Comprehensive Analysis of a Spring Extreme Blizzard Event in Western Southern Xinjiang (Post-Print)

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Abstract

Using FY2E satellite data, Doppler weather radar products, conventional upper-air and surface observational data, and NCEP (0.25°$×0.25°)$reanalysisdatafromtheUSNationalCentersforE
westerlyandsoutherlyroutesinthemiddleanduppertroposphere, andaneasterlyrouteinthelowerandmiddletrop
seasonelevatedconvection : theeasterlyjetformedbycoldairintrudingeastwardintotheSouthernXinjiangBas
700hPaliftedtherelativelywarmandmoistairinwesternSouthernXinjiangtoacertainaltitude, functioningas
scale convective cloud clusters with black body temperature (TBB) <-65 ℃ and scales ranging from 80 to 200 km; radar echoes were characterized by stratiform echoes interspersed with convective echoes, with maximum reflectivity >40 dBZ and echo top height >6 km; further analysis of geostrophic absolute momentum (Mg) and pseudo-equivalent potential temperature (se) revealed that slantwise convection resulting from conditional symmetric instability led to the occurrence of heavy snowfall.

Full Text

Comprehensively analysis of an extreme snowstorm in the west of southern Xinjiang in spring

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Abstract

Based on high-resolution radiosonde observation data, national surface weather station observations, NCEP (0.25°$×0.25°)$reanalysisdata, FY2Esatellitedata, andproductsfromtheKashgar
westerlyandsoutherlypathsinthemiddle−uppertroposphere, andaneasterlypathinthelower−

middletroposphere.Thelong−termmaintenanceofaneasterlylow−leveljetbetween850–700hPaplayedadualrol
itwascriticalfortransportingwatervaporfromtheeasternTarimBasinwestwardtoformaconvergencecenterin
65°Candhorizontalscalesof80–200km—werethemainfactorsresponsibleforthehighsnowfallintensity.Doppl
h^{-1}$. Further analysis reveals that this extreme snowstorm exhibited characteristics of elevated convection in the cold season. Latitude-height cross-sections of geostrophic absolute momentum (M_g) and pseudo-equivalent potential temperature (_{se}) along 75°15 E (through the Wuqia station, the location of maximum snowfall) show that between 700–550 hPa, the slope of _{se} was greater than that of M_g, satisfying the criterion for conditional symmetric instability. It is preliminarily concluded that the extreme snowfall was caused by slantwise convection triggered by conditional symmetric instability.

Keywords: snowstorm; low-level jet; instability mechanism; slantwise convection; western southern Xinjiang

1. Data and Methods

This study utilizes conventional sounding and surface observation data from the Kizilsu Kirghiz Autonomous Prefecture (hereafter referred to as Kezhou) and Kashgar region, NCEP (0.25°$×$0.25°) reanalysis data, FY2E satellite data, and products from the Kashgar Doppler weather radar station. Synoptic-dynamic methods were employed to analyze the atmospheric circulation, vertical configuration, and dynamic characteristics of the extreme snowstorm. The water vapor budget was calculated for the region bounded by 35°-43°N, 73°-80°E, with the western boundary along 73°E, eastern boundary along 80°E, southern boundary along 35°N, and northern boundary along 43°N. Water vapor transport and budget analysis were performed for three layers: surface to 700 hPa (low-level), 700-500 hPa (mid-level), and 500-300 hPa (high-level). The 500-300 hPa layer was selected for the high-level analysis because water vapor content above 300 hPa is negligible. Satellite infrared cloud images were processed to obtain cloud-top black body temperature (TBB), and radar data were processed using GR2Analyst software. Snowfall intensity classifications follow Xinjiang local standards: 6.1-12.0 mm as heavy snow, 12.1-24.0 mm as severe snowstorm, and $ $24.1 mm as extreme snowstorm, with the daily snowfall period defined from 20:00 to 20:00 Beijing Time.

2. Results and Analysis

2.1 Snowstorm Observations and Extreme Characteristics

From March 3-6, 2017, a strong snowfall event occurred from west to east across Kezhou and Kashgar in western southern Xinjiang (Fig. 1). The cumulative snowfall exceeded 12.0 mm at multiple stations. Both Wuqia station and Harabulak Township station in Akqi County broke historical records. Wuqia station recorded 18.6 mm of snowfall, approaching its annual average precipitation, with a maximum daily snowfall of 15.0 mm—the highest since records began. Harabulak Township station recorded 23.2 mm, ranking first historically for the same period, with both cumulative and daily snowfall reaching record highs since station establishment. Additionally, Kerekeqike Township in Akto County, Akqi County, and Turugart Pass station experienced severe snowstorms with snowfall amounts of 16.4 mm, 15.6 mm, and 14.8 mm, respectively. Maximum snow depth increases were 28.0 cm at Wuqia, 37.5 cm at Harabulak, and 33.0 cm at Turugart—all record highs for the same period—severely impacting local agriculture, animal husbandry, and transportation.

The snowstorm exhibited high hourly intensity, with the strongest period occurring from the early morning through daytime on March 4. At Wuqia station, hourly snowfall rates reached 2.1 $mm \cdot h^{-1}$ (07:00–09:00) and 2.6 $mm \cdot h^{-1}$ (13:00-15:00). Harabulak station recorded the maximum hourly intensity of 3.1 $mm \cdot h^{-1}$ during 07:00–09:00.

2.2 Large-scale Circulation Background

The primary influence system for this snowstorm was a Central Asian low vortex. At 500 hPa, a closed vortex formed over the Tashkent region at 08:00 on March 3, with a central geopotential height of 548 dagpm and a -32°C cold center. Influenced by an unstable shortwave trough over Europe, the Caspian Sea ridge retreated southeastward, and the low vortex continued to deepen. Its southwestern airflow covered the Pamir Plateau, Kezhou, Kashgar, and western Hotan regions. The maintenance of this southwestern flow favored positive vorticity advection, promoting vertical motion development. By 20:00 on March 4, as the system shifted to northwesterly flow, the snowfall process ended.

At 850 hPa, a Mongolian high-pressure center with intensity of 1040 hPa slowly moved eastward, creating a north-south pressure gradient of 17.5 hPa across northern and southern Xinjiang. By 20:00 on March 4, the high strengthened to 1045 hPa, with the pressure gradient increasing to 27.5 hPa. The surface pressure field exhibited high pressure in the north and east, and low pressure in the south and west, establishing an "eastward intrusion" pattern. The easterly winds in the Tarim Basin gradually intensified, with a low-level easterly jet of 14 $m \cdot s^{-1}$ developing at Ruoqiang station. This easterly jet transported cold air from eastern Xinjiang into the Tarim Basin, creating a temperature configuration with warm air in the basin and cold air in eastern regions, with an 850 hPa temperature difference of 16°C. Concurrently, a northwest-southeast oriented shear line formed between Kashgar and Hotan, where cold and warm air masses intersected for an extended period. The snowfall area was located near this shear line and within the convergence zone between easterly and southeasterly winds at 700–850 hPa, which favored moisture convergence and strong snowfall over the eastern Pamir Plateau. The cold air "pad" from the eastward intrusion provided favorable synoptic-scale conditions for the instability mechanisms analyzed below.

2.3 Water Vapor Characteristics Analysis

Three moisture transport pathways supplied water vapor for this snowstorm: a westerly path from the Caspian Sea region, a southerly path from southern Central Asia, and an easterly path from the eastern Tarim Basin. The water vapor budget analysis (Fig. 3) shows that in the middle-upper layers, water vapor entered through the western and southern boundaries via westerly and southerly flows, while in the lower-middle layers, water vapor entered through the eastern boundary via easterly flow. Throughout the event, net water vapor input through the western and southern boundaries in the middle-upper layers was 16.12×10^{6} $\mathrm{kg\cdot s^{-1}}$ and 19.57×10^{6} $\mathrm{kg\cdot s^{-1}}$, respectively, while input through the eastern boundary in the lower-middle layers was 29.73×10^{6} $\mathrm{kg\cdot s^{-1}}$. This indicates that the westerly and southerly paths provided the primary moisture source, though the easterly path also contributed significantly.

Water vapor transport at the western and southern boundaries peaked at the onset of snowfall, while easterly transport strengthened gradually. The easterly water vapor transport intensified most strongly at 08:00 on March 4, corresponding to the period of maximum snowfall intensity. After weakening at 20:00 on March 4, water vapor transport through all boundaries strengthened again, corresponding to the second intense snowfall period. Thus, the westerly and southerly moisture transport provided a stable moisture environment, while the easterly transport showed close correspondence with snowfall intensity variations.

2.4 Mesoscale System Characteristics

2.4.1 Satellite Cloud Image Features Satellite cloud images reveal the evolution of cloud systems and effectively monitor the development of mesoscale cloud clusters during heavy snowfall periods. At 11:30 on March 3, a cloud band along the western border of southern Xinjiang began moving eastward and northward toward Kezhou. By 22:30, this band developed into a 1000 km-long stratiform cloud system with TBB<-30°C, covering an expanded area. As the system moved over Kashgar and Kezhou, snowfall began but with relatively low intensity.

From 01:30 on March 4, the cloud system intensified significantly, with TBB dropping below -45°C over most of the area and strong centers reaching TBB<-55°C. By 07:00, TBB in some centers fell below -60°C. During 01:30–09:30, when TBB<-45°C, snowfall intensity increased markedly, with Wuqia station recording 2.3 $\mathrm{mm\cdot h^{-1}}$. At 09:00, Harabulak station reached its maximum hourly intensity of 3.1 $\mathrm{mm\cdot h^{-1}}$. At 15:00, a nearly circular mesoscale cloud cluster about 80 km across with TBB<-60°C appeared over central Kezhou, producing hourly snowfall rates exceeding 1.5 $\mathrm{mm\cdot h^{-1}}$. The development, movement, and dissipation of these mesoscale convective cloud clusters corresponded well with the timing and location of heavy snowfall, with multiple TBB<-45°C clusters playing a decisive role in producing intense snowfall.

2.4.2 Radar Echo Characteristics Analysis of Kashgar Doppler radar data using GR2Analyst software reveals three evolutionary stages: development, maturity, and dissipation.

Development stage (00:00-04:00 on March 4): Relatively strong stratiform echoes appeared northwest and west of the radar station, with several embedded convective cells. The radial velocity field showed easterly flow at low levels, with a convergence line between easterly and westerly winds near the station.

Maturity stage (04:00-06:00 on March 4): As new echoes continuously merged into the stratiform echo from the southwest, the echo area expanded. Reflectivity factors exceeded 40 dBZ near 3 km altitude, with echo tops approaching 6 km. At 05:00, Akto County's Kerekeqike Township station recorded its maximum hourly snowfall intensity. The vertical structure showed strong echo columns near the surface, with the strongest echoes reaching the ground, indicating ongoing or persistent snowfall.

Dissipation stage (06:00-14:00 on March 4): After 06:00, the area of convective cells gradually decreased. By 11:00, the stratiform echo had dissipated into banded and cellular echoes with obvious gaps and weaker intensity. By 14:00, only scattered echoes below 15 dBZ remained, and the snowstorm essentially ended.

2.5 Dynamic Conditions and Instability Mechanism Analysis

Both satellite imagery (mesoscale convective cloud clusters) and radar echoes (convective cells with reflectivity >45 dBZ) indicate that this snowstorm possessed distinct convective characteristics, which are rare in spring compared to summer. Therefore, analyzing the dynamic lifting conditions and instability mechanisms is essential.

2.5.1 Dynamic Lifting Conditions Key parameters for atmospheric dynamic processes include divergence, vorticity, and vertical motion. Divergence describes atmospheric convergence and divergence, vorticity describes rotational motion, and vertical motion provides the primary driving force for snowstorms.

Cross-sections of vorticity, divergence, and vertical velocity along 75°15 E (Fig. 7) show that before snowfall began, a divergence zone existed above 500 hPa over the snowstorm area (38°-41°N), with convergence below 700 hPa. At 20:00 on March 3, low-level convergence intensified rapidly, with a -10×10^{-5} s^{-1} convergence center below 700 hPa and a 12×10^{-5} s^{-1} divergence center above 500 hPa, establishing a typical lower-level convergence/upper-level divergence pattern. This configuration enhanced vertical motion throughout the troposphere, which persisted until 08:00 on March 4, corresponding to the strongest snowfall period.

Similarly, the vorticity zone over the snowfall area gradually intensified and expanded. By 20:00 on March 3, a positive vorticity center of 10$×10^{-5}$ s^{-1} existed at 500 hPa, strengthening to 25$×10^{-5}$ s^{-1} by 02:00 on March 4, with the entire column becoming positively vortical. This favorable configuration of divergence and vorticity fields enhanced vertical motion and increased snowfall intensity.

2.5.2 Instability Mechanism Analysis Since lifting and thermal conditions in winter are weaker than in summer, vertical convection is difficult to develop. However, slantwise convection is more easily triggered under conditional symmetric instability (CSI), where even small lifting can initiate convection if the atmosphere is saturated and slantwise ascent exists. Does this snowstorm belong to this mechanism? Further analysis of CSI provides an answer.

The strongest snowfall occurred from the early morning through daytime on March 4. The 08:00 sounding at Kashgar station (Fig. 8) shows easterly winds below 500 hPa, transitioning to southwesterly winds at 15 m·s^{-1} around 600 hPa. The 0-6 km wind shear vector reached 22 m·s^{-1}, with strong vertical wind shear and baroclinicity. The temperature-dewpoint difference in the 700-600 hPa layer was only 1-2°C, indicating a near-saturated layer. The convective available potential energy (CAPE) increased significantly from 20:00 on March 3 to 08:00 on March 4, suggesting enhanced convective potential. An inversion layer existed at 900-800 hPa, which, combined with the circulation analysis, indicates that cold air from the east formed a "cold pad" near the surface while relatively warm and moist air existed above. This configuration is characteristic of elevated convection in the cold season.

To diagnose CSI, we examine the latitude-height cross-section of geostrophic absolute momentum (M_g) and pseudo-equivalent potential temperature (_{se}) along 75°15 E (through Wuqia station, the maximum snowfall center). During the snowstorm, between 700-550 hPa, the slope of _{se} exceeded that of M_g (Fig. 8), satisfying the CSI criterion. This indicates that the extreme snowfall resulted from slantwise convection triggered by conditional symmetric instability.

3. Conclusions

Using multi-source data, this study comprehensively analyzes the synoptic background, water vapor conditions, and triggering mechanisms of an extreme spring snowstorm in western southern Xinjiang, reaching the following conclusions:

1) This extreme snowstorm resulted from the interaction of multiple-scale weather systems. The Central Asian low vortex at 500 hPa was the primary influence system, with its southwestern flow guiding warm moist air from southern Central Asia northward and providing positive vorticity advection favorable for vertical motion. The "eastward intrusion" of cold air formed a low-level easterly jet that converged over western southern

Xinjiang, creating a "wedge" that lifted relatively warm and moist air to a certain height and formed a near-surface "cold pad."

2) Three moisture transport pathways existed: a westerly path from the Caspian Sea region, a southerly path from southern Central Asia, and an easterly path from the eastern Tarim Basin. The water vapor budget shows net input through the western and southern boundaries in the middle-upper layers, and through the eastern boundary in the lower-middle layers. The intensity variation of easterly moisture transport corresponded well with snowfall intensity changes.

3) Both satellite and radar data revealed convective characteristics. The development, movement, and dissipation of meso-β-scale convective cloud clusters with TBB<-65°C and scales of 80-200 km corresponded well with the timing and location of heavy snowfall, representing the primary cause of high snowfall intensity. Although radar echoes were predominantly stratiform (15-25 dBZ), embedded convective blocks exhibited reflectivity factors exceeding 40 dBZ with echo tops above 5 km, comparable to weak summer convective precipitation.

4) This snowstorm exhibited characteristics of elevated convection in the cold season. The Kashgar sounding showed easterly cold flow at low levels and warm moist southerly flow aloft, with an inversion layer at 900-800 hPa. Cross-sections of M_g and _{se} revealed that between 700-550 hPa, the slope of _{se} exceeded that of M_g, satisfying the CSI criterion. It is preliminarily determined that slantwise convection triggered by conditional symmetric instability caused the extreme snowfall. The presence of strong vertical velocity centers in both lower and middle-upper levels, differing from previous studies, may be related to slantwise convection development due to CSI.

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Note: Figure translations are in progress. See original paper for figures.