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Postprint: Analysis of Microphysical Characteristics of an Atypical Hailstorm Event in the Liupan Mountains

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Abstract

Using ground-based laser precipitation spectrometers, a severe convective hailfall event that occurred on the night of July 14, 2017, in the Liupan Mountain area was captured. The microphysical characteristics of rainfall and hailfall indicate that during hailfall, various microphysical characteristic quantities of particles increased significantly, with number concentration and average kinetic energy flux showing the most pronounced increases, growing by factors of 6.3 and 13, respectively. In the early stage of hailfall, larger-diameter hail particles increased more rapidly; as energy was released and convection weakened, smaller-diameter hail particles increased more rapidly. Gamma distribution is more suitable for fitting particle spectra before and after hailfall. Using the particle terminal velocity formula V = aDb to fit particle velocities during this hailfall process yielded excellent results, with a correlation coefficient exceeding 0.98. The parameter a varied between 4.55 and 5.02, and parameter h varied between 0.53 and 0.59.

Full Text

A Case Analysis of Microphysical Characteristics of a Typical Hail Formation over Liupan Mountain, China

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Abstract: Hail is one of the most destructive weather phenomena in Ningxia Province, China. While its circulation background and spatiotemporal distribution characteristics have been extensively studied, research utilizing the latest generation of detection equipment remains limited. This study addresses this gap by examining hail events using a DSG5 laser raindrop spectrometer to obtain measurements of instantaneous precipitation intensity, total precipitation particle count, cumulative precipitation, visibility, and radar reflectivity. The precipitation and microphysical characteristics of hailfall during severe convective weather in the Liupan Mountain area of Ningxia Province on the night of July 14, 2017, were systematically analyzed. The results showed: (1) During the hail process, the microphysical characteristics of precipitation particles increased significantly relative to baseline values, with number density and mean kinetic energy flux reaching 6.3 and 13 times their initial values, respectively. (2) In the early hailing stage, large hail particles grew faster than smaller particles; however, as energy was released and convection weakened, smaller hailstones increased rapidly. (3) A gamma-type distribution was most suitable for fitting the particle distribution characteristics before and after the hail process. (4) Particle velocity during the hailfall process was well fitted using the particle falling velocity formula V = aD^b (R^2 0.98). Fitted to our data, the constant a ranged from 4.55 to 5.02, while b varied from 0.53 to 0.59.

Keywords: Liupan Mountain; hail cloud; hail particle size distribution; microphysical characteristics

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1.3 Data Sources and Parameters

The primary instrument used in this study was the DSG5 laser raindrop spectrometer, which provides high-resolution measurements of precipitation particle size distributions. The radar data were obtained from the Kongtong radar station. Key microphysical parameters analyzed include: number concentration N (m ^{3}), water content Q (g · m ^{3}), precipitation intensity I (mm · h ^{1}), radar reflectivity factor Z (mm · m ^{3}), kinetic energy flux KE (J · m ^{2} · s ^{1}), mean diameter D (mm), maximum diameter D (mm), and terminal velocity V (m · s ^{1}).

The particle size distribution function $N(D\ )$ (m ^{3} · mm ^{1}) follows the gamma distribution model [13]. Atmospheric profile data were obtained from the Kongtong station at 700 hPa. The environmental parameters include: temperature lapse rate, wind shear, and convective available potential energy (CAPE). The density of hail particles was assumed to be = 890 kg · m ^{3} [10].

2.2 Case Overview

Table 1 presents the radar echo grid points and echo areas during the hailing process on July 14, 2017. The hail event evolved through several distinct stages:

Table 1. Radar echo grid points and echo areas during the hailing process

Time (UTC)	Echo Intensity (dBZ)	Echo Area (km^2)
22:40	>45	40
22:50	>45	60
23:00	>45	60
23:10	>45	60
23:20	>45	50
23:30	>45	50
23:40	>45	50
23:50	>45	40

The hail process exhibited three distinct phases: (1) initial development (22:40-22:50 UTC), (2) mature stage (23:00-23:20 UTC), and (3) dissipation stage (23:30-23:50 UTC). During the mature stage, the maximum echo area reached 60 km^2 with reflectivity exceeding 45 dBZ.

2.3 Evolution of Microphysical Characteristics

Figure 5 illustrates the temporal evolution of raindrop mean kinetic energy flux, precipitation intensity, and radar reflectivity factor during the hail process. At 22:59 UTC, the number concentration reached 1193 m ^{3}, approximately 6.3 times the pre-hail baseline value of 817 m ^{3}. The kinetic energy flux peaked at 0.069 J · m ^{2} · s ^{1}, representing a 13-fold increase from initial values.

The vertical structure showed that the 45 dBZ echo top extended to 6 km altitude at 23:00 UTC, with the strongest updrafts located between 2-6 km. The maximum reflectivity of 60 dBZ was observed at 3 km altitude, corresponding to the primary hail growth zone. The environmental conditions at 20:00 UTC showed a temperature difference ΔT of 21°C, CAPE of 248.7 J · kg ^{1}, and Showalter index (Si) of -1.72, indicating strong convective instability.

2.4 Particle Size Distribution and Velocity Characteristics

The particle size distribution evolution is shown in Figure 6. During the early hail stage (22:56-23:04 UTC), the distribution exhibited a bimodal structure with peaks at 2-2.4 mm and 3.8-4.3 mm. As the hail process intensified, the concentration of particles larger than 3 mm increased dramatically, with the spectrum broadening to include particles up to 9 mm.

The velocity-diameter relationship was well characterized by the power-law formula V = aD^b. Fitting results yielded coefficients a ranging from 4.55 to 5.02 (mean 4.85) and b ranging from 0.53 to 0.59 (mean 0.56), with correlation coefficients exceeding 0.98. These values are consistent with previous observations of hailfall velocity [10].

Figure 9 shows the evolution of microphysical parameters during the hail event. The precipitation intensity I, radar reflectivity factor Z, and kinetic energy flux KE all peaked during the mature stage (23:00–23:10 UTC), coinciding with the maximum in particle number concentration and size. The rapid increase in smaller particles (D $<$ 3 mm) during the dissipation stage suggests fragmentation of larger hailstones as the updraft weakened.

3. Summary

The primary conclusions are: (1) The DSG5 spectrometer effectively captured the dramatic microphysical changes during hail events, with number concentration and kinetic energy flux increasing by factors of 6.3 and 13, respectively. (2) The gamma distribution provided the best fit for particle size spectra throughout the hail process. (3) The velocity-diameter relationship followed V = aD^b with coefficients $a = 4.55$–5.02 and $b = 0.53$–0.59. (4) The hail process exhibited distinct microphysical signatures during development, mature, and dissipation stages, with the mature stage characterized by maximum particle sizes, concentrations, and kinetic energy flux.

References

[1] SUN Jisong, SHI Zengyun, WANG Ling. A study on topography impacting on distribution of hail events [J]. Climatic and Environmental Research, 2006, 11(1): 76-84.

[2] SUN Xuying, QU Yongxing, WANG Jian. Effects of geographical factors on the formation of hailstorm [J]. Arid Zone Research, 2008, 25(3): 452-456.

[3] JI Xiaoling, CHEN Xiaoguang, JIA Hongyuan, et al. Characteristics of hail distribution in Ningxia [J]. Journal of Catastrophology, 2006, 21(4): 14-17.

[4] [Citation text appears corrupted in original]

[5] HUANG Zhiyong, ZHOU Zhimin, XU Guirong, et al. Monitoring application of hailstorm event with the observation of wind profiler radar and ground-based microwave radiometer [J]. Plateau Meteorology, 2015, 34(1): 269-278.

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

[7] LIU Fenggui, ZHANG Haifeng, ZHOU Qiang, et al. Distribution features of hail disasters and its formation analysis of the Three-River Headwaters Region

[J]. Arid Land Geography, 2013, 36(2): 238-244.

[8] JI Xiaoling, MA Shaiyan, DING Yonghong, et al. Analysis of disastrous hail weather in Ningxia in recent 40 years [J]. Journal of Natural Disasters, 2007, 16(3): 24-28.

[9] YANG Kan, SANG Jianren, LI Yanchun, et al. Analysis of climatic and extreme features of hail in Ningxia in recent 50 years [J]. Journal of Arid Meteorology, 2012, 30(4): 609-614.

[10] NIU Shengjie, MA Lei, ZHAI Tao. Preliminary analysis of the hailstone spectrum distribution and the relations between Ze and E [J]. Acta Meteorologica Sinica, 1999, 57(2): 217-225.

[11] XU Yangchun. A comprehensive indexes recognizing hail cloud by using weather radar in mountain area of south Ningxia [J]. Plateau Meteorology, 1991, 10(4): 420-425.

[12] LÖFFLER-MANG M, JOSS J. An optical disdrometer for measuring size and velocity of hydrometeors [J]. Journal of Atmospheric & Oceanic Technology, 2000, 17(2): 130-139.

[13] PU Jiangping, ZHAO Guoqiang, CAI Dingjun, et al. Parsivel (R) precipitation particle spectrometer and application in meteorological realm [J]. Meteorological and Environmental Sciences, 2007, 30(2): 3-8.

[14] CHEN B, HU Z, LIU L, et al. Raindrop size distribution measurement at 4500 m on the Tibetan Plateau during TIPex-III [J]. Journal of Geophysical Research Atmospheres, 2017, 122: 11092-11106.

[15] LI Dongliang, LIU Dexiang. Climate in Gansu Province [M]. Beijing: China Meteorological Press, 2000: 255-256.

[16] SHI Anying, SUN Yuwen. Study of the characteristics of hail size distribution [J]. Plateau Meteorology, 1989, 8(3): 279-283.

[17] GUO Enming. The observation of hail in Xizang Province [J]. Acta Meteorologica Sinica, 1984, 42(1): 110-113.

[18] MARSHALL JS. The distribution of raindrops with size [J]. Journal of the Meteorological Sciences, 1948, 5(4): 165-166.

[19] ULBRICH CW. Natural variations in the analytical form of the raindrop size distribution [J]. Journal of Climate Applied Meteorology, 1983, 22(10): 1764-1775.

[20] ZHENG Jiangheng, CHEN Baojun. Comparative study of exponential and gamma functional fits to observed raindrop size distribution [J]. Scientia Meteorologica Sinica, 2007, 27(1): 17-25.

[21] CHEN Wankui, YAN Caifan. A case study of raindrop spectra and its characteristic parameters along horizontal level [J]. Meteorological Monthly, 1988, 14(1): 8-11.

[22] SHI Aili, ZHENG Guoguang, HUANG Geng, et al. Characteristics of raindrop spectra of stratiform cloud precipitation in autumn 2002 in Henan Province [J]. Meteorological Monthly, 2004, 30(8): 12-17.

[23] CHEN Delin, GU Shufang. Research on the mean spectrum of the rainstorm [J]. Acta Meteorologica Sinica, 1989, 47(1): 124-127.

[24] XU Jialiu. The microphysics of hail and the mechanism of hail formation [M]. Beijing: China Agriculture Press, 1979: 110.

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