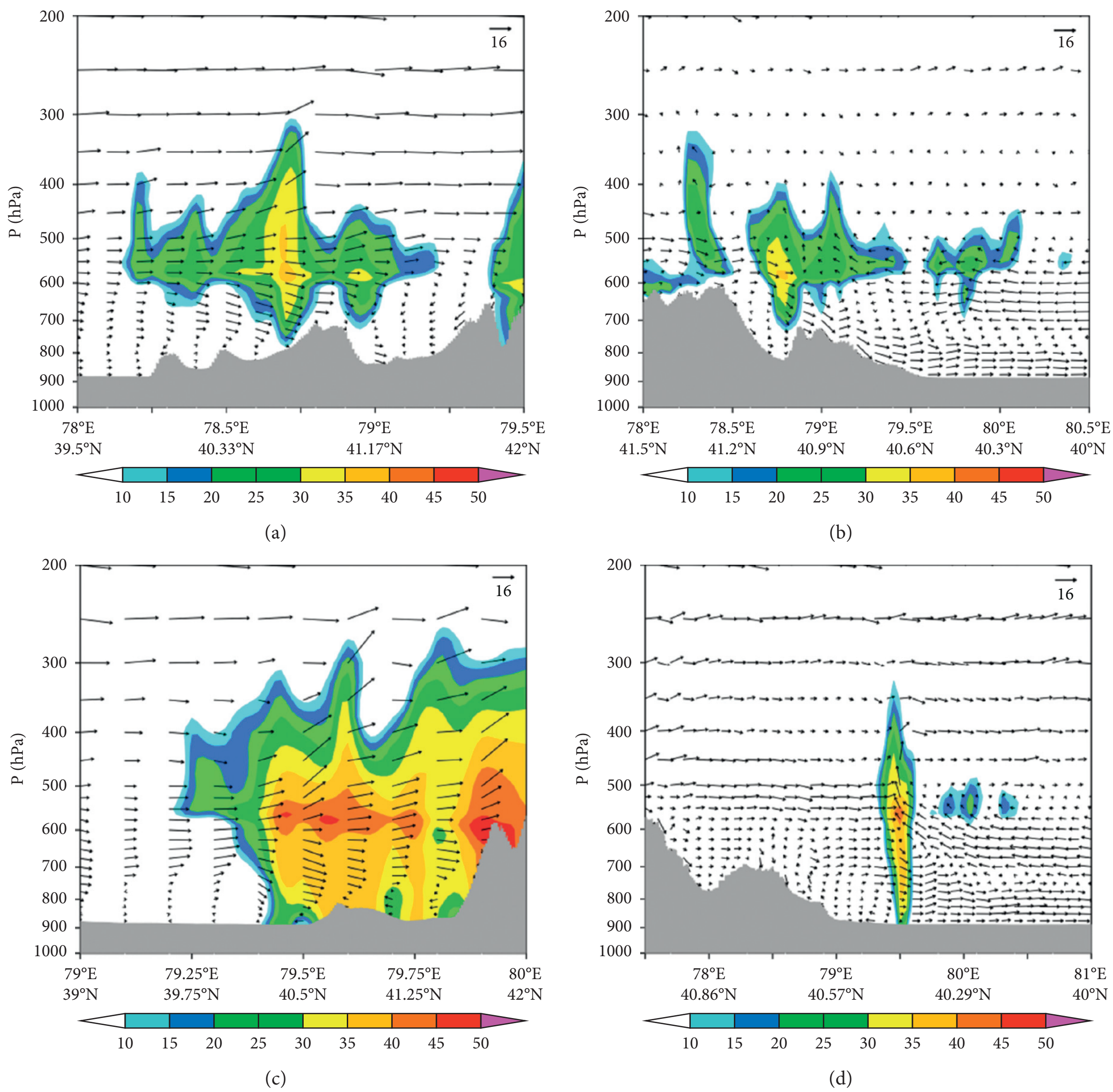


Figure 6: The 700 hPa flow field (streamline) and high wind speed area (colored and shaded, unit: m·s^{-1}; gray shading represents the terrain of the Tianshan Mountains above 3000 m). (a) Initiation stage at 12:00 on July 31, (b) development stage at 16:00 on July 31, (c) maturity stage at 17:30 on July 31, and (d) extinction stage at 22:00 on July 31, 2016.



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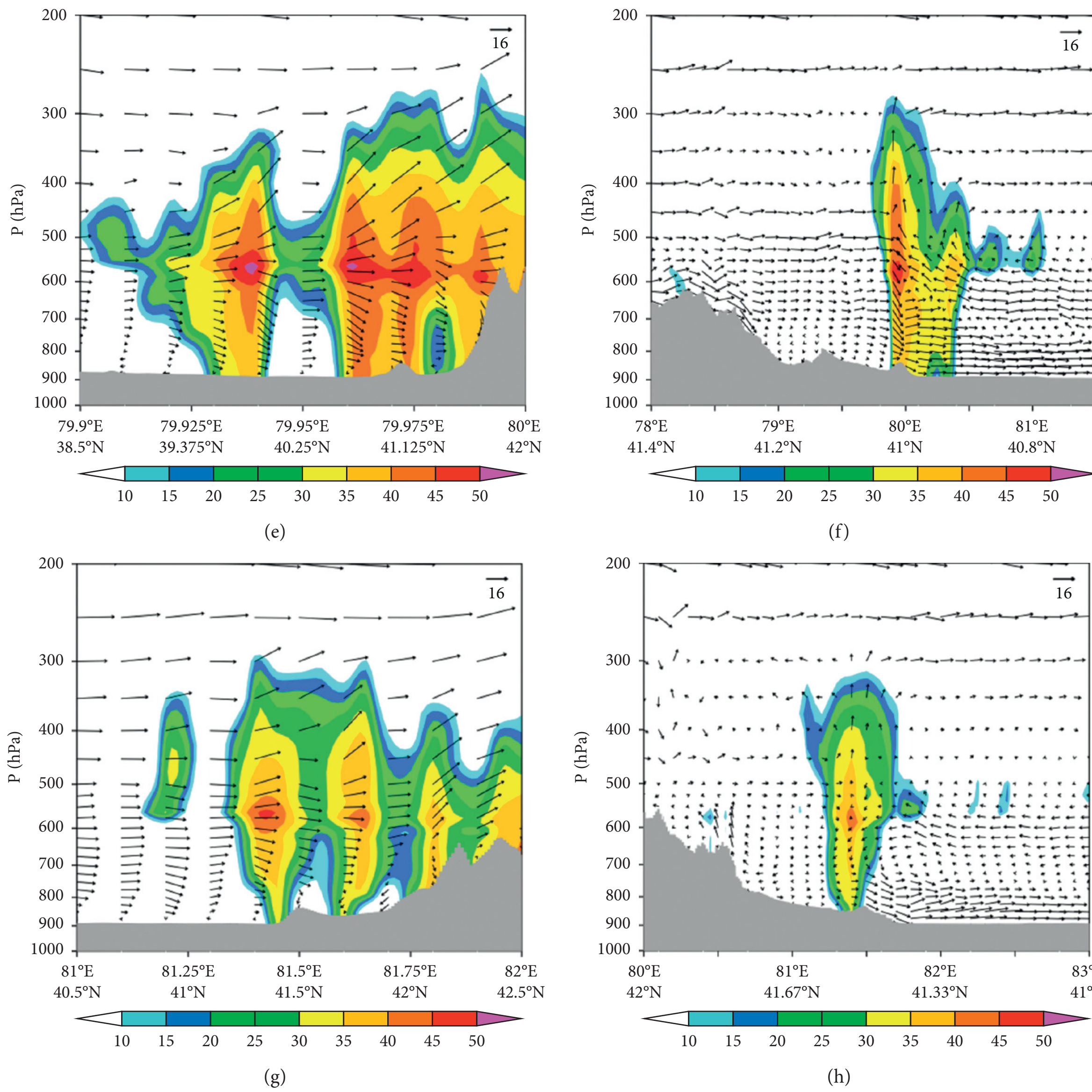

Figure 7: Vertical cross sections of simulated radar reflectivity (shaded, unit: dBZ) and wind vectors (arrow, unit: m·s^{-1}; for the convenience of analysis, the vertical velocity is multiplied by 10, and gray shading represents the terrain of the Tianshan Mountains, the same as below) along the black solid line shown in Figure 5. (a) Along AB in the initiation stage at 12:00 on July 31. (b) Along CD in the initiation stage at 12:00 on July 31. (c) Along AB in the development stage at 16:00 on July 31. (d) Along CD in the development stage at 16:00 on July 31. (e) Along AB in the maturity stage at 17:30 on July 31. (f) Along CD in the maturity stage at 17:30 on July 31. (g) Along AB in the extinction stage at 22:00 on July 31, 2016. (h) Along CD in the extinction stage at 22:00 on July 31, 2016.

3.6. Triggering Mechanism of the Rainstorm Process. The occurrence of heavy rain was inseparable from the convergence and relative movement of cold and warm air. Temperature disturbance could indicate the activity of cold and warm air. In the initiation stage of system evolution, cold air was transported from the Tianshan Mountains to Aksu, while the southeastern airflow in the middle layer was a positive temperature disturbance, and the cold and warm air converged near the convergence line (Figure 8(a)). As the system evolved further, at the stage of development, the low-level cold air lifted the warm air, and the upper atmosphere above the warm air was cold air. The vertical distribution of temperature disturbances enhanced atmospheric instability and was beneficial to the development of rainstorm systems (Figure 8(b)). At the maturity stage of the system, the contrast between the cold air and warm air near the convergence line was more obvious, and the negative and positive temperature disturbances were further strengthened, the atmospheric instability was strengthened, and the system was further developed (Figure 8(c)). During the system extinction phase, the confrontation between the cold air and warm air was weakened, which was not conducive to the development of the system (Figure 8(d)).

Heavy rain could not be separated from the large amount of water vapor transportation and convergence, and favorable water vapor conditions were one of the necessary

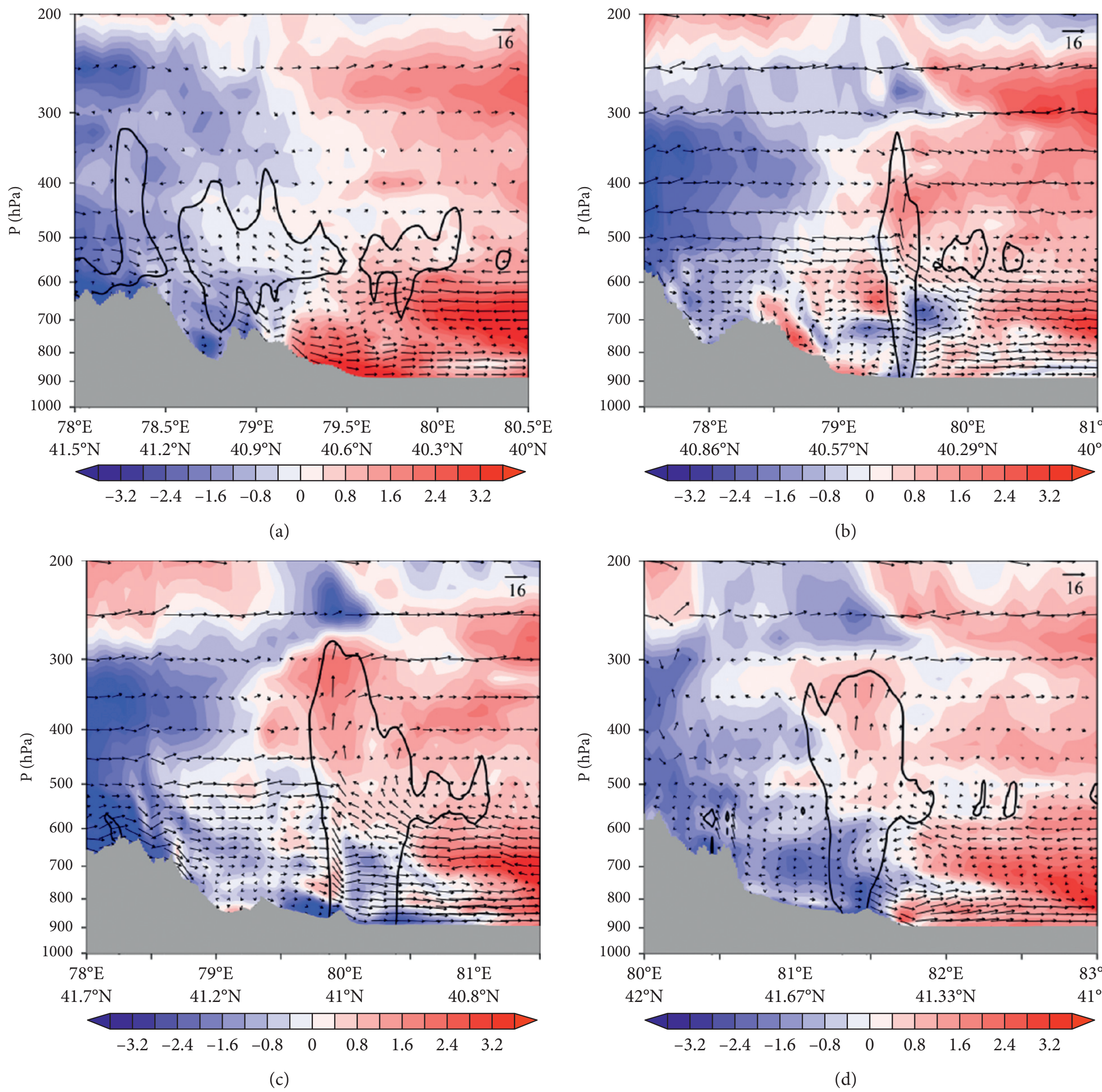

Figure 8: Vertical cross sections of simulated temperature disturbance (shaded, unit: °C; the solid black line is the area where the echo was greater than 10 dBZ representing the rainstorm system, the same as below) along the black solid line CD shown in Figure 5. (a) Initiation stage at 12:00 on July 31. (b) Development stage at 16:00 on July 31. (c) Maturity stage at 17:30 on July 31. (d) Extinction stage at 22:00 on July 31, 2016.

conditions for heavy rain. In the initiation stage of system evolution, the specific humidity of Aksu was $10\,\mathrm{g{\cdot}kg^{-1}}$, the water vapor flux from the Tianshan Mountains to Aksu was $10\,\mathrm{g{\cdot}cm^{-1}{\cdot}hPa^{-1}{\cdot}s^{-1}}$ in the lower layer, and the water vapor flux from Aksu to the Tianshan Mountains was $-10\,\mathrm{g{\cdot}cm^{-1}{\cdot}hPa^{-1}{\cdot}s^{-1}}$ from 700 to 500 hPa; however, the value of water vapor flux in the rainstorm system was only less than $5\,\mathrm{g{\cdot}cm^{-1}{\cdot}hPa^{-1}{\cdot}s^{-1}}$ near 79°E and 40.9°N (Figure 9(a)). In the development stage of the system, the northwestward water vapor channel and the southeastward water vapor channel met inside the rainstorm system, producing a water vapor flux divergence center of $-60\times10^{-8}\,\mathrm{g{\cdot}cm^{-2}{\cdot}hPa^{-1}{\cdot}s^{-1}}$ from 700 to 500 hPa (Figure 9(b)). At the maturity stage of system development, the specific humidity of the lower layer increased to $12\,\mathrm{g{\cdot}cm^{-1}{\cdot}hPa^{-1}{\cdot}s^{-1}}$, and the ascending airflow brought water vapor to a high altitude, which made the rainstorm system develop a humidity tongue, and the water vapor flux inside the rainstorm system further converged, which was conducive to the occurrence of heavy rain (Figure 9(c)). During the extinction phase of system evolution, both the water vapor flux and the water vapor flux divergence were weakened, which was not conducive to the maintenance of the rainstorm system, and the system gradually weakened and disappeared (Figure 9(d)).

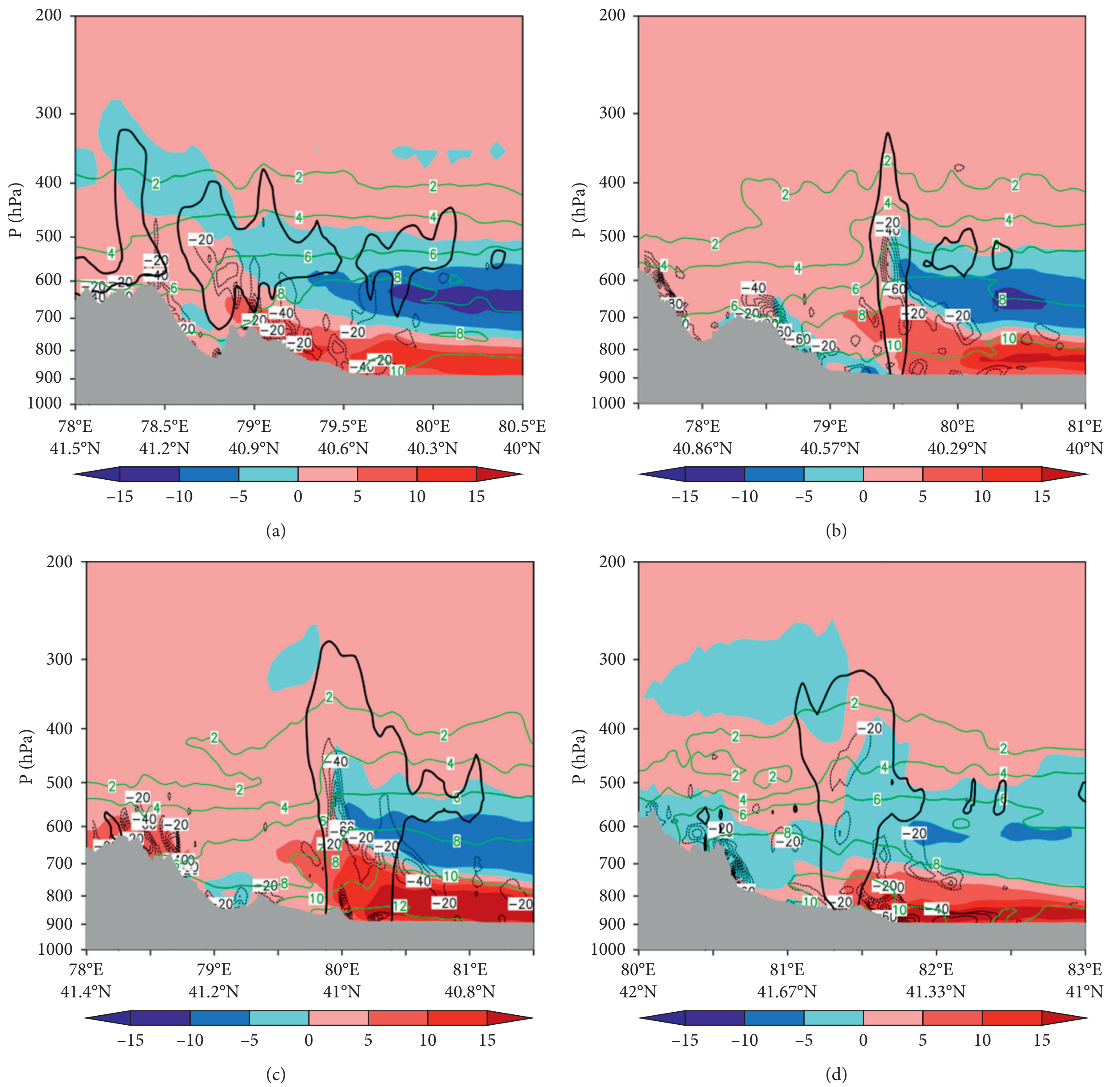

Figure 9: Vertical cross sections of simulated water vapor flux (shaded, unit: $g\cdot cm^{-1}\cdot hPa^{-1}\cdot s^{-1}$; the positive value mean transport from the Tianshan Mountains to Aksu and the negative value mean transport from Aksu to the Tianshan Mountains), divergence of water vapor flux (black-dotted line; unit: $10^{-8}\ g\cdot cm^{-2}\cdot hPa^{-1}\cdot s^{-1}$), and specific humidity (green solid line, unit: $g\cdot kg^{-1}$) along the black solid line CD shown in Figure 5. (a) Initiation stage at 12:00 on July 31. (b) Development stage at 16:00 on July 31. (c) Maturity stage at 17:30 on July 31. (d) Extinction stage at 22:00 on July 31, 2016.

In the initiation stage of system evolution, the ice-phase particles (including ice, snow, and graupel) were mainly located in the atmosphere above the Tianshan Mountains, and the atmosphere above Aksu was mainly distributed with cloud water. The ice-phase particles and cloud water coexisted near the convergence line (Figure 10(a)). During the development stage of system evolution, the ramping airflow near the convergence line brought a large amount of ice-phase particles to the upper atmosphere, and the maximum concentration of the ice-phase particles reached $1.6\ g\cdot kg^{-1}$ at 500 hPa (Figure 10(b)). With the further evolution of the system, the ascending airflow transported cloud water to a height of 350 hPa in the maturity stage. There was a large amount of supercooled cloud water above the 0°C temperature line. The concentration of cloud water near the convergence line exceeded $0.5\ g\cdot kg^{-1}$, the large concentration of ice-phase particles reached $2.4\ g\cdot kg^{-1}$, and the area where the ice particles and cloud water overlapped in the vertical distribution and the supercooled cloud water area were conducive to the transformation of ice-phase particles and liquid-phase particles, enhancing the heavy rain (Figure 10(c)). During the extinction stage of system

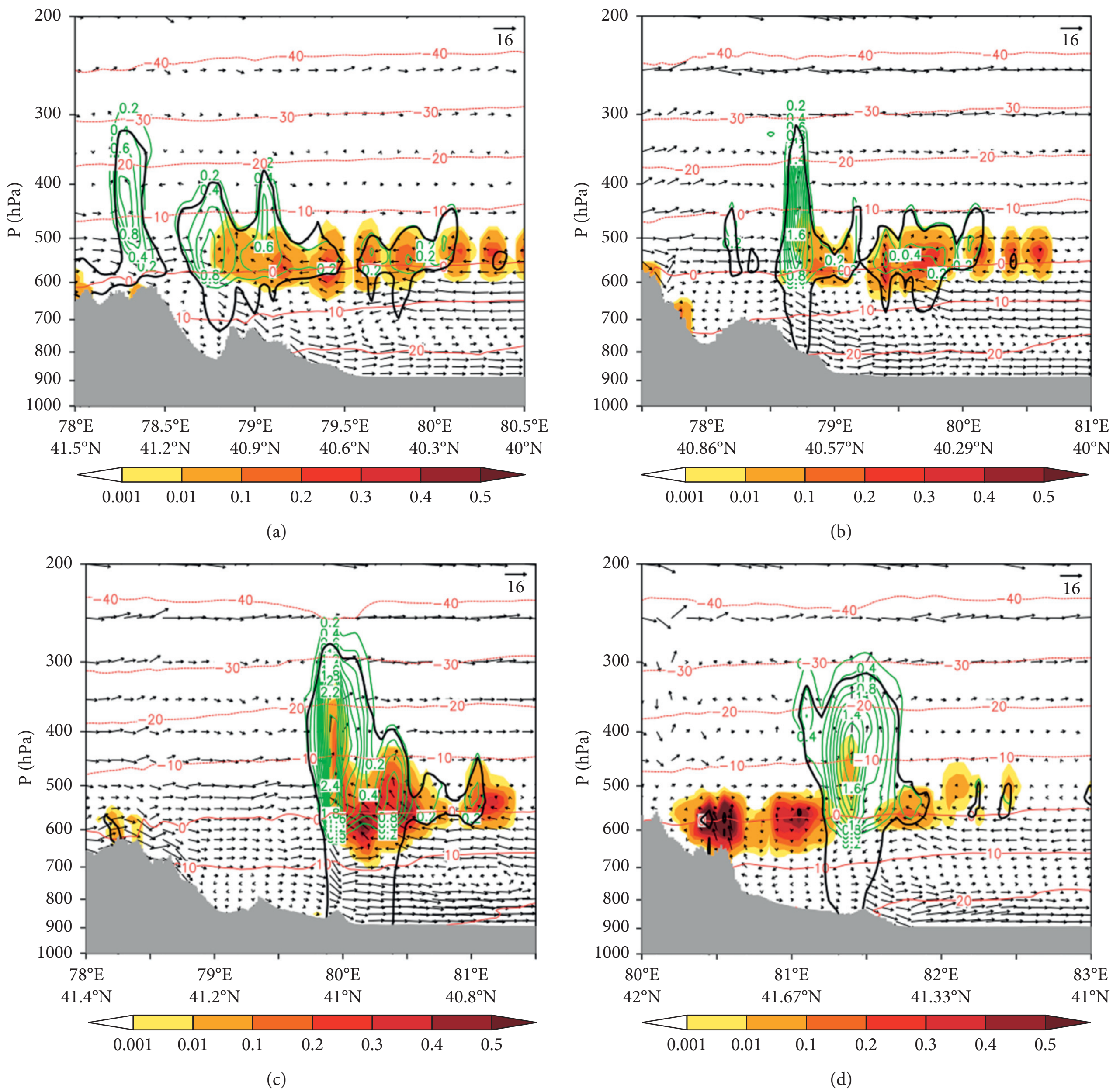

Figure 10: Vertical cross sections of the simulated concentration of ice-phase particles (shaded, unit: g·kg^{-1}, including ice, snow, and graupel), the concentration of cloud water (green solid line; unit: g·kg^{-1}), and temperature (red solid line, unit: °C) along the black solid line CD shown in Figure 5. (a) Initiation stage at 12:00 on July 31. (b) Development stage at 16:00 on July 31. (c) Maturity stage at 17:30 on July 31. (d) Extinction stage at 22:00 on July 31, 2016.

evolution, a large concentration of cloud water and ice particles still existed, but they were separated, which was not conducive to the maintenance of the system (Figure 10(d)).

4. Discussion and Conclusions

In this study, a rare rainstorm process in the area near the Tianshan Mountains in China under the background of an arid climate was investigated based on numerical simulation. By studying the different performances of the rainstorm system in different stages of evolution, the trigger mechanism of the storm was revealed from the evolution of power, heat, water vapor, and water condensate particles, and the trigger mechanism is significantly different from other parts of China. The warm-sector heavy rainfall in South China is mainly caused by terrain uplift and near-ground air instability in the afternoon induced by heating via solar radiation [42], and the combined effect of urban heat islands, sea breezes, and the terrain is the key to the rainstorm [43]. The heavy rain in the Yangtze–Huai River basin is closely related to the mesoscale convective system on the Meiyu front [44, 45]. In North China, the production of rainfall is often accompanied by strong convection, with a high intensity of short-duration precipitation [46], and heavy rainfall is more complex as a result of the sea-land circulation, mountain-valley winds, and the atmospheric circulation induced by the urban areas [47, 48].

Different from the monsoon climate zone, under the background of arid climate in Xinjiang, the huge terrain and complex underlying surfaces including deserts, oasis, cities, and scarce water vapor make the trigger mechanism of heavy rains in this area have obvious local characteristics. Through in-depth research on the trigger mechanism of a typical rainstorm in this area, the trigger mechanism of this heavy rain has been revealed. The main conclusions are as follows:

(1) The rainstorm system started in the western Aksu area near the Tianshan Mountains and was related to the thermal properties and topographic distribution of the Tianshan Mountains. The southwestern airflow at the east of the trough and the southeastern airflow from Aksu to the Tianshan Mountains formed a clear convergence line, and the rainstorm system that formed near the convergence line was linearly distributed and contained multiple mesoscale convection systems.

(2) The cold air from the Tianshan Mountains lifted the warm air from Aksu and formed a significant convergence in the middle atmosphere, causing the warm air to be transported upward; additionally, the inclined updraft and downdraft were in a separated state, which was beneficial to the development and maintenance of the system.

(3) The southeast water vapor transport met the westward water vapor transport near the convergence line in the middle atmosphere, forming an obvious center of water vapor convergence and creating good water vapor conditions for the storm system. The ascending air transported a large amount of cloud water and ice-phase particles to high altitudes and fully mixed them, which was conducive to the conversion of ice-phase particles and liquid-phase particles. At the same time, the abundant supercooled cloud water played an important role in the process of enhancing the rainstorm.

Data Availability

The data used in this paper can be provided by Yong Zeng (15099610397@163.com) upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

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