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Satellite-Retrieved Cloud Parameter Characteristics and Cause Analysis of a Short-Duration Heavy Rainfall Event on the Central Northern Slope of the Tianshan Mountains Postprint

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Abstract

Using conventional upper-air and surface observations, automatic weather stations, NCAR/NCEP FNL 0.5°$×$0.5° reanalysis data, and FY-4A satellite Advanced Geostationary Radiation Imager (AGRI) L2-level quantitative product data, an analysis was conducted of the cloud parameter characteristics and causes of the short-duration heavy rainfall event that occurred on June 16, 2019 in the Shihezi reclamation area on the northern slope of the Tianshan Mountains. Results indicate: (1) This short-duration heavy rainfall process occurred under a circulation pattern influenced by a short-wave trough split from an upper-level trough near Lake Balkhash, together with a 700 hPa shear line and an 850 hPa convergence line in the middle and lower troposphere. (2) The development and merging of black body temperature (Temperature black body, TBB) exhibited good correspondence with the rapid development, merging, and intensification of heavy rainfall cloud clusters. The heavy rainfall cloud clusters developed rapidly in the heavy rainfall region, became stable and quasi-stationary after maturation, and continuously merged and intensified with upstream cloud clusters. Precipitation commenced when the TBB of the heavy rainfall cloud clusters rapidly dropped to -52 °C. The heavy rainfall region was primarily located in the dense TBB contour zone of the heavy rainfall cloud clusters. The cloud top height of the heavy rainfall cloud clusters could develop up to 12 km. During the development of the cloud clusters, the cloud top phase consisted of mixed clouds containing water clouds and ice clouds, but was dominated by supercooled water clouds. (3) The presence of the 700 hPa shear line and the 850 hPa and surface convergence lines provided favorable dynamic conditions for the heavy rainfall. Moreover, the stable and quasi-stationary surface convergence line was conducive to strong vertical upward motion carrying abundant water vapor to accumulate in the heavy rainfall region, resulting in the occurrence of heavy rainfall. The water vapor pathways for this heavy rainfall event were primarily from the west and south.

Full Text

Satellite Retrieval of Cloud Parameter Characteristics and Causal Analysis of a Short-term Rainstorm in the Central Northern Slope of Tianshan Mountains

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Abstract

Using conventional upper-air and surface observations, automatic weather station data, NCAR/NCEP FNL 0.5°$×$0.5° reanalysis data, and Level 2 quantitative products from the FY-4A satellite Advanced Geosynchronous Radiation Imager (AGRI), this study analyzes the cloud microphysical structure characteristics and causative mechanisms of a short-term rainstorm event that occurred on June 16, 2019 in the Shihezi reclamation area on the northern slope of the Tianshan Mountains. The results indicate: (1) The rainstorm occurred under a circulation pattern jointly influenced by a shortwave trough split from a larger trough near Lake Balkhash and shear/convergence lines at 700 hPa and 850 hPa. (2) The development and merging of blackbody temperature (TBB) showed good correspondence with the rapid development, merging, and intensification of the rainstorm cloud cluster. Precipitation began when TBB dropped to −52 °C, with the rainstorm area primarily located in the dense gradient region of TBB isolines. The cloud top height of the rainstorm cluster could develop up to 12 km. During cloud cluster development, the cloud top phase consisted of mixed water and ice clouds, with supercooled water clouds being dominant. (3) The 700 hPa and 850 hPa shear/convergence lines, together with surface convergence, provided favorable dynamic conditions for the rainstorm. Strong vertical upward motion transported abundant water vapor into the rainstorm area, and the water vapor pathways primarily included a western path and a southern path.

Keywords: cloud microphysical structure; blackbody temperature (TBB); β-mesoscale; short-term rainstorm; FY-4A

1 Data and Methods

The data used in this study include conventional upper-air and surface observations, automatic weather station data, NCAR/NCEP FNL 0.5°$×$0.5° reanalysis data, and Xinjiang regional data. The precipitation analysis focuses on several stations in the southern Shihezi reclamation area, including Sidao Station, Kuangou Station, Niujuanzi Station, and Jiashiyao Station in Shawan County. Precipitation was concentrated within a short duration, characterized by high hourly rainfall intensity.

2.1 Weather Overview

Based on the hourly precipitation distribution (Figure 1), a local short-term heavy precipitation event occurred on June 16, 2019 in the Shihezi reclamation area of the Xinjiang Production and Construction Corps. Precipitation was concentrated between certain hours (hereinafter referred to as the primary precipitation period), with short duration and strong hourly intensity. At Sidao Station in Shawan County, precipitation reached 28.6 mm, while Niujuanzi Station recorded 64.8 mm, both exceeding the China Meteorological Administration' s standard for heavy rain ($ $24 mm). This extreme precipitation event was rare for the region, prompting this detailed analysis of cloud microphysical structure characteristics and causative mechanisms.

2.2 Circulation Pattern

At 500 hPa, Xinjiang was controlled by relatively straight westerly flow with multiple shortwave activities before the rainstorm. Siberia to the east of the Ural Mountains was dominated by a low vortex, while the European plain featured a high-pressure ridge. The ridge' s leading northwest airflow was strong, maintaining a jet stream with maximum wind speeds reaching 24 $\mathrm{m \cdot s^{-1}}$. On June 24, the European ridge intensified, with the leading northwest airflow guiding cold air southward, causing a trough to split from the southern Ural region and move eastward. At 700 hPa (Figure 2), the main trough near Lake Balkhash split, with a shortwave trough entering the rainstorm area, creating obvious wind speed convergence that caused the local short-term rainstorm in the southern Shihezi reclamation area. At 850 hPa, wind direction and speed convergence lines formed near the rainstorm area. The angle between the 500 hPa shortwave trough and the 700 hPa wind direction-speed convergence line, combined with orographic lifting by the Tianshan Mountains, favored rainstorm formation. In summary, the 500 hPa shortwave trough, 700 hPa wind direction-speed convergence line, and 850 hPa convergence line constituted the primary influencing systems for this rainstorm.

3 Evolution of Satellite-Retrieved Cloud Parameters

The new generation FY-4A geostationary meteorological satellite provides numerous Level 2 cloud quantitative products. This study uses blackbody temperature (TBB), cloud top height (CTH), and cloud phase products to investigate the cloud microphysical structure characteristics and evolution in the rainstorm area.

3.1 Evolution of the Rainstorm Mesoscale Convective System

At 08:00, a weak convective cloud cluster with TBB ≤ −22 °C existed southwest of the rainstorm area near Kuitun. The cloud cluster' s southwestern head began to expand in scope, with the central intensity reaching TBB ≤ −32 °C. The convective cloud cluster developed rapidly, forming a nearly circular system with TBB ≤ −42 °C. As the cloud cluster moved northeastward toward the rainstorm area, a new convective cloud cluster formed to its east, with the overall area significantly expanding (Figure 3). The cloud cluster exhibited a "northeast-southwest" elongated shape with northern and southern centers. The upstream cloud cluster merged with the rainstorm area cloud cluster, forming a "mountain" shape (Figure 3). The TBB center intensified to below −52 °C, with the rainstorm area located within the strengthened dense gradient region of TBB isolines. Precipitation had already begun in the rainstorm area. The cloud cluster reached its maximum development, with the TBB ≤ −52 °C area reaching its largest extent. Subsequently, the cloud cluster gradually weakened and moved eastward, with precipitation significantly decreasing as the convective weather system dissipated.

3.2 Evolution Characteristics of Cloud Top Height and Phase in the Rainstorm Area

At the initial stage, a convective cloud cluster with cloud top height of 6,000 m existed west of the rainstorm area, while the cloud top height above the rainstorm area was 8,000 m. As the convective cells in the southern Shihezi rainstorm area developed, the cloud top height continued to rise to 10,000 m, then rapidly ascended to 12,000 m at its most vigorous stage. The high cloud top area continuously expanded, forming a "northeast-southwest"oriented ellipse with its long axis, reaching maximum area. Thereafter, the system maintained this intensity before gradually decreasing to 10,000 m as it moved eastward and precipitation ended. Cloud phase and classification products detected supercooled water clouds in the newly formed convective cells near the rainstorm area. In the Kuitun-Shihezi rainstorm area, as the cloud top further developed, the cloud phase transitioned from mixed water-ice clouds to being dominated by supercooled water clouds. Analysis of TBB time series evolution at rainstorm stations (Figure 4) shows that before the rainstorm, TBB at stations like Niujuanzi, Kuangou, Sidao, and Jiashiyao in the rainstorm area all experienced slight increases, associated with the accumulation of unstable energy before precipitation. TBB then rapidly decreased to −32 °C, and when it dropped to −58 °C, surface precipitation intensity reached its maximum. Cloud phase and classification products both displayed mixed cirrus clouds, consistent with the strongest cloud top height development described in the previous section.

4.2 Dynamic Conditions

Heavy rainstorms require strong vertical motion. A time series of vertical velocity along the rainstorm area (Figure 7) shows that before the rainstorm, the rainstorm area was dominated by weak subsidence. Beginning at 750-1000 hPa, upward motion appeared above the rainstorm area with intensities of −0.3$\times10^{-1}$ m·s^{-1} at 500-650 hPa. As surface northerly winds strengthened and combined with terrain blocking effects, the upward motion intensified further. At 450 hPa, upward motion reached its maximum of −0.6$\times10^{-1}$ m·s^{-1}, with the entire column above the rainstorm area experiencing updrafts. Two upward motion maxima appeared at 200 hPa and 800 hPa with corresponding intensities of −3.0$\times10^{-1}$ m·s^{-1} and −1.2$\times10^{-1}$ m·s^{-1}, respectively. Such strong upward motion facilitated water vapor pumping, which was extremely favorable for rainstorm generation. After the rainstorm, the rainstorm area was dominated by subsidence throughout the column, marking the end of the rainstorm process.

4.3 Surface Convergence Line

The surface wind field showed consistent northwesterly winds of 2-8 m·s^{-1} in the Shihezi-Dushanzi-Karamay belt. The wind field in the southern Shihezi rainstorm area was mainly southeasterly and southerly winds at 2-4 m·s^{-1}, with a convergence line already generated west of the rainstorm area. As the convergence line stabilized and moved little, it was favorable for strong vertical upward motion to transport abundant water vapor into the rainstorm area, causing the rainstorm. The water vapor path analysis reveals two primary channels: one from the Caspian Sea-Aral Sea-Balkhash Lake region (westward path), evident at 850 hPa, and another from the Bay of Bengal crossing the Tibetan Plateau (southward path). These two water vapor channels converged near the rainstorm area. Water vapor flux divergence diagrams show that water vapor aggregation was not obvious at 700 hPa but became significant at 500-700 hPa, reaching maximum convergence. Under dynamic forcing, water vapor condensed and released latent heat, producing the rainstorm.

5 Conclusions

(1) This short-term rainstorm process was primarily caused by a shortwave trough split from a larger trough near Lake Balkhash, combined with shear and convergence lines at 700 hPa and 850 hPa that formed a closed circulation. The development and merging of TBB showed good correspondence with the rapid development and consolidation of the rainstorm cloud cluster. Precipitation began after TBB rapidly dropped to −52 °C, with the rainstorm area mainly located in the dense gradient region of TBB isolines. The cloud top height could develop up to 12 km, and during cloud cluster development, the cloud top phase consisted of mixed water and ice clouds dominated by supercooled water clouds.

(2) The 700 hPa and 850 hPa shear/convergence lines and surface convergence provided favorable dynamic conditions for the rainstorm. Strong vertical upward motion transported abundant water vapor, leading to rainstorm

occurrence. The water vapor pathways included primarily a western path and a southern path. Surface wind convergence between northwesterly and northeasterly winds, combined with orographic lifting from the southern Tianshan Mountains, favored the development and maintenance of the mesoscale convective system.

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