Postprint: Analysis of Lightning Disaster Characteristics in Xinjiang, 2005–2020

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Abstract

Using lightning disaster statistical data from Xinjiang for the period 2005–2020 and lightning location monitoring data from Xinjiang for the period 2013–2020, this study analyzes the characteristics of lightning disasters in Xinjiang from 2005 to 2020 from the perspectives of industry distribution, casualties, and economic losses. The results indicate: (1) A total of 154 lightning disaster events occurred in Xinjiang from 2005 to 2020, resulting in 82 casualties. Over the past 16 years, lightning disaster events have exhibited a year-on-year decreasing trend, with the monthly peak period occurring from April to August, which is consistent with the monthly lightning activity pattern in Xinjiang. (2) The spatial distribution characteristics of lightning disasters demonstrate strong correlation with geographical factors; lightning disasters are primarily concentrated in the Altay region of northern Xinjiang, the southeastern area of Tacheng, and the belt of directly-administered counties and cities of Ili Kazakh Autonomous Prefecture, whereas lightning disasters in southern Xinjiang are significantly fewer. (3) Lightning disaster events predominantly occurred in rural areas, accounting for 62.3% of the total number of lightning disaster events. The proportion of industry damage caused by lightning disaster events, in descending order, is civilian electronic equipment, factory equipment, power equipment, and buildings. The findings of this study can provide an important theoretical basis for lightning protection and disaster mitigation efforts in Xinjiang.

Full Text

Analysis of Lightning Disaster Characteristics in Xinjiang from 2005 to 2020

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Abstract

Based on Xinjiang lightning disaster statistical data from 2005–2020 and lightning location monitoring data from 2013–2020, this study analyzes the characteristics of lightning disasters in Xinjiang from perspectives of industry distribution, casualties, and economic losses. The results show: (1) Lightning disaster events exhibit a year-by-year decreasing trend, with the monthly distribution peaking in summer months, consistent with Xinjiang' s lightning activity patterns. (2) The spatial distribution characteristics show strong regional correlation, with lightning disasters concentrated primarily in the Altay region, southeastern Tacheng region, and the directly-administered counties of Ili Kazakh Autonomous Prefecture in northern Xinjiang, while lightning disasters in southern Xinjiang are relatively rare. (3) Lightning disaster events occur mainly in rural areas, accounting for 62.3% of the total. The proportion of industry damage caused by lightning disasters, from highest to lowest, is: civil electronic equipment, factory equipment, power equipment, and buildings. These findings provide an important theoretical basis for lightning protection and disaster reduction efforts in Xinjiang.

Keywords: lightning disaster events; spatial and temporal distribution; ground lightning activity; Xinjiang

1. Introduction

Lightning is an instantaneous high-voltage, high-current, strong electromagnetic radiation disaster weather phenomenon occurring in the atmosphere. Lightning disasters generally refer to events where lightning strikes or lightning electromagnetic pulse intrusion and influence cause casualties or property damage, partial or complete loss of function, resulting in adverse social and economic consequences. Lightning disasters are among the most severe ten natural disasters announced by the United Nations' "International Decade for Natural Disaster Reduction," frequently causing significant impacts on production safety and leading to recurring catastrophic events worldwide.

Numerous domestic meteorological scholars have conducted research on lightning activity patterns and lightning disaster characteristics. Studies have shown that lightning disasters in China caused a decreasing trend in casualties from

1997 to 2006, with lightning-induced casualties occurring mainly in rural areas. Lightning disasters are more frequent in China' s eastern coastal and southern regions. Statistical analyses of lightning disaster characteristics in Guangdong, Hainan Island, Shandong, Hebei, and other regions have found that July–August is the peak period for lightning disasters. Additionally, Liu et al. analyzed the correlation between lightning disasters and disaster-causing factors, hazard-bearing bodies, and disaster-pregnant environments in Yunnan, finding that active ground lightning activity is the main disaster-causing factor, and that seasonal variation characteristics of positive ground lightning proportion can serve as an important indicator for determining the start and end of high lightning periods. Huang et al. found that the monthly distribution of lightning disasters in Hubei is basically consistent with thunderstorm days, both showing a bimodal pattern. Beyond regional statistical analyses, scholars have also conducted vulnerability assessments and zoning analyses for lightning disasters in various regions to further investigate the causes of lightning disaster events.

Xinjiang is located in the hinterland of the Eurasian continent and is a typical arid region. Compared with eastern China at the same latitude, Xinjiang experiences fewer lightning occurrences and weaker lightning disasters. However, due to the unique topography of "three mountains sandwiching two basins" and its geographical location, Xinjiang frequently experiences strong convective weather in summer, accompanied by lightning activity that poses significant hazards to economic construction and the production and livelihood of farmers and herders. With the rapid socio-economic development of Xinjiang, the impact of lightning-induced disasters has become increasingly severe. Therefore, studying and understanding the distribution characteristics of lightning disasters in Xinjiang and seeking effective protective measures hold practical significance for lightning disaster prevention and reduction.

In recent years, Xinjiang meteorological scholars have conducted extensive research on thunderstorm activities in Xinjiang, providing regional thunderstorm climate characteristics and noting that Xinjiang' s thunderstorm distribution is highly regional, with thunderstorm days gradually increasing from south to north and more in the east than in the west. Additionally, research has shown that Xinjiang' s annual variation in ground lightning presents a single-peak distribution, with the high-incidence period in June–August, and conducted risk zoning for lightning disasters in Xinjiang. However, the aforementioned studies have not yet presented the spatial and temporal distribution characteristics of lightning disasters in Xinjiang, and research on the relationship between lightning disasters and ground lightning activity remains limited.

Therefore, this paper utilizes Xinjiang lightning disaster cases from 2005–2020, analyzing the spatial and temporal distribution of lightning disaster losses across various cities and counties, industry distribution, and differences in casualties and economic losses. Combined with lightning location monitoring data on ground lightning frequency, lightning density, and intensity characteristics, this study explores the distribution characteristics of lightning disaster events in

Xinjiang and their relationships with ground lightning counts, density, and intensity, aiming to develop a systematic understanding of Xinjiang' s lightning disasters and provide reference for lightning disaster defense work in the region.

1.1 Data Sources

Lightning disaster data were obtained from lightning disaster statistics reported by the Xinjiang Meteorological Bureau from 2005–2020, including annual lightning disaster counts, casualties, and economic losses by county and city. Xinjiang has a vast territory, and some regions have missing or incomplete statistical data. The lightning disaster statistics in this paper represent an incomplete dataset; however, after classification and statistical processing of the raw data, the representativeness of the lightning disaster data can be ensured.

Ground lightning data were obtained from daily ground lightning data from the Xinjiang Meteorological Bureau' s ADTD lightning location system from 2013–2020. The Xinjiang ground lightning location monitoring network was installed in 2013, with a total of 18 monitoring stations deployed (Fig. 1), covering the entire Xinjiang region. Daily ground lightning data from 2013–2020 were selected, and mathematical statistics methods were used to analyze ground lightning activity characteristics in Xinjiang. To reduce interference from errors in lightning data on the overall dataset, overseas ground lightning data and small-amplitude current data were removed from the raw data.

Population numbers and regional area data for Xinjiang' s cities and prefectures were obtained from the *Xinjiang Statistical Yearbook*.

1.2 Research Methods

This study uses the life vulnerability modulus to characterize the vulnerability of lightning disaster hazard-bearing bodies, where the life vulnerability modulus is defined as the number of people per square kilometer.

To investigate the relationship between lightning disaster events and ground lightning activity in Xinjiang, this paper calculates ground lightning counts, lightning density, and lightning intensity from daily ground lightning data, and analyzes their spatial distribution correlations with lightning disaster event frequency.

Ground lightning density: Using daily ground lightning data, the annual average ground lightning frequency for each Xinjiang region was calculated. Then, using a 0.05°$×0.05°$grid, theannualaveragegroundlightningdensity(times \cdot km^{\{-2\}\cdot a}$\{-1\}$) was obtained by dividing the annual average ground lightning frequency by the corresponding regional area.

Lightning intensity: Ground lightning intensity was classified into intervals (\$ $80kA, 80 < I$ \$200 kA). The frequency of positive and negative ground lightning within each intensity interval was statistically analyzed.

2.1 Overview of Lightning Disasters

Statistical analysis of Xinjiang lightning disaster data from 2005-2020 (Table 1) reveals that during this period, Xinjiang reported a total of 154 lightning disaster events, resulting in 82 casualties (47 deaths and 35 injuries), with an average of 9.6 events per year. Lightning disasters caused 47 incidents of human and livestock casualties, 56 incidents of civil electronic equipment damage, 36 incidents of factory equipment damage, 16 incidents of power equipment damage, and 16 incidents of building and rural housing damage. Direct economic losses amounted to 1071.5$\times10^{4}$ yuan, indirect economic losses were 53.7$\times10^{4}$ yuan, and total economic losses reached 1125.2$\times10^{4}$ yuan, averaging 70.3$\times10^{4}$ yuan per year.

Xinjiang' s urban lightning disasters primarily cause electronic equipment damage, while rural lightning disasters mainly result in human and livestock casualties. The year 2005 saw the highest number of lightning disaster events (31), accounting for 20.1% of the total. After 2012, lightning disaster events showed a clear downward trend. The main reasons for this trend may be the popularization of lightning protection knowledge and improved awareness of lightning disaster prevention.

2.2 Temporal Distribution Characteristics

2.2.1 Annual Variation

From 2005-2020, Xinjiang experienced a total of 154 lightning disaster events. Analysis of annual variation characteristics (Fig. 2) shows that lightning disaster events generally present a decreasing trend year by year. The year with the most lightning disaster events was 2005 (31 events), accounting for 20.1% of the total; the fewest events occurred in 2016, 2017, and 2020 (1 event each). The relatively high number of events in 2005 may be attributed to the increasing impact of lightning disasters on social life and the wider application of electronic equipment in daily life without corresponding strengthening of lightning protection capabilities, thereby increasing the risk of lightning damage. After 2012, lightning disaster events showed a significant downward trend, likely due to the popularization of lightning protection and disaster reduction knowledge and improved lightning protection awareness.

2.2.2 Monthly Variation

Analysis of monthly variation in Xinjiang lightning disaster events from 2005-2020 (Fig. 3) shows that no lightning disaster events occurred from November to March of the following year. The high-incidence period for lightning disaster events was June-August (150 events), accounting for 97.4% of the total. Fewer events occurred in April, May, September, and October (4 events total), representing only 2.6% of the total. The seasonal pattern of lightning disasters in Xinjiang is quite pronounced, concentrating mainly in summer. This is closely related to Xinjiang' s complex terrain, vast territory, and diverse natural environment.

2.2.3 Spatial Distribution

Xinjiang is located in the hinterland of the Eurasian continent, with the Tianshan Mountains as its central axis dividing Xinjiang into southern and northern regions with distinct differences. Complex terrain, population distribution, and economic conditions create significant variations in lightning disaster event distribution. From 2005–2020, a total of 154 lightning disaster events occurred (Table 3). The highest frequency was in Karamay City (14 events), accounting for 9.1% of the total. The second highest frequencies were in Altay City and Fuyun County (9 events each), representing 5.8% of the total. Third were Fuhai County, Hoboksar Mongolian Autonomous County, Qinghe County, and Zhaosu County (8 events each). Lightning disasters were concentrated primarily in the Altay region, southeastern Tacheng region, and the line of directly-administered counties of Ili Kazakh Autonomous Prefecture in northern Xinjiang, while southern Xinjiang experienced very few lightning disasters. This may be due to regional differences: northern Xinjiang has lower temperatures, more precipitation, and more lightning, while the desert barrier makes southern Xinjiang dry with low air humidity, less cloud and rain, and consequently less lightning.

2.3 Temporal and Spatial Distribution of Lightning Disaster Losses

From 2005–2020, lightning disasters in Xinjiang caused total economic losses of 1125.2×10^{4} yuan, averaging 70.3×10^{4} yuan annually. Particularly in 2005, economic losses reached 453.4×10^{4} yuan, accounting for 40.3% of total losses, despite the number of events not being exceptionally high. The main reason was a rare lightning disaster in Wusu City on June 25, 2005, where a single event caused losses as high as 386.8×10^{4} yuan. Economic losses in 2006 and 2007 also exceeded the annual average.

Analysis of economic losses by prefecture (Fig. 5) shows that Changji Hui Autonomous Prefecture ranked first with losses of 386.8×10^{4} yuan (34.4% of total losses), followed by Tacheng Prefecture with 134.3×10^{4} yuan (11.9% of total). Hotan Prefecture, Kashgar Prefecture, and Turpan City experienced relatively light economic losses, with a combined total of 7.7×10^{4} yuan (0.7% of total). Analysis reveals that regions with severe economic losses did not necessarily have the most lightning disaster events, possibly because a single major event caused significant losses, or due to underreporting, as well as correlations with lightning protection installation, economic development, and thunderstorm activity levels.

2.4 Industry Loss Characteristics

According to the *Lightning Disaster Statistics Specification* (QX/T191—2013) and actual conditions in Xinjiang, damaged industries were categorized into agriculture, forestry, and animal husbandry; manufacturing; electric power; communications; transportation; information transmission; residential services; finance; and others (including education, water conservancy, public management, and services).

Among damaged industries, electric power, communications, and other industries suffered the most lightning strikes, accounting for 21.2% of industry-damaging events. Manufacturing, agriculture/forestry/animal husbandry, and residential services were next, accounting for 20.0%, 17.6%, and 16.5% respectively. Transportation, information transmission, and finance suffered fewer strikes, collectively accounting for 13.0%. Lightning damage to industries occurs for two main reasons: First, much industry equipment is exposed outdoors with protection systems comprising direct strike protection, surge protection, and grounding systems—once damaged, lightning strike risk increases, and outdoor personnel may suffer direct strikes. Some buildings lack lightning protection or have improperly installed systems, leading to losses during lightning events. Second, modern intelligent equipment is widely used in civil electronic devices, but public lightning protection awareness remains low, increasing lightning strike risk.

2.5 Casualty Characteristics

2.5.1 Temporal Distribution of Casualties

From 2005–2020, lightning disasters in Xinjiang caused 82 casualties, showing a clear downward trend with an annual average of 5.1 casualties. The years 2005 and 2007 had the most casualties (15 and 14 respectively), accounting for 35.4% of total casualties. After 2012, casualties declined year by year, with no casualties reported after 2017. Lightning disaster casualties have some randomness—while 2007 had only 5 events, a major disaster in Akqi County, Kizilsu Kirghiz Autonomous Prefecture on July 26 caused a tent in a state-owned horse farm to be struck, killing one 13-year-old girl and injuring four others.

2.5.2 Spatial Distribution of Casualties

From 2005–2020, Xinjiang lightning disasters caused 47 deaths and 35 injuries (a ratio of 1.16:1). Analysis of casualty distribution shows the directly-administered counties of Ili Kazakh Autonomous Prefecture ranked first (19 casualties, 23.2% of total), followed by Tacheng Prefecture (16 casualties) and Altay Prefecture (14 casualties). Karamay City and Urumqi City were low-incidence areas for casualties, with no reported lightning disaster casualties. Interestingly, Hotan Prefecture experienced only 2 lightning disaster events but had 4 casualties, suggesting possible underreporting. Casualty distribution does not perfectly align with event distribution—for example, Aksu Prefecture had many events but fewer casualties. This distribution may correlate with regional lightning activity intensity, population distribution, and economic levels.

3.1 Temporal Correlation Between Lightning Disaster Events and Ground Lightning Counts

Analysis of monthly distributions of lightning disaster events, casualties, and ground lightning counts in Xinjiang (Fig. 9) reveals that ground lightning activity is the main disaster-causing factor for lightning disasters. Xinjiang' s ground lightning activity concentrates in June–August, accounting for 91.2% of total ground lightning counts, with July reaching the annual peak at 35.9% of the total. Lightning disasters and casualties mainly occur in June–August, with these months accounting for 68.1% of events and 84.3% of casualties. After September, ground lightning counts decrease significantly. The monthly distribution of lightning disaster events matches well with ground lightning counts, with a correlation coefficient of 0.768 ($P<0.05$).

3.2 Spatial Correlation Between Lightning Disaster Events and Ground Lightning Counts/Density

3.2.1 Spatial Distribution of Ground Lightning Counts and Density

Analysis of spatial distribution of ground lightning counts from 2013–2020 (Fig. 10) shows that Altay Prefecture, Aksu Prefecture, Tacheng Prefecture, Hami City, and Kizilsu Kirghiz Autonomous Prefecture have the most frequent ground lightning activity. These regions account for 46.1% of total ground lightning counts. Kashgar Prefecture and Hotan Prefecture have the fewest ground lightning counts, with very weak activity—Kashgar City and Zepu County experienced only 2 and 1 ground lightning events respectively.

Analysis of annual average ground lightning density distribution (Fig. 11) reveals that Xinjiang' s ground lightning density exhibits banded and patchy spatial patterns, concentrated mainly in Altay Prefecture, Tacheng Prefecture, Karamay City, the directly-administered counties of Ili Kazakh Autonomous Prefecture, Shihezi City, and Urumqi City. Southern Xinjiang has the lowest ground lightning density. Table 5 shows that Karamay City has the highest average ground lightning density at 718$\times10^{-2}$ times·km^{-2}·a^{-1}, followed by Bortala Mongolian Autonomous Prefecture, Urumqi City, and Shihezi City, all exceeding 50$\times10^{-2}$ times·km^{-2}·a^{-1}. Kashgar Prefecture, Turpan City, and Hami City have average ground lightning densities below 10$\times10^{-2}$ times·km^{-2}·a^{-1}, indicating weak ground lightning activity. The minimum ground lightning density occurs in Hotan Prefecture and Bayingolin Mongolian Autonomous Prefecture, at only 1$\times10^{-2}$ times·km^{-2}·a^{-1}.

3.2.2 Spatial Correlation Analysis

The above analysis reveals that while Altay Prefecture, Tacheng Prefecture, and Kashgar Prefecture have high ground lightning counts and density, they experience relatively few lightning disaster events. Conversely, Karamay City and the directly-administered counties of Ili Kazakh Autonomous Prefecture have fewer ground lightning counts but higher lightning intensity, and these regions have relatively more lightning disaster events. Statistical analysis shows a significant correlation between lightning disaster events and ground lightning counts ($r=0.571$, $P<0.05$), indicating a positive correlation. However, casualty distribution shows some inconsistency with event distribution, likely influenced by regional differences in population density, urban construction, and topography.

3.3 Ground Lightning Intensity Characteristics

3.3.1 Spatial Distribution of Ground Lightning Intensity

Analysis of ground lightning intensity spatial distribution (Fig. 13) shows that intensity tends to increase from north to south, with maximum values in the southeastern mountainous areas of Bayingolin Mongolian Autonomous Prefecture and southern mountainous areas of Kashgar Prefecture. However, these regions have ground lightning density not exceeding 10$×10^{-2}$ times·km^{-2}·a^{-1} and relatively few ground lightning counts. Regions with frequent ground lightning activity in northern Xinjiang, western southern Xinjiang, and eastern Xinjiang have relatively low lightning intensity. The spatial correlation coefficients between lightning intensity and lightning density, and between lightning intensity and lightning counts, are -0.132 and -0.178 respectively, indicating weak correlations.

3.3.2 Characteristics of Positive and Negative Ground Lightning Proportion and Monthly Distribution

From 2013–2020, Xinjiang experienced 45,299 positive ground lightning events and 283,481 negative ground lightning events, with negative lightning accounting for 86.2% of total ground lightning counts. Positive lightning accounts for 13.8%, with an average current intensity of 59.24 kA, peaking at 40–60 kA and decreasing rapidly toward both sides. Negative lightning has an average current intensity of 33.57 kA, peaking at 20–40 kA and decreasing rapidly toward both sides.

During Xinjiang's summer flood season (June–August), ground lightning activity is dominated by negative lightning. After entering September, the proportion of positive lightning shows an increasing trend, with positive lightning accounting for 24.6% in September and 26.8% in October. Positive lightning activity is concentrated mainly in September–October, and the proportion change of positive lightning can serve as an important indicator for determining the beginning and end of high lightning periods.

3.4 Multiple Linear Regression Analysis

Using ground lightning counts, life vulnerability modulus, lightning disaster casualties, and average ground lightning density as independent variables and lightning disaster frequency as the dependent variable, a multiple linear regression model was established using SPSS software:

$$Y = 1.571 \times X_1 + 0.768 \times X_2$$

where Y is lightning disaster frequency, X_1 is ground lightning counts, and X_2 is casualties. The regression model shows significant statistical significance ($F=8.734$, $P<0.005$), indicating that ground lightning counts and casualties significantly affect lightning disaster frequency. However, the significance levels for average lightning density and average lightning intensity are greater than 0.05, so they were excluded from the final model.

4. Conclusions

Based on Xinjiang lightning disaster data from 2005-2020, this study statistically analyzed the spatial and temporal distribution, loss characteristics, casualties, and disaster-causing factors of lightning disaster events, combined with ground lightning count, density, and intensity characteristics from lightning location monitoring data. The main conclusions are:

1) From 2005-2020, Xinjiang experienced 154 lightning disaster events, concentrated mainly in the Altay region, southeastern Tacheng region, and the directly-administered counties of Ili Kazakh Autonomous Prefecture. Events occurred primarily in June-August, causing 82 casualties (47 deaths, 35 injuries). After 2012, both lightning disaster events and casualties showed a clear downward trend. Casualty distribution correlates with regional lightning activity intensity, population distribution, and economic levels.

2) From 2005-2020, lightning disasters in Xinjiang caused total economic losses of 1125.2$×10^{4}$ yuan, averaging 70.3$×10^{4}$ yuan annually. Among industry losses, human/livestock casualties, civil electronic equipment damage, and factory equipment damage ranked top three. Most lightning disaster events occurred in rural areas (62.3% of total).

3) Ground lightning activity is the main disaster-causing factor for lightning disasters. Xinjiang' s ground lightning activity concentrates in June-August (91.2% of total), with spatial distribution concentrated in Altay Prefecture, Tacheng Prefecture, Aksu Prefecture, and Hami City, showing good correspondence with lightning disaster event distribution. Ground lightning density exhibits banded and patchy spatial patterns, with high-density zones concentrated along the line of Altay Prefecture, Tacheng Prefecture, Karamay City, directly-administered counties of Ili Kazakh Autonomous Prefecture, Shihezi City, and Urumqi City, while southern

Xinjiang has the lowest density. Spatial distribution shows good correspondence with lightning density and counts, but weak correlation with lightning intensity.

4) After entering the flood season, Xinjiang' s ground lightning activity is dominated by negative lightning, with positive lightning proportion relatively small. After September, the proportion of positive lightning shows an increasing trend. The proportion change of positive lightning can serve as an important indicator marking the beginning and end of lightning disaster events.

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