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Research Article

Keywords: Beijing-Tianjin-Hebei region, ADTD, FY-4A, lightning characteristics, spatiotemporal distribution, data complementarity

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Article

Comparison of Spatiotemporal Characteristics and Complementarity of ADTD and FY-4A Lightning Observation Data in the Beijing-Tianjin-Hebei Region

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Abstract

To clarify the spatiotemporal characteristics and complementarity of lightning observation data in the Beijing-Tianjin-Hebei region, this study used ADTD ground-based and FY-4A satellite lightning data from April to September 2020-2022 for comparative analysis, focusing on frequency, density, intensity and typical cases. The results show that the interannual and diurnal variations of lightning frequency from both datasets are consistent, with concentration in summer (June-August) and high activity from afternoon to evening, and the peak of lightning "events" is earlier than cloud-to-ground (CG) lightning. There are differences in monthly peaks, related to detection principles and capabilities for different lightning types. Spatially, both show a "south more and north less" pattern: FY-4A has a wider observation range and obvious advantages in cloud-to-cloud (CC) lightning-dominated areas, while ADTD clearly reflects the topographic correlation of CG lightning. The high-value areas of ADTD CG lightning are scattered in the eastern coastal plains, and those of FY-4A are in the northwest and northern topographic uplift areas, showing significant complementarity. For diurnal intensity variation, ADTD CG lightning intensity is uniform throughout the day, while FY-4A optical radiation intensity peaks at 11:00-13:00. In terms of precipitation correlation, lightning frequency of both datasets increases near precipitation peaks: ADTD CG lightning concentrates 0-30 minutes before the peak, while FY-4A total lightning activity is earlier, verifying the classic convective electrical activity model. There are obvious differences in the timing of intensity peaks, reflecting the phased response of optical detection. This study clarifies the characteristics and complementary value of the two datasets, providing support for regional severe convection monitoring and early warning.

Keywords: Beijing-Tianjin-Hebei region; ADTD; FY-4A; lightning characteristics; spatiotemporal distribution; data complementarity

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1. Introduction

Lightning is a common weather phenomenon accompanied by sound, light and electricity, with strong electromagnetic radiation, high current intensity and instantaneous high voltage, causing increasing losses to people's lives and property (Cummins,K.L.1998). As an important economically developed and densely populated area in

China, the Beijing-Tianjin-Hebei region is vulnerable to severe convection weather and accompanying lightning activities(Xu Zhenyu.2021)Therefore, accurately grasping the spatiotemporal distribution characteristics and variation rules of lightning in this region is of great significance.

The ADTD system is a lightning monitoring system based on ground electric field changes, which can real-time monitor the location, time and polarity of CG lightning (Cao Dongjie,2018). The FY-4A satellite is equipped with an advanced Lightning Mapping Imager (LMI), which can realize high-frequency observation of large-scale lightning activities, including CC lightning and CG lightning(Qie XS,2024). Different observation methods lead to different characteristics of lightning monitoring data. Comparative analysis of these data helps improve the accuracy and reliability of lightning observation, and provides more comprehensive data support for in-depth study of lightning characteristics. In recent years, many scholars have used CG lightning data detected by ground-based lightning detectors to analyze the spatiotemporal characteristics of lightning (Li Jing,2022;Pan YC,2023), but there are relatively few comparative studies on ADTD and FY-4A lightning characteristics in the Beijing-Tianjin-Hebei region. This study aims to reveal the spatiotemporal variation characteristics of lightning activities in the Beijing-Tianjin-Hebei region through comparative analysis of ADTD and FY-4A lightning data from April to September 2020-2022, providing a scientific basis for disaster prevention and mitigation and meteorological services in this region.

2. Materials and Methods

2.1 Data Sources

The lightning data used in this study are mainly from the ADTD ground-based lightning monitoring system and the FY-4A satellite LMI. The ADTD system has relatively dense monitoring stations distributed in the Beijing-Tianjin-Hebei region, which can accurately record the occurrence time, location and current intensity of CG lightning, with high detection efficiency and good positioning accuracy(Li Jing,2022). The LMI on the FY-4A geostationary meteorological satellite adopts the optical detection principle, which can capture lightning optical radiation signals, thus realizing high spatiotemporal resolution monitoring of lightning activities in East Asia(Yuan T.,2004). The 1-minute event product (LMIE) of the LMI is the L2-level product provided by FY-4A LMI, and a signal unit is defined as a lightning "event"(ZHI Shulin,2019).

The study period is from April 1 to September 30, 2020 to 2022. Strict quality control is carried out on the two datasets to eliminate obvious errors and abnormal data points. The CG lightning data are obtained by processing according to the CG lightning collection method of GB/T37047—2018.

2.2 Research Methods

For the lightning data obtained by ADTD and FY-4A, their lightning frequencies are counted respectively. In this study, lightning occurring within 1 hour after the whole hour is defined as hourly lightning. From the interannual perspective, the total lightning frequency of each year from 2020 to 2022 is compared; on the monthly scale, the variation of lightning frequency in each month is analyzed; for the diurnal variation, the distribution of lightning frequency at different times of the day is calculated.

Lightning density is the number of lightning divided by the statistical area, representing the frequency of lightning occurrence in a certain area. In this study, the grid method is used to calculate lightning density, with a sampling range of 0.05°×0.05°. Their interannual and monthly variation characteristics are studied respectively.

The lightning density is normalized to eliminate the impact caused by the frequency gap between the two types of lightning. The calculation formula is:

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (1)$$

Where, x' is the normalized data; x is the sample data; x_{min} is the minimum value in the sample data; x_{max} is the maximum value in the sample data.

Lightning intensity mainly analyzes the current intensity in ADTD data and the optical radiation intensity of lightning "events". Mathematical statistics methods are used to intuitively show the spatiotemporal differences of lightning intensity characteristics.

3. Results

3.1. Interannual and Monthly Variation Characteristics of Lightning Frequency

From the lightning frequencies monitored by ADTD and FY-4A in the Beijing-Tianjin-Hebei region from April to September 2020-2022 (Tab 1), ADTD monitored about 75,168 lightning strikes in 2020, and FY-4A monitored about 83,476; in 2021, ADTD lightning frequency was 70,602, and FY-4A data was 83,908; in 2022, ADTD monitored 44,691 lightning strikes, and FY-4A monitored 69,213. The interannual variation of the two datasets shows that the lightning frequency was relatively high in 2020 and 2021, and relatively low in 2022, with basically consistent interannual variation trends. Moreover, the specific frequency values are consistent with the theoretical result of existing research that the frequency of lightning "events" should be higher than that of CG lightning in the same period (Dowden RL,2008).

3.2 Monthly Variation Characteristics

In terms of monthly variation, the monitoring results of ADTD and FY-4A lightning datasets are roughly similar. Overall, both datasets show that lightning activities are mainly concentrated in summer (June-August), and the proportion of lightning frequency reaches the highest in July, 28.19% and 36.71% respectively; the second highest value appears in June; the lowest value appears in April, 2.46% and 4.74% respectively. Starting from April, the lightning frequency of both datasets gradually increases, reaching the peak in July. After that, the proportion of FY-4A lightning frequency decreases rapidly, while that of ADTD remains at a high level in August and begins to decrease significantly in September.

The reason for this difference may be that the two monitoring methods have different detection capabilities for different types of lightning (CC lightning and CG lightning): FY-4A-LMI realizes optical detection of lightning according to the optical radiation characteristics of lightning, and is relatively more sensitive to higher CC lightning. Since the Beijing-Tianjin-Hebei region is mainly dominated by deep cloud precipitation in August, the optical radiation of lightning will be attenuated when transmitting in the cloud, and the optical radiation signal of some lightning reaching the cloud top is weak, resulting in LMI not identifying it as a lightning signal (Ruan Y Q,2024).

Tab 1. Monthly distribution of lightning frequency proportion (%) from ADTD and FY-4A in the Beijing-Tianjin-Hebei region (April-September 2020-2022). The proportion is calculated as the ratio of monthly lightning count to the total three-year count.

Frequency of lightning "events" (times) and monthly proportion (%)							
Year	total frequency	April	May	June	July	August	September

2020	83476	9.50%	15.30%	18.40%	31.60%	15.40%	9.50%
2021	83908	3.30%	8.90%	14.90%	40.60%	20.90%	11.10%
2022	69213	0.60%	4.60%	46.60%	38%	5.50%	4.40%
average	78866	4.74%	9.95%	25.46%	36.71%	14.50%	8.64%

ADTD lightning frequency/times and monthly proportion (%)

Year	total frequency	April	May	June	July	August	September
2020	75168	3.50%	20.80%	13.80%	24.60%	-27%	10%
2021	70602	2.10%	9.60%	24.10%	37.90%	15.10%	11%
2022	44691	1.20%	8.56%	43.60%	18.70%	20.30%	7.50%
average	63487	2.46%	13.80%	24.68%	28.19%	21.08%	9.79%

3.3 Diurnal Variation Characteristics

The diurnal variation characteristics of lightning frequency from the two datasets show similar trends, with frequent lightning activities from afternoon to evening. The ADTD lightning frequency peaks at 16:00-18:00, accounting for about 10% of the whole day; the FY-4A lightning frequency is active throughout 11:00-21:00 with fluctuations, and the proportion is highest at 10:00-12:00 and 19:00-21:00, reaching more than 10%. The frequency of both lightning datasets is low from midnight to morning, indicating that the atmosphere is relatively stable at this time, which is not conducive to lightning occurrence. This is consistent with the occurrence period characteristics of severe convection weather in the Beijing-Tianjin-Hebei region.

The reason for the above results may be that the underlying surface is easily strongly heated in the afternoon, leading to vigorous air convection, which is conducive to the development of thunderstorm clouds and the generation of lightning [13]. The difference in the specific peak periods of the two lightning frequencies may be due to the fact that ADTD CG lightning often occurs in the vigorous stage of convective weather processes, while the lightning type in the initial and dissipating stages of the process is mainly CC lightning, which is more easily captured and recorded by FY-4A-LMI.

3.4 Monthly Variation Characteristics of Lightning Density Spatial Distribution

As the initial stage of lightning activities in the Beijing-Tianjin-Hebei region, April has shown preliminary spatial differentiation characteristics of regional lightning density (Fig 1a,Fig 1b). From the spatial distribution, the high-density areas observed by ADTD are mainly located in the central and southeastern plains; the distribution pattern of FY-4A is similar to that of ADTD, with high-density areas in the southeastern plains, but FY-4A also monitors a certain intensity of lightning activities in the northeastern region. At the same time, the high-value area of FY-4A lightning density is not only significantly wider than that of ADTD in spatial scope, but also its maximum density is significantly higher, showing the advantage of satellite data in capturing early and weak lightning activities(Wang J,2015).

This spatial distribution characteristic may be related to the synergistic effect of the gradually active warm and humid air currents and the urban heat island effect in April.

In May, with the continuous northward advance of the summer monsoon, the water vapor conditions and atmospheric energy in the Beijing-Tianjin-Hebei region are further improved, and lightning activities enter an enhanced stage (Fig 1c,Fig 1d). From the spatial distribution, the two lightning datasets of ADTD and FY-4A show high consistency in

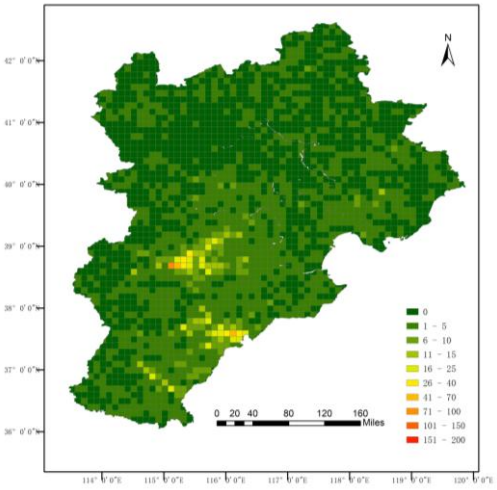
the southern part of the Beijing-Tianjin-Hebei region. Compared with April, the high-density areas have significantly expanded southward and westward, forming a continuous high lightning density belt, while the central and northwestern parts are stable low-value areas, and the distribution patterns of the two datasets in these areas are basically consistent. However, in the northern region, the lightning activities observed by FY-4A are significantly stronger than those by ADTD, reflecting more active convective characteristics.

In June, as the Beijing-Tianjin-Hebei region fully enters the main flood season, lightning activities are further enhanced, and the spatial distribution differences between the two detection datasets are more obvious (Fig 1e,Fig 1f). From the specific distribution, ADTD observations show that CG lightning activities in the western and northwestern mountainous areas are already relatively active, while FY-4A not only forms a prominent high-density center in the northwest, but also presents a large-scale and continuous high-density area in the entire north-central region, indicating that the total lightning activities in this region are extremely vigorous. The extensive high-density area in the north-central region reflected by FY-4A is not reflected by ADTD, indicating that there are a large number of intra-cloud discharge processes in the north-central region in June, resulting in the total lightning frequency being much higher than the CG lightning frequency.

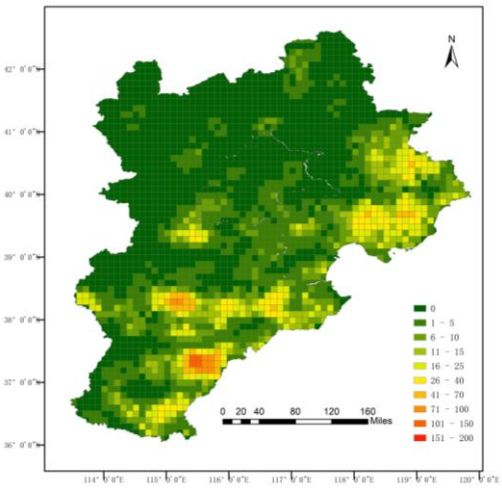
July is the month with the most vigorous lightning activities in the Beijing-Tianjin-Hebei region, and the spatial distribution of lightning density between ADTD and FY-4A also shows significant differences (Fig 1g,Fig 1h). The ADTD lightning density shows an obvious high-value center in the northwest mountainous areas, and the lightning density in the overall high-altitude areas is significantly higher than that in the plain areas, reflecting that the cloud-ground discharge activities in the high-altitude areas are more active and concentrated; the total lightning density reflected by FY-4A is relatively uniformly distributed in space, and except for scattered low-value areas in the northeast and southwest, the lightning activities in the entire Beijing-Tianjin-Hebei region generally maintain a high level, without overly prominent and concentrated high-value areas.

In August, the lightning activities in the Beijing-Tianjin-Hebei region shrink significantly from the large-scale high-value area in July, and the spatial distribution shows a significant change (Fig 1i,Fig 1j). The FY-4A lightning density is still scattered in space, but the scope of the high-value area is significantly reduced, shrinking to the central region. Moreover, the overall maximum density is significantly lower than that in July; while the ADTD lightning density still maintains a high-value area in the western mountainous areas, but the high-value area moves southward as a whole and is more scattered. At the same time, relatively concentrated high-value areas are formed in the eastern and southern plain areas, indicating that the convection in the mountainous areas continues but weakens at this time, while the plain areas are more likely to trigger mesoscale and microscale convection dominated by CG lightning under the influence of thermal and urban effects.

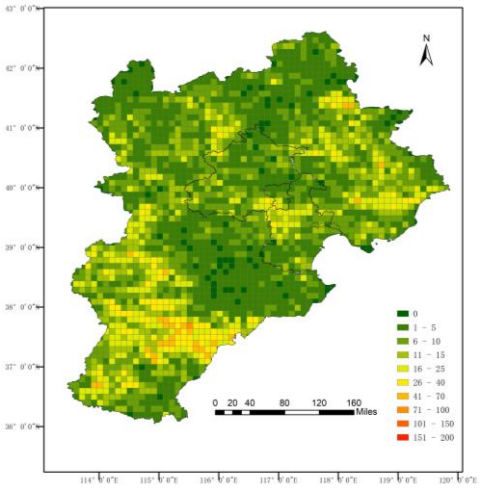
In September, with the end of the flood season and the southward withdrawal of the summer monsoon, the overall convection activities in the Beijing-Tianjin-Hebei region are significantly weakened, but the spatial distribution pattern of lightning density between ADTD and FY-4A shows obvious differences from that in summer (Fig 1k,Fig 1l). The ADTD CG lightning activities have been significantly weakened, only scattered in the northern region, indicating that the CG lightning activities in the Beijing-Tianjin-Hebei region are very limited at this time; while the FY-4A lightning still maintains a certain range of active areas with high central values from the central to the northern regions, indicating that although the scope of total lightning activities shrinks, it still maintains a certain intensity in the north-central region of the Beijing-Tianjin-Hebei region.


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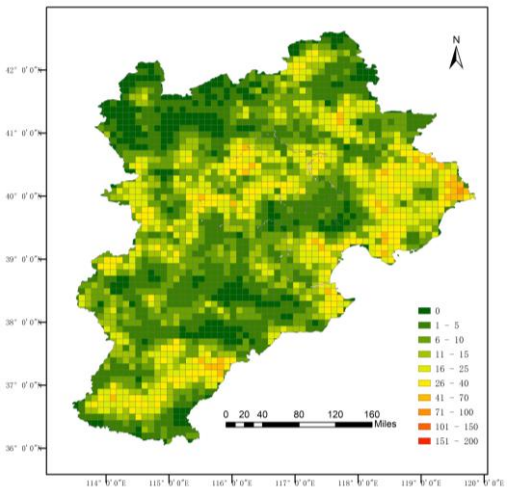
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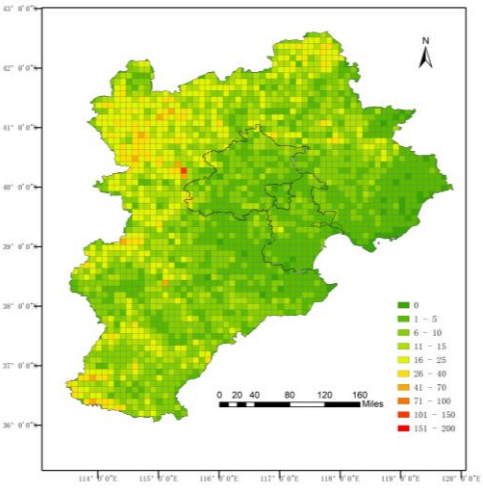
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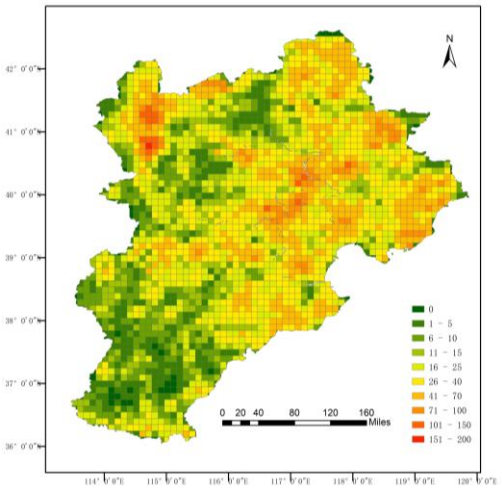
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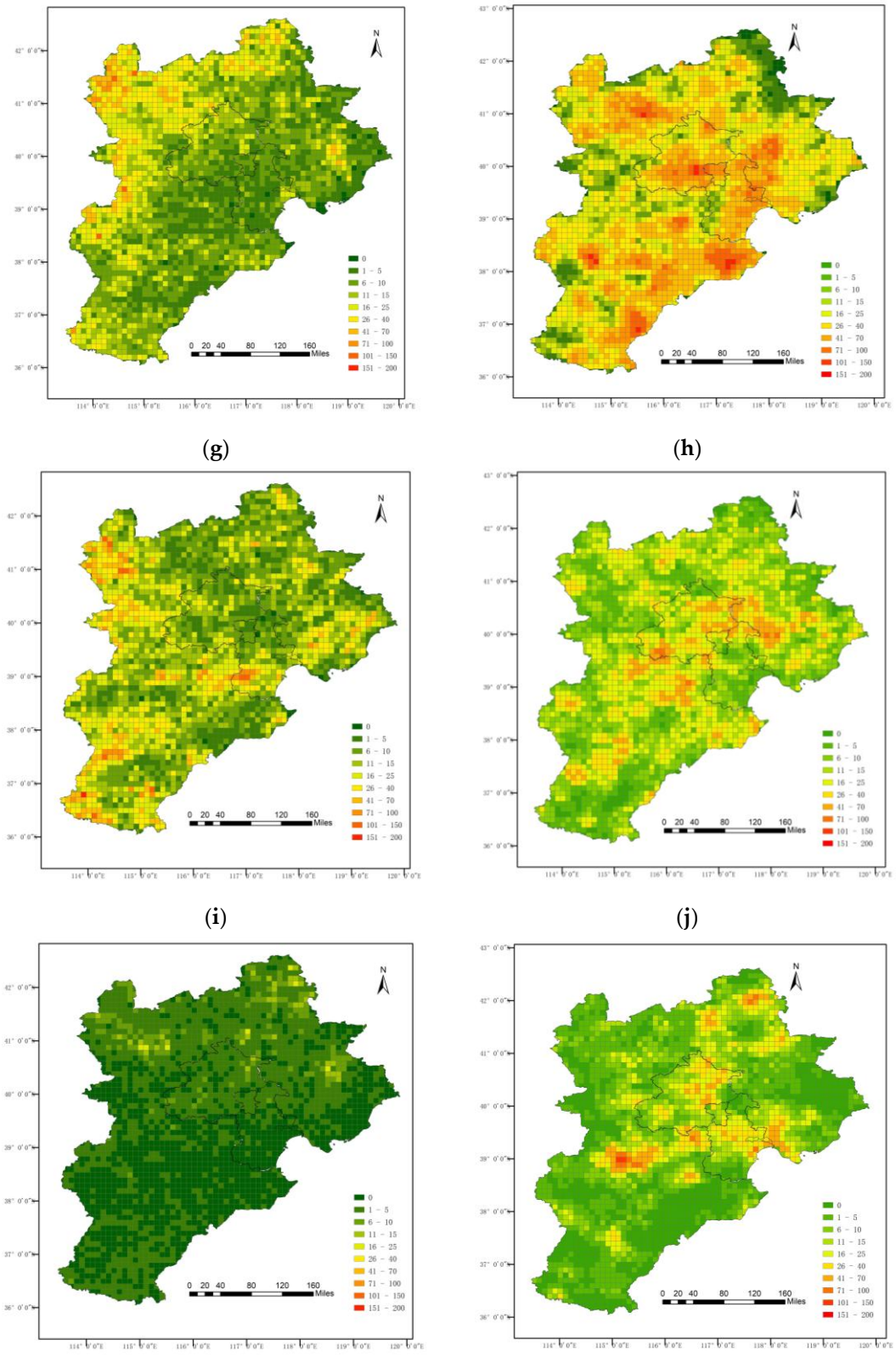


Fig 1. Spatial distribution of lightning density (events/grid) in April- September 2020-2022: (light) ADTD CG lightning; (right) FY-4A total lightning :**(a)**April ADTD;**(b)**April FY-4A;**(c)**May ADTD;**(d)**May FY-4A;**(e)**June ADTD;**(f)**June FY-4A;**(g)**July ADTD;**(h)**July FY-4A;**(i)**August ADTD;**(j)**August FY-4A;**(k)**September ADTD;**(l)**September FY-4A.

3.5 Spatiotemporal Variation Characteristics of Lightning Intensity

3.5.1 Interannual Variation Characteristics of Lightning Intensity Spatial Distribution

A comparative analysis of the interannual variation of lightning intensity in the Beijing-Tianjin-Hebei region (Fig omitted) shows that there are significant differences in the spatial distribution characteristics of lightning between the two datasets. The ADTD lightning data show that the northeastern part of the Beijing-Tianjin-Hebei region and the coastal areas of the Bohai Sea have been large-value areas of lightning intensity for three consecutive years, indicating that the strong CG lightning activities in this region have relatively stable interannual continuity and high incidence. The FY-4A lightning data show that there is no obvious stable high-value center during the three years from 2020 to 2022, the relatively large-value areas are more obvious in the northern part of the Beijing-Tianjin-Hebei region, and the lightning distribution in other areas is relatively scattered. This difference may be the result of the combined influence of different detection methods, regional terrain, land-sea processes and human activities. Future research needs to integrate multi-source lightning data to more comprehensively evaluate lightning risks and climate effects .

3.5.2 Monthly Variation Characteristics of Lightning Intensity Spatial Distribution

In terms of spatial distribution (Fig 2a,Fig 2b), the large-value areas of lightning intensity from ADTD and FY-4A datasets in April are both located in the northern part of the Beijing-Tianjin-Hebei region, but there are certain differences in specific forms: the large-value areas of ADTD CG lightning intensity are obviously shifted to the northeast, showing a relatively discrete distribution with multiple centers and fragmentation; while the large-value areas of FY-4A total lightning are relatively concentrated in the inland north.

In May, the lightning activities in the Beijing-Tianjin-Hebei region show distinct observation characteristic differences (Fig 2c,Fig 2d): the spatial distribution of ADTD lightning intensity tends to be scattered, failing to form a prominent high-value center like that in April, and the overall intensity level is lower than that in the previous period; the high-value areas of FY-4A lightning radiation intensity are very prominent in the northwest mountainous areas and the junction of Beijing and Tianjin, with significant spatial concentration.

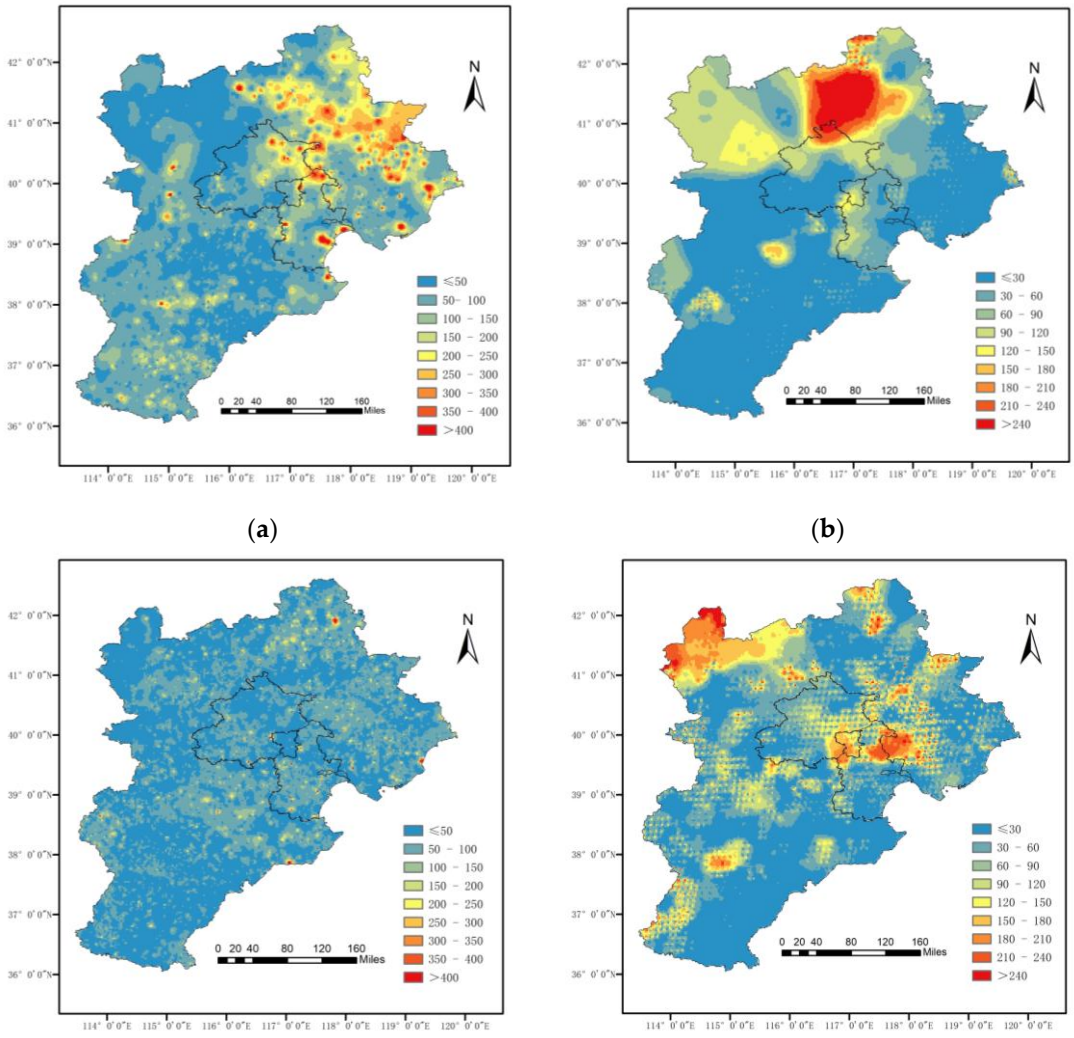
In June, the high-value areas characterized by ADTD and FY-4A lightning datasets still show obvious differences in space(Fig 2e,Fig 2f): the high-value areas of ADTD CG lightning intensity are significantly concentrated in the coastal areas of Tangshan-Qinhuangdao in the northeast, the overall intensity is further enhanced compared with May, and the spatial aggregation is prominent; while the high-value center of FY-4A lightning radiation intensity is located in the southern part of Zhangjiakou in the west. The two have almost no overlap in space.

In July, with North China entering the main flood season, the spatial distribution changes of ADTD and FY-4A lightning datasets have certain similarities, but the differences are still obvious(Fig 2g,Fig 2h). The overall ADTD CG lightning intensity still maintains a relatively uniform distribution pattern, without forming a stable high-value center, and the overall intensity is not high, with a scattered characteristic similar to that in May. The overall FY-4A lightning radiation intensity is also significantly lower than before, showing generally low values in the east-central part of the Beijing-Tianjin-Hebei region, and scattered high values in other areas, forming relative high-value centers in the south and northwest.

In August, as North China enters the late midsummer, the differences in spatial distribution characteristics presented by ADTD and FY-4A lightning datasets are still significant (Fig 2i,Fig 2j). The ADTD CG lightning intensity continues to maintain a scattered

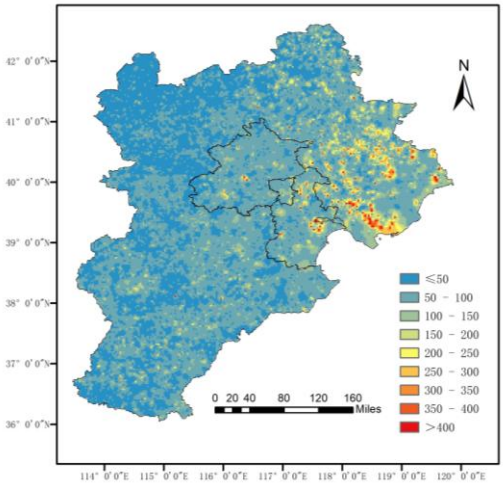
trend in space, with relatively high-value areas only in the southeastern plain areas and local western areas, but the overall intensity gradient is small, and no significant spatial aggregation phenomenon is formed; in contrast, the high-value areas of FY-4A lightning radiation intensity are clearly concentrated in the high-altitude mountainous areas in the northwest and north, with a more compact and continuous spatial structure.

In September, as the East Asian summer monsoon system enters a declining period, the overall convection activities in the Beijing-Tianjin-Hebei region are significantly weakened, but the spatial distribution pattern of lightning intensity between ADTD and FY-4A shows obvious differences from that in summer (Fig 2k,Fig 2l). The ADTD CG lightning intensity forms a large high-value area in the eastern region, with significantly enhanced spatial continuity, which is in sharp contrast to the scattered distribution in June-August; at the same time, the high-value areas of FY-4A lightning radiation intensity shrink to several isolated centers in the northwest and northeast, with more discrete distribution. It is worth noting that the spatial gradients of both lightning datasets are significantly larger than those in summer months, reflecting the increased sensitivity of lightning activities to local environmental factors during the autumn transition period.

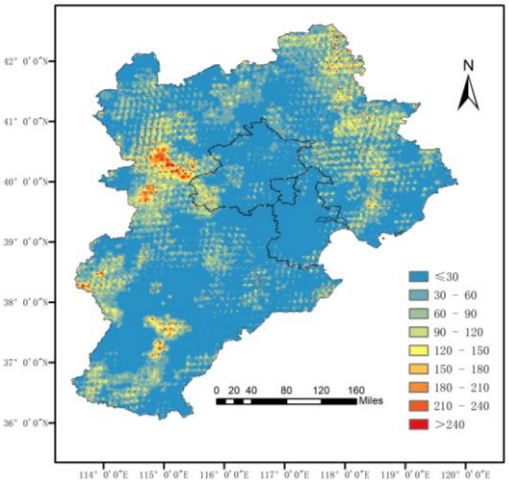


(**a**) (**b**)

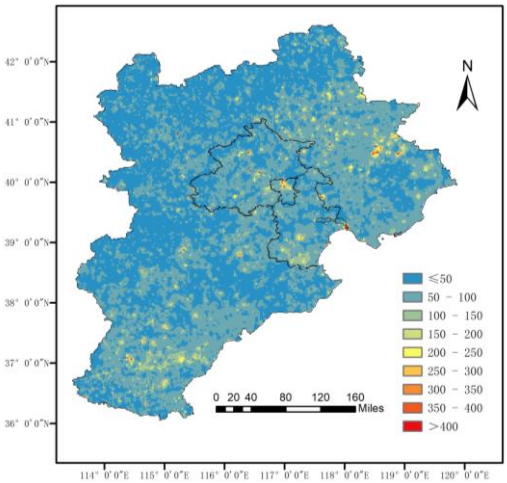
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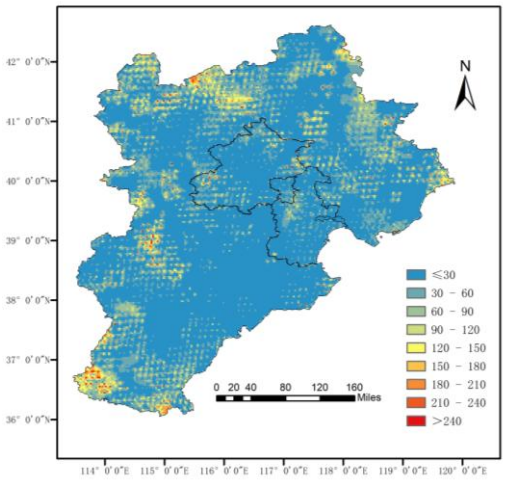
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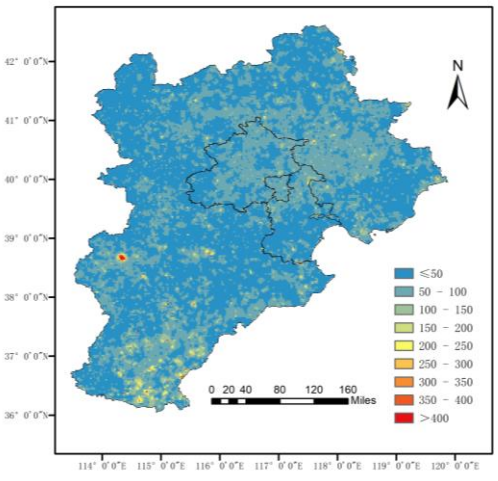
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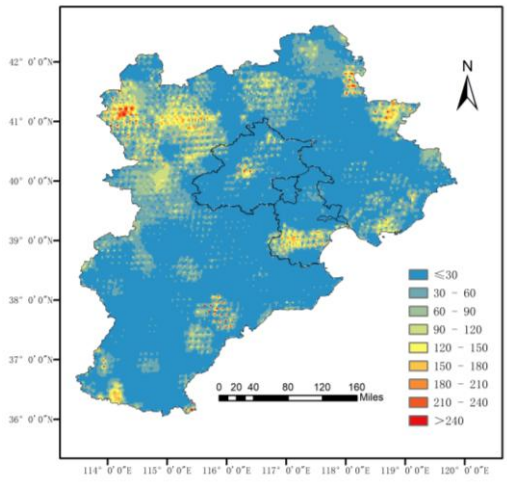
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120 - 150
150 - 180
180 - 210
210 - 240
>240
0 20 40 80 120 160
Miles

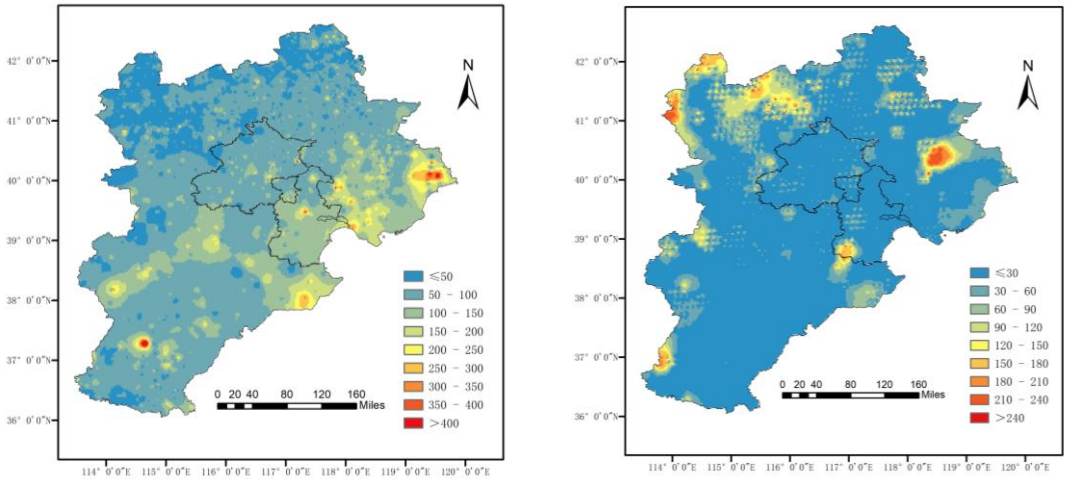
(h)


N
≤50
50 - 100
100 - 150
150 - 200
200 - 250
250 - 300
300 - 350
350 - 400
>400
0 20 40 80 120 160
Miles

(i)


N
≤30
30 - 60
60 - 90
90 - 120
120 - 150
150 - 180
180 - 210
210 - 240
>240
0 20 40 80 120 160
Miles

(j)



(**k**) (**l**)

Fig 2. Spatial distribution of lightning intensity in April-September: (light) ADTD CG lightning (unit: kA); (right) FY-4A total lightning (unit: μJ·m^{-2}·sr^{-1}):**(a)**April ADTD;**(b)**April FY-4A;**(c)**May ADTD;**(d)**May FY-4A;**(e)**June ADTD;**(f)**June FY-4A;**(g)**July ADTD;**(h)**July FY-4A;**(i)**August ADTD;**(j)**August FY-4A;**(k)**September ADTD;**(l)**September FY-4A.

Based on the monthly analysis, the spatial distribution of lightning intensity in the Beijing-Tianjin-Hebei region presents interrelated and focused evolution characteristics in ADTD and FY-4A datasets, which profoundly reveals the differential responses of CG lightning and total lightning activities to terrain, land-sea thermal effects and mesoscale convective systems, and also reflects the good complementary value of the two types of lightning datasets in monitoring and understanding regional severe convective weather and climate characteristics.

3.5.3 Diurnal Variation Characteristics of Lightning Intensity

In terms of diurnal variation characteristics (Fig 18), the variation trends of the two lightning intensities in different years are basically consistent, but there are significant differences between ADTD and FY-4A datasets. The ADTD CG lightning intensity has no obvious peak period throughout the day and is relatively uniformly distributed; while the average optical radiation intensity of FY-4A lightning "events" shows a typical unimodal diurnal variation, gradually increasing from 06:00, peaking at 11:00-13:00, then continuously decreasing, and maintaining a low level after 18:00.

This difference is mainly due to the different detection principles and response characteristics of the two types of datasets: as an optical detection method, FY-4A's signal recognition is significantly affected by the daytime background light, and only when the optical radiation intensity exceeds a certain threshold can it be effectively recorded as a lightning "event", thus showing an optical response peak centered at noon. The ADTD system detects CG lightning based on electromagnetic signals, which is not affected by lighting conditions, so it can more uniformly capture all-day CG lightning activities, reflecting the more continuous characteristics of the CG lightning generation mechanism in the time dimension. This comparison shows that when analyzing the diurnal variation of lightning activities, the observation bias caused by the detection method itself must be considered.

3.6 Analysis and Application of Satellite-Ground Lightning Data in Typical Weather Cases

Taking April to September 2020-2022 as the study period, the minute-level precipitation observation data from all national meteorological observation stations (national stations) in the Beijing-Tianjin-Hebei region were selected as the basic data to calculate the

maximum 10-minute cumulative precipitation during each continuous precipitation process.

For each precipitation peak event at each station, the percentage of lightning frequency at each time interval to the total lightning number (within the past 1 hour) was calculated, that is, the lightning frequency proportion. At the same time, the arithmetic mean of all lightning intensities within each time interval was calculated to obtain the average lightning intensity within that interval.

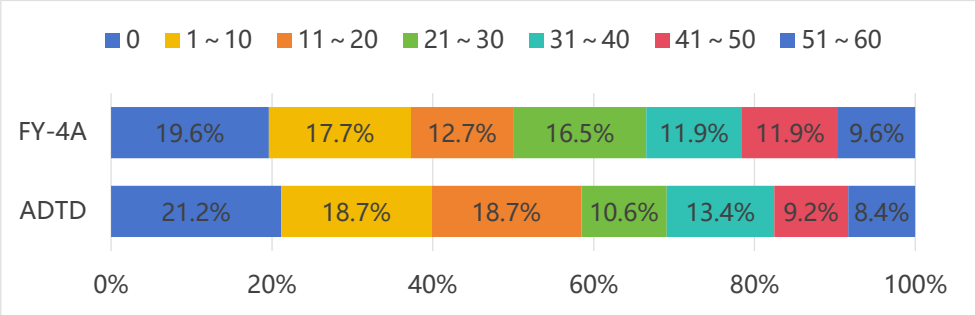


Fig 3. Lightning frequency proportion (%) at different time intervals before precipitation peak in the Beijing-Tianjin-Hebei region (average of 2020-2022).

From the time series of lightning frequency proportion(Tab 2.), the two datasets show similar but significantly different distribution patterns: as the precipitation peak approaches, both lightning datasets show an increasing trend of frequency. However, ADTD data show that lightning activities are mainly concentrated 0-30 minutes before the precipitation peak (cumulative proportion 57%), while FY-4A data show an earlier and relatively uniform distribution, and its lightning frequency proportion 30-60 minutes before the peak is significantly higher than that of ADTD. This distribution difference is consistent with the content of the diurnal variation characteristics of lightning frequency earlier, indicating that during the precipitation process, the lightning activities observed by FY-4A are overall earlier than those by ADTD, which exactly verifies the classic convective electrical activity development model that CC lightning is more vigorous in the early stage of convection development; CG lightning mostly appears in the mature stage of severe precipitation.

From the analysis of the variation law of lightning intensity, ADTD data show that the average intensity peak appears 30-40 minutes before the precipitation peak. This phenomenon may correspond to the stage of the most intense charge separation process in convective clouds, and the cloud-ground lightning generated at this time often has a stronger current. In contrast, the intensity distribution of FY-4A shows an average intensity peak 11-20 minutes before the precipitation peak and an average intensity valley 31-40 minutes before the precipitation peak.

Tab 2.Average lightning intensity at different time intervals before precipitation peak in the Beijing-Tianjin-Hebei region (average of 2020-2022).

Time interval (min)	**0**	**1-10**	**11-20**	**21-30**	**31-40**	**41-50**	**51-60**
ADTD（kA）	72.26	73.92	75.53	94.10	85.76	80.44	66.77
FY-4A (μJ·m²·sr¹)	20.92	31.96	42.66	32.28	12.71	36.53	30.43

It is worth mentioning that to explore the intrinsic link between precipitation intensity and lightning activities, this study systematically calculated various linear correlation coefficients between the precipitation peak and multiple statistics of the corresponding lightning intensity, but no significant linear correlation was found. The correlation coefficients are generally very low and fail to pass the statistical significance test. This finding

can be explained from the perspective of the physical process of convective systems: the two are not simply driven by the same source in physical causes, but are controlled by different physical processes in the cloud, which leads to the lack of consistent linear synergistic variation rules in statistics. This conclusion also reminds us that when using lightning activity characteristics to infer or warn precipitation information, we must be extremely cautious and not carry out blind correlation analysis.

4 .Discussion

The comparative analysis of ADTD and FY-4A lightning data in the Beijing-Tianjin-Hebei region shows obvious complementarity between the two datasets. FY-4A has advantages in monitoring large-scale and CC-dominated lightning activities, especially in the initial and declining stages of lightning activities (April-May and September), which can capture weak lightning signals that are difficult to detect by ADTD. ADTD is more accurate in monitoring CG lightning, and can clearly reflect the local concentration characteristics of CG lightning affected by terrain, which is of great significance for grasping the key areas of ground lightning hazards.

The difference in the timing of lightning frequency and intensity relative to precipitation peaks between the two datasets verifies the classic convective electrical activity model. The earlier occurrence of FY-4A total lightning activity relative to precipitation peaks indicates that CC lightning is active in the early stage of convection development, which can provide an early signal for the prediction of severe convection weather. The concentration of ADTD CG lightning near the precipitation peak reflects that CG lightning is mainly generated in the mature stage of convection, which is closely related to the intense charge separation process in the cloud.

It is worth noting that there is no significant linear correlation between precipitation intensity and lightning intensity, which indicates that the physical mechanisms controlling the two are different. Lightning activity is affected by the dynamic and microphysical processes of convective clouds, while precipitation intensity is related to the condensation and collection process of water vapor in the cloud. This result suggests that when using lightning characteristics to predict precipitation information, it is necessary to comprehensively consider multiple factors and avoid simple linear correlation analysis.

5. Conclusions

1.In terms of the interannual variation characteristics of lightning frequency, ADTD and FY-4A lightning datasets are basically consistent; in terms of monthly variation characteristics, both datasets monitor that lightning activities are mainly concentrated in summer (June-August), but there are differences in the specific peak months, which may be caused by different detection principles and detection capabilities for different types of lightning. In terms of the diurnal variation characteristics of lightning frequency, the two datasets are basically consistent, with frequent lightning activities from afternoon to evening and relatively few in the early morning and night. The peak time of lightning "events" is several hours earlier than that of CG lightning, which is related to the occurrence characteristics of CG lightning and CC lightning in different stages of convective weather processes.

2.Both ADTD and FY-4A datasets show that lightning activities in the Beijing-Tianjin-Hebei region present a life cycle from development, prosperity to decline from April to September, with an overall "south more and north less" spatial pattern. The monthly variation of the two datasets is significant: FY-4A observes lightning activities with a wider

spatial range and more uniform distribution, especially in CC-dominated areas and periods; ADTD can more clearly reflect the concentration and locality of CG lightning affected by terrain. The two form effective complementarity in lightning types and spatial distribution, which can more completely depict the spatiotemporal evolution characteristics of regional lightning activities.

3.Overall, the high-value areas of ADTD CG lightning are generally eastward, active and scattered in coastal and plain areas; the high-value areas of FY-4A stably appear in the northwest and northern topographic uplift areas with good continuity. This spatiotemporal evolution pattern reveals the differential responses of the two types of lightning activities to terrain, land-sea thermal forces and convective systems, reflecting the good complementarity between observation datasets. In terms of diurnal variation, there are significant differences in lightning intensity between ADTD and FY-4A: ADTD CG lightning intensity is uniformly distributed throughout the day without obvious peak periods; FY-4A optical radiation intensity shows a unimodal diurnal variation, peaking at 11:00-13:00 and being low in the morning and evening.

4.In terms of lightning frequency, as the precipitation peak approaches, both datasets show an increasing trend, but there are differences in distribution characteristics: ADTD CG lightning is mainly concentrated 0-30 minutes before the peak, while FY-4A total lightning activity is earlier and more uniformly distributed. This difference verifies the classic convective electrical activity model, that is, CC lightning is more active in the early stage of convection development, and CG lightning mostly appears in the mature stage of convection. In terms of lightning intensity, ADTD has an average intensity peak 30-40 minutes before the precipitation peak, which may correspond to the stage of the most intense charge separation; FY-4A has an intensity peak 11-20 minutes before the precipitation peak and a valley 31-40 minutes before, reflecting the phased response of optical detection to lightning optical radiation.

The results of this study provide an important reference for lightning monitoring and early warning research in the Beijing-Tianjin-Hebei region, and help improve the understanding and response ability to severe convection weather in this region. Future research can further combine more observation data to deeply explore the relationship between lightning activities and severe convection weather and meteorological elements, providing more powerful scientific support for regional disaster prevention and mitigation.

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