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23

24 **Abstract**

25 This study comprehensively investigates the spatiotemporal characteristics, diurnal
26 variations, and topographic modulation of convective initiation (CI) over Hunan
27 Province and its surrounding regions using 2025 operational FY-4B Level-2 CI and
28 Atmospheric Motion Vector (AMV) products, and further evaluate the practical early
29 warning performance of FY-4B CI products based on a typical severe convective case.
30 The statistical results show that CI activities exhibit significant seasonal heterogeneity,
31 with an active warm season from March to October and the annual maximum CI
32 frequency occurring in July. Spatially, high CI occurrences are mainly concentrated in
33 southern and southwestern Hunan and multi-provincial border mountainous areas,
34 whereas central and northern Hunan present relatively low CI frequency. This study
35 establishes two identification schemes to differentiate developing and decaying CI.
36 Adopting stricter discrimination criteria reduces the proportion of developing CI from
37 80.54% to 65.90%, and its spatial distribution is highly consistent with total CI,
38 confirming the reliable indicative capability of FY-4B CI for subsequent convective
39 evolution. The regional average CI diurnal peak appears at 06:00 UTC with distinct
40 spatial divergence, which is consistent with the diurnal variation of mesoscale
41 convective systems observed by radar. CI frequency increases with elevation within 0–
42 1000 m, peaks at altitudes above 1000 m, and slightly decreases beyond 1200 m,
43 indicating that moderate mountainous terrain favors local CI via orographic lifting and
44 thermal heterogeneity. Case analysis of a severe hail event demonstrates that FY-4B CI

can provide 1–2 hours of advanced early warning signals. However, a small fraction of CI signals decay afterward, underscoring the necessity of distinguishing sustainably developing CI to reduce the false alarm rate of early warnings.

Keywords

Fengyun meteorological satellite, Convective initiation, Hunan province, Topographic effect

Statements and Declarations

Financial interests: The authors declare they have no financial interests.

1 Introduction

Convective initiation (CI) acts as a crucial precursor to severe convective weather phenomena, including short-duration heavy rainfall, hail, and thunderstorm gales. CI detection is primarily achieved through ground-based radar and satellite remote sensing observations. In radar-based identification, CI is defined as the moment or process when convective echoes exceeding 35 dBZ are first captured. From a satellite perspective, CI corresponds to the initial phase of vigorous vertical development of cumulus clouds, accompanied by substantial cooling of cloud tops and the transition from shallow cumulus to mature convective clouds. By employing convection-sensitive spectral channels, optimized channel combinations, and temporal evolution criteria, incipient convective activity can be effectively monitored. Notably, satellite-based CI monitoring can provide earlier alerts of evolving rainfall systems compared with ground radar observations, exhibiting great application prospects in convective nowcasting (Liu et al., 2025).

The algorithm flow of CI can be roughly divided into three parts: target identification, target tracking, and initial convection identification (Qin et al., 2014). One of the early developed CI identification algorithms for geostationary meteorological satellites was established in 2006 based on time-series infrared brightness temperature from Geostationary Operational Environmental Satellite (GOES) satellites which is called SATCAST (Satellite Convection Analysis and Tracking) (Mecikalski and Bedka, 2006). Multiple physical criteria, including cloud top cooling rate, cloud cluster area growth rate and spatial gradient of brightness

temperature, were adopted by this algorithm to screen convection initiation. Walker et al. (2012) extended this framework by tracking developing cloud (DC) “objects” instead of single pixels to calculate spectral features (SATCASTv2). Despite these advances, high false alarm rates remain an issue with these algorithms (Mecikalski et al., 2015). Mecikalski et al. (2015) use the Numerical Weather Prediction (NWP) information to identify environmental conditions (as favorable or unfavorable) for the development of convective storms and to improve the skill of the CI nowcasts that operate on GOES-based cloud objects, as compared with when the satellite IR fields are used alone. On the basis of this algorithm, the CI products for U.S. GOES satellites were further developed subsequently.

CI nowcasting over China has a problem of a high false-alarm rate (FAR) due to the local convective processes, most of which do not produce severe weather. In order to focus on those CIs with severe weather, a new 0–2 h CI nowcasting system is developed, named rapidly developed convection monitoring system (RDCMS), using the data from the advanced geosynchronous radiation imager onboard China Fengyun-4A (FY-4A) satellite (Sun et al., 2019). CI definition used FY-4A satellite cloud imagery in central and eastern China developed a single-channel algorithm for the rapid identification and tracking of CI based on the 15-min cooling rates over a continuous 30-min period which is transferable across regions and seasons through regional and seasonal threshold calibration (Peng et al., 2025). Algorithms for CI identification using FY-4A observations focus on detecting developing CI features. Traditional algorithms adopt fixed thresholds and thus fail to adapt to complex environmental conditions

across different seasons, latitudes, and plateau terrains.

Hunan Province is located in the core area of the Jiangnan Hilly Region in China, featuring complex and diverse landforms. Bordered by the Wuling Mountains to the west and the Nanling Mountains to the south, its territory consists of interlaced mountains, hills, river valleys and lakes. Such a unique topographic pattern forms distinctive thermal and dynamic conditions in the regional boundary layer. Compared with plain regions, the complex terrain of Hunan can initiate local convection through multiple mechanisms including orographic lifting, mountain-valley wind circulations, heterogeneous surface heating, and lake-land thermal contrasts. Meanwhile, the alternating influences of mid-latitude westerly systems, low-latitude monsoon circulations and the subtropical high lead to frequent convective activities and complicated, variable CI processes during the warm season. Consequently, Hunan acts as a high-incidence and sensitive region for severe convective weather in southern China. Coupled by multi-scale weather systems and complex terrain, convection initiation in Hunan exhibits strong randomness in triggering, along with prominent diurnal variations and regional differentiation characteristics. Conventional numerical weather models struggle to accurately represent its evolutionary behaviors, which greatly raises the difficulty of nowcasting local severe convective weather (Tu et al., 2014; Tao et al., 2019; Zhou et al., 2025).

Most studies on CI and convective activities focus on convective climatic characteristics over extensive areas of China, the Qinghai-Xizang Plateau, the coastal regions of South China and other key zones. Targeted research concerning Hunan is

largely limited to diagnostic analyses of individual extreme severe convection and heavy rainfall cases within the province. Systematic climatological statistical investigations into the spatiotemporal distribution, diurnal cycle features and classification mechanisms of convection initiation across the whole province remain insufficient (Ye et al., 2013; Tang et al., 2019; Ma et al., 2026).

Accordingly, this study takes Hunan Province and its surrounding areas as the research domain. Using the recently improved and operationally released FY-4B Level-2 (L2) CI products, we investigate the spatiotemporal characteristics of CI over Hunan and demonstrate the operational application of CI features based on typical thunderstorm cases. The results can complement regional CI studies over the complex terrain of the Jiangnan Hilly Region and provide important observational evidence and technical support for accurate identification, nowcasting, and disaster prevention and mitigation of severe convective weather in Hunan.

2 Data and Method

2.1 Study Area

Convection developed after CI propagates with atmospheric circulations and affects adjacent regions. Weather systems upstream of Hunan Province are generally located to its west and south. Therefore, the study area is defined as (108°E–112.2°E, 24.2°N–30.3°N) (Figure 1), covering southern Hubei Province, southeastern Chongqing City, western Guizhou Province, northern Guangxi and parts of northern

Guangdong Province. As shown in the terrain distribution, Hunan Province is surrounded by mountains in the west, south, and east, with mountain terrain elevations ranging approximately from 800 m to 1500 m.

2.2 FY-4B satellite products

FY-4B was successfully launched in June 2021. It is the first operational satellite of China's new-generation geostationary meteorological satellite FY-4 series. FY-4B carries four payloads, three of which are weather-related instruments, namely the Advanced Geostationary Radiation Imager (AGRI), Geostationary Interferometric Infrared Sounder (GIIRS), and Geostationary High-speed Imager (GHI). Since 00:00 UTC on 5 March 2024, FY-4B has been conducting operational services positioned at 105°E. The datasets adopted in this paper include FY-4B/AGRI Level-1 (L1) channel brightness temperature (BT), CI product, and Atmospheric Motion Vectors (AMV) product. The data cover the year 2025, and the data download portal is available at <http://data.nsmc.org.cn>.

2.2.1 FY-4B CI

The algorithm for the FY-4B CI was updated in May 2025, after which the product entered operational service. The CI identification algorithm adopts traditional physical retrieval methods. The major satellite channels and discrimination criteria are listed as follows: (1) BT and its temporal variability of the 10.8 μm channel; (2) BT difference between the 6.25 μm and 6.95 μm channels; (3) BT difference between the 10.8 μm and 6.25 μm channels; (4) BT difference between the 10.8 μm and 13.3 μm channels; (5)

reflectance of the 1.38 μm shortwave infrared (SWIR) channel; (6) variations in target area, etc. Cloud cluster evolution characteristics can be obtained by analyzing the BT differences and temporal variability from different channel combinations.

To improve the identification accuracy of CI and extend the lead time of convection early warning, the algorithm upgrades include the following aspects compared to operational FY-4A L2 CI product. Firstly, the 1.38 μm SWIR channel is newly added as an extra daytime identification criterion. Secondly, cloud top features of CI vary across different regions, making fixed thresholds universally inapplicable. Accordingly, the algorithm incorporates dynamic thresholds that shift with latitude zones. Thirdly, to sustain continuity in CI identification outcomes, a multi-temporal identification strategy is adopted. The cloud top development status is assessed simultaneously at time T_0 , T_0-1 and T_0-2 . A CI event is confirmed if the criteria are satisfied at any of these three moments. The operationally released FY-4B L2 CI product adopts the full-disk nominal projection with a spatial resolution of 4 km and a temporal resolution of 15 minutes. The dataset is stored in binary values of 0 and 1, where 1 denotes CI and 0 indicates no CI. For the research of this paper, the same CI retrieval algorithm is used to reprocess all data of 2025. Example of CI product is presented in Figure 2.

2.2.2 FY-4B AMV

The AMV product comprises retrievals from four channels: three water vapor channels (CH09, CH10, CH11, with central wavelengths of 6.25 μm , 6.95 μm , and 7.42

μm , respectively) and one longwave infrared channel (CH13, central wavelength of $10.8\ \mu\text{m}$). Generated at a 15-minute temporal interval starting at 00:00 UTC, the dataset covers the full disk of FY-4B with a horizontal spatial resolution of 64 km. The gridded AMV product contains wind speed, wind direction and atmospheric pressure for each grid point. Notably, AMVs derived from the CH13 longwave infrared channel are assigned heights consistent with the cloud-top height (Ren et al., 2025). Accordingly, CH13 AMVs are utilized to track the displacement of CI clouds. An example of FY-4B AMV product is shown in Figure 3.

2.3 Methods

2.3.1 CI occurrence frequency

The CI occurrence frequency is defined as the number of CI occurrences within a certain period divided by the total number of satellite observations during the same period.

2.3.2 CI evolution characteristics

Method for distinguishing developing and decaying CI. For pixels identified as CI with BT denoted as TBB0, the mean wind speed and wind direction of longwave infrared ($10.8\ \mu\text{m}$) AMV within a 0.4° longitude-latitude box centered on the CI pixel are adopted for tracking. The pixel positions at two subsequent consecutive time steps spanning a total of 30 minutes are traced, and the corresponding pixel locations at the two time steps are determined. The minimum BT are calculated for the traced pixels at both time steps, together with their eight immediate neighboring pixels and sixteen

secondary neighboring pixels (TBB1 for 15 minutes and TBB2 for 30 minutes).

Two discrimination schemes are designed. Scheme 1 defines CI as developing if TBB1 is lower than TBB0. Otherwise, the CI is classified as decaying. Scheme 2 classifies CI as developing only when both TBB1 and TBB2 are lower than TBB0. Otherwise, the CI is decaying (Liu et al., 2026). The identification results of the two schemes are analyzed separately. The technical flowchart for CI evolution characteristic discrimination is shown in Figure 4.

3 Research Results

3.1 Characteristics of CI frequency

The monthly distribution of cumulative total frequency of CI activities within the study region (108°E–114.2°E; 24.2°N–30.3°N) in 2025 is shown in Figure 5. The frequency of CI activities is relatively low in January, February, November and December. CI activities gradually become active in spring and summer (March, April, May, June and July), with the total frequency of CI activities peaking in July, followed by a gradual decline from August to October. Based on the characteristics of monthly cumulative CI frequency, this study focuses on analyzing the CI activity characteristics during March and October.

3.1.1 Spatial distribution

The spatial distribution of mean CI activity frequency during March and October 2025 (Figure 6a) indicates that regions with high frequent CI occurrences are primarily situated over southern Hunan, northern Guangxi, northern Guangdong, the Hunan and

Jiangxi border, the junction of Hunan Hubei and Chongqing, and southwestern Hunan.

Central and northern Hunan feature relatively low CI activity frequency.

Based on the identification method for CI evolution characteristics shown in Figure 4, statistical analyses of CI activity characteristics in the study region from March to October were conducted. The statistics reveal that for Scheme 1, the total number of developing CI reaches 640,049 and decaying CI totals 154,617, with developing CI accounting for 80.54%. For Scheme 2, the total number of developing CI is 523,708 and decaying CI totals 270,958, where developing CI accounts for 65.90%. These results indicate that FY-4B CI possesses good indicative and early-warning significance for the initiation and subsequent evolution of convection. The spatial distribution of developing CI is broadly consistent with the overall CI distribution (Figures 6b and 6d). The decaying CI under Scheme 1 exhibits no prominent spatial pattern, while decaying CI in Scheme 2 occurs slightly more frequently over southern and eastern Hunan and northern Guangxi (Figures 6c and 6e).

The spatial pattern of mean CI frequency for March–October in 2025 (Figure 7) indicates that CI reaches its peak activity in July and high-frequency zones with frequencies greater than 0.6% appear over south-central and northwestern portions of the research domain. August and September have the next highest CI activity and high-frequency CI regions in August are concentrated in the western, southern and eastern areas, while those in September are located in the northwest, central and east. CI activity progressively strengthens in spring, with frequencies mostly below 0.3% during March and May. CI events mainly occur over the western and southern regions in April. CI

activity remains weak in January, February, November and December, with frequencies under 0.2% (figures omitted).

3.1.2 Diurnal evolution

The diurnal variation of CI frequency within the study region (Figures 8a and 8b) shows that the region-averaged maximum CI activity frequency during March–October occurs at 06:00 UTC, followed by 07:00 UTC, 08:00 UTC, and 05:00 UTC. The diurnal variation of CI frequency is pronounced from June to September, with peak frequencies observed at 06:00 UTC, 06:00 UTC, 07:00 UTC and 06:00 UTC, respectively. For months with relatively low CI activity (March–May and October), the frequency maxima of CI also appear around noon and afternoon hours.

Figure 8c shows the time of maximum CI frequency within each grid cell. Except for small portions of northern and central Hunan where the peak frequency occurs at nighttime (shown in blue), the maximum CI frequency in most areas appears during daytime. In parts of northern Hunan, the highest CI frequency occurs between 02:00 and 04:00 UTC. For most of central Hunan, the CI frequency maximum emerges from noon to early afternoon (04:00–06:00 UTC), while in parts of the western, southern and eastern regions, the peak CI frequency takes place in the afternoon from 06:00 to 09:00 UTC. This diurnal evolution feature is generally consistent with the peak activity time of CI identified by radar observations and also exhibits a diurnal cycle consistent with that of mesoscale convective systems (Liu et al., 2026).

3.2 Terrain Effects on CI Activities

Hunan and its surrounding areas feature complex topography (Figure 1), which exerts varying influences on the occurrence and spatial distribution of CI. This study quantitatively investigates CI activity characteristics within different terrain height intervals (Table 1). Based on the topographic features of Hunan shown in Figure1, we calculated the number of terrain grid, area percentage, total CI count, and grid-mean CI activity frequency (total CI frequency divided by the number of terrain grid cells) for each elevation intervals across the study region. The results reveal that the area percentage of terrain above 600 m, 800 m, 1000 m and 1200 m are 29.97%, 16.49%, 8.04% and 3.73%, respectively. Within the elevation range of 0–1000 m, the grid-mean CI activity frequency slightly rises with increasing altitude. Specifically, the grid-mean CI frequency reaches 0.171% for elevations from 0 to 600 m, and 0.201% for terrain higher than 1000 m. This finding is consistent with the spatial distribution of CI activity frequency during March–October 2025, whereby higher CI frequencies are observed over mountainous regions in the western, southern and eastern parts of the domain (Figure 6a). This result is consistent with the research of CI over mountain slopes in North China (Yang, et al., 2026) showing convergence of the upslope winds and strong downslope winds induced by orographic waves favored CI over the slopes.

3.3 Typical CI case application

3.3.1 CI induced strong convection case overview

Spring is the high-incidence season of severe convective weather in Hunan Province. Under the combined influence of cold and warm air masses, the convective weather is mainly characterized by hazardous weather phenomena including short-duration heavy rainfall, thunderstorm gales and hail. Ye et al. (2013) investigated the first disastrous severe convective weather event in Hunan in 2013. Their results indicated that clear-sky radiative warming near the surface, convectively unstable stratification and favorable near-surface moisture conditions provided favorable potential conditions for the evolution of convective storms, and mid-low level cold air acted as the primary triggering factor for this convection.

From the afternoon to nighttime of 2 March 2025, a severe convective weather event occurred in western Hunan (Xiangxi). The event produced extremely large hail with a maximum diameter of 6 cm, and hailfall lasted approximately 30 minutes (09:07-09:23 UTC, reporting recorded hail at multiple intervals), accompanied by short-duration heavy rainfall (40.5mm h^{-1} , 09:00-10:00 UTC) and thunderstorm gales (max wind speed 17.6m s^{-1} , 09:15 UTC)(Ma et al., 2026). As shown in the precipitation observations (Figure 9a), under the influence of severe convective weather, widespread precipitation occurred over north-central Hunan from 00:00 UTC 2 March to 00:00 UTC 3 March. Rainstorms and heavy rainstorms exhibited an east–west zonal distribution. Heavy rainstorms were concentrated in northwestern Hunan, where seven observation stations recorded precipitation exceeding 100 mm, with the maximum

rainfall reaching 127.3 mm. This severe convective event was triggered by intense convergence of cold and warm air masses. Strong low-level northerly winds prevailed over Hubei, Henan, Anhui and other regions to the north, while southerly winds dominated south-central Hunan. The maximum hourly rainfall intensity exceeded 50 mm, accompanied by dense lightning activity (Figure 9b). Taking this severe convection case as an example, this study analyzes the application of the FY-4B CI product in monitoring and early warning.

The time series of regional daily accumulated CI frequency in March 2025 (Figure10) shows three prominent CI active episodes: 1–4 March, 11–14 March, and 27 March. Within the 1–4 March event, the CI frequency reached its peak on 2 March.

3.3.2 Convection Initiation (CI) and Convection Evolution Characteristics

As shown in Figure11 the accumulated counts of FY-4B CI with 15-min temporal resolution from 00:00 UTC 2 March to 00:00 UTC 3 March 2025 indicate that within the study domain, the CI events induced the severe convection over northern Hunan originated in mountainous areas at the junction of Guizhou, Hunan and Chongqing, with a maximum accumulated count of 5. Another active CI zone was located in northeastern Hunan, associated with the convective train effect, where CI counts ranged from 1 to 3.

FY-4B CI and BT from 10.8 μm channel observations on 2 March (Figure12) indicate that northern Hunan was covered by clouds with BT below $-32\text{ }^{\circ}\text{C}$ at 07:00 UTC, with no subsequent convection development. The first CI process was detected at 07:30 UTC in central-eastern Guizhou (West of Hunan). Continuous CI signals were

observed afterwards, and new CI emerged north of the original site at 08:15 UTC. By 09:00 UTC, CIs developed into two convective cells, which intensified, merged gradually and propagated east-northeastward. The warning lead time was about 2 hours from the initial CI at 07:00 UTC to mature convection at 09:00 UTC.

As severe convection sustained, three CI events appeared on its west and south sides at 12:00 UTC (the second CI process). The two western CIs developed into intensifying convection by 13:00 UTC and evolved into severe convection west of the original storm at 15:00 UTC, whereas the southern CI decayed. For the second CI activity process, the warning lead time was about 1 hour (from CI detected at 12:00 UTC to convection formation at 13:00 UTC). The convective warning lead time throughout this event varied between 1 and 2 hours.

4 Conclusion and discussion

4.1 Main conclusions

In this study, the operational FY-4B Level 2 Convective Initiation (CI) products in 2025, combined with FY-4B Atmospheric Motion Vector (AMV) data, are adopted. The research domain covers Hunan Province and its surrounding areas (108°E–114.2°E, 24.2°N–30.3°N). We statistically analyze the spatiotemporal distribution, diurnal variations and topographic effects of CI, and select a typical severe convection case to verify the monitoring and early warning capability of FY-4B CI products. The main conclusions are summarized as follows:

(1) Monthly seasonal characteristics of CI distribution

CI activities exhibit remarkable seasonal differences in the study area. CI frequency remains low from January to February and November to December; CI gradually becomes active from March to July and reaches its annual peak in July, followed by a continuous decline from August to October. The warm season spanning March–October is identified as the key research period.

(2) Spatial distribution pattern of CI (March–October)

High-frequency CI regions are concentrated in southern Hunan, northern Guangxi, northern Guangdong, the Hunan-Jiangxi border, the junction of Hunan, Guizhou and Chongqing, and southwestern Hunan, while CI frequency is relatively low in central and northern Hunan. Two schemes are designed to distinguish developing and decaying CI. Under Scheme 1, developing CI accounts for 80.54%; under Scheme 2 with stricter discrimination criterion, developing CI accounts for 65.90%. The spatial distribution of developing CI is generally consistent with that of total CI, demonstrating that FY-4B CI has indicative significance for early warning of convection subsequent evolution.

(3) Diurnal variation characteristics of CI

The regional averaged diurnal peak of CI frequency occurs at 06:00 UTC, and the diurnal cycle is most prominent from June to September. Obvious regional differentiation exists spatially: the CI peak appears at nighttime in partial northern Hunan; the peak is concentrated at 04:00–06:00 UTC over central Hunan; the maximum CI frequency emerges at 06:00–09:00 UTC in western, southern and eastern Hunan. Such features generally agree with the diurnal evolution of mesoscale convective systems revealed by radar observations.

(4) Modulation effect of topography on CI

Within the elevation range of 0–1000 m, the grid-mean CI frequency rises slowly with increasing altitude. Areas above 1000 m exhibit the highest mean CI frequency (0.201%), higher than that over plains and hilly regions (0–600 m, 0.171%); CI frequency declines slightly above 1200 m. Mountainous terrain facilitates local convection initiation via mechanisms including orographic lifting, mountain-valley wind circulations and heterogeneous surface heating, which is consistent with relevant domestic studies on mountain CI.

(5) Application performance of FY-4B CI products in a typical severe convection case

A severe convective event characterized by extreme hail, short-duration heavy rainfall and thunderstorm gales in western Hunan on 2 March 2025 is selected for verification. The initial CI of this severe convection originated in mountainous areas at the Guizhou–Hunan–Chongqing junction, accompanied by multiple rounds of CI generation. FY-4B CI can identify early convection initiation signals with a lead warning time of 1–2 hours. Nevertheless, some CI signals decay afterwards, and not all CI events can evolve into severe convection. This highlights the vital value of distinguishing developing and decaying CI for reducing the false alarm rate of early warnings.

4.2 Discussions

Hunan lies within the complex terrain of the Jiangnan Hilly Region. Orographic lifting, mountain-valley wind circulations and heterogeneous surface thermal forcing create favorable conditions for local CI. Meanwhile, under the joint influences of mid-

latitude westerly systems, monsoon circulations and the subtropical high, the spatiotemporal distribution of CI exhibits evident regional differentiation. Statistical terrain analysis suggests that mountain slopes at moderate elevations are most susceptible to CI triggering. At altitudes above 1200 m, convective development is suppressed due to limited water vapor availability, leading to reduced CI frequency. Differences between the two identification schemes for developing CI indicate that reliance solely on single-time CI signals yields considerable false alarms. Incorporating continuous temporal evolution information of cloud-top brightness temperature enables effective identification of convective clouds with sustained development potential. Compared with the FY-4A operational L2 CI algorithm, the FY-4B CI algorithm incorporates the 1.38 μm shortwave infrared channel, latitude-dependent dynamic thresholds and multi-temporal joint judgment criteria, improving its suitability for regions with complex underlying surfaces. Nevertheless, these products only reflect cloud-top observational features and lack sub-cloud environmental information including temperature, moisture and wind fields; consequently, some CI events cannot evolve further into hazardous severe convection.

This study has certain limitations. Only FY-4B data for 2025 are adopted, which prevents an analysis of interannual variations in CI activity. Weather classification research using instability parameters derived from numerical models or observational data has not been carried out, and quantitative verification of the products against radar observations is lacking. Furthermore, the cloud tracking scheme does not fully consider the splitting and merging of convective clouds. Future work will extend the satellite

dataset to multiple years and construct a joint discrimination model integrating environmental variables such as convective available potential energy and low-level wind shear. Combined with radar network observations, objective evaluation of CI products will be performed, cloud-object tracking algorithms will be optimized, and regionally localized CI identification thresholds will be established to enhance the nowcasting capability for severe convection across the Jiangnan Hilly Region. From an operational perspective, FY-4B CI can be used as an important complement to radar observations. Forecasters should pay close attention to mountainous areas with frequent CI in southwestern and southern Hunan, screen developing CI based on continuous cloud-top evolutionary characteristics, and conduct comprehensive assessments combined with low-level environmental conditions to lower the false alarm rate associated with standalone satellite CI early warnings.

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Author contributions

Ren Suling performed the analysis and drafted the manuscript. Han Bowei provided the CI algorithm and reprocessed the datasets. Deng Jianbo conceived the research idea. Ye Chengzhi carried out the analysis of CI events over Hunan. Yang

Bingyun and Niu Ning conducted the research progress analysis and edited the manuscript.

Data Availability Statement

FY-4B data is provided by China National Satellite Meteorological Center, China Meteorological Administration (CMA), available at <https://satellite.nsmc.org.cn/DataPortal/en/home/index.html>. Meteorological station observation data are provided by National Meteorological Information Center, CMA.

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Figure Legends

Fig. 1 Terrain elevations (shading, unit: m) and study area (blue rectangle, 108°E - 114.2°E; 24.2°N -30.3°N).

Fig. 2 FY-4B L2 CI (pink color) and BT of the 10.8 μ m channel (shading, unit: °C) at 09:00UTC on 7 August 2025.

Fig. 3 FY-4B L2 AMV of the 10.8 μ m channel at 09:00UTC on 7 August 2025.

Fig. 4 Technical flowchart for identification of CI evolution characteristics.

Fig. 5 Monthly total CI frequency in the region (108°E–114.2°E; 24.2°N–30.3°E) from January to December 2025.

Fig. 6 The average distribution of CI frequency (%) from March to October in 2025 (blue rectangle, same as in Figure1), (a) total CI frequency, (b) developing CI for Scheme 1, (c) decaying CI for Scheme 1, (d) developing CI for Scheme 2, (e) decaying CI for Scheme 2.

Fig. 7 The monthly average distribution of CI frequency (%) form March to October in 2025 (blue rectangle, same as in Figure 1)

Fig. 8 Diurnal variations of monthly mean CI frequency (%) in research region during March–October in 2025, (a) Diurnal variation for March–October, (b) Enlarged view of diurnal variations during March–May and October, (c) Time of maximum frequency (UTC) (blue rectangle, same as in Figure 1).

Fig. 9 Accumulated precipitation (a) and severe convective weather observations (b) from 00:00 UTC 2 March to 00:00 UTC 3 March 2025.

Fig. 10 Time series of daily accumulated CI frequency over the region (108°E–114.2°E;

534 24.2°N–30.3°N) in March 2025.

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536 rectangle, same as in Figure 1).

537 **Fig. 12** FY-4B CI (pink color) and brightness temperature of 10.8 μm (shaded, unit: °C)
538 from 07:00 to 15:00 UTC on 2 March 2025 (blue rectangle, same as in Figure 1).

539

Figures

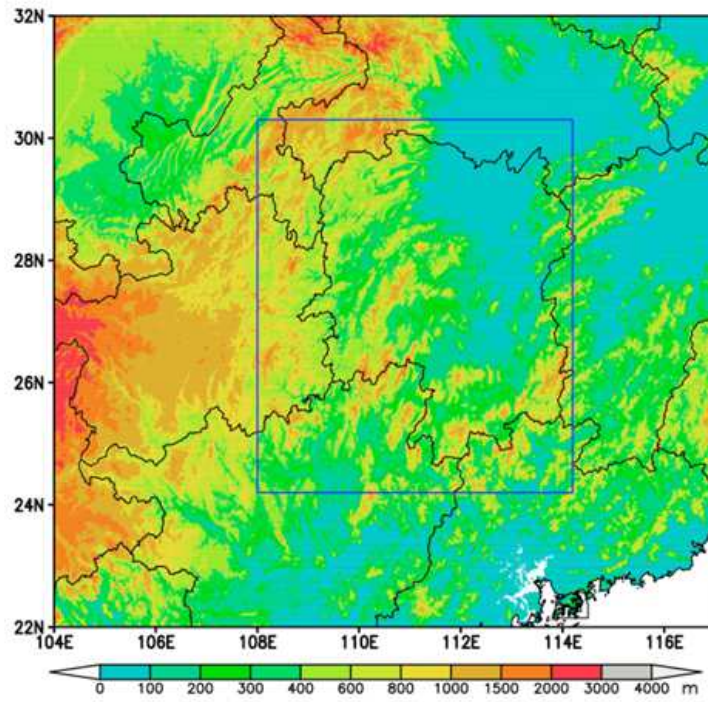


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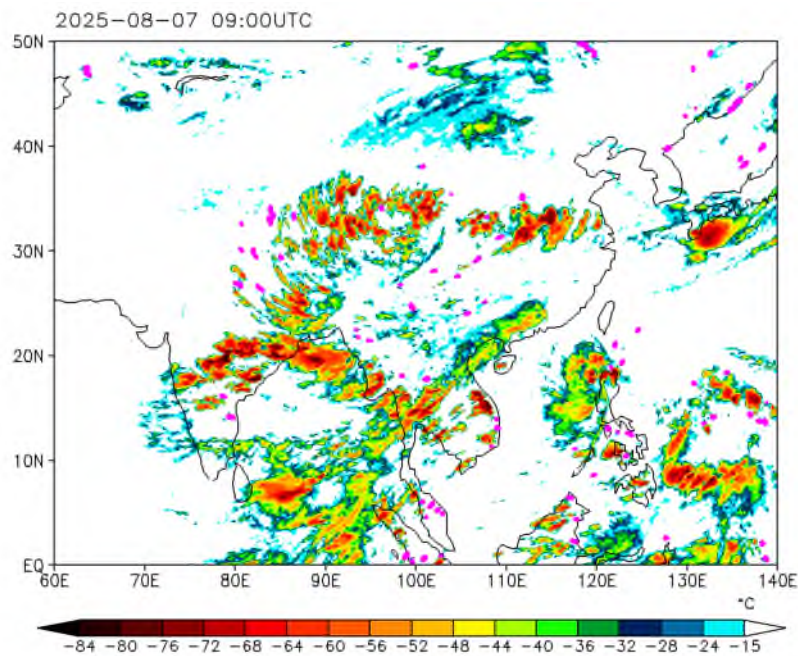
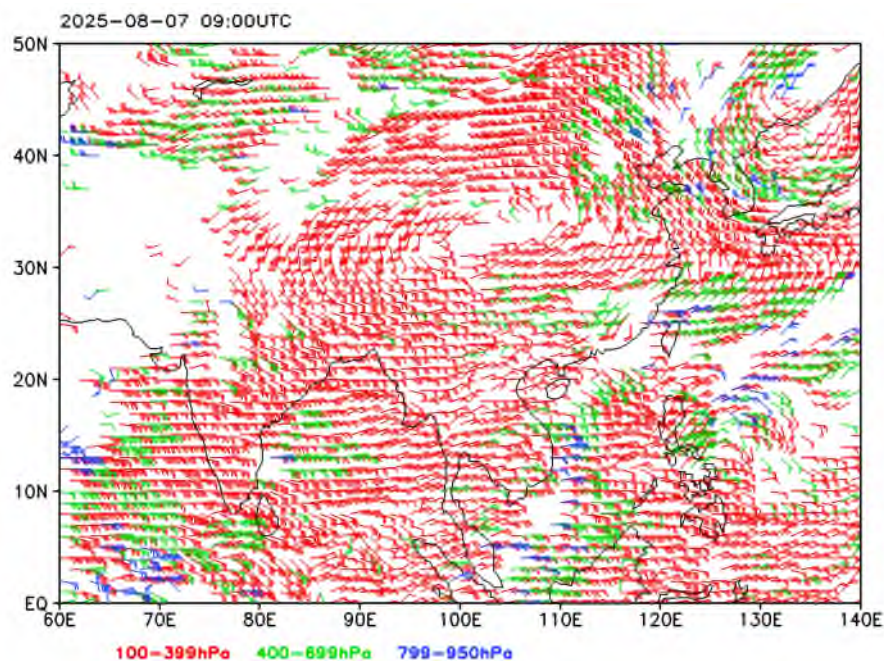
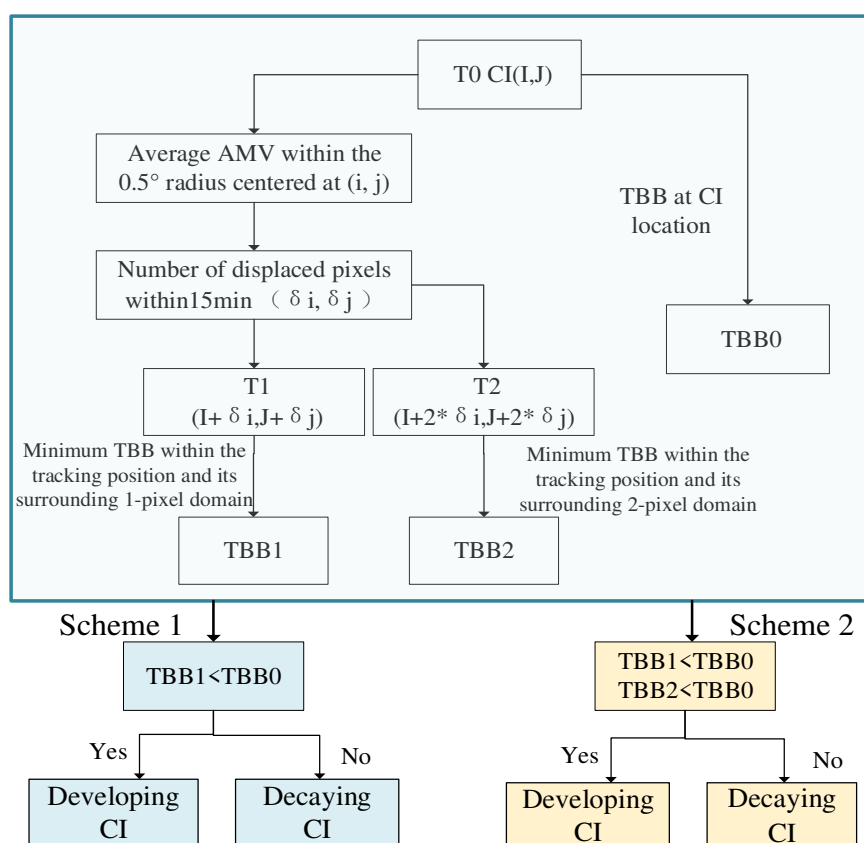


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549

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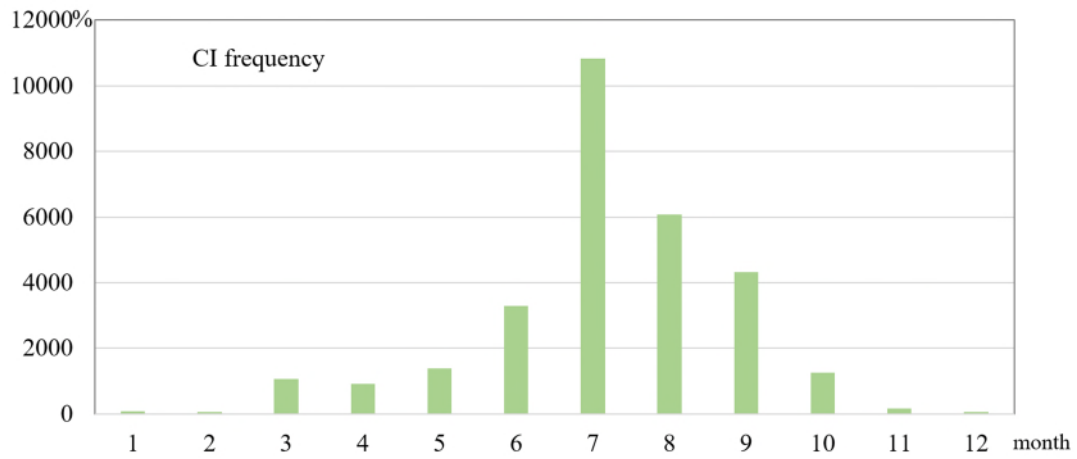


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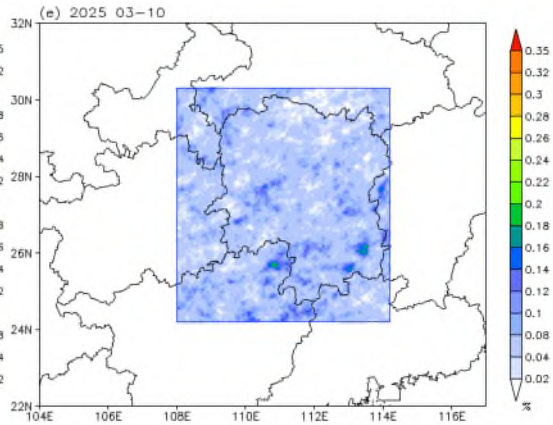
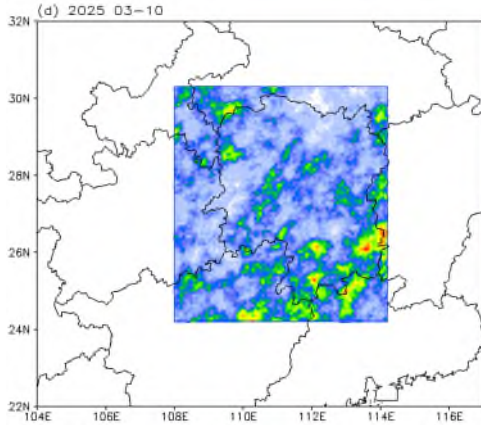
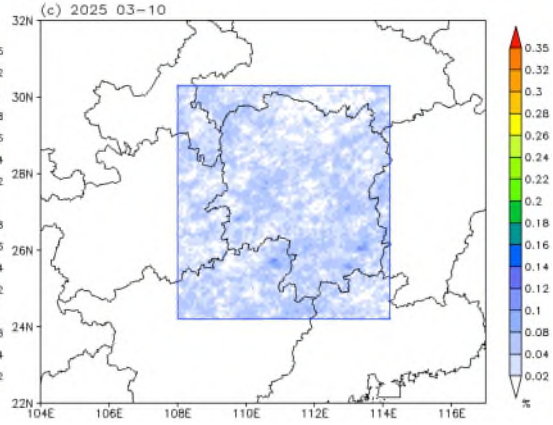
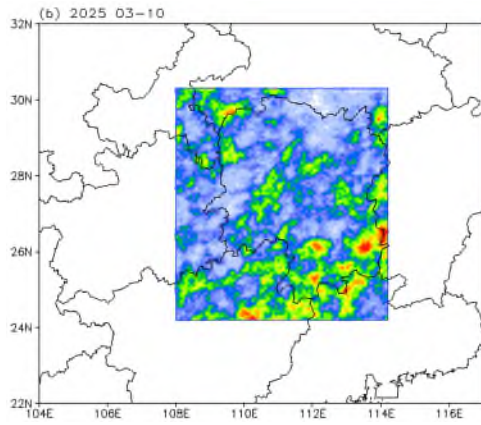
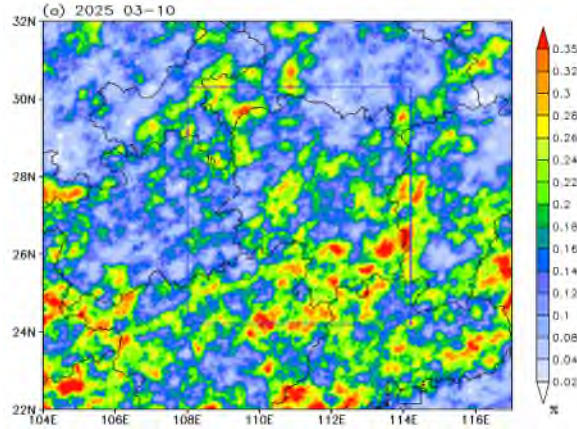


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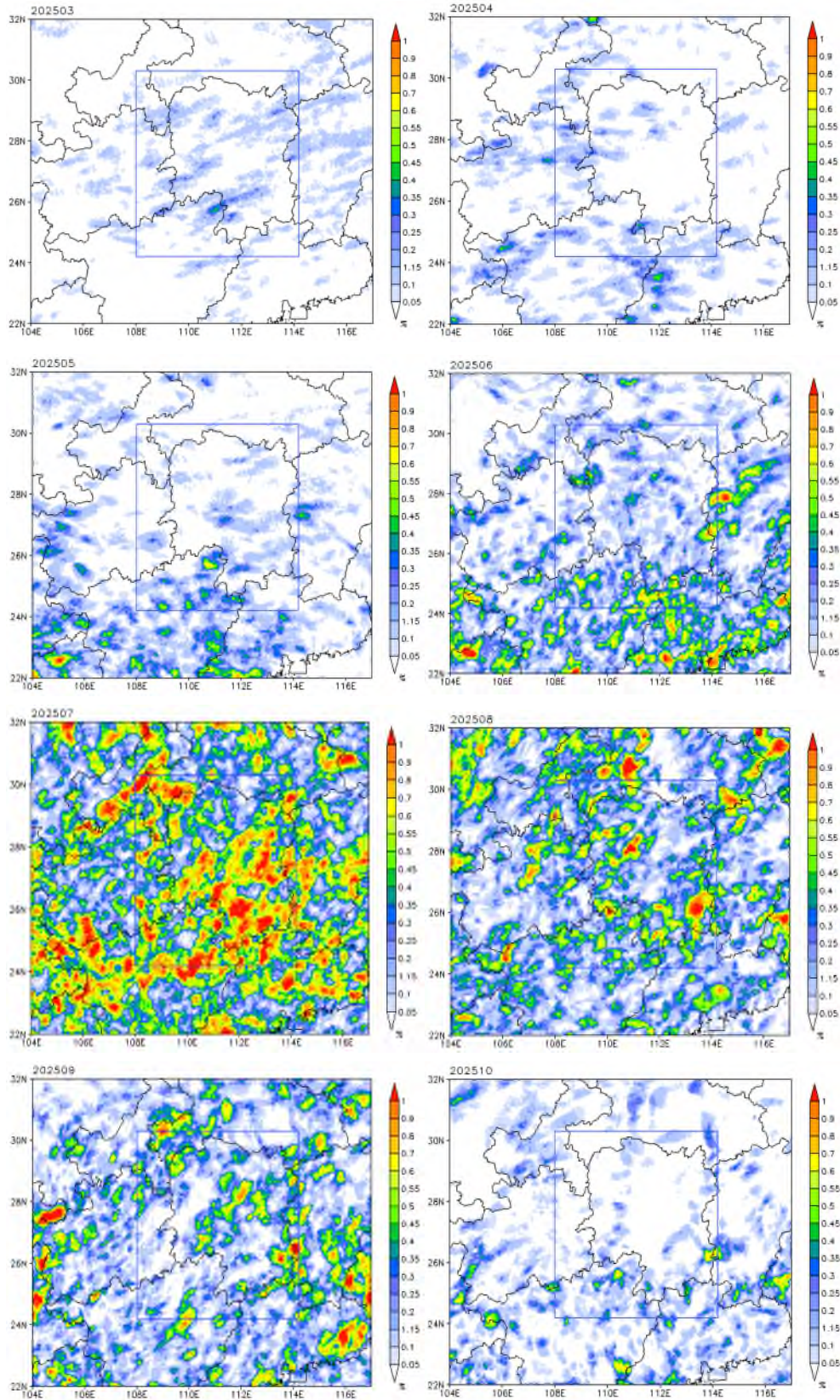


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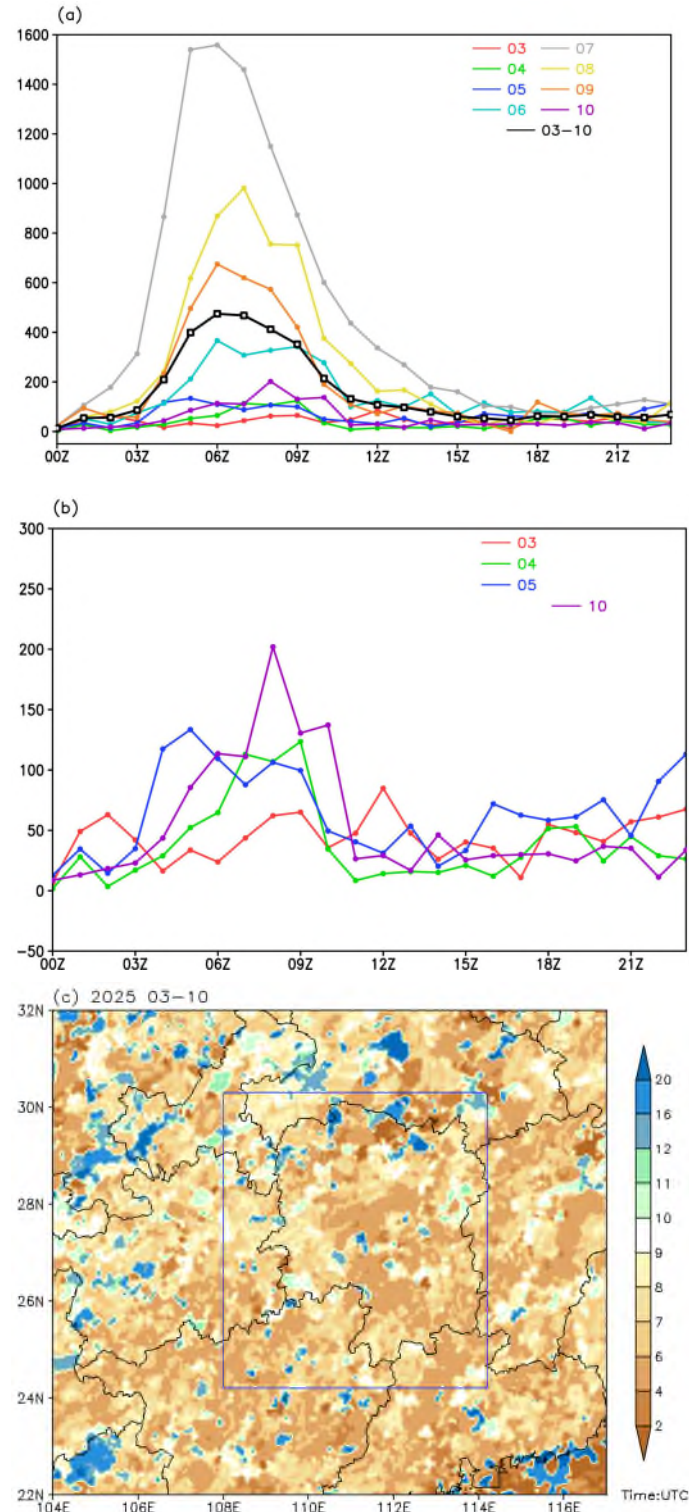
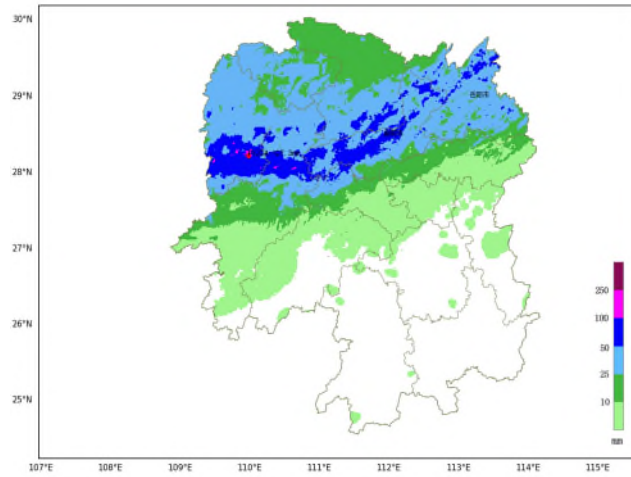
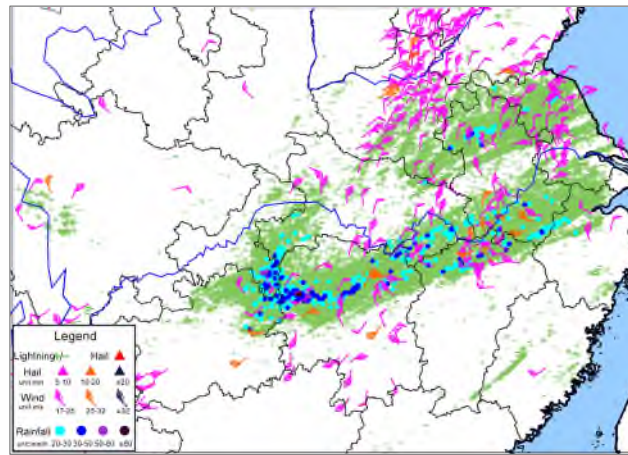


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(a)



(b)

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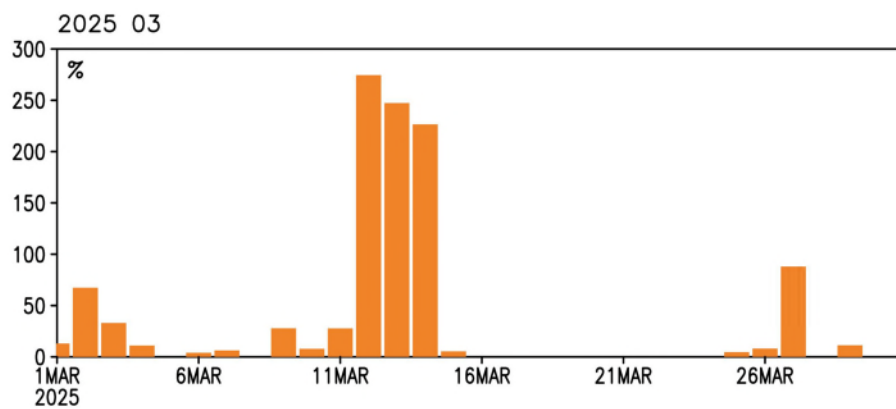


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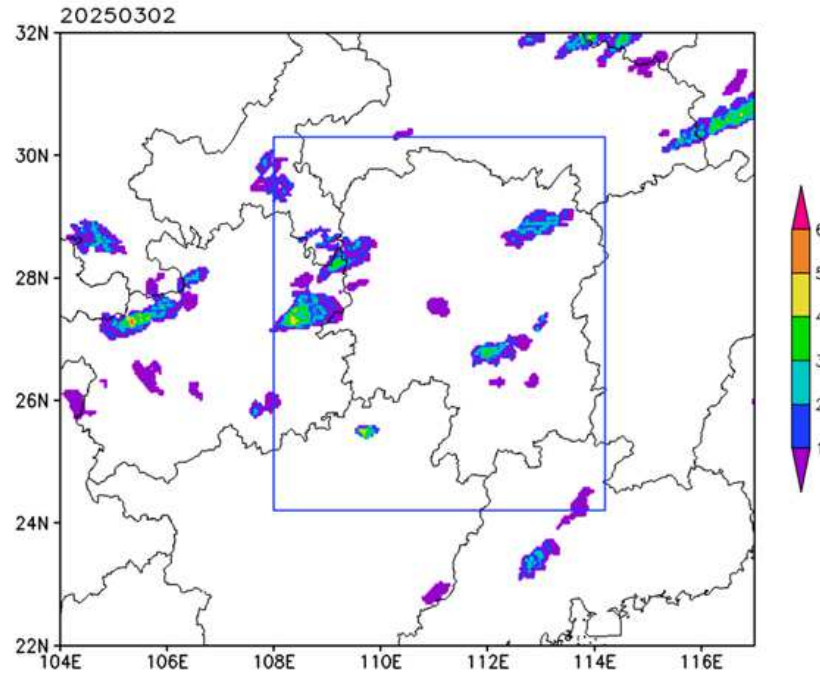
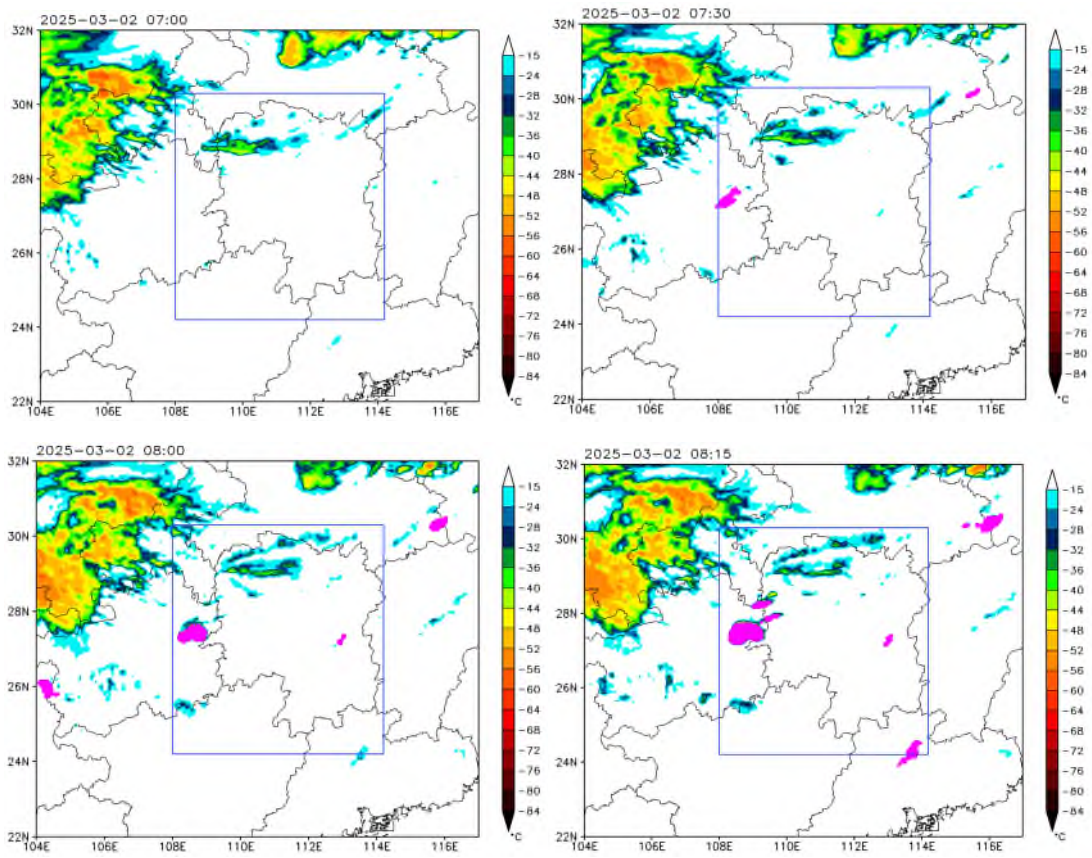


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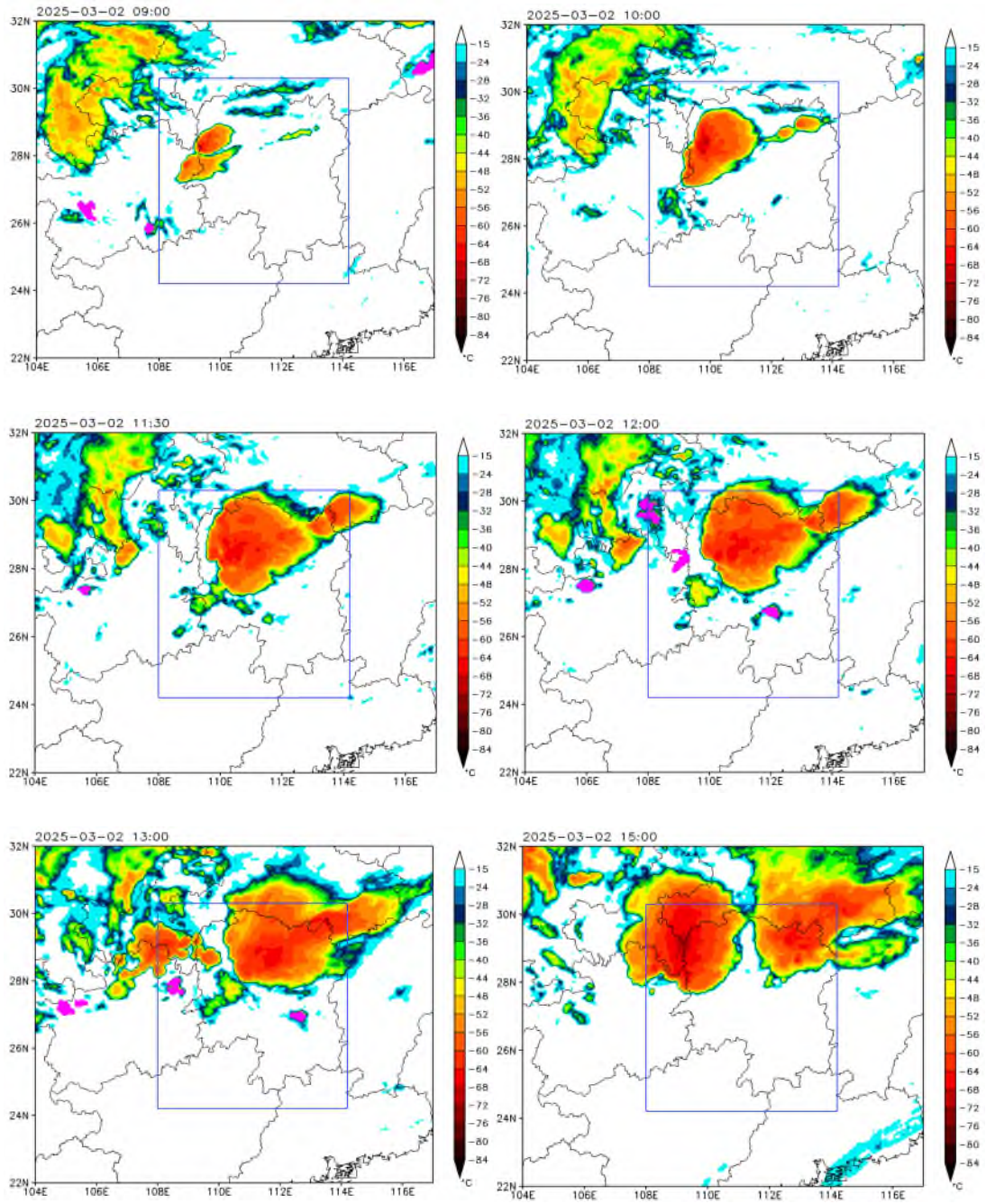


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Tables

Table 1. CI activity characteristics at different terrain heights in the region (108.0°E–114.2°E; 24.2°N–30.3°N) during March–October 2025

Terrain heights	0~600m	>=600m	>=800m	>=1000m	>=1200m
Number of terrain grids	14643	6268	3448	1681	780
Area percentage	70.03%	29.97%	16.49%	8.04%	3.73%
CI total count	554801	263429	148192	74979	34165
Total CI number / number of terrain grids	37.89	42.03	42.98	44.60	43.80
Total CI frequency	2498.65%	1186.4%	667.41%	337.68%	153.87%
Total CI frequency / number of terrain grids	0.171%	0.189%	0.194%	0.201%	0.197%