Postprint: Comparative Analysis of Two Blizzard Events in the Northern Foothills of the Tianshan Mountains

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Abstract

Using conventional meteorological observation data, NCEP/NCAR 1°×1° (U.S. National Centers for Environmental Prediction—NCEP and National Center for Atmospheric Research—NCAR) reanalysis data, Global Data Assimilation System (GDAS) data, the Lagrangian-based airflow trajectory model (HYSPLIT_v4.9), FY-2E satellite data, and Doppler radar products, a diagnostic analysis was conducted on two snowstorm weather processes at the northern foothills of the Tianshan Mountains in February 2014 and March 2016. The results indicate that the snowfall areas of both snowstorm processes occurred in the overlapping region of the area ahead of the 500 hPa trough, low-level shear or convergence zones, upper-level divergence zones, regions with large vertical temperature advection gradients, and large-gradient regions at the periphery of the equivalent blackbody brightness temperature (TBB) center. Through diagnostic analysis, it was found that moist symmetric instability similar to that in heavy rainfall processes existed over the snowstorm area during the 2016 snowstorm event, resulting in relatively large atmospheric potential instability energy and providing an instability mechanism for the snowstorm. However, moist symmetric instability was not found in the 2014 snowstorm event, indicating that conditional symmetric instability is not the sole cause of snowstorms and may also be influenced by other instability mechanisms or dynamic and thermal factors, but it has a significant amplifying effect on snowfall intensity per unit time. Analysis of the evolution of radar echo characteristics revealed that the intensity, duration, and extent of the radar echo center were consistent with the changes in the heavy snowfall center.

Full Text

Preamble

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Abstract: Two heavy blizzards in northern Xinjiang, China occurred on February 23, 2014 and March 2, 2016. Although the central location and snowfall size of the two blizzards were similar, the hourly snowfall and snowfall duration of the two snowstorms were different. In particular, during the heavy snowfall in March 2016, the maximum hourly snowfall at some observation stations was nearly 4.0 mm, reaching the historical maximum since the establishment of the recording system. However, the maximum hourly snowfall of the blizzard in February 2014 was only 1.8 mm at the observatory. In order to understand the difference between the two blizzard weather events, this paper investigated the weather process about the two events using the meteorological observational data, NCEP/NCAR 1°×1° reanalysis data, the GDAS (Global Data Assimilation System) data and the HYSPLIT 4.9 model, FY-2E data and Doppler radar product. The results are summarized as follows: The snowfall areas of the two blizzards were both located in the overlaying area in front of the 500 hPa trough with shearing or converging at the low-levels, diverging at the high-level, and large temperature advection gradient in the vertical direction, and in the larger gradient of the edge of the cloud TBB center. Domestic researchers have studied more about the effects of frontal forcing and symmetric instability on heavy rain, but their application in blizzard was less involved. Diagnosing atmospheric stability through moist potential vorticity revealed that the location of the blizzard center in 2016 and the area with moist potential vorticity negative value were basically the same. There was a moist symmetric instability over the blizzard area which is similar to that of a rainstorm. This mechanism can help the inclined updraft be formed and developed, then cause the release of a large potential unstable energy in the atmosphere and provide unstable mechanism for blizzard. When moist symmetric instability was gone, the hourly snowfall was also decreased. Therefore, this moist symmetric instability structure was the main cause of the large amount of snowfall in the blizzard in 2016. However, no moist symmetric instability was found in the blizzard in 2014, indicating that the conditional symmetric instability was not the only cause in northern Xinjiang. It may be affected by other mechanisms of instability, dynamic factors and thermal factors, but it had a significant effect on the increase of snowfall intensity per unit time. Snowfall was closely related to low-level jet. The inten-

sity, duration and scope of the echo center were consistent with the changes in the center of the strong snowfall.

Keywords: northern Tianshan Mountains; blizzard; moist potential vorticity; diagnostic analysis

1. Introduction and Data

Two heavy blizzard events in northern Xinjiang were selected for comparative analysis: the February 23-26, 2014 blizzard (hereafter "20140223 blizzard") and the March 1-4, 2016 blizzard (hereafter "20160302 blizzard"). The study utilized multiple data sources including conventional meteorological observations, NCEP/NCAR 1°×1° reanalysis data, Global Data Assimilation System (GDAS) data, the HYSPLIT_v4.9 trajectory model, FY-2E satellite data, and Doppler radar products from the Urumqi radar station.

1.1 Data Sources and Methodology

The primary data periods correspond to the two blizzard events. The NCEP/NCAR 1°×1° reanalysis dataset provided atmospheric background fields, while GDAS data supplied three-dimensional meteorological fields for trajectory analysis. Satellite data from FY-2E offered cloud top brightness temperature (TBB) observations. The HYSPLIT-4.9 model was employed for 120-hour backward trajectory simulations at multiple levels.

The diagnostic analysis employed the moist potential vorticity (MPV) equation:

$$MPV \approx -\frac{g}{\theta_e}(\zeta + f)\frac{\partial \theta_e}{\partial p}$$

where g is gravitational acceleration, θ_e is equivalent potential temperature, ζ is relative vorticity, and f is the Coriolis parameter. The equation components represent: g/θ_e accounts for static stability, $(\zeta + f)$ represents absolute vorticity, and $\partial\theta_e/\partial p$ denotes vertical stratification. Positive ζ indicates cyclonic rotation, while negative ζ indicates anticyclonic rotation. The term $(\zeta + f)$ reflects inertial stability, and the product of these terms quantifies atmospheric instability.

Snowfall intensity was classified according to standard thresholds: moderate snow (6.1–12.0 mm) and heavy snow (12.1 mm) based on 24-hour accumulated precipitation.

1.2 Case Overview

The 20140223 blizzard was associated with a central pressure of 1023 hPa, while the 20160302 blizzard had a much lower central pressure of 1002 hPa. Total snowfall amounts for the 2014 event reached 13.8 mm, 13.1 mm, and 11.0 mm at different stations, with a maximum hourly intensity of only 1.8 mm. In contrast, the 2016 event produced maximum hourly snowfall approaching 4.0 mm at several locations, establishing new records since the implementation of automated observation systems.

[Figure 1: see original paper] shows the 500 hPa geopotential height and wind fields for both events. The Rossby wave pattern [21] and MPV distribution indicate that the 20160302 blizzard developed within a region of strong negative MPV values, suggesting enhanced moist symmetric instability. The 2014 event, however, exhibited weaker instability signals.

[Figure 2: see original paper] presents the geopotential height and wind vectors at 300 hPa, 500 hPa, and 700 hPa, with the blizzard center marked. The 20160302 event featured a more intense upper-level trough and stronger jet streams, with wind speeds reaching 54 m · s ^{1} at 300 hPa and 30 m · s ^{1} at 700 hPa, compared to 44 m · s ^{1} and 18 m · s ^{1} respectively for the 2014 event. The vertical wind shear between 850 hPa and 500 hPa exceeded 24 m · s ^{1} in both cases, but the 2016 event showed stronger thermal advection gradients.

3. Analysis of Temperature Advection

The vertical cross-section along 87°E reveals significant differences in temperature advection between the two events. For the 20160302 blizzard, strong warm advection exceeding 10×10^{-5} K · s ^{1} was observed at 850 hPa, with a pronounced T-lnP curve indicating steep lapse rates. The 20140223 event showed weaker warm advection confined to mid-levels around 500 hPa.

[Figure 3: see original paper] illustrates the vertical velocity (color shading) and circulation (streamlines) along 87°E. The 2016 event exhibited stronger upward motion, with vertical velocities exceeding 80×10^{-2} m · s ^{1} in the 45°-48°N latitude band between 300-600 hPa. This ascending branch was collocated with the region of maximum moisture flux convergence.

[Figure 4: see original paper] depicts the temperature advection cross-section, showing that the 20160302 blizzard had deeper and more intense warm advection extending from the surface to 500 hPa, which contributed to greater atmospheric destabilization.

3.3 Moisture Flux and Vorticity Analysis

[Figure 5: see original paper] presents the vertical distribution of MPV (contours) and vorticity (color shading) along 87°E. At 20:00 on February 24, 2014, the blizzard center was characterized by MPV > 0 and MPV $<$ -0.9 PVU, indicating conditional symmetric instability. The 20160302 event showed even stronger negative MPV values, with MPV reaching -1.2 PVU at 850 hPa and -0.8 PVU at 700 hPa. The negative MPV region extended from 82°E to 83°E, coinciding with the heavy snowfall band.

The moisture flux divergence pattern [Figure 7: see original paper] along 44°N shows that the 20160302 blizzard had stronger moisture convergence, with values reaching -30×10^{-7} $\mathrm{g\cdot cm^{2}\cdot hPa^{1}\cdot s^{1}}$ and specific humidity exceeding 6.5 $\mathrm{g\cdot kg^{1}}$. This moisture was transported by low-level jets from the west and southwest, as confirmed by HYSPLIT backward trajectories [Figure 6: see original paper].

4.2 Mechanism Discussion

The HYSPLIT trajectory analysis at 1000 m, 2000 m, and 3000 m levels shows that air parcels originated from different source regions. For the 20140223 event, trajectories came primarily from the northwest, while the 20160302 event had more southerly and westerly moisture pathways, indicating better water vapor transport from warmer regions.

The radar analysis reveals distinct echo structures. [Figure 8: see original paper] shows the TBB evolution, with the 2016 event maintaining cloud top temperatures below -40°C for over 12 hours. The radar reflectivity [Figure 9: see original paper] exhibited a characteristic "V" -shaped echo pattern in both cases, but the 20160302 blizzard had higher reflectivity values (35–45 dBZ) and stronger radial velocity convergence (26 $\mathrm{m\cdot s^{1}}$) compared to the 2014 event (15-20 dBZ, 11 $\mathrm{m\cdot s^{1}}$). The echo top heights exceeded 4 km in 2016 versus 2 km in 2014.

5.2 Radar Echo Characteristics

The Doppler radar observations at Urumqi station show that the 20160302 blizzard produced reflectivity values of 25-30 dBZ with a well-defined "V" -shaped echo structure [Figure 9: see original paper]. The radial velocity field indicated strong convergence within the echo center, with a velocity couplet of 26 $\mathrm{m\cdot s^{1}}$. The 20140223 event showed weaker reflectivity (15-20 dBZ) and lower echo tops (~2 km), consistent with its lower snowfall rates.

The mesoscale structure analysis along 1.5° azimuth shows that the 2016 event had a more organized vertical velocity field, with persistent updrafts exceeding 20×10^{-2} $\mathrm{m\cdot s^{1}}$ at 850 hPa. This was supported by stronger low-level jet transport and better moisture convergence.

5.3 Summary and Conclusions

The comparative analysis reveals four key differences between the two blizzards:

1. **Dynamic Structure**: The 20160302 blizzard had a deeper 500 hPa trough, stronger vertical wind shear, and more intense upper-level divergence, which favored stronger vertical motion development.
2. **Thermodynamic Conditions**: The 2016 event exhibited pronounced moist symmetric instability (negative MPV) throughout the lower and middle troposphere, providing an unstable energy release mechanism that enhanced snowfall intensity. The 2014 event lacked this instability.

3. **Moisture Transport**: Backward trajectories show that the 2016 blizzard had more efficient moisture transport from southwestern pathways, with specific humidity exceeding 6.5 $\mathrm{g \cdot kg^{\ 1}}$ and moisture flux convergence reaching -30×10^{-7} $\mathrm{g \cdot cm^{\ 2} \cdot hPa^{\ 1} \cdot s^{\ 1}}$.

4. **Radar Characteristics**: The 2016 event produced stronger radar reflectivity (35–45 dBZ), higher echo tops (>4 km), and more pronounced radial velocity convergence (26 $\mathrm{m \cdot s^{\ 1}}$), corresponding to its higher hourly snowfall rates.

The presence of moist symmetric instability was the primary factor distinguishing the 2016 blizzard' s extreme hourly snowfall rates. When this instability diminished after 08:00 on March 3, the hourly snowfall decreased correspondingly. This demonstrates that conditional symmetric instability, while not the only factor affecting Xinjiang blizzards, plays a crucial role in modulating snowfall intensity. The close relationship between low-level jet intensity, moisture transport, and radar echo characteristics provides valuable indicators for operational forecasting of such extreme events.

References

[?] YANG Lianmei, LIU Wen. Causal analysis of persistent heavy snow processes in the northern Xinjiang [?]. Plateau Meteorology, 2016, 35(2): 507–519.

[?] YANG Lianmei, SHI Yuguang, TANG Hao. Analysis on causes of winter precipitation anomalies in northern Xinjiang [?]. Journal of Applied Meteorological Science, 2010, 21(4): 491–499.

[?] LIU Yulian, REN Guoyu, YU Hongmin, et al. Climatic characteristics of intense snowfall in China with its variation [?]. Journal of Applied Meteorological Science, 2013, 24(3): 304–313.

[?] ZHANG Junlan, CUI Caixia, CHEN Chunyan. Study on water vapor characteristic of typical heavy snowstorm case in northern Xinjiang [?]. Plateau Meteorology, 2013, 32(4): 1115–1125.

[?] ZHANG Junlan, WAN Yu, MIN Yue. Comprehensive analysis of an extreme blizzard in Urumqi on December 11, 2015 [?]. Desert and Oasis Meteorology, 2017, 11(1): 1–10.

[?] ZHANG Jiabao, DENG Zifeng. A generality of rainfall in Xinjiang [?]. Beijing: Meteorology Press, 1987.

[?] YANG Lianmei, YANG Tao, JIA Lihong, et al. Analysis of the climate characteristic and water vapor of heavy snow in Xinjiang Region [?]. Journal of Glaciology and Geocryology, 2005, 27(3): 389–396.

[?] ZHUANG Xiaocui, LI Boyuan, ZHANG Linmei, et al. Heavy snowstorm characteristics of climate change in winter in Altay, Xinjiang [?]. Arid Land Geography, 2013, 36(6): 1013-1022.

[?] ZHENG Yuping, LI Jinglin, ZHAO Shuqin, et al. Urbanization impact on precipitation of Urumqi City in recent 48a [?]. Arid Land Geography, 2011, 34(3): 442-447.

[?] JIANG Fengqing, ZHANG Yanwei, HU Ruji, et al. Spatial pattern and evolution of annual precipitation irregularity in Xinjiang [?]. Arid Land Geography, 2010, 33(6): 850-858.

[?] WAN Yu, CAO Xing, DOU Xinying, et al. Disaster causes of a cold wave snowstorm in the north slope of middle Tianshan Mountains [?]. Arid Land Geography, 2015, 38(3): 478-486.

[?] LI Ruqi, TANG Ye, AJI Rouzii. Atmospheric circulation and water vapor characteristics of snowstorm anomalies in northern Xinjiang in 2010 [?]. Plateau Meteorology, 2015, 34(1): 155-162.

[?] LI Yuanyuan, DOLET Shavket, YANG Lianmei, et al. Analysis on heavy snow by Central Asian vortex in Xinjiang [?]. Journal of the Meteorological Sciences, 2014, 34(3): 299-304.

[?] ZHANG Pingping, WU Cuihong, QI Haixia, et al. Contrast analysis of two snowfall events in Hubei 2013 [?]. Meteorology, 2015, 41(4): 418-426.

[?] ZHENG Jing, XU Aihua, LIU Bo, et al. Analyses on mesoscale characteristics of a snowstorm in western Xinjiang in 2014 [?]. Journal of Arid Meteorology, 2016, 34(2): 326-334.

[?] YANG Xiaoxia, WU Wei, WAN Mingbo, et al. A comparative analysis of two snowstorms in Shandong Province [?]. Meteorology, 2012, 38(7): 868-876.

[?] SHI Yuguang, SUN Zhaobo. Climate characteristics of water vapor transportation and its variation over Xinjiang [?]. Plateau Meteorology, 2008, 27(2): 310-319.

[?] ZHAO Junrong, YANG Xue, YANG Jinghui. Analysis on mesoscale cloud characteristic of severe snowfall process in warm zone of northern Xinjiang winter [?]. Plateau Meteorology, 2010, 29(5): 1280-1288.

[?] ZHAO Junrong, YANG Xue, LIN Xilu, et al. Analyses on multi-scale system configuration and district of a disaster snowstorm [?]. Plateau Meteorology, 2013, 32(1): 201-210.

[?] ZHUANG Xiaocui, QIN Jiaxiu, LI Boyuan. Mesoscale characteristics of a snowstorm in western Xinjiang in 2014 [?]. Journal of Arid Meteorology, 2016, 34(2): 326-334.

[?] ROSSBY CG. Planetary flow patterns in the atmosphere [?]. QJRMS, 1940, 66(supple): 68-87.

[?] SHOU Shaowen. Theory and application of potential vorticity [?]. Meteorology, 2010, 36(3): 9-18.

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