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Statistical Analysis of Severe Convective Weather Characteristics in Shijingshan District from 2011 to 2023

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Abstract: *This paper selects 128 severe convective weather events in the Shijingshan area from 2011 to 2023 and analyzes the annual and monthly variations, synoptic situation types, categories, temporal, spatial and movement path distributions of severe convective weather. The results show that: (1) From 2011 to 2023, severe convective weather exhibited a fluctuating increasing trend, with short-duration heavy rainfall occurring most frequently, accounting for approximately 68%; (2) In the upper-level systems, the main type was the Westward-moving Shortwave Trough (WST), followed by the Northwest China Trough (NWCT); in surface systems, the dominant patterns were the Forward Sector of Low Pressure (FLP) and the Convergence Zone of Low Pressure (CZLP); (3) Severe convective weather mainly occurred at 15:00 and between 17:00-21:00, most frequently in the northwest region, with major influence paths being the northwest route, southwest route, southeast route and west route.*

Keywords: *Severe Convection; Synoptic Situation; Temporal Domain; Spatial Domain; Movement Path*

1. Introduction

Severe convective weather mainly includes hail with a diameter of 20 mm or more, convective straight-line winds with speeds of 17.2 m/s or above, short-duration heavy rainfall with an intensity of 20 mm/h or more, and tornadoes of any grade occurring on land [1]. It is one of the most damaging types of weather disasters, often causing casualties and property losses. For a megacity like Beijing, the impact of a single severe convective event can be even more severe.As one of the six central districts of Beijing, Shijingshan District is the smallest in area but features complex terrain. Bordered by mountains on the west and north sides, it is situated in a trumpet-shaped topography where easterly winds can easily trigger severe convective weather on the windward slopes in front of the mountains. Statistics show that the historical extreme value of hourly precipitation in the Beijing area was recorded at the Modekou station in Shijingshan District, with an hourly rainfall intensity of 128.9 mm (on June 23, 2011). On July 21, 2012, an extraordinary rainstorm occurred at Modekou station, lasting 20 hours with a cumulative precipitation of 328 mm, making it the station with the highest rainfall among 50 automatic stations in urban Beijing. On July 20, 2016, the daily precipitation at the Shijingshan National Meteorological Station broke the historical record since its establishment, with the highest regional station cumulative rainfall reaching 335.7 mm that day.

Analyzing severe convective weather is essential for effective urban disaster prevention and support services for major events. Some researchers have conducted valuable studies on severe convective weather in the Beijing area. Ding Qinglan et al. [2] summarized the temporal and geographical distribution characteristics of convective weather during the warm seasons from 1994 to 2005. Li Jian et al. [3] analyzed the basic climatological characteristics and long-term evolution trends of summer precipitation diurnal variation in Beijing from 1961 to 2004. The study by Wang Guorong et al. [4] showed that short-duration heavy rainfall in Beijing during the summer from 2006 to 2010 was mainly distributed in the areas in front of the mountains and the adjacent plains, with Shijingshan located in a high-incidence zone. These studies have provided a solid foundation for severe convective weather forecasting in the Beijing area. However, the research specific to Shijingshan District remains insufficient.With the recent increase in the deployment of automatic stations and the growing demand for refined forecasting and early warning services, it is urgent to analyze severe convective weather in Shijingshan District using more observation data.

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This study utilizes conventional surface observation data from May to October between 2011 and 2023, densified surface automatic stations in Beijing, Beijing S-band Doppler radar, FY-4 satellite images and reports of hazardous weather events to conduct statistical analyses of severe convective weather in Shijingshan District, aiming to reveal its spatiotemporal distribution characteristics.

2. Data and Methods

Based on the definition of severe convective weather and the characteristics of disaster-inducing weather in the Shijingshan area, this study categorizes severe convective weather into three types: (1) Short-duration heavy rainfall (precipitation ≥20 mm/h or ≥50 mm/6h); (2) Thunderstorm gale (wind speed ≥17.2 m/s accompanied by thunderstorm activity); (3) Hail of all sizes.

By reviewing records of hazardous weather reports in the Shijingshan area from 2011 to 2023, severe convective weather events were selected. Weather charts and satellite cloud images were consulted to re-examine individual cases, resulting in the identification of 128 severe convective weather events. Based on the synoptic field characteristics at the time of occurrence, types of weather systems and features in the satellite images, the selected cases were classified into different synoptic situation types. Using conventional meteorological data and radar data, statistical analysis was conducted on the influencing systems and movement paths of these events to study the spatiotemporal distribution characteristics and activity patterns of severe convective weather.

3. Statistical Analysis Results

3.1 Annual and Monthly Variation of Severe Convective Weather in Shijingshan District from 2011 to 2023

The 128 severe convective weather events recorded in Shijingshan District from 2011 to 2023 exhibit a clear annual variation pattern (Figure 1). From 2012 to 2015, the total number of severe convective weather events was relatively low; from 2016 to 2018, the frequency increased year by year. In 2019, it decreased with some fluctuation, followed by a rebound in 2020. The highest number of events occurred in 2021, with 18 cases. In that year, the Western Pacific Subtropical High (WPSH) was located farther north and was stronger than usual. Combined with the frequent activity of cold air from mid- and high latitudes, this led to a significantly higher occurrence of severe convective weather compared with other years.In terms of event types in Shijingshan District, short-duration heavy rainfall occurred most frequently, with 87 cases, accounting for approximately 68.0% of the total severe convective events. Thunderstorm gale events ranked second, accounting for about 20.3%, while hail was relatively rare, accounting for about 11.7%. The annual variation in thunderstorm gales and hail was relatively stable, with a maximum of three occurrences in a single year. There were six cases of short-duration heavy rainfall accompanied by thunderstorm gales, and one case of hail accompanied by a thunderstorm gale. Overall, the severe convective weather in Shijingshan District shows a trend of fluctuating increase.

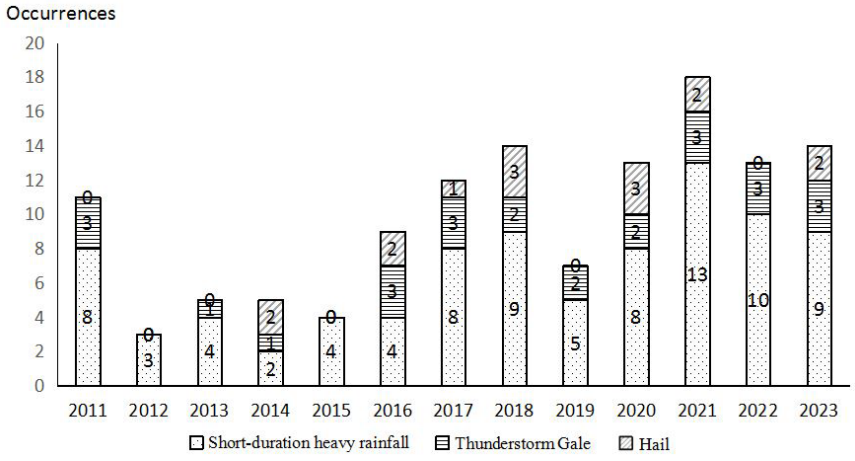

Figure 1: Annual Variation of Severe Convective Weather in Shijingshan District from 2011 to 2023

Analysis of the monthly variation characteristics of severe convective weather in Shijingshan

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District shows that July had the highest number of events, with 61 cases; June and August followed with 29 and 21 cases, respectively. May and September had relatively fewer events, with 7 and 10 cases, respectively. This pattern is closely related to the continental monsoon climate of Beijing. From June to August, the East Asian summer monsoon dominates, bringing abundant moisture, which easily leads to severe convective weather. There are significant differences in the types of severe convective weather occurring across the months. Short-duration heavy rainfall events in June, July and August were significantly more frequent than in other months, accounting for 89.7% of such events, with July alone accounting for 73.8%. Hail was relatively rare, with 15 occurrences, distributed in May, June, July and September, and no records of hail larger than 20 mm. Thunderstorm gales mainly occurred in June and July.

3.2 Synoptic Situation Types of Severe Convective Weather

The occurrence of severe convective weather is closely related to the background atmospheric circulation. Based on the most recent upper-air and surface observations prior to each event, as well as the observed weather phenomena, the circulation patterns were analyzed. The main upper-level systems influencing severe convective weather include: Mongolian Low Vortex (MLV), Northeast China Cold Vortex (NCCV), periphery of the Western Pacific Subtropical High (WPSH periphery), Northwest China Trough (NWCT), Westward-moving Shortwave Trough (WST) and Southwest China Trough (SWCT). The main surface systems include: Weak Convergence Zone (WCZ), Rear Sector of High Pressure (RHP), Forward Sector of Low Pressure (FLP), Convergence Zone of Low Pressure (CZLP), Northeast China High (NECH) and Inverted Trough (IT).As shown in Figure 2, the primary upper-level system affecting short-duration heavy rainfall, thunderstorm gales and hail in Shijingshan District is the Westward-moving Shortwave Trough (WST), accounting for 60.9% of all cases, followed by the Northwest China Trough (NWCT) with 16.4%, and the Mongolian Low Vortex (MLV) with 10.2%.The dominant surface systems influencing severe convective weather in Shijingshan District are the Forward Sector of Low Pressure (FLP) and the Convergence Zone of Low Pressure (CZLP), which together account for 82.0% of cases, followed by the Weak Convergence Zone (WCZ), Rear Sector of High Pressure (RHP) and Inverted Trough (IT).

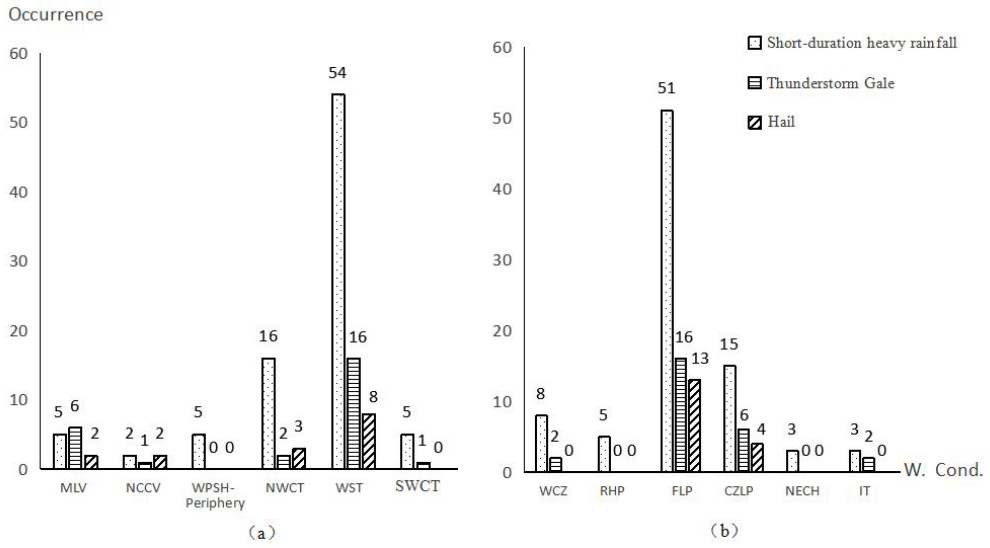

Figure 2: Upper-level systems influencing severe convective weather in Shijingshan District (a); distribution of surface system types (b)

3.3 Temporal and Spatial Distribution Characteristics, Sources and Movement Paths of Severe Convective Weather

3.3.1 Temporal Distribution

As shown in the statistical results in Figure 3, severe convective weather in Shijingshan District mainly occurs around 15:00 and between 17:00-21:00, corresponding to the afternoon, evening and early nighttime hours. In addition, 04:00, 07:00, 10:00 and 11:00 are also identified as peak occurrence times. Short-duration heavy rainfall events primarily occur at 15:00 and 21:00. This is mainly because

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such rainfall is typically convective in nature, and the period from afternoon to early night provides the most favorable thermodynamic conditions for severe convection. The secondary peaks appear at 04:00 and 07:00. Thunderstorm gales mainly occur at 10:00, while hail events primarily occur at 15:00.

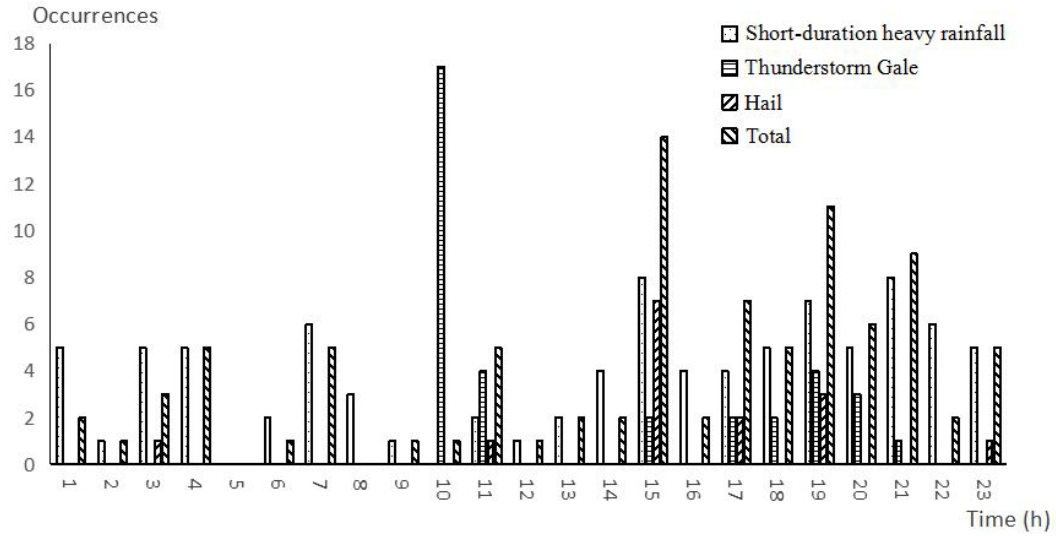

Figure 3: Temporal Distribution of Severe Convective Weather Affecting Shijingshan District

3.3.2 Spatial Distribution

In terms of spatial distribution, short-duration heavy rainfall events in Shijingshan District occur most frequently in the mountainous areas and mountain front in the northwest, followed by the southeastern part. This pattern is mainly related to the trumpet-shaped terrain of Shijingshan and the influence of easterly winds. Hail occurs significantly more in mountainous regions than in the plains, which is closely related to both the hail path characteristics in the Beijing area and the topography of Shijingshan District. Hail paths in the Beijing region primarily follow northwest and westward routes, and most severe convective systems tend to weaken after descending the mountains.

According to statistics on severe convective weather in Shijingshan District from 2011 to 2023:Short-duration heavy rainfall events with 20-30 mm/h occurred 30 times, 30-50 mm/h occurred 22 times, 50-70 mm/h occurred 3 times, 70-100 mm/h occurred 5 times. As for thunderstorm gales: Level 8 winds occurred 12 times, Level 9 winds occurred 4 times,Level 10 wind occurred once. The top three hourly rainfall intensities in Shijingshan District from 2011 to 2023 were: 128.9 mm/h at Modekou Station on June 23, 2011, accounting for 66.0% of the daily total; 91.7 mm/h at Sculpture Park Station on August 16, 2021, accounting for 98.4% of the daily total; 82.0 mm/h at Shijingshan National Station on July 31, 2020, accounting for 85.9% of the daily total.

3.3.3 Movement Paths

Statistical results show that the movement paths of severe convective systems entering Shijingshan District mainly fall into four categories: Northwest route: 52 cases, Southwest route: 27 cases, Southeast route: 18 cases, West route: 9 cases. A small number of cases also followed a southern route. Northern, eastern and northeastern paths were relatively rare. This distribution is consistent with the conclusion that upper-level systems influencing the area are predominantly the Northwest China Trough (NWCT), Westward-moving Shortwave Trough (WST) and Mongolian Low Vortex (MLV).

4. Conclusion

(1) From 2011 to 2023, severe convective weather in Shijingshan District showed a trend of fluctuating increase. July was the month with the highest frequency of severe convective events, while May and September also saw occurrences, though with relatively lower probabilities.

(2) In Shijingshan District, short-duration heavy rainfall was the most frequent type of severe convective weather, accounting for approximately 68%, followed by thunderstorm gales at about 20%, and hail was less frequent, accounting for around 12%.

(3) The primary upper-level system influencing severe convective weather in Shijingshan District

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was the Westward-moving Shortwave Trough (WST), followed by the Northwest China Trough (NWCT), and thirdly the Mongolian Low Vortex (MLV). The dominant surface systems were the Forward Sector of Low Pressure (FLP) and the Convergence Zone of Low Pressure (CZLP).

(4) Severe convective weather in Shijingshan District mainly occurred around 15:00 and between 17:00-21:00, i.e., in the afternoon, evening and early night. Thunderstorm gales mainly occurred at 10:00, while hail events were concentrated around 15:00. In terms of spatial distribution, short-duration heavy rainfall occurred most frequently in the mountainous and mountain-front areas in the northwest, followed by the southeastern part. Hail was significantly more frequent in mountainous areas than in plains.

(5) The main movement paths of severe convective systems entering Shijingshan District were classified into four routes: northwest, southwest, southeast and west. A small portion followed a southern route, while northern, eastern and northeastern routes were relatively rare.

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