Postprint: Hail Potential Forecasting and Early Warning Indicators for the Kashgar Region on the Southern Slopes of the Tianshan Mountains

Authors: Wang Yun, Lu Pinrui, Wang Xu

Date: 2018-10-23T00:00:00+00:00

Abstract

This study utilizes meteorological station observation records, artificial hail suppression operation point records, disaster survey data, and other materials from the Kashgar region on the southern side of the Tianshan Mountains during May–August of 2008–2017, together with 08:00 and 20:00 sounding data from the Kashgar sounding station, Kashgar radar detection data and its base data retrieval products, to analyze the annual, monthly, and diurnal variation characteristics of hail, summarize the radar echo characteristics and movement paths of hail clouds, and determine hail forecasting indices represented by the 0 ℃ layer height, -20 ℃ layer height, freezing layer thickness, Total Totals Index, Jefferson Index, K-index, and Showalter Index based on the percentile method, as well as radar characteristic warning indices represented by echo top height and its difference from the daily 0 ℃ layer height, 40–50 dBZ echo height and its difference from the daily 0 ℃ layer height, composite reflectivity, and vertically integrated liquid water content.

Full Text

Abstract

In this study, we analyzed the spatiotemporal characteristics of hail events from May to August during 2008–2017 using meteorological observation records from the southern Tianshan Mountains in Kashgar, Xinjiang, artificial hail suppression operation logs, 08:00 and 20:00 sounding data, and radar detection data. We investigated the radar echo characteristics and movement patterns of hail clouds, and established forecasting and warning indicators based on the percentile method. The results demonstrate: (1) Hail occurrence in the southern Tianshan Mountains over the past decade concentrated between May and August, with peak activity in June, particularly between 18:00–24:00 UTC (most frequently at 20:00 UTC). (2) Hail clouds exhibited four primary movement trajectories: northwest, north, west, and southward. Approximately half of the hail clouds originated in the southern Tianshan mountainous region, while the other half formed in the eastern plains of Kashgar Prefecture. (3) The potential forecasting indicators for hail during May–August are: 0°C layer height 4.6 km, -20°C layer height 7.5 km, freezing layer thickness 3.0 km, Total Totals index (TT) 46°C, Jefferson index (JI) 114.0°C, K-index 21°C, and Showalter index (SI) 1.8°C at 08:00 UTC. (4) The radar-based nowcasting indicators for hail 15 minutes prior to occurrence are: echo top height (ET) 12.2 km, height difference from the 0°C layer 7.7 km, 40 dBZ echo height 9.4 km, 45 dBZ echo height 8.6 km, 50 dBZ echo height 7.8 km, with corresponding 0°C layer height differences 4.9 km, 4.0 km, and 3.4 km respectively, composite reflectivity (CR) 53 dBZ, vertically integrated liquid (VIL) 13 kg · m ^{2}, and updraft thickness in the radial velocity field 1.8 km. For 30-minute lead times, the thresholds are: ET 12.3 km, 0°C layer height difference 7.8 km, 40/45/50 dBZ echo heights 9.6/8.1/7.3 km respectively, corresponding 0°C layer height differences 5.1/3.5/2.7 km, CR 47 dBZ, VIL 7 kg · m ^{2}, and radial velocity updraft thickness 1.5 km.

Keywords: echo tops (ET); vertically integrated liquid (VIL); composite reflectivity (CR); movement path; nowcasting indicators

1. Data and Methods

The study utilized 33 hail cases from May to August during 2008–2017, with 3 cases in May, 6 in June, 13 in July, and 11 in August. The data sources included surface meteorological observations, hail suppression operation records, 08:00 and 20:00 soundings, and Doppler radar measurements from the Kashgar radar station. Statistical analysis employed the percentile method to determine characteristic parameters and establish operational forecasting thresholds.

[Figure 1: see original paper] shows the monthly distribution of hail days, revealing that 54% of events occurred in July, 46% in June and August, with peak activity during June–August. [Figure 2: see original paper] illustrates the movement trajectories, indicating that 48% of hail clouds moved from mountainous areas to plains, while 52% moved within plain areas, with average path lengths under 200 km and predominant directions from northwest to southeast.

2. Hail Cloud Characteristics

2.1 Thermodynamic Parameters

Analysis of 26 hail cases with complete sounding data yielded the following characteristic values: 0°C layer height (H) averaged 3.4–4.9 km (mean 4.2 km), -20°C layer height (H) averaged 6.3–8.3 km (mean 7.0 km), and freezing layer thickness (ΔH) averaged 2.4–3.5 km (mean 2.8 km). The TT index ranged 39-53°C (mean 48°C), JI 92-186°C (mean 133°C), K-index 17-38°C (mean 26°C), and SI -2.1 to 4.6°C (mean 0.6°C). Approximately 50% of cases exhibited SI 0, with a minimum of -33°C indicating strong instability. Only 12% of cases had CAPE > 100 J · kg ^{1}, while 68% showed CAPE 10 J · kg ^{1}, suggesting limited convective available potential energy in this region.

2.2 Radar Echo Parameters

For the 33 hail cases, the echo top height (ET) averaged 9.1–16.2 km (mean 13.7 km), with 82% exceeding 10 km. The 40 dBZ echo height (H) averaged 7.2–16.0 km (mean 11.1 km), 45 dBZ echo height (H) 6.5–15.9 km (mean 10.2 km), and 50 dBZ echo height (H) 5.2–15.7 km (mean 9.1 km). The height differences above the 0°C layer were: ΔET 5.4–12.4 km (mean 9.3 km), ΔH 3.6–11.8 km (mean 6.8 km), ΔH 2.8–11.7 km (mean 5.9 km), and ΔH 0.8–11.5 km (mean 4.8 km). Composite reflectivity (CR) ranged 50–70 dBZ (mean 59 dBZ), with 55% exceeding 60 dBZ. VIL ranged 7–104 kg · m ^{2} (mean 33 kg · m ^{2}), with 85% exceeding 15 kg · m ^{2}.

3. Nowcasting Indicators

3.1 15-Minute Warning Thresholds

Based on percentile analysis, the 15-minute nowcasting indicators for May–August are: ET 12.2 km, H 9.4 km, H 8.6 km, H 7.8 km, ΔET 7.7 km, ΔH 4.9 km, ΔH 4.0 km, ΔH 3.4 km, CR 53 dBZ, and VIL 13 kg · m ^{2}. The updraft thickness in radial velocity fields should exceed 1.8 km, corresponding to the "velocity couplet" signature in Doppler radar observations.

3.2 30-Minute Warning Thresholds

For 30-minute lead times, the indicators are: ET 12.3 km, H 9.6 km, H 8.1 km, H 7.3 km, ΔET 7.8 km, ΔH 5.1 km, ΔH 3.5 km, ΔH 2.7 km, CR 47 dBZ, VIL 7 kg · m ^{2}, and radial velocity updraft thickness 1.5 km.

Monthly average echo characteristics of hail clouds
15-minute nowcasting indicators before hail
30-minute nowcasting indicators before hail

4. Discussion

The study reveals that hail formation in this region is primarily influenced by orographic forcing and local thermodynamic conditions. The relatively low CAPE values suggest that hail development depends more on vertical wind shear and orographic lifting than on high instability. The established percentile-based thresholds provide operational guidance for hail nowcasting, with the 15-minute indicators showing higher discriminative skill than the 30-minute ones. The velocity couplet signature in radial velocity fields serves as a reliable indicator of updraft strength, with thickness >1.8 km correlating strongly with severe hail production.

5. Conclusion

This analysis of 10 years of hail data from the southern Tianshan Mountains establishes quantitative radar-based nowcasting indicators for the May–August period. The four primary movement patterns and characteristic thermodynamic thresholds provide a foundation for operational hail forecasting and warning systems in this region. Future work should integrate these indicators with numerical weather prediction models to improve lead times and accuracy.

References

[?] LI Bin, ZHENG Bohua, SHI Lianmei, et al. Statistical evaluation of hail suppression effect in Akesu, Xinjiang. *Xinjiang Agricultural Sciences*, 2016, 53(5): 942–948.

[?] TOWERY N G, CHANGNON S A. Characteristics of hail-producing radar echoes in Illinois. *Monthly Weather Review*, 1970, 98(5): 346–353.

[?] CANAVERO F G. Hailstorm discrimination by radar measurements. *Meteorology*, 1987, 10(2): 184–190.

[?] DYE J E, MARTNER B E. The relationship between radar reflectivity factor and hail at the ground for northeast Colorado thunderstorms. *Journal of Applied Meteorology*, 1978, 17(9): 1335–1341.

[?] CICA R, BURCEA S, BOJARIU A R. Assessment of severe hail-garo of Xinjiang. *Journal of Glaciology and Geocryology*, 2014, 36(1): 95–105.

[?] RIGO T, LLASAT M C. Forecasting hailfall using parameters for convective cells identified by radar. *Atmospheric Research*, 2016, 69: 366–376.

[?] LOPEZ L, SANCHEZ J L. Discriminant methods for radar detection of hail. *Atmospheric Research*, 2009, 93(1): 358–368.

[?] SKRIPNIKOVA K, REZACOVA D. Radar-based hail detection. *Atmospheric Research*, 2014, 144: 175–185.

[?] PUSKIELER M, KUNZ M, SCHMIDBERGER M. Hail statistics for Germany derived from single-polarization radar data. *Atmospheric Research*, 2016, 178–179: 459–470.

[?] LIU Jun, XIAO Xiuzhu, ZHANG Wei. Analysis of hail radar data in recent 10 years over western Fujian. *Meteorological Science and Technology*, 2013, 41(2): 339–342.

[?] WANG Ruosheng, ZHANG Tong, FAN Xiaochun, et al. Analysis of the climate features and radar echo of the hail weather in Pingliang of Gansu Province. *Journal of Arid Meteorology*, 2013, 31(2): 373–377.

[?] DUAN He, YAN Huasheng, MA Xuewen, et al. Study of the method for hail forecasting and warning in southern Yunnan. *Meteorological Monthly*, 2014, 40(2): 174–185.

[?] ZHANG Zhengguo, ZOU Guangyuan, LIU Lijun, et al. Analysis of hail radar data in recent 10 years over western Fujian. *Meteorological Monthly*, 2014, 40(2): 174–185.

[?] ZHANG Zhengguo, ZOU Guangyuan, LIU Lijun, et al. Study on the method of hail forecasting using echo top height (ET). *Plateau Meteorology*, 2014, 35(4): 89–93.

[?] LU Dejin, CHEN Zhongrong, YUAN Ye, et al. Analysis on radar echo characteristics of hail clouds in spring and summer of Anhui Province. *Meteorological Monthly*, 2015, 41(9): 1104–1110.

[?] LI Junxia, TANG Dazhang, LI Peiren, et al. Analysis of meso- and small-scale Doppler velocity features. *Scientia Meteorologica Sinica*, 2007, 27(5): 557–563.

[?] ZHI Jun, CHEN Chunyan, MAO Weiyi. Study of hailstone warning indexes of the new generation weather radar products in western Kashgar. *Arid Land Geography*, 2014, 36(1): 95–105.

[?] WANG Yun, XIE Xiangyang, MA Yu, et al. Moving paths and nowcasting indicators of radar of hail cloud in northern Tianshan Mountains. *Arid Land Geography*, 2017, 40(6): 1152–1164.

[?] MA Yu, WANG Xu, ZHAO Bingke, et al. Spatial and temporal statistical character of hail in Xinjiang. *Xinjiang Meteorological Monthly*, 2002, 25(1): 4–5.

[?] JIA Junping. *Statistics*. Beijing: Tsinghua University Press, 2004: 68–71.

[?] ZHAO Qingbo, LI Li. Method of calculating percentiles using original data. *China Health Statistics*, 1999, 16(3): 185.

[?] MILLER R C. Notes on analysis and severe-storm forecasting procedures of the air force global weather central, Technical report 200 (Rev.). Air Weather Service (MAC), United States Air Force, 190 pp.

[?] JEFFERSON G J. A modified stability index. *Meteorological Magazine*, 1963, 92: 92–96.

[?] JEFFERSON G J. A further development of the instability index. *Bulletin of the American Meteorological Society*, 1953, 34: 250–252.

[?] MONCRIEFF M W, MILLER M J. The dynamics and simulation of tropical cumulonimbus and squall lines. *Quarterly Journal of the Royal Meteorological Society*, 1976, 102(432): 373–394.

[?] BLANCHARD D O. Assessing the vertical distribution of convective available potential energy. *Weather and Forecasting*, 1998, 13(3): 870–877.

[?] ZHANG Peichang, DU Bingyu, DAI Tiepi. *Radar Meteorology*. Beijing: Meteorological Press, 2001: 388-463.

[?] XIA Wenmei, ZHANG Yaping, TANG Dazhang, et al. Analysis of Doppler velocity features of adverse wind area in a local heavy rain process in Shenyang, Liaoning Province. *Journal of Meteorology and Environment*, 2011, 27(3): 12-17.

[?] CHEN Baofa, WEI Ming, LIU Shouyu. The echo evolution of adverse wind area and the structure of strong convection weather. *Torrential Rain and Disasters*, 2008, 27(2): 127-134.

[?] LIANG Hong, CHEN Li, LI Dawei, et al. Radar echo evolution of adverse wind area in a local heavy rain process in Shenyang, Liaoning Province. *Meteorological Monthly*, 2011, 27(3): 12-17.

[?] FENG Jinqin, TONG Yichang, LUO Xiaojin. CINRAD radar echo features of a mesoscale- local heavy rainfall convective system. *Meteorological Monthly*, 2008, 34(10): 50-54.

[?] LIANG Hong, CHEN Li, LI Dawei, et al. Radar echo evolution of adverse wind area in a local heavy rain process in Shenyang, Liaoning Province. *Journal of Meteorology and Environment*, 2011, 27(3): 12-17.

[?] FAN Biao. Analysis of radial velocity features of Doppler radar on a torrential rainstorm in eastern Fanjing Mountain in late spring of 2015. *Journal of Arid Meteorology*, 2016, 34(6): 1064-1070.

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