

Observational Analysis of a Typical Hail Process in Northeastern Qinghai (Postprint)

Authors: Wang Qihua, Lin Chunying, Liu Xiao, Zhang Liyan, Zhao Zhanxiu, Zhang Boyue, Gong Jing

Date: 2024-03-01T00:00:00+00:00

Abstract

Northeastern Qinghai is the principal crop production region of Qinghai Province and also a high-incidence area for hail and high-risk zone for disaster impacts. Hail forecasting and warning, together with artificial hail suppression operations, constitute important measures for mitigating hail disaster losses. Mastering the variation characteristics of various monitoring data during hail events is a prerequisite for enhancing hail forecasting capabilities and initiating artificial hail suppression operations at the earliest opportunity. On June 29, 2021, a large-scale hail weather process occurred in northeastern Qinghai, which was analyzed using Doppler weather radar, raindrop spectrum data, and conventional upper-air and surface meteorological observations. The results demonstrate that the synoptic background for this hail event was characterized by upper-level cold advection transport and significant surface warming over northeastern Qinghai, resulting in unstable stratification. During the hailfall stage in the Ping' an area, both the average raindrop spectrum and velocity spectrum displayed multi-peak distributions. The maximum hail diameter observed manually in Ping' an differed little from that observed by the raindrop spectrometer, indicating that the instrument can effectively detect hail particles and determine the timing of maximum hail occurrence. The hail cloud development generally underwent initiation, rapid intensification, hailfall, and dissipation stages. Prior to hailfall, a distinct "V" -shaped inflow notch appeared in the low-level radar reflectivity factor. During the mature stage, the hail cloud exhibited a pronounced bounded weak echo region structure, with evident southerly airflow inflow at middle and low levels. Concurrently, a clear "zero line" was observed on the radial velocity map, extending vertically upward through the upper portion of the overhanging echo and bounded weak echo region toward the hail cloud top. This case analysis holds important guiding significance for hail forecasting in northeastern Qinghai, and the variation characteristics of various elements prior to hail occurrence serve as critical

criteria for scientifically guiding hail suppression operation sites to conduct artificial hail suppression operations in a timely and appropriate manner.

Full Text

Observational Analysis of a Typical Hailstorm Process in Northeastern Qinghai

WANG Qihua¹, LIN Chunying¹, LIU Xiao², ZHANG Liyan¹, ZHAO Zhanxiu³, ZHANG Boyue¹, GONG Jing¹

¹Weather Modification Office of Qinghai Province, Xining 810001, Qinghai, China

²Shanxi Artificial Precipitation Enhancement and Lightning Protection Technical Center, Taiyuan 030032, Shanxi, China

³Haibei Meteorological Bureau, Haiyan 812200, Qinghai, China

Abstract

Northeastern Qinghai represents the primary agricultural production region of Qinghai Province but is also a high-frequency hail area and disaster risk zone. Hail forecasting, early warning, and artificial hail suppression operations are critical for mitigating hail disasters, and understanding the evolution characteristics of monitoring data during hail events is fundamental to improving forecasting capabilities and enabling timely hail suppression interventions. On June 29, 2021, a widespread hailstorm occurred in northeastern Qinghai. Using Doppler weather radar, raindrop spectrum data, and conventional upper-air and surface meteorological observations, this study analyzed the hailstorm process. Results indicate that cold advection at upper levels combined with significant surface warming created an extremely unstable stratification, providing the synoptic background for this hail event. During the hailfall period in Ping'an, both the average raindrop size distribution and velocity spectrum exhibited multi-peak patterns. The maximum hail diameter observed manually at Ping'an differed minimally from that measured by the disdrometer, demonstrating the instrument's capability to effectively detect hail particles and identify the timing of maximum hail occurrence. The hail cloud development generally progressed through four stages: initiation, rapid intensification, hailfall, and dissipation. A distinct V-shaped inflow notch appeared in low-level radar reflectivity before hail onset. At maturity, the hail cloud exhibited a pronounced bounded weak echo region (BWER) with evident southerly inflow at middle and low levels, while the radial velocity field displayed a clear zero line extending vertically upward through the overhanging echo and BWER toward the cloud top. This case analysis provides important guidance for hail forecasting in northeastern Qinghai, with pre-hail variations in key parameters serving as critical criteria for scientifically directing the timing and intensity of artificial hail suppression operations.

Keywords: hail; raindrop spectrum characteristics; echo characteristics; obser-

vational analysis; northeastern Qinghai

Introduction

Hail represents a rapidly developing, highly destructive severe weather phenomenon caused by strong convection [1], posing significant challenges for disaster prevention and meteorological forecasting. Northeastern Qinghai constitutes a major agricultural region of Qinghai Province, characterized by complex terrain with numerous mountains and valleys that create distinctive local weather patterns [2]. Hail systems forming in this region's mountainous areas are influenced by northwesterly airflow, moving southeastward with upper-level winds, with hail centers typically located on the southern slopes of east-west oriented mountain ranges and eastern slopes of north-south ranges [3]. The June-August period coincides with critical crop development stages (jointing, milk-ripe, maturity, and harvest) and represents the peak hail season, during which hail causes severe damage to crop growth and yields. Currently, limited detection technology in Qinghai restricts hail research primarily to analyses using conventional meteorological elements and weather radar, focusing on variations in upper-level environmental conditions and radar characteristic parameters to establish hail forecasting thresholds. However, the accuracy and timeliness of such forecasts require further improvement.

Recent advances in detection technology and numerical simulation capabilities have enabled extensive research on hail formation mechanisms and evolution characteristics. Studies based on surface and sounding data demonstrate that atmospheric instability featuring dry-cold mid-to-upper layers and warm-moist lower layers, coupled with upper-level divergence and low-level convergence, strong vertical wind shear, upper-level jet streams, and the -20°C level height, all favor hail development [4-6]. Due to high spatiotemporal resolution, Doppler weather radar is widely applied in hail forecasting and suppression operations [7]. Typical hail signatures include echo overhang, low-level inflow notches, bounded weak echo regions, three-body scattering, mid-level radial convergence, and storm-top divergence [8-10], which constitute crucial reference elements for hail forecasting and warning. Beyond these classic features, radar data have been used to track hail processes and establish radar characteristic parameter thresholds for discriminating hail occurrence and potential hail size [11-13], leading to conceptual models of regional hail weather and explanations of large hail growth mechanisms [14-16].

Numerical models, with their high timeliness and ability to simulate hail cloud microphysical processes, are extensively used in hail forecasting [17]. Many researchers have employed WRF and hail cloud spectral-bin models to investigate hail generation and evolution. Studies of severe weather processes on the northeastern edge of the Tibetan Plateau reveal that maximum convective boundary layer height increases significantly before strong weather events, with latent and sensible heat fluxes substantially exceeding climatological means and boundary layer friction velocity increasing markedly before and after event onset [18]. Mi-

microphysical mechanisms show that graupel and cloud water constitute primary sources for rain and hail [19], while snow particles [20], frozen drops from supercooled water freezing [21], and ice crystal riming of raindrops and graupel [22] through collision-coalescence with rain and cloud water form hail particles that grow continuously. During initial hail formation, both the growth mechanism for small hail ($D < 10$ mm) in convergence zones with decreasing updrafts and the “seeder-feeder” mechanism around -10°C are important, while for typical and large hail ($D > 10$ mm), the “seeder-feeder” mechanism represents the most critical growth process [23]. Recent deployment of microwave radiometers, wind profilers, and disdrometers enables all-weather monitoring of whole-layer water vapor variations, wind field evolution, and microstructural characteristics of precipitation particles [24-26], facilitating understanding of synoptic patterns at various heights and macro/microphysical property changes before and after severe convective weather.

This study utilizes surface and upper-air data, Ping’ an disdrometer observations, and Xining Doppler radar data to analyze the June 29, 2021 hailstorm in northeastern Qinghai, exploring the application of disdrometers in hail monitoring and early warning to provide references for future hail observation and research.

1. Data and Methods

Observational data include MICAPS 4.5 hourly conventional meteorological elements, 08:00 and 20:00 upper-air charts, Xining C-band Doppler weather radar data, and raindrop spectrum observations from the OTT Parsivel laser disdrometer [27] at Ping’ an Station. Figure 1 shows the hail event and instrument distribution. The disdrometer measures particle diameters from 0.2-25 mm and fall velocities from $0.2\text{-}20\text{ m}\cdot\text{s}^{-1}$, with a sampling area of 54 cm^2 and 1-minute sampling intervals.

The number density per unit size interval for particles in each size channel is calculated using:

$$D_i) = \sum_j AtV_j\Delta$$

where n_{ij} represents particle count in the i -th size channel and j -th velocity channel; A is the disdrometer sampling area (cm^2); t is sampling time; V_j is particle fall velocity in the j -th velocity channel; and D_i is the width of the i -th size channel.

2. Results and Analysis

2.1 Hail Event Overview Between 17:00-20:00 on June 29, 2021, a widespread hailstorm affected northeastern Qinghai, with multiple townships along the hail cloud path reporting hail and varying degrees of damage. Table 1 details the hail observations. The largest hail occurred in Huzhu, reaching

16 mm maximum diameter. Ping' an Station observed hail from 18:03-18:11, with maximum diameter of 14 mm. This intense, long-duration, large-area hailstorm represents a typical event for northeastern Qinghai.

Using Ping' an Station as an example, analysis of surface meteorological elements before and after the hail event (Figure 2) shows the pre-hail period began with clear skies and temperatures above 25°C, with southeasterly surface winds. As the hail cloud approached, winds shifted to northerly, temperature decreased, and relative humidity increased. Hail began at 18:03, with temperature continuing to drop and humidity rising rapidly. By 18:12, the hail cloud controlled Ping' an Station with precipitation-dominated weather and northerly winds. Around 18:25, the hail cloud moved out of Ping' an, winds shifted to southeasterly and remained so, temperature stabilized, and humidity remained high with fluctuations.

2.2 Weather Situation Analysis The severe convective weather on June 29 occurred under the influence of a stable ridge with northwesterly flow aloft combined with a cold temperature trough. At 08:00, the 500 hPa chart (Figure 3a) shows northwest flow controlling northwestern China, with a strong wind area ($16\text{ m} \cdot \text{s}^{-1}$) from northern Xinjiang through Hexi Corridor to northeastern Qinghai, and a -16°C cold center over Mongolia extending to northeastern Qinghai. The 14:00 surface chart (Figure 3b) shows most of Qinghai in a negative pressure tendency zone, with easterly winds backing into the eastern region. Clear skies and warming reached 25°C in the east, creating extremely unstable stratification favorable for afternoon severe convection.

The Xining sounding at 08:00 (Figure 3c) and temperature/humidity profiles (Figure 3d) reveal wind shear $>10\text{ m} \cdot \text{s}^{-1}$ from surface to 650 hPa, with wind direction veering with height, good low-level moisture, and a pronounced cold-dry layer at mid-to-upper levels. This configuration of cold/warm advection and large-scale analysis indicates unstable stratification and appropriate heights conducive to hail development.

2.3 Raindrop Spectrum Characteristics Raindrop spectrum parameters reflect microphysical characteristics including particle diameter, number concentration, and fall velocity, enabling precipitation type discrimination through diameter-velocity distributions.

2.3.1 Temporal Evolution of Raindrop Spectrum Using Ping'an Station's hail event (18:03-18:11) as an example, Figure 4 shows the temporal evolution of raindrop size and velocity spectra. The disdrometer began detecting precipitation at 18:04 (data represent the previous interval), coinciding with surface observations. From 18:04-18:12, particle number concentrations were high with broad size and velocity spectra, dominated by 1-5 mm particles falling at $1-5\text{ m} \cdot \text{s}^{-1}$. Particles $>5\text{ mm}$ accounted for a significant portion of total concentration. At 18:06, the disdrometer observed the largest hail particle (Figure

5) with 14 mm diameter and $14 \text{ m} \cdot \text{s}^{-1}$ fall speed, closely matching manual observations and demonstrating the instrument's capability to detect hail and identify maximum hail timing.

The velocity-diameter relationship during hailfall was fitted using $V = aD^b$ with least squares method, yielding correlation coefficients of 0.97-0.98 and parameters $a = 4.2-5.2$, $b = 0.52-0.65$ (Figure 5), consistent with Xu Jialiu's [28] formula $V = D^{0.5}$.

Comparing average spectra during (18:04-18:12) and after (18:13-18:51) hail (Figure 6) reveals distinct differences. During hail, both size and velocity spectra show multi-peak distributions, broader than post-hail spectra, with significantly higher number concentrations across all size and velocity ranges, clearly detecting particles $>5 \text{ mm}$. After hail, the size spectrum becomes single-peaked while the velocity spectrum remains multi-peaked, with maximum particle diameter only 3.5 mm and no hail detection.

2.3.2 Diameter-Velocity Distribution at Hail Time Raindrop spectrum diameter-velocity distributions directly identify precipitation type. During hail, numerous particles $>5 \text{ mm}$ were observed. At Ping'an, manual observation recorded 16 mm maximum hail diameter while the disdrometer measured 14 mm, showing good agreement.

2.4 Radar Echo Characteristics

2.4.1 Hail Cloud Development Stages Figure 7 illustrates radar parameter evolution from initiation to dissipation. Around 16:00, convective clouds formed in Datong, developing and moving southeastward. At 17:27, the hail cloud in Huzhu intensified with maximum reflectivity ($\max\{\text{dBZ}\}$) of 53 dBZ, echo top (ET) of 8.5 km, and vertically integrated liquid water (VIL) of $27.5 \text{ kg} \cdot \text{m}^{-2}$. During continued development, VIL jumped to $62.5 \text{ kg} \cdot \text{m}^{-2}$ and ET reached 9.5 km when Huzhu experienced hail. After hailfall, both $\max\{\text{dBZ}\}$ and VIL decreased. The hail cloud then moved southeastward, producing hail in Ping'an, Ledu, and Minhe with varying intensity.

The hail cloud development comprised four stages: a brief initiation stage, rapid intensification with VIL increasing by $10 \text{ kg} \cdot \text{m}^{-2}$ within 10 minutes, a hail stage with fluctuating ET and VIL, and a dissipation stage. For example, after hail in Huzhu and Ping'an, ET decreased from 12.5 km to 10.5 km and VIL dropped from 62 dBZ to 53 dBZ.

2.4.2 Radar Parameters at Typical Times Xining's new-generation weather radar reveals typical pre-hail signatures. From 17:47-18:11, Ping'an experienced multiple hail events. Figure 8 shows a V-shaped inflow notch (black line) in low-level reflectivity before hail. At 17:48, hail occurred in Huzhu with the V-shaped notch still evident. Post-hail, the cloud remained strong but the low-level V-shaped notch disappeared.

At 17:54, CAPPI images (Figure 9) show a pronounced BWER with clear southerly inflow at middle and low levels. The BWER opens southeastward at 1–3 km, indicating the updraft inflow region. Above 12 km, the BWER corresponds to strong inflow reaching $12 \text{ m} \cdot \text{s}^{-1}$, with southwesterly inflow at mid-levels converging with northerly flow. Maximum convergence occurs at 4–7 km, weakening with height. A distinct zero line extends vertically through the overhanging echo and BWER toward the cloud top, representing the main updraft direction and consistent with the “seeder-feeder” structure in Tibetan Plateau hail clouds [29].

2.4.3 Hail Cloud Structure and Growth Mechanism Cross-sections along the black dashed line in Figure 8c (Figure 10) reveal vertical structure and airflow convergence/divergence. The hail cloud exhibits a clear BWER and echo wall, with the echo wall extending to the ground. The zero line in radial velocity extends vertically upward through the overhanging echo and BWER toward the cloud top. Hail particles primarily form and grow in the $-20\text{--}0^\circ\text{C}$ region, consistent with the “seeder-feeder” mechanism.

3. Conclusions and Discussion

This analysis of the June 29, 2021 hailstorm in northeastern Qinghai yields the following conclusions:

- 1) Cold advection at upper levels combined with clear skies and significant surface warming created extremely unstable stratification favorable for afternoon severe convection in northeastern Qinghai.
- 2) During hail at Ping’ an, high particle number concentrations and broad size/velocity spectra were observed. After hail, both particle diameter and velocity decreased markedly. The multi-peak size and velocity spectra during hail allowed clear hail detection and timing of maximum hail occurrence.
- 3) Hail cloud development progressed through initiation, rapid intensification, hail, and dissipation stages, with a V-shaped inflow notch in low-level reflectivity before hail. The mature stage featured a distinct BWER with southerly inflow at middle/low levels. Cross-sections showed a clear BWER and echo wall, with a vertical zero line extending through the overhanging echo and BWER toward the cloud top.

Comparison with hail spectra from Nanjing Liuhe [30] and Liupan Mountain [31] shows that northeastern Qinghai’ s hail stage exhibits multi-peak spectra while Liuhe and Liupan show exponential decreases. Velocity spectra also differ, with northeastern Qinghai showing multi-peak distributions versus single-peak or exponential decreases elsewhere. The zero line structure varies regionally, being vertical in northeastern Qinghai and Shandan Zhucheng [32], but segmented in Hebei Xingtai [33].

Hail formation is complex, involving not only updrafts but also particle phase transitions in cloud microphysical processes. This study focused on conventional C-band radar characteristics and hail growth mechanisms. Future work should employ C-band dual-polarization radar and specialized observations to analyze water vapor variations and particle phase transitions at different hail cloud stages and heights in northeastern Qinghai.

References

- [1] Zhao Xianping, Liu Shoudong, Liu Liping, et al. Analysis of main agrometeorological disasters from 1988 to 2007 in Liaoning Province[J]. *Journal of Meteorology and Environment*, 2009, 25(2): 33-37.
- [2] Gong Jing, Wang Qingchuan. Evaluation of hail suppression effect of anti-aircraft artillery in eastern agricultural area of Qinghai Province[J]. *Qinghai Science and Technology*, 2008, 14(6): 36-39.
- [3] Sun Honglie, Zheng Du, Yao Tandong, et al. Protection and construction of the national ecological security shelter zone on Tibetan Plateau[J]. *Acta Geographica Sinica*, 2012, 67(1): 3-12.
- [4] Zhou Wei, Zhang Qiang, Kang Fengqin. Recent advancements of hail research in Northwest China[J]. *Advances in Earth Science*, 2005, 20(9): 1029-1036.
- [5] Johns R H, Doswell III C A. Severe local storms forecasting[J]. *Weather Forecast*, 1992, 7: 588-612.
- [6] Liu Xiaolu, Liu Jianxi, Zhang Shilin, et al. Hail forecast based on factor combination analysis method and sounding data[J]. *Journal of Applied Meteorological Science*, 2014, 25(2): 168-175.
- [7] Wang Yanlan, Wang Juan, Wu Jing, et al. Comparative analysis of characteristics of extreme gale and hailstorm in Guilin in 2019[J]. *Journal of Tropical Meteorology*, 2021, 37(2): 175-185.
- [8] Zhang Tengfei, Duan Xu, Lu Yabin, et al. Circulation background for a severe convective hailstorm weather process in Yunnan and its dopplar radar echo features[J]. *Plateau Meteorology*, 2006, 25(3): 531-538.
- [9] Wu Jiankun, Yu Xiaoding. Review of detection and warning methods for sever hail events by doppler weather radars[J]. *Journal of Arid Meteorology*, 2009, 27(3): 197-206.
- [10] Cao Shuya, Sun Wei, Wei Fenfen, et al. Study of hail event in Jiangsu based on dual polarization weather radar observations[J]. *Transactions of Atmospheric Sciences*, 2021, 44(4): 549-557.
- [11] Sun Wei, Cao Shuya, Shen Jian. Characteristic analysis of atypical hail based on multi source data[J]. *Journal of Tropical Meteorology*, 2021, 37(2): 218-232.

- [12] Zhang Fang, Hu Wenjun, Chao Jian. Analysis of hail weather characteristics and early warning indexes in agricultural regions in eastern Qinghai Province[J]. *Desert and Oasis Meteorology*, 2020, 14(1): 63-71.
- [13] Zhu Ping, Xiao Jianshe, Fu Yang. Analysis on identification characters of storm cells for early warning of hail and thunder storms in the Northeast Qinghai Tibetan Plateau[J]. *Arid Zone Research*, 2012, 29(6): 941-948.
- [14] Zhao Ruijin, Yang Debao, Dong Baohua, et al. The analysis of environment condition of hail in Shijiazhuang using doppler weather radar products[J]. *Journal of the Meteorological Sciences*, 2008, 28(6): 689-696.
- [15] Wang Peitao, Wang Fengjiao, Zhang Tingting. Study on classification of synoptic systems and forecasting method of hail in Binzhou Shandong Province[J]. *Desert and Oasis Meteorology*, 2019, 13(3): 33-40.
- [16] Shen Shuqin, Gu Fengfeng. A composite analysis of surface factors in advanced of hail and the nowcasting of hail[J]. *Meteorological Monthly*, 1988, 14(6): 5-8.
- [17] Duan li, Li Liguang, Jia Qingyu, et al. Application of cinrad mosaic products on artificial hail suppression[J]. *Plateau Meteorology*, 2014, 33(5): 1426-1439.
- [18] Tao Lan, Guan Li, Sun Min, et al. Evolution analysis of a hail-producing supercell using dual polarization doppler radar[J]. *Journal of the Meteorological Sciences*, 2019, 39(5): 685-697.
- [19] Li Jia, Ma Zhongyuan, Zheng Yuanyuan, et al. Evolution of multi scale echo system during a strong squall line process[J]. *Journal of the Meteorological Sciences*, 2022, 42(5): 622-630.
- [20] Fan Hao, Yang Yongsheng, Duan Ying, et al. An observational analysis of the cloud structure of a severe convective hailstorm over the eastern foothill of Taihang Mountain[J]. *Acta Meteorological Sinica*, 2019, 77(5): 823-834.
- [21] Gong Dianli, Wang Hong, Xu Huanbin, et al. Observational analysis of a rare and severe hailstorm cloud structure and large hailstones formation on 16 August 2019 in Zhucheng, Shandong Province[J]. *Acta Meteorological Sinica*, 2021, 79(4): 674-688.
- [22] Cai Miao, Zhou Yuquan, Jiang Yuanhua, et al. Observations, analysis, and forming area identification of a supercell hailstorm[J]. *Chinese Journal of Atmospheric Sciences*, 2014, 38(5): 845-860.
- [23] Li Hongbin, Sun Hongyan, Cheng Xiangkun, et al. Climate characteristic of hail and conceptual model of hail suppression in Dalian region[J]. *Plateau Meteorology*, 2010, 29(6): 1565-1570.
- [24] Zhang Zhixian, Zhang Qiang, Tao Jichun. Diagnostic analysis of the effect of planet boundary layer on a hail event in the northeastern edge of Qinghai Tibetan Plateau[J]. *Arid Zone Research*, 2015, 32(2): 321-328.

- [25] Hong Yanchao, Xiao Hui, Li Hongyu, et al. Studies on microphysical processes in hail cloud[J]. Chinese Journal of Atmospheric Sciences, 2002, 26(3): 421-432.
- [26] Zhu Haoqi, Ping Fan, Tan Guirong, et al. Numerical simulation and study on the microphysical mechanism of hail formation in Beijing[J]. Chinese Journal of Atmospheric Sciences. doi: 10.3878/j.issn.1006-9895.2303.22213.
- [27] Liu Chunwen, Guo Xueliang, Duan Wei, et al. Numerical simulation on the microphysical formation mechanism of a typical hailstorm process in Yunnan, southwestern China[J]. Chinese Journal of Atmospheric Sciences, 2021, 45(5): 965-980.
- [28] Li Cong, Jiang Youshan, Jiang Di, et al. Study on the evolution of hailstorm and its cloud physical characteristics[J]. Meteorological Monthly, 2019, 45(3): 415-425.
- [29] Tao Tao, Zhang Lixin, Sang Jianren, et al. A case analysis of microphysical characteristics of atypical hail formation over Liupan Mountain, China[J]. Arid Land Geography, 2020, 43(2): 299-307.
- [30] Ke Liping, Gu Xiaoping, Zhang Yan, et al. Characteristics of raindrop spectrum and precipitation estimation in Wumeng Mountain area, Guizhou Province[J]. Journal of Yunnan University: Natural Sciences Edition, 2021, 43(6): 1166-1175.
- [31] Pu Jiangping, Zhao Guoqiang, Cai Dingjun, et al. Parsivel precipitation particle spectrometer and application in meteorological realm[J]. Meteorological and Environmental Sciences, 2007, 30(2): 3-8.
- [32] Yue Zhiguo, Liang Gu. Characteristics of precipitation particles in a hailstorm process in Weibei area of Shaanxi Province[J]. Plateau Meteorology, 2018, 37(6): 1716-1724.
- [33] Xu Jialiu. The Microphysics of Hail and the Mechanism of Hail Formation[M]. Beijing: China Agriculture Press, 1979: 110.
- [34] Zhang Xiaojuan, Tao Yue, Liu Guoqiang, et al. Observation and analysis of a hailstorm event based on multi source data[J]. Meteorological Monthly, 2017, 43(9): 1084-1094.
- [35] Kang Fengqin, Zhang Qiang, Ma Shengping, et al. Mechanism of hail formation on the Northeast border of Qinghai Xizang Plateau and its Neighbourhood[J]. Plateau Meteorology, 2004, 23(6): 749-757.
- [36] Kang Fengqin, Zhang Qiang, Lu Shihua. Validation and development of a new hailstone formation theory numerical simulations of a strong hailstorm occurring over the Qinghai Tibetan Plateau[J]. Journal of Geophysical Research: Atmospheres, 2007, 112: 1-13.
- [37] Huang Zhiyong, Xu Guirong, Wang Xiaofang, et al. Analysis on two hailstorm events in Xianning based on observations of ground based microwave

radiometer[J]. Meteorological Monthly, 2014, 40(2): 216-222.

[38] Huang Zhiyong, Zhou Zhimin, Xu Guirong, et al. Monitoring application of hailstorm event with the observation of wind profile radar and ground based microwave radiometer[J]. Plateau Meteorology, 2015, 34(1): 269-278.

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

Source: ChinaXiv –Machine translation. Verify with original.