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Research Article

Development of Lightning Nowcasting and Warning Technique and Its Application

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The Chinese Academy of Meteorological Sciences Lightning Nowcasting and Warning System (CAMS_LNWS) was designed to predict lightning within the upcoming 0-1 h and provide lightning activity potential and warning products. Multiple remote sensing data and numerical simulation of an electrification and discharge model were integrated in the system. Two core algorithms were implemented: (1) an area identification, tracking, and extrapolating algorithm and (2) a decision tree algorithm. The system was designed using a framework and modular structure, and integrated warning methods were applied in the warning program. Two new algorithms related to the early warning of the first lightning and thunderstorm dissipation were also introduced into the system during the upgrade process. Thunderstorms occurring in Beijing, Tianjin, and Hebei during 2016-2017 were used to evaluate the CAMS_LNWS by the low-frequency cloud to ground lightning detection data, and the results showed that the system has good forecasting and warning ability for local lightning activities. The TS score in 0-1 h ranged from 0.11 to 0.32, with a mean of 0.20. Operational experiments and promotional work for the CAMS_LNWS are now in progress.

1. Introduction

Lightning is a natural phenomenon with the potential to destroy buildings, power supply systems, and communication equipment. Cloud-to-ground lightning is the most hazardous form of lightning and can result in both economic losses and human casualties. Approximately 100 people are killed or injured by cloud to ground lightning in China each year [1]. To prevent and reduce lightning disasters, apart from adopting lightning protection engineering and technical measures to protect specific targets, lightning potential predictions, short-term predictions, and nowcasting are carried out. With advances in economic and societal development in China, there is now an urgent need to monitor and forecast lightning to protect important facilities, regions, and activities [2]. Early warning systems for lightning are part of the national public meteorological forecasting and warning system. Improving the accuracy of lightning monitoring and the early warning system will improve safety in many industries and may also save lives.

Nowcasting of severe convective weather is generally extrapolated from satellite or radar data. Researchers have used the same method for early warning of lightning systems and nowcasting (0-1 h). Lightning nowcasting refers to the prediction of areas and times where lightning activity may occur within 0-1 h based on the laws of lightning activity or observed possible precursors. The parameters observed by radar (e.g., radar reflectivity values, vertically integrated ice) and satellite (e.g., integrated precipitable water vapor) systems close to where the lightning occurs are used for lightning nowcasting [3–6]. Lightning detection data have become increasingly available in recent years and can be used directly in early warning systems to predict lightning activity [7]. Radar, satellite, lightning locator, atmospheric electric field meter, and conventional meteorological observation data are used to continuously monitor and track areas of potential lightning activity, identify the intensity change and moving path of lightning activity, and use extrapolation algorithms to predict lightning activity areas and the probability of occurrence, development, evolution, and extinction in the next 0-1 h.

Currently, there are few nowcasting and early warning systems, especially for lightning activity. Most of the mature systems integrate various thunderstorm detection data for warnings on the occurrence and development of thunderstorms. The main warning products include thunderstorm intensity level, precipitation, and hail. NCAR (National Center for Atmospheric Research) has developed an integrated 0-1 h auto nowcasting system (ANC) [8, 9], which uses a variety of mesoscale observation data and algorithms to obtain information on the occurrence, development, and extinction of storms. One of the main characteristics of the ANC is that it can monitor and identify the location of the boundary layer convergence line. By combining boundary layer convergence line features with storm and cloud feature information, it can nowcast storms. The nowcasting system GANDOLF (Generating Advanced Nowcasts for Deployment in Operational Landbased Flood Forecasts) [10] developed by the Met Office of the UK (United Kingdom) is used to predict convective precipitation. To identify convective cells, the GANDOLF system synthesizes a target-oriented method and a conceptual model of the convective cell life cycle and uses multibeam radar reflectivity data, infrared and visible satellite cloud images, and prediction results of the mesoscale numerical model to establish a 0–3 h convective precipitation movement and development prediction.

Although there have been many studies of lightning nowcasting [3–6], these studies have been largely based on single observation data and were academic rather than functional attempts to develop early warning systems to predict lightning activity. Different observation data for the early warning of lightning have their advantages and disadvantages. For example, lightning monitoring data have good real-time performance, but the early warning advance time is limited. The real-time nature of ground electric field data is very good, but the single station warning area is limited in terms of scope. The spatial and temporal resolutions of radar data are good, but strong echoes occur only after precipitation particles have formed, limiting the time frame for early warnings. The spatial scale of satellite data is very large and can reach thousands of km, but the space-time resolution of satellite data currently available is relatively coarse, and its role in the warning of approaching lightning is still limited. In response to the growing demand for early lightning warning systems in China, the State Key Laboratory of Severe Weather at the Chinese Academy of Meteorological Sciences developed the Lightning Nowcasting and Warning System (CAMS_LNWS) [11, 12]. This system can provide warnings for lightning activity in the local area during the next 0–1 h. This paper introduces the platform and algorithm used in the system and then carries out an example analysis and evaluation test based on the latest results from an early warning test.

The second part of this article focuses on the design and algorithm of the early warning system. The third part introduces the statistical results of the evaluation test. The fourth part introduces the early warning results in two thunderstorms. Finally, the discussion and conclusion of this study are given.

2. Platform Design and Algorithm

2.1. Basic Design. The CAMS_LNWS was designed using a framework and modular structure and integrates warning methods in the program [11]. The system can identify, track, and extrapolate areas at potential risk of lightning and produce lightning nowcasting and warning products. These products automatically provide the probability of lightning in key areas and the moving trend of the lightning activity area. The system provides parameter interfaces and human-machine interaction functions. It can be applied in a variety of situations and geographical areas.

In view of the severe convective weather systems in a local area, the system was based on the lightning characteristics in a typical region and adopted a multidata, multiparameter, and multialgorithm lightning nowcasting method [13]. The foundation of the system is the analysis of the distribution of lightning in space and time and the radar echo characteristics of the thunderstorm monomer in the local region. The CAMS_LNWS integrates observational data from radar, satellites, lightning detection systems, ground electric instruments, and sounding instruments with synoptic pattern forecasting products and a two-dimensional charge-discharge model [14, 15]. By analyzing and extraction parameters closely related to lightning occurrence and combining them with the lightning short-term forecast method, the system is specifically designed for lightning prediction.

The CAMS_LNWS works 24 hours a day and renews the warning products every 15 mins automatically. Warning products are published via the China Meteorological Administration (CMA), which can realize 0-1 h lightning nowcasting with a 1×1 km grid and provide rapid response to meteorological information sharing via the Internet. CAMS_LNWS applications can be easily implemented as a result of its user-friendly interface and rich control parameters. It can run without manual intervention in automatic mode, which can save business department human resources, reduce the burden on forecasters, and improve work efficiency. Figure 1 shows the user interface and basic system form.

Quasi-real-time and real-time observation data with fine spatial and temporal resolutions, such as lightning and radar data, were considered in the design scheme. Because the real-time ground electric field instrument observation data were related to lightning activity directly, ground electric field records were also important references for lightning nowcasting and warnings. The design diagram is shown in Figure 2. Each application used separate modules, such as the lightning data application module, radar and ground electric field data application modules, and one integrated forecasting module in this system. Considering different runnable situations, the system can not only use a single data application module to generate forecasting products for different temporal and spatial scales, but it can also synthesize different application modules to generate products through a weighted combination method.

In CAMS_LNWS, users can set the warning area, grid resolution, the application data used, and the weight of

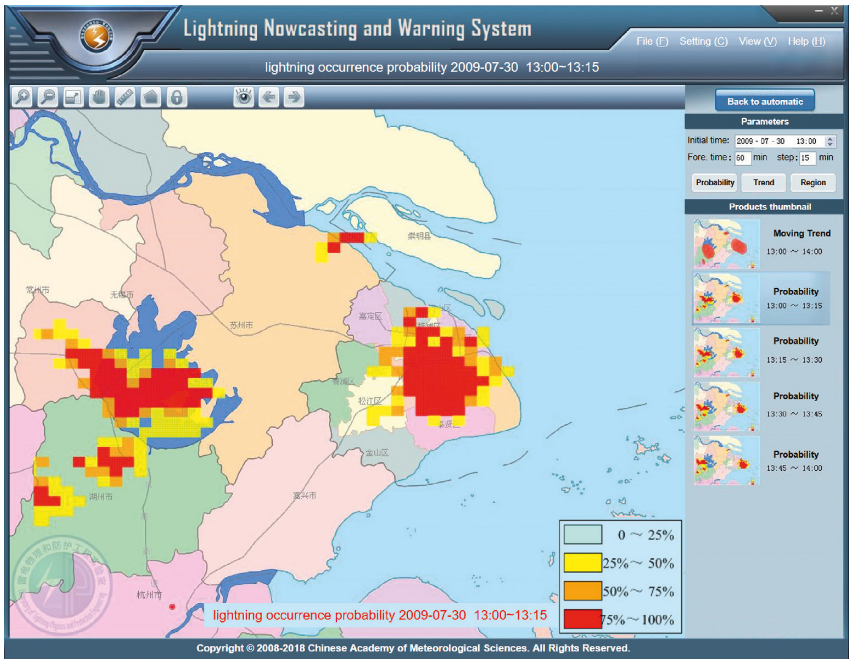


FIGURE 1: The user interface and basic system form, with different colors representing the lightning occurrence probability early warnings.

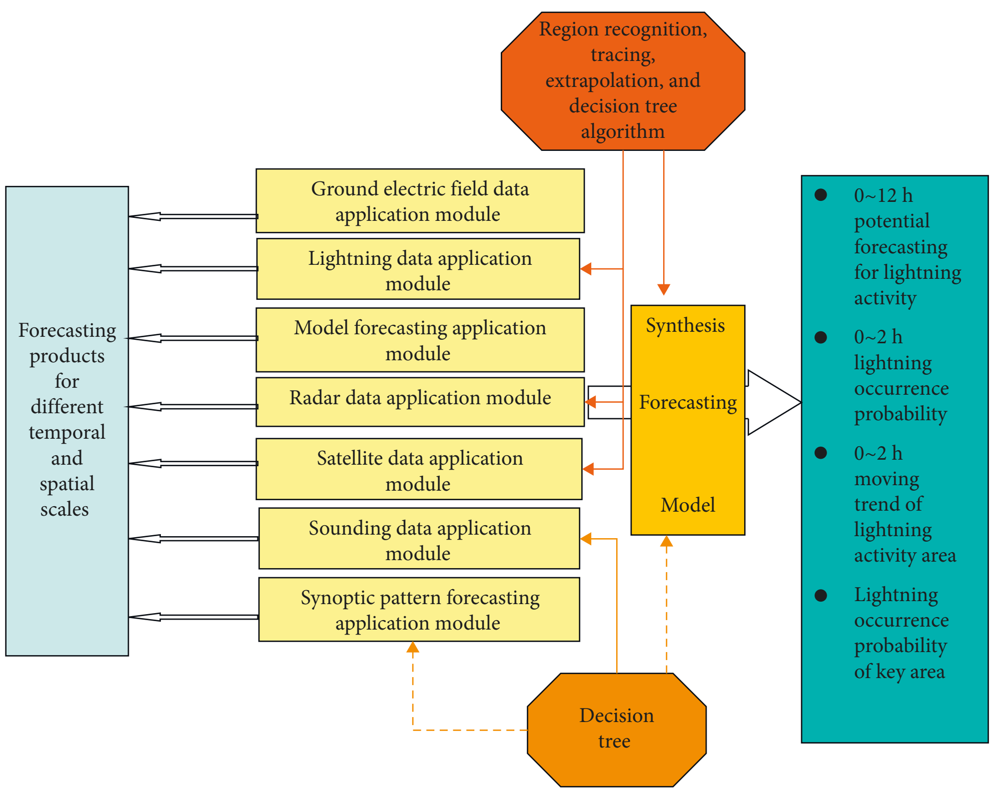


FIGURE 2: The design diagram of CAMS_LNWS.

each dataset, and they can also set the parameters for the validity reprocessing period and the warning step parameters. First, the system can preprocess corresponding data according to the user's settings, then use a single application module one by one, and finally integrate the nowcasting and warning products. Data preprocessing ensures effective operation. Each valid data file was grid-processed according to the parameters set by the users, and the interpolation methods adopt a bilinear interpolation method. For real-time lightning monitoring data, the time step should be specified, which could preprocess to generate multiple periods of gridded data;

the data of each grid point included the lightning frequency within the time interval.

2.2. Algorithm. Different core algorithms are used in different data modules (as shown in Figure 2). Algorithms for regional recognition, regional tracing, and extrapolation are used in the radar, lightning, and satellite data application modules [16–18]. Any one of these three types of data alone can be used as early warnings of lightning, but the radar and lightning data usually have the best fit and are used as the core data in our algorithm. CAMS_LNWS can operate normally as long as either radar or lightning data are available. Decision tree algorithms are used in the module for the application of sounding data [19, 20], and these algorithms need to be trained based on a large number of thunderstorms. The electric field instrument module is used for single point lightning warnings [21]. The synoptic pattern and cloud model simulation results, which were not integrated in the objective prediction, are used to predict the potential of lightning with longer prediction time limits and serve as a subjective reference for forecasters.

Systematic updates of the CAMS_LNWS have been carried out since 2016, and improvements in the system's user interface have made the system more convenient to use. Other improvements have focused on early warning algorithms and the identification of storms. A lightning-based clustering algorithm has been added [22]. The system updates the recognition algorithm for convective and stratiform regions in thunderstorms [23], reducing the rate of false alarms in lightning forecasts.

From 2008 to 2015, the preupgrade system was put into operation. Some problems were found during operational tests. (1) For severe storms in local areas, the hit rate of lightning in the initial stage was relatively low. (2) The false alarm rate was high during the storm dissipation stage. In fact, early warning of the first lightning flash and thunderstorm dissipation is an important goal for the improvement of the system. Understanding the relationship between the characteristics of radar echoes at the initial stage of cloud formation and the first generation of lightning is also important in lightning nowcasting. The radar echo volume per flash (VPF) can be used to determine the end of the thunderstorm [24]. Two algorithms related to the early warning of the first lightning flash and thunderstorm dissipation are introduced into the system.

The algorithm for the first lightning strike [6]: If the top height of the 40 dBZ echo in the monomer radar data can rise above the 0°C temperature stratification height and remain above it, then it is considered that the monomer is likely to be a thunderstorm cell, but it can be identified as a nonthunderstorm cell. After the monomer meets the previous judgment basis, if the top height of the 40 dBZ echo continues to rise above the −10°C temperature stratification height, it is identified that the monomer's first lightning strike occurs within 15 mins after the radar volume sweep time, which meets the condition. However, if the top height of the 40 dBZ echo does not continue to rise above the −10°C layer boundary height, and the P value (above the 0°C temperature layer junction height, the volume of the echo above 40 dBZ in the monomer accounts for the percentage of the echo volume above 25 dBZ) in the monomer can reach more than 5 %, then it is identified that the initial lightning also occurs within 15 mins after the radar volume sweep time, which satisfies this condition.

The algorithm for the thunderstorm dissipation [24]: A single lightning strike was proposed to characterize the echo volume characteristics, defined as VPF. Shi et al. [24] analyzed thunderstorm weather processes in Beijing and found that the VPF is relatively small within 6 mins before lightning activity ends. Therefore, the VPF is used as an indicator for the thunderstorm dissipation. VPF changes are combined with lightning frequency as the identification conditions for the early warning of lightning extinction, which may improve the accuracy of early warnings.

The example thunderstorms presented for analysis and evaluation in this paper all took place after the system updates.

3. Operational Applications and Verification

3.1. Operational Status. The CAMS_LNWS operated in China from 2008 to 2017. Beijing, Shanghai, Hubei, Yunnan, Henan, Chongqing, Qingdao, Liaoning, and Hei Longjiang realized the localization of the CAMS_LNWS and began to provide lightning warning services for their local areas. The CAMS_LNWS played an important role in the lightning forecasting service for the 2008 Beijing Olympic Games.

The CAMS_LNWS functioned 24 hours a day, and warning products were published via the China Meteorological Administration website in real time. The nationwide operation allowed experiments and evaluation work for the lightning warning products to be carried out to improve the forecasting and diagnostic techniques and to establish a quick-response operational system for the lightning warning service.

Operational tests were carried out in most meteorological departments across the country. The results of the operational tests showed that the accuracy rate of the lightning nowcasting system could reach more than 60 % at a resolution of 5 km (only 50% before the system update). The system met the requirements of lightning nowcasting in local areas and provided an important reference basis for the release of lightning warning signals in meteorological offices of various provinces and cities.

3.2. Verification Methodology. The conventional threat score (TS, i.e., Critical Success Index) method [25] is used to evaluate the forecasting performance of the CAMS_LNWS from a quantitative point of view. The TS method for computing the scores uses a 2×2 contingency table of possible forecast outcomes at individual grid points wherein the table elements are hits (correct forecast of events), misses (observed but not forecast events), and false alarms (forecast but not observed events). Then three indices of TS, false alarm rate (FAR), and probability of detection (POD) are further calculated, respectively.

The area for forecast verification is selected at Beijing and its surrounding areas. See Figure 3 for the specific location. The products of the nowcasting system is the lightning occurrence probability in 1 km × 1 km grid for the next 1h in 15-minute interval, and the forecasting results are also evaluated by point-to-point method on the same grid resolution. If the lightning occurrence probability of one grid is greater than 25%, predicted lightning activity is considered to occur at this grid.

The nationwide cloud-to-ground (CG) lightning observation data from the Advanced Time of Arrival and Direction (ADTD) system network of China were used to compare with the forecasting results. The detection efficiency and accuracy of the ADTD system have been reported by Yao et al. [26]. First, the observation CG lightning data is treated through quality control, and then it will be gridded in 1 km × 1 km resolution. If the flash number of one grid is greater than zero, observed lightning activity is considered occur at the grid.

The operational experiments are used to evaluate the accuracy of the warning products in the CAMS_LNWS. The evaluation was based on a comparison of the predicted and observed results from several different thunderstorms. Since the warning system can realize the forecasting products for the next 1 h in 15-minute interval at one time, and the forecasting products will be updated every 15 minutes. Four different forecasting periods of 0–15, 15–30, 30–45, and 45–60 min will be formed. In order to understand the performance of the system in different forecasting periods, all the 15-minute interval forecasting results during each thunderstorm are evaluated in the study.

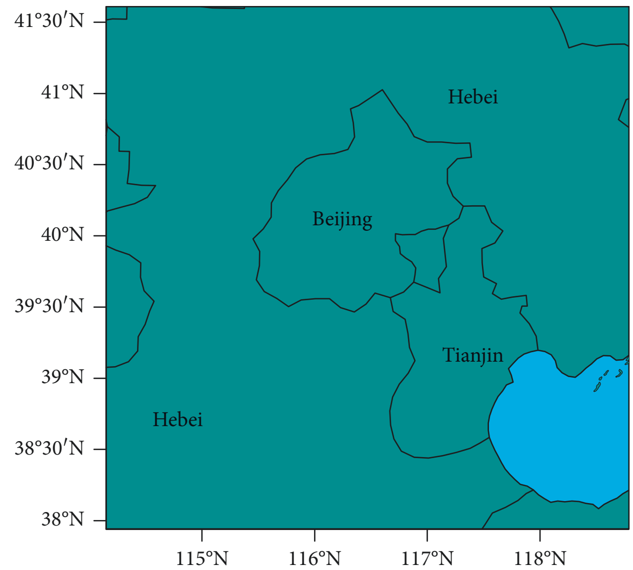


Figure 3: The domain of the verification.

3.3. Verification Results. A total of 16 thunderstorms occurring in Beijing, Tianjin, and Hebei during 2016–2017 were evaluated using ADTD data. Table 1 lists the TS scores and the POD and FAR parameters (mean value) representing the evaluation results for the forecasting products at 15-minute intervals. The time used here and after is Beijing time (UTC + 8). The TS score ranged from 0.11 to 0.32, with a mean of 0.20. The POD ranged from 0.26 to 0.54, with a mean of 0.41. The FAR score ranged from 0.51 to 0.87, with a mean of 0.71, indicating a relatively high FAR. This is an important factor and affects the TS score. Effective methods will be taken to reduce the FAR in future work.

Table 2 shows the mean value of TS scores, POD, and FAR parameters at different forecasting times for the 16 thunderstorms. Both the TS score and POD in 0–15 min reached the highest levels. The mean value of the TS score from 0 to 15 min was 0.24; before the system was updated in 2016, the results of the forecast assessment showed that the TS score from 0-15 min was 0.19 [11], indicating a significant improvement in the predictive power of the system through system upgrades.

Judging by the forecast of lightning activities, the lightning nowcasting system has a positive effect on the forecast of the starting time and ending time of lightning activities for systematic or frequent lightning activities, which corresponds well to the actual lightning data (not shown). The false alarm rate of the early warning system is relatively high for local lightning events with sporadic lightning activity which has a lifespan less than 30 min.

Judging from the forecast of the lightning falling area, the lightning approaching the warning system also shows good results. The forecasted lightning position shows a good superposition effect with the actual lightning position (not shown); that is, the actual lightning distribution has a strong consistency with the forecasted result.

4. Nowcasting Results for the Case Study

4.1. Thunderstorm Case Study: 12 August 2016. The previous section introduced the statistical results; this section describes two thunderstorms in detail. From 08 : 00 to 16 : 00 (Beijing Time) on 12 August 2016, thunderstorms occurred in most areas of Beijing due to local rain clouds. Although rainfall was widely distributed, the rainfall distribution was extremely uneven and the observed precipitation exceeded 100 mm. This weather process was mainly caused by the combined influence of the upper westerly trough, shear line, and surface front. At 08 : 00, the maximum convective available potential energy (CAPE) was 2900 J/kg, the free convection level was lower than 925 hPa, which was conducive to the development of deep convection. The maximum temperature difference between high (500 hPa) and low (850 hPa) air reaches 24°C, and the stratification was very unstable.

This thunderstorm was accompanied by a large number of lightning activities. Figure 4 shows the location results of the Beijing area flash from 09 : 45 to 10 : 45 on August 12. According to the distribution of the lightning location results during different periods of time, it can be judged that the lightning activity areas during this process gradually moved from west to east.

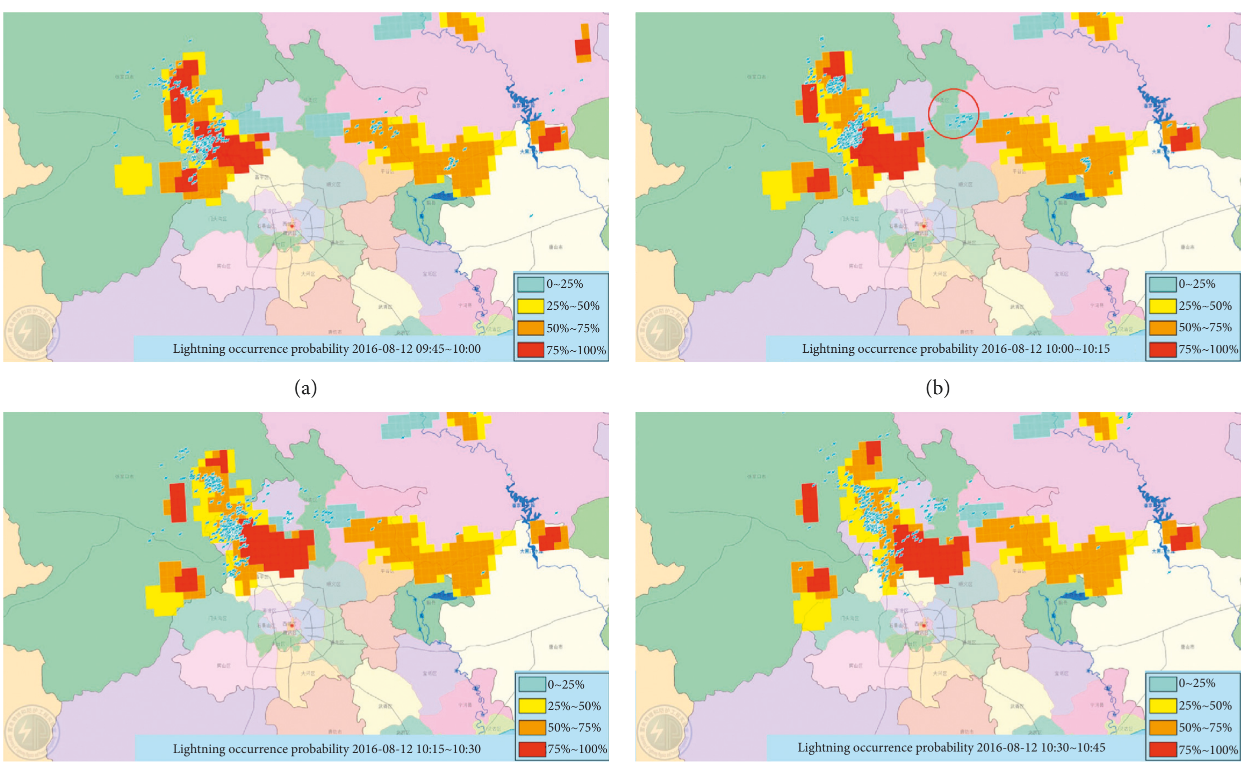
The CAMS_LNWS provided the probability of the occurrence of lightning for the period 09 : 45–10 : 45 at

Table 1: The mean TS scores and POD and FAR parameters of the evaluated thunderstorm cases.

No.	Time and date (Beijing time)	POD	FAR	TS	Sample point number
1	21 : 00–22 : 45, 11 May 2016	0.42	0.66	0.23	8
2	16 : 00–23 : 00, 6 June 2016	0.26	0.82	0.12	29
3	14 : 00–03 : 45, 9-10 June 2016	0.37	0.66	0.23	56
4	0 : 00–03 : 00, 13 June 2016	0.36	0.87	0.11	13
5	16 : 00–23 : 00, 21 June 2016	0.45	0.83	0.14	29
6	0 : 00–10 : 45, 28 June 2016	0.40	0.82	0.13	44
7	12 : 00–22 : 30, 28 June 2016	0.37	0.68	0.23	43
8	3 : 00–7 : 30, 30 June 2016	0.47	0.70	0.22	19
9	15 : 00–03 : 45, 6-7 August 2016	0.40	0.80	0.19	52
10	08 : 00–15 : 45, 12 August 2016	0.54	0.73	0.22	32
11	15 : 00–04 : 30, 4-5 September 2016	0.45	0.65	0.21	55
12	0 : 00–6 : 00, 11 September 2016	0.48	0.51	0.32	25
13	12 : 00–17 : 45, 18 June 2017	0.35	0.66	0.19	24
14	20 : 00–01 : 00, 19-20 June 2017	0.38	0.62	0.21	19
15	16 : 00–19 : 45, 25 June 2017	0.41	0.59	0.15	16
16	16 : 00–19 : 15, 27 June 2017	0.51	0.74	0.27	14
	Mean	0.41	0.71	0.20	~30

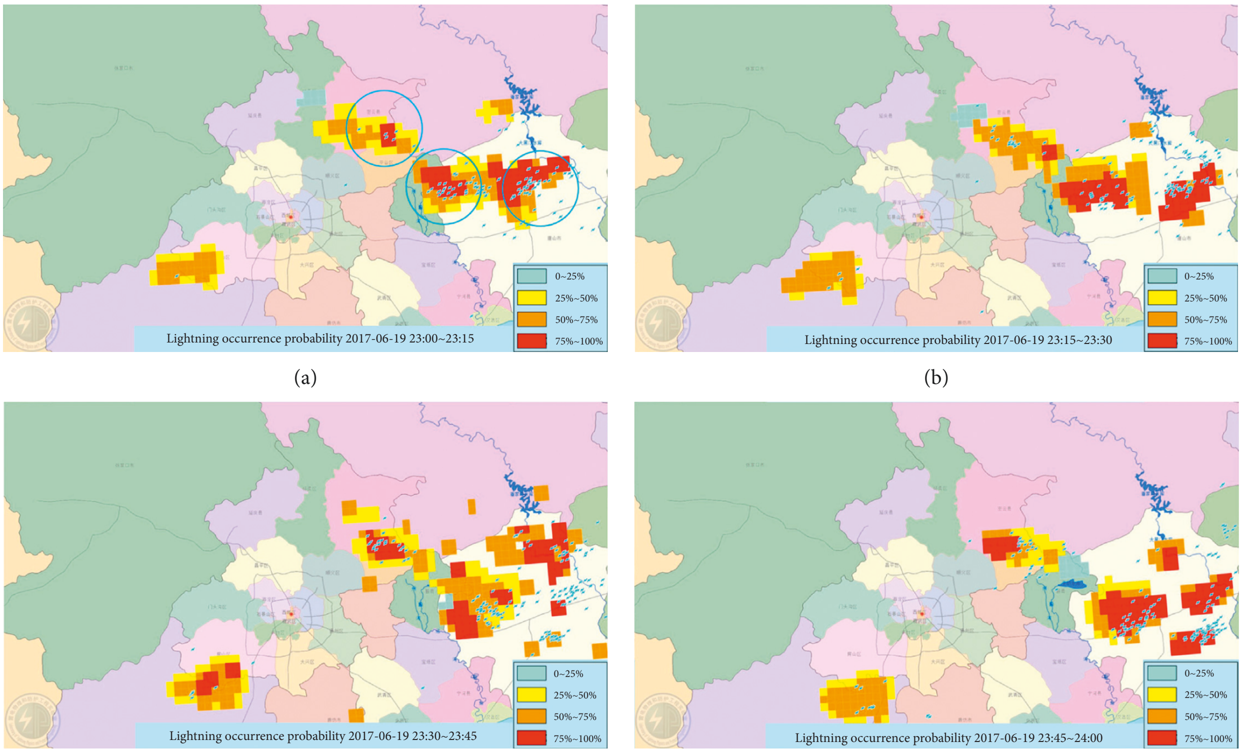
Table 2: The mean TS scores and POD and FAR parameters of different forecasting time.

Parameter	0–15 min	15–30 min	30–45 min	45–60 min
POD	0.49	0.46	0.41	0.37
FAR	0.67	0.69	0.74	0.77
TS	0.24	0.22	0.19	0.16



(a) (b) (c) (d)

Figure 4: CAMS_LNWS lightning occurrence probability products from 09 : 45–10 : 45 on 12 August 2016, overlain by the observed lightning events. The time periods of the four images are (a) 09 : 45–10 : 00, (b) 10 : 00–10 : 15, (c) 10 : 15–10 : 30, and (d) 10 : 30–10 : 45. Blue flash symbols indicate the lightning location results using the ADTD system.



(a) (b) (c) (d)

Figure 5: CAMS_LNWS 0–15 min lightning occurrence probability products for 23 : 00–00 : 00 on 19–20 June 2017, overlain by the observed lightning events. The time periods of the four images are (a) 23 : 00–23 : 15, (b) 23 : 15–23 : 30, (c) 23 : 30–23 : 45, and (d) 23 : 45–00 : 00. Blue flash symbols indicate the lightning location results using the ADTD system.

09 : 45 during this thunderstorm. Figure 4 shows images for each 15-minute interval from 09 : 45 to 10 : 45. The major area of thunderstorm activity was at the junction between northwest Beijing and Hebei, although the observed lightning activity moved eastward. In Figure 4(b), there is a new cell initiated in the red circle region. At 09 : 45, the warning products show that the lighting occurrence probability is 25% in the 10 : 00–10 : 15 period, and the first lightning of the initiated cell occurred in 10 : 12, which means that the warning system can early warning the first lightning of the cell.

The early warning results from the CAMS_LNWS give the movement trend of the lightning activity in advance. Based on the results of the comprehensive forecast and observations (Figure 4), the region of potential lightning activity forecast by the CAMS_LNWS was consistent with the region in which lightning was actually observed using location systems. Judging from the movement direction of the lightning activities, the lightning nowcasting system has a good grasp of the movement trend in lightning activities. The 0–15 and 15–30 min forecasting products correspond well to the movement trends of the actual lightning activities. It is also found that the warning system has a high false alarm rate during the analysis period.

4.2. Thunderstorm Case Study: 19 June 2017. From 20 : 00 at night on June 19 to 01 : 00 on the morning on June 20 (Beijing Time), many thunderstorms accompanied by strong lightning activity occurred in Hebei Province. Overall, the lightning activity areas were distributed along a southeast-northwest belt and gradually moved from west to east. In the previous case study, the products of the forecasting for the next 1 hour were given at one initial time. According to the TS scores in section 3.3, the warning system works best for the 0–15 min forecasting. Figure 5 shows lightning occurrence probability for the 23 : 00–00 : 00 generated by CAMS_LNWS at different times. All the products (Figures 5(a)–5(d)) are of the 0–15 min forecasting.

Three small regions of lightning activity (indicated by blue circles in Figure 5(a)) could be predicted well by CAMS_LNWS as the thunderstorm moved through the area. There was a good spatiotemporal relationship between the observational lightning data and the forecast provided by the CAMS_LNWS.

The lightning activity was more scattered than that in the previous thunderstorm. From the statistical results of the whole process, the POD, FAR, and TS scores of the 0–15 min products reached 49.0 %, 51.0 %, and 0.28, respectively. In this event, the system had a high hit rate for lightning, a low false alarm rate, and a high TS score, which shows that 0–15 min products achieved a good early warning for this lightning activity within this period of time. However, as the system strengthened, the hit rate gradually increased, but the false alarm rate also increased.

The results for these two thunderstorm case studies show that the CAMS_LNWS provides a good forecast for local weather processes, and the lightning probability forecasts were consistent with the measured lightning locations. We plan to conduct statistical studies on the forecasting of more thunderstorms.

5. Conclusions

The CAMS_LNWS is the first professional early warning of lightning service system in China to form a complete business platform and provide products for potential lightning activity and lightning warnings 0-1 h into the future. Based on the latest results for methods on early warning systems for lightning, the CAMS_LNWS integrates the application of a decision tree, regional identification, and tracking and extrapolation algorithms. Observational data from radar, satellites, lightning detection systems, ground electric instruments and sounding instruments with synoptic pattern forecasting products, and numerical simulation of the electrification and discharge model are also integrated into the CAMS_LNWS.

The qualitative and quantitative test results obtained for thunderstorms occurring in the Beijing region in 2016–2017 showed that the CAMS_LNWS has a good forecasting and warning ability for lightning activities in the local area. The CAMS_LNWS works steadily and provides a variety of products. It can read multisource detection data in real time, automatically provide warning products, and display updates.

The results of the TS score show that the system performed satisfactorily for thunderstorms. The TS score ranged from 0.11 to 0.32, with a mean of 0.20. The POD ranged from 0.26 to 0.54, with a mean of 0.41. Both the TS score and POD reached relatively high levels. The lightning nowcasting system has a good effect on forecasting the start time and end time of lightning under systematic or frequent lightning activities, which corresponds well to the actual lightning data. The system has a good grasp of the lightning falling area and the movement trend of lightning activities.

The overall consistency between the warning results and measured lightning results is good. However, judging from the forecast results of individual cases, the system still has a high false alarm rate, especially for the thunderstorm dissipation phase. The main reason may be related to the use of CG lightning data as the comparatively measured lightning data. Currently, the operational lightning location system in North China mainly obtains CG flash data. The CG flash accounts for only approximately 20% of the total lightning activities [27] and cannot reflect the cloud flash activities in thunderstorms. The early warning products of CAMS_LNWS aimed for prediction of the total lightning. In the verification, only CG flash data are used as the standard to evaluate the early warning results of the total lightning activities, which results in a high false alarm rate.

In the future, we plan to carry out in-depth studies to show the evolution of lightning activity in different areas, set up a regional lightning warning model, and further improve the regional lightning nowcasting index and algorithm. A 0–6 h mesoscale numerical forecasting method for lightning activity will be developed to improve the forecasting of lightning [28, 29]. The integration of the 0-1 h nowcasting products with the 0–6 h products of the mesoscale numerical model is also an important direction for future research.

Data Availability

All the data modules were designed as optional part, and the Lightning Nowcasting and Warning System (LNWS) could work normally with even one data module. The lightning data, radar data, satellite data, atmospheric sounding data, and synoptic pattern forecasting data used to support this study were supplied by National Meteorological Information Center of China under license and so cannot be made freely available. Requests for access to these data should be made to National Meteorological Information Center (http://data.cma.cn; data@cma.gov.cn; +8610-68407499). The model forecasting data were generated by an electrical model based on the atmospheric sounding data. The model description was included within the article "Numerical simulations of the bilevel and branched structure of intracloud lightning flashes" (https://doi.org/10.1007/s11430-006-0661-5). The ground electric field data used to support the operational application were supplied by Chinese Academy of Meteorological Sciences (CAMS). The ground electric field meter was located on the top of the CAMS office building, and only some testing data were used in this study.

Conflicts of Interest

The authors declare no conflicts of interest.

Acknowledgments

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