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Spatiotemporal Variability of Convective Events in Romania Based on METAR Data

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Abstract: Convective weather, through its heavy showers, strong winds and hail, significantly impacts human activities, having the potential to inflict serious damage on social and environmental sectors. Limited research has been conducted on this phenomenon within Romanian territory, and currently there is no referenced climatological study primarily aimed at air traffic management users in this context. This study aims to assess the climatological aspects related to convective events based on sub-hourly observation data recorded at 17 airport weather stations throughout Romania during an 11-year period (2012–2022). The spatiotemporal distribution of convective events was analyzed based on occurrences of Cumulus Congestus (TCU) clouds, Cumulonimbus (CB) clouds, thunderstorms (TSs), heavy showers (+SHs), and hail (GR). With the data being extracted from meteorological aerodrome reports (METARs) and special meteorological aerodrome reports (SPECIs). Short-term trends were determined using Sen's slope estimator, and statistical significance was assessed through the Mann–Kendall test. The main findings indicated that the highest occurrence of convective events is located over central and western Romania, with June emerging as the extreme month in terms of convective events, while the hourly distribution emphasizes that the highest frequency of convective events occurred in the afternoon. Trend analysis in TCU, CB, and TS show tendencies toward higher frequency of convective events while the results related to +SH and GR indicate a high variability across Romanian territory. Trend analysis disclosed more substantial changes in the TS variable. The results of this study bear potential significance for a broad spectrum of human activities and the management of natural environments.

Keywords: climate change; convective weather; METAR; SPECI; Romania

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1. Introduction

Convective weather has a substantial influence on human activities, generating heavy showers, strong winds, and hailfalls, with the potential to cause serious damages to social and environmental sectors. Moreover, severe convective weather possesses strong destructive power, significantly exacerbating economical losses [1]. For instance, convective events can severely damage crops and affect the supply of electricity, communications, and air traffic [2]. This type of weather poses a serious risk to aircraft flights through associated hazardous phenomena [3]. Furthermore, convective weather is affected by the ongoing climate change, which can significantly increase its impact on society and the environment [4–6]. However, different sustainable measures and concepts for protection should be regularly developed based on the newest scientific results.

Convective weather is quite frequent during the warm season (April–September) in temperate regions of the globe [7–10]. The main elements for convection development include a high amount of moisture in the lower and mid-atmosphere, atmospheric instability, and strong heating of the terrestrial surface [2]. The main products of convection are Cumulus Congestus and Cumulonimbus clouds, along with convective systems of different sizes and complexity that can generate thunderstorms, lightning, heavy precipitation in a short period of time, hail, wind shear, turbulence, and even tornados. Deep convective clouds, such as Cumulus Congestus and Cumulonimbus clouds, play a major role in weather and climate by facilitating the transport of heat and moisture from the Earth's surface to the upper tropospheric level [3]. These clouds can particularly be threatening when they form near an airport, leading to constraints in airspace and the handling of operations [2]. Cumulus Congestus clouds exhibit robust updrafts, distinct edges, and generally significant vertical expansion [2]. They often evolve into Cumulonimbus clouds, which are dangerous to aviation and other sectors as they can generate strong winds, severe turbulence, severe icing, lightning, heavy showers and hail falls. Typically, atmospheric convection comprises both deep convection and shallow convection. Deep convection mainly includes ordinary, multicellular and supercell thunderstorms, as well as mesoscale convective systems, while shallow convection includes Cumulus and Stratocumulus clouds [4].

The occurrences of severe weather events, including hailstorms, thunderstorms, and lightning, are escalating in numerous parts of the world, posing threats to various aspects of natural and social environments, including sustainable development [11]. Climate change is expected to affect the climatology of convective events [12]. The interest in studying convection events and associated hazards has grown in recent decades due to climate change and the increasing number of flights [13]. Identifying patterns in the occurrence and strength of convective events has been challenging due to restricted and incomplete direct observations [14–16]. Many studies have analyzed changes in convective events by examining trends in CAPE index and wind shear, emphasizing that the effect of shear is more important than that of CAPE [5,12].

Taszarek et al. [15] investigated the climatology of thunderstorms across Europe and found that these events are most frequent in the central Mediterranean, the Alps, the Balkan Peninsula, and the Carpathians, including large areas of Romania. Studies investigating the climatology of convection and associated hazards have found increasing trends in the frequency of these events in different regions of the world [16,17]. Mohr and Kunz [18] found that the atmosphere became more unstable and prone to convective processes over the last few decades in large areas of Europe. Llasat et al. [19] found a significant increase in convective events, convective precipitation, and precipitation over the Júcar Hydrographic Confederation of the Spanish Mediterranean region. Molnar et al. [16] found that, in the past three decades, there has been a notable rise in the occurrence of convective events in the Swiss Alps. Decreasing trends were found only in a few regions of the world, such as Tehran, parts of southwestern, far southeastern, and south-central Europe, and Australia [8,12,15]. Decreasing trends may be an effect of local urban factors for some regions [6]; nevertheless, large-scale atmospheric mechanisms may also play an important role. Other studies found mixed results in trend analysis of convection and associated hazards [14,20].

Studies that analyzed future changes in convection characteristics showed a consistent transition towards a higher frequency environment that is supportive for convection and convective storms [21,22]. In contrast, other studies showed that changes in favorable convective environments are only partially consistent for Europe and the United States [7]. The predominant factor driving the rise in convective environments is primarily the thermodynamic instability associated with the increased availability of moisture in the lower atmosphere [7]. This area of study requires needs more research to better understand such processes and relationships.

In Romania, there are only a few studies that have investigated convective events, and such studies examined severe convective storms and tornadoes [23–25]. Manea et al. [17] have found statistically significant increasing trends in the frequency of days with rain showers and snow showers over most of Eastern Romania, with no statistically significant trends in the frequency of sleet showers. Statistical correlations were observed between these changes and the trends in Cumulonimbus cloud frequency. Additionally, convective phenomena have shown an increase in late spring and early autumn, prompting a transition from a stratiform nature to a more convective one. During the winter, convection frequency recorded only a slight increase [17]. Mixed trends were found in Romania in the frequency of days with hail, and only few were statistically significant [17].

Data from meteorological aerodrome reports (METARs) and special meteorological aerodrome reports (SPECIs) have been extensively used worldwide in meteorological and climatological studies [2,12,26–31]. However, to our knowledge, in Romania only a few studies employed METAR and SPECI data, and only one of them examined convection-related variables, with this study being restricted to a limited area (Southern Romania) [32,33].

Convection processes are a complex issue due to a series of factors such as synoptic systems, interaction between micro- and meso-scale systems, and terrain configuration [28]. The specific terrain characteristics in a given area are essential in shaping and amplifying the intensity of convective weather events. Romanian topography has a great degree of complexity and includes plain, hilly and mountainous areas, which are almost equally distributed across the country (Figure 1). The different orientation of the Carpathian ranges across Romania further complicates the convection processes.

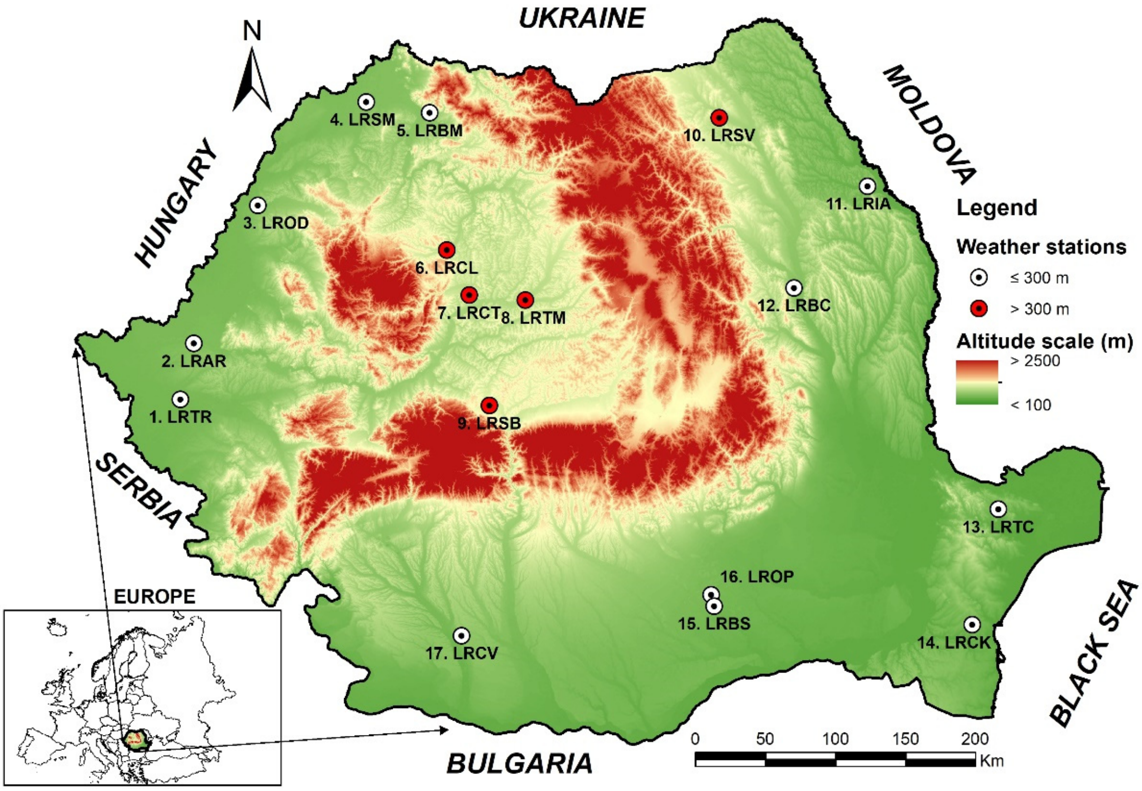

Figure 1. The Romanian topography and the airports used in this study that operate weather stations (WS).

Although convective events have a great spatiotemporal variability, climatological studies can provide valuable information in respect to their spatial and temporal differences in a particular region, as well as providing trends on various time-scales [34,35]. Based on climatological scientific results, the user can anticipate important changes in local or regional weather, as well as severe weather associated with convection events [29].

The main objective of this study is to evaluate the convective episodes based on METAR and SPECI data collected from 17 Romanian airports from 2012 to 2022. Extensive METAR data has not been previously utilized for such analysis on a Romanian scale. To the authors' knowledge, none of the studies investigating convective events in Romania or in larger areas that overlap Romania have specifically examined the climatological aspects of convective-related variables at airports within Romania. Additionally, there is currently no referenced climatological study primarily aimed at air traffic management users in this context. Despite the limited weather data covering only an 11-year period, this study can be useful for a diverse range of sectors, especially for aviation. Thus, this study investigates convective events by analyzing the spatiotemporal distribution of Cumulus Congestus clouds (TCU), Cumulonimbus clouds (CB), thunderstorms (TS), heavy showers (+SH), and hail (GR).

The paper is structured as follows. Section 2 illustrates the data and methods. Section 3 presents the results and discussion in terms of annual, monthly, and hourly distribution of convective-related variables, as well as annual trends. Concluding remarks are given in Section 4.

2. Data and Methods

METAR messages provide real-time weather information at an airport and its surrounding area [36,37]. Issued regularly, these reports are primarily utilized by pilots and air traffic controllers for flight-planning purposes. This type of meteorological information is measured automatically by instruments and sensors located at the aerodromes. However, a human observer is present to monitor the weather, adjusting and completing the METAR when it is needed. Romanian airports operate automated weather stations assisted by meteorologists that deliver observations as Meteorological Terminal Aviation Routine—METAR (SPECI included). METARs are generated every half hour, while SPECIs are emitted every time a meteorological parameter improves or exceeds a certain threshold. The proximity of an airport is typically defined as the area extending approximately 8 to 16 km from the aerodrome reference point. This reference point corresponds to the location of the human observer [3].

For this study, METAR and SPECI data from 17 Romanian airport weather stations were used over an 11-year period between 2012 and 2022 (Figure 1). The airport indicative, location, elevation, and geographical coordinates are given in Table 1.

Table 1. The airports' indicative, location, geographical coordinates, and elevation.

No	Station	Location	Latitude (deg)	Longitude (deg)	Elevation (m)
1.	LRTR	Timişoara	45.7711	21.2582	88
2.	LRAR	Arad	46.1336	21.3536	118
3.	LROD	Oradea	47.0358	21.8958	140
4.	LRSM	Satu Mare	47.7214	22.8872	124
5.	LRBM	Baia Mare	47.6608	23.4917	185
6.	LRCL	Cluj-Napoca	46.7821	23.6758	413
7.	LRCT	Câmpia Turzii	46.4957	23.8925	325
8.	LRTM	Târgu-Mureş	46.4681	24.413	309
9.	LRSB	Sibiu	45.7893	24.0913	444
10.	LRSV	Suceava	47.6328	26.2406	351
11.	LRIA	Iaşi	47.1708	27.6283	104
12.	LRBC	Bacău	46.5319	26.9125	185
13.	LRTC	Tulcea	45.0667	28.7167	6
14.	LRCK	Constanţa (Mihail Kogălniceanu)	44.3333	28.4333	108
15.	LRBS	Bucureşti-Băneasa	44.5	26.13	91
16.	LROP	Otopeni	44.5722	26.1022	95
17.	LRCV	Craiova	44.3103	23.8669	191

Data sets were obtained from the Iowa State University Environmental Mesonet database (IOWA, 2023). The Mesonet database was also used by several previous studies on convective events [38–40]. The data have a half-hour frequency, except SPECI reports, which may increase the frequency of reports. For ease of reading, in the following, only the

METAR terms will be mentioned, which will also include SPECI reports. The availability of reliable METAR/SPECI data for Romania from the Mesonet database begins only from 2012 onwards. Prior to this year, significant amounts of missing and incomplete data were identified. Despite the relatively short duration of the data series, these analyses hold significance for air traffic management users.

To comprehensively analyze the convective events across Romania, data of TCU, CB, TS, +SH and GR were extracted from METAR reports. Subsequently, in order to assess monthly and annual spatiotemporal variability for each variable, the monthly and annual number of days were calculated from half-hour reports for each of them. Each day where at least one METAR message was reported was considered as a day with that reported event in question. Furthermore, to analyze hourly distribution of variables related to convective events, every METAR containing the variable of interest was counted and associated with the time of observation. To better represent the hourly distribution of TCU clouds, CB clouds, and TS, we expressed the values as frequencies. Notably, +SH are considered those episodes of precipitation in which the accumulation rate has a value higher than 10 mm per hour. GR episodes are defined as events in which the largest hailstones observed have a diameter of 5 mm or more. The variables were organized and analyzed for distinct regions of Romania—western region (station no. 1, 2, 3), northwestern region (station no. 4, 5, 6), central region (station no. 7, 8, 9), eastern region (station no. 10, 11, 12), southeastern region (station no. 13, 14), and southern region (station no. 15, 16, 17)—as the climate of each region is influenced differently by the presence of the Carpathian chain and the Black Sea [41,42].

Trend detection was performed by employing Sen's slope estimator for the magnitude of the trend and a Mann–Kendall test for statistical significance of the trend [43]. Mann–Kendall is a non-parametric test widely used in the trend analysis of the hydroclimatological variables. In this study a trend was considered statistically significant at a 5% level ($p < 0.05$). Due to the limited availability of METAR data, trends were computed over an 11-year period. It's important to note that this timeframe may not be sufficient to capture long-term changes in convective-related variables, and, as such, the results should be interpreted with caution. Longer datasets will be required to comprehensively assess changes in these variables over time. Notably, similar short-term trend analyses have been conducted in various climatological studies [44–47].

3. Results and Discussions

3.1. Eleven-Year Climatology of METAR Variables Related to Convective Events

3.1.1. Annual Distribution of Convective-Related Variables

The results indicate that the territory of Romania experiences, on average, between 12.7 days per year with TCU clouds over northwestern Romania and 57.6 days per year with TCU clouds in the central region of Romania (Figure 2a). The highest values of the annual number of days with TCU clouds were found in central and northwestern regions of the country. The number of days with TCU clouds is considerably lower than the number of days with CB clouds. The time required to develop from a TCU cloud to a CB cloud is relatively shorter compared to the total life cycle of a CB. Thus, the observation frequency of TCU is considerably lower compared to the occurrence of CB. Henken et al. [3] observed the same situation at Amsterdam Airport Schiphol and explained it on the basis of more pronounced characteristics of CB clouds compared with TCU clouds. Therefore, the latter is often difficult to distinguish from cumulus clouds, resulting in less frequent reporting.

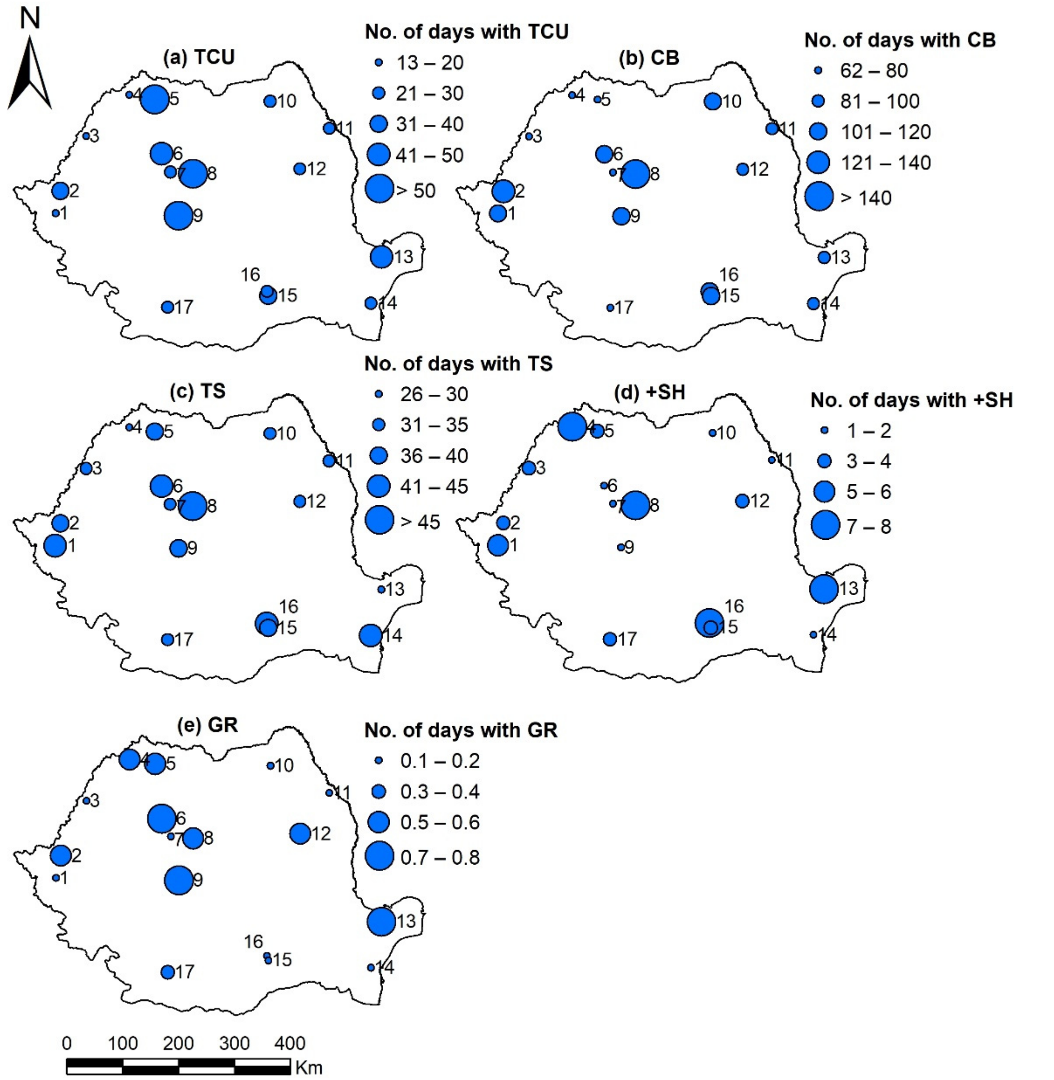

Figure 2. Average number of days per year with TCU (**a**), CB (**b**), TS (**c**), +SH (**d**), and GR (**e**). The numbers on map represent the station number as they are assigned in Table 1.

The average annual number of days with CB clouds is between 61.6 in western Romania (LROD) and 141.8 in central region of Romania (LRTM), following a similar pattern with spatial distribution of TCU clouds in respect to maximum values (Figure 2b). The spatial distribution of the average number of days with CB across Romanian territory indicates that the highest values were recorded in the western, central, northeastern, and capital city areas (southern Romania). Local factors, such as topography and land use, play a major role in the distribution of the average number of days with CB. For example, in the capital city of Romania (LROP and LRBS), with similar topography and land use, the annual number of CBs have similar values. This is also the case of LRSM and LRBM with similar land use and topography, which favors the same exposure to air masses direction. However, this pattern does not apply to the annual number of days with TCU, where there is a significant difference between LRSM and LRBM stations. This consistent difference in the case of the annual number of TCU might be explained by the presence of the Gutâi Mountains, north of LRBM, which favors convection.

The TCU and CB clouds are reliable Indicators of the presence of a convective event. Furthermore, their products, such as TSs, +SHs, and GR, indicate intense convection.

A TS is a meteorological phenomenon typically marked by the occurrence of lightning and thunder within deep convective clouds and systems. TS occurrence is heavily influenced by factors such as convective instability, moisture within the lower troposphere, significant wind shear, and dynamic lifting mechanisms [48]. Considering the annual average number of days with TS, their values follow a similar spatial distribution with the values of the annual number of days with TCU and the annual number of days with CB clouds (Figure 2c). The highest number of days with TS was recorded in the central region of Romania (45.5 days/yr), where convective activity is often forced by orographic influence.

The highest number of days with TCU clouds, CB clouds, and TS in central Romania might be also explained by a higher frequency of moist air masses coming from western Europe and crossing the Romanian Western Carpathians. This information could be useful for airports operating in the central regions of Romania for better flight planning.

Additionally, +SHs pose potential hazards to flights by causing a substantial drop in visibility and also can contribute to flight delays. The spatial distribution of the average annual number of days with +SH presents a high variability, indicating that the highest values were recorded in northwestern, central, southern, and southeastern Romania (Figure 2d).

GR phenomena is one of the most important perils in Romania. Hailstorms cause considerable damage to crops, buildings, automobiles, sustainable agriculture, and elements of sustainable infrastructure, such as solar panels and wind power plants [11,49,50]. The mechanical effect of hail negatively affects the photovoltaic modules, as it may cause silicon to crack, resulting in considerable renewable power loss and shortening of operational lifespan [51]. The annual average number of days with GR indicated the highest values in the central and southeastern regions of Romania (Figure 2e). These results are in accordance with those of [9], in which the mean annual number of days with hail were assessed over a 54-year period.

The occurrence of the convective-related variables vary over time (not shown here), suggesting interannual variability in atmospheric conditions influencing their occurrence. Factors such as temperature, humidity, and atmospheric instability may contribute to these interannual differences. Further in-depth analysis of meteorological data could provide insights into the underlying mechanisms driving the variability.

3.1.2. Monthly Distribution of Convective-Related Variables

The monthly distribution of TCU clouds (Figure 3, black columns) indicates that the highest frequency is occurring, as expected, during the warm season, with a maximum in June for the most of the weather stations when convective processes are most intense.

The CB clouds' monthly distribution (Figure 3, blue columns) shows intense convective processes starting from April to May and ending in August−September. As in the case of the monthly distribution of TCU, the maximum is reached in June in most of the analyzed locations. Weather stations located mainly in plain areas (LRTR, LRAR, LRBS, LROP) indicate that CB clouds occur in winter months with a higher frequency than in the rest of the country (up to 6 days per month).

TS monthly distribution follows in general the same patterns as TCU and CB cloud distribution, with the highest frequency in June, followed by July (Figure 3, red columns). Generally, the season of TS starts in March and ends in October. Most of the stations did not record or had recorded a minimal electrical activity during the November−February period.

The monthly distribution of +SH shows great spatial and temporal variability (Figure 4). The highest average number of days with +SH occurred in weather stations located in western, central, and southeastern Romania. In general, +SH had the highest frequency in May and June (1.0–1.5 days). The highest frequency during the summer months was recorded in weather stations located in western, central, and southern Romania. The LRCK station, located near the Black Sea coast, recorded the highest frequency of +SH in January and February. This might be explained by local factors, such as the proximity of the Black Sea and the characteristic eastern atmospheric circulation pattern [42].

Generally, GR phenomena occurred from April to September. Few exceptions were recorded in March and October (not presented). The highest frequency of GR events during the 2012−2022 period was recorded in May and June, which is in accordance with the study of Istrate et al. [52] which assessed hail climatology in Romania over the 2007–2016 period.

The increased frequency of convective events during May and June likely accounts for their highest occurrence, consequently elevating the probability of TS and GR.

By comparing the variables values related to convective events, it turns out that June is the most extreme month in terms of convective events. These results could be particularly useful for flight planning, air force missions, and others. With the rise in temperatures and the intensification of climate change, we can expect that convective events will be more frequent and of higher intensity. Also, the convective season can extend, affecting more and more of the off-season periods.

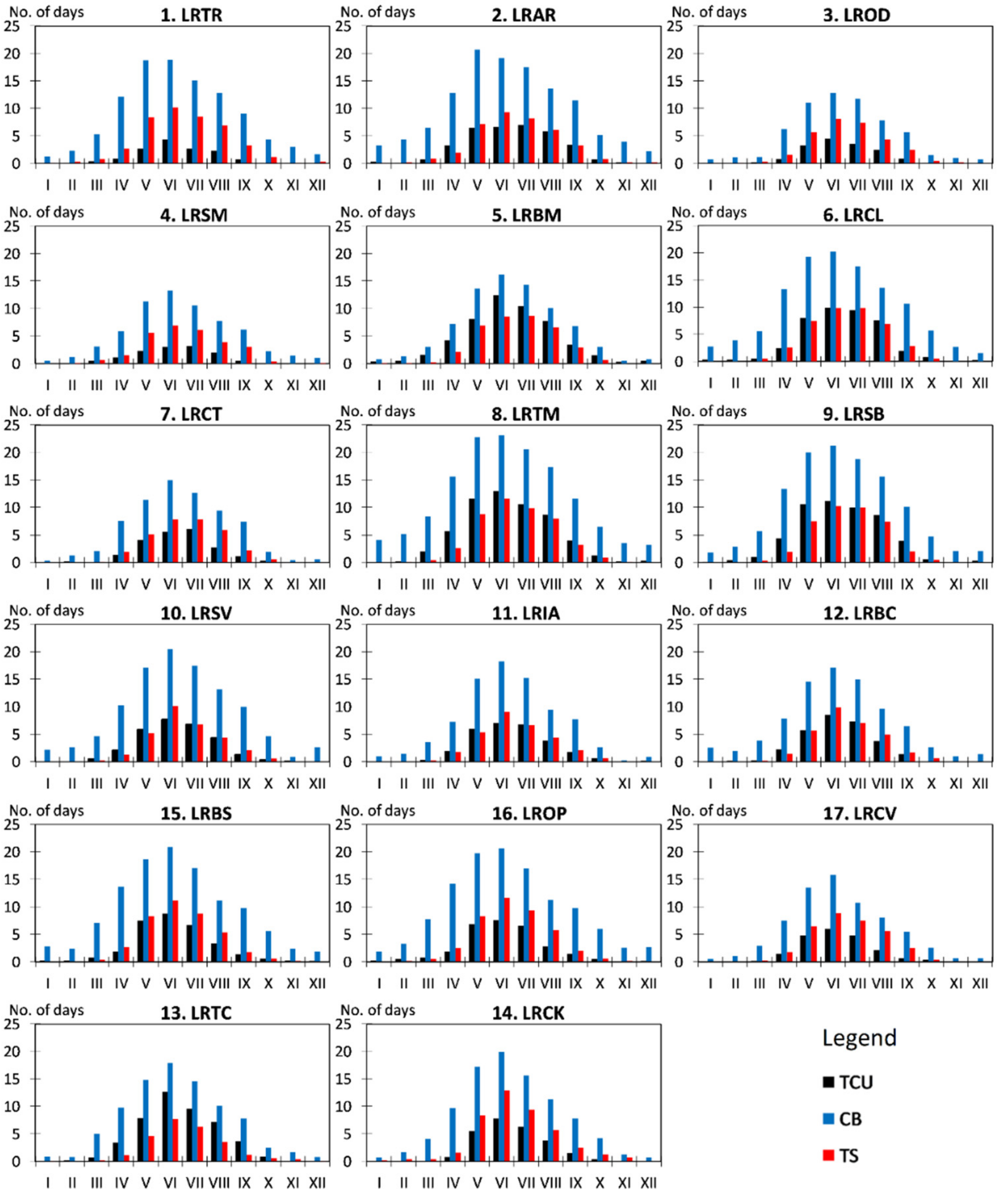

Figure 3. Monthly distribution of TCU (black), CB (blue) and TS (red) for each airport weather station during 2012–2022.

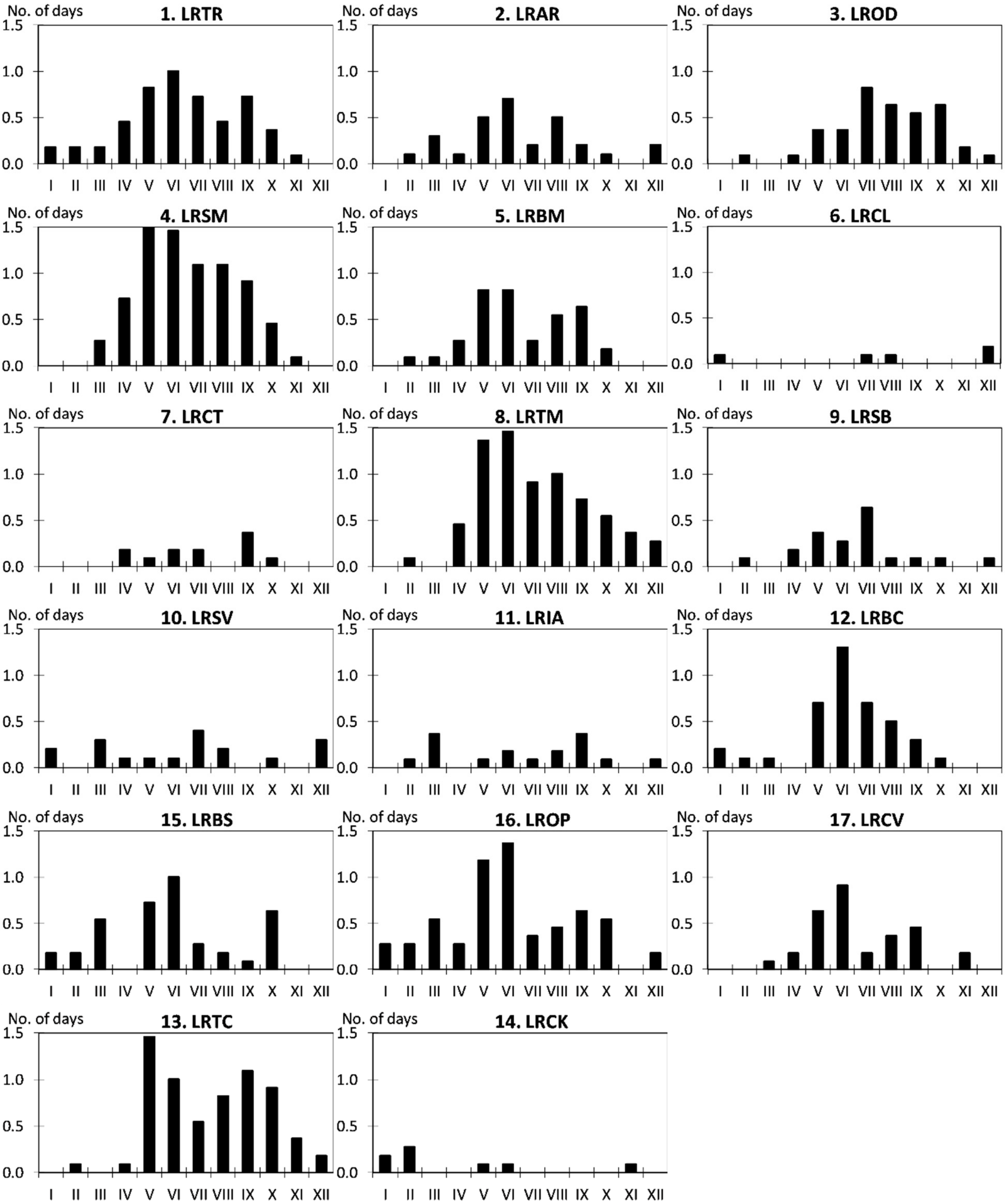

Figure 4. Monthly distribution of +SH for each airport weather station during 2012–2022.

3.1.3. Hourly Distribution of Convective-Related Variables

The hourly distribution of TCU clouds indicates that the convective processes generally start between 07 and 09 Universal Time Coordinated (UTC) and end between 18 and 20 UTC, with the highest frequency being recorded around 12 UTC (Figure 5, black contour). Spatially, the highest frequency during mid-day was recorded in northeastern, central, and eastern Romania, while the lowest frequency was registered in stations located in western and southern Romania.

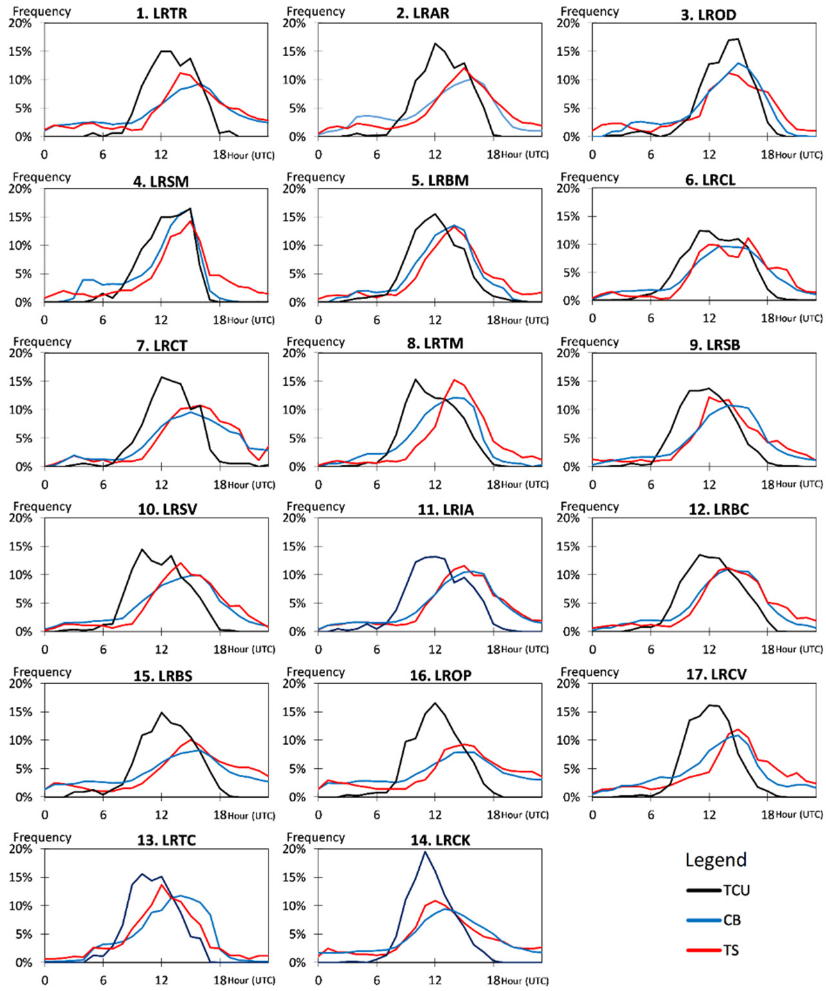

Figure 5. Hourly distribution of TCU (black contour), CB (blue contour), and TS (red contour) for each airport weather station during 2012–2022.

CB clouds' hourly distribution showed a few differences compared with TCU clouds' hourly distribution (Figure 5, blue contour). Since the development of CB clouds takes longer than the TCU clouds, the highest convective frequency according to CB clouds occurrence was generally recorded in the afternoon between 14 UTC and 16 UTC. Spatially, the highest frequency of CB clouds in the afternoon occurred in western and central Romania. This may be explained by higher frequency of moist air masses coming from western Europe and/or from the Mediterranean Sea, which contributes to the development of CB clouds. Most of the weather stations recorded a sharp decrease in CB clouds frequency after 16 UTC, indicating that convective processes have considerably decreased their intensity after that hour.

As expected, TS hourly distribution showed a similar pattern to CB clouds' hourly distribution (Figure 5, red contour). Generally, the highest frequency values were between 14 and 15% in the analyzed period and occurred in the 12–14 UTC interval. The lowest hourly frequency of TS was recorded between 04 and 08 UTC.

The hourly distribution of +SH showed a great spatial and temporal variability (Figure 6, blue columns). Generally, the highest frequency of +SH occurred in the afternoon (12–18 UTC) in 8 stations out of 17. The majority of them are located in western, eastern, and southern Romania. In six weather stations located in western, central, and southern Romania, the highest frequency of +SH was recorded in the evening (19–00 UTC). In LRSB and LRSV aerodrome weather stations, the highest frequency of +SH was recorded in the morning (06–11 UTC). The results in hourly distribution of +SH indicate that the highest frequency during the day is not necessarily related to the highest frequency of CB clouds, which generates this type of precipitation. This is also the case with the monthly distribution of the two variables. Thus, one cannot assume that a higher frequency of CB clouds translates to a higher frequency of +SH. Beyond the station's local topography, the environmental conditions and atmospheric circulation play a significant role in shaping the occurrence and timing of convective phenomena. Therefore, future research endeavors should explore these atmospheric circulation principles to better understand the observed temporal patterns of heavy showers (+SH) across different regions.

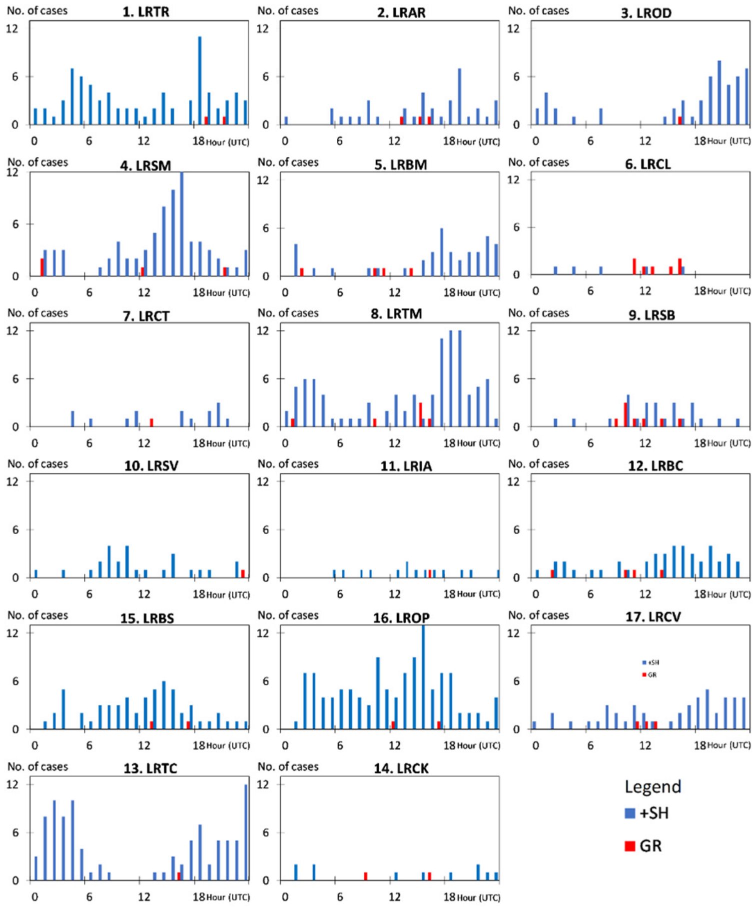

Figure 6. Hourly distribution of +SH (blue columns) and GR (red columns) for each airport weather station during 2012–2022.

Since GR is quite a rare phenomenon and occurs in limited areas, only a few cases were observed at each station (Figure 6, red columns). Their occurrence during the study period does not exhibit any clear pattern or relationship with the other analyzed variables. Laviola et al. [53] analyzed hail climatology in the Mediterranean Basin, including the Romania region across the 1999–2021 period based on remote sensing data, showing that the highest frequency of GR was concentrated during the 00–06 and 18–00 UTC intervals. A longer period of analysis may show particular distributions during the day and relationships with other variables related to convective processes.

3.2. Trends in METAR Variables Related to Convective Events

Trend analysis showed modest significant changes in variables related to convective events (Figure 7). However, few patterns are observed in the spatial distribution of TCU clouds, CB clouds, TS and +SH trends. The number of days with TCU clouds are decreasing at an average rate of 5.25 days/decade in western Romania (Figure 7a). Only the LRSM station indicated a statistically significant decreasing trend. Increasing trends were recorded over the most stations, but only the LRCT station indicated a statistically significant trend. A similar pattern is observed in the number of days with CB clouds, indicating a climate heading towards more frequent convection events (Figure 7b). Statistically significant trends were found in central (LRTM) and northeastern Romania (LRSV). Rusz [54] analyzed CB clouds at Târgu Mureș (where LRTM is located) for the 1971–2005 period and found statistically significant increasing trends.

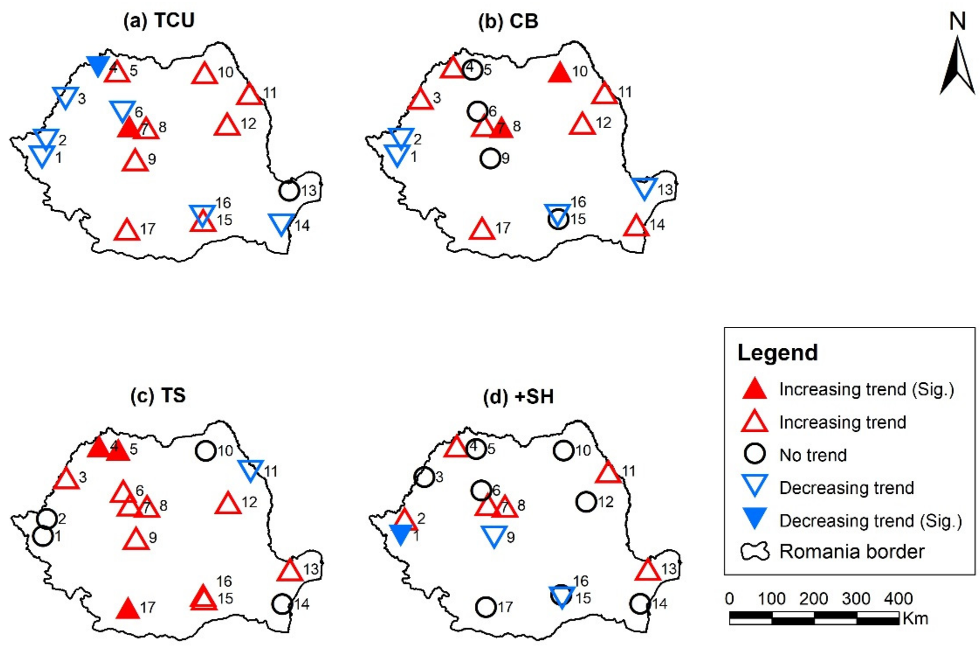

Figure 7. Trend analysis for TCU (**a**), CB (**b**), TS (**c**) and +SH (**d**) for each airport weather station during 2012–2022. The numbers on map represent the station number as they are assigned in Table 1.

The annual frequency of days with thunderstorms TS has shown an upward trend for the majority of weather stations (Figure 7c). Statistically significant increasing trends at a confidence of 95% were recorded in northwestern and southwestern Romania. These results indicate a tendency towards a higher number of days with TS on Romanian territory. Other studies focused on Europe found significant increasing trends in the frequency of TS [15,16].

The number of days with +SH showed mixed results in respect to spatial distribution; only the central region of Romania presented a significant increasing trend.

Trends in the annual number of days with hail (GR) could not be identified due to the limited time-series and the rarity of hail events. Burcea et al. [9] analyzed trends in the annual number of days with hail in 105 weather stations across Romania over a 54-year period and found statistically significant increasing trends in 58 of the stations, while only four stations exhibited a significant downward trend at a confidence of 95%. There is evidence suggesting that the fluctuation in the average annual number of days with GR in Romania is intricately linked to the variability in the occurrence of low-pressure systems originating in the Atlantic. These systems may subsequently lead to the development of low-pressure systems over the Mediterranean Basin and the advection of moist air toward the eastern regions of Europe [9]. Laviola et al. [53] also showed increasing trends in GR events over the entire Mediterranean basin, including Romania.

Several studies have shown an increase in convective cloudiness across northern Eurasia in recent decades [14,55–57]. An increase in convective cloud frequency indicates the intensification of convective processes across large areas of Europe. An increase in CB and TCU cloud frequency leads to higher frequency of TS, which further has the potential to raise the risk of forest fire initiation [14]. Moreover, Rädler et al. [6] showed that the occurrence of detrimental convective weather events, including thunderstorms (TS) and hail (GR), is anticipated to elevate across Europe until the conclusion of the century.

4. Conclusions

In this study, climatology and trends in convective events were analyzed based on variables related to convection that occurred between 2012 and 2022, using data extracted from METAR and SPECI telegrams issued for 17 airport weather stations in Romania.

The results revealed that certain regions of Romania are prone to a considerably higher frequency of convective events than others due to local factors, such as topography and different zonal atmospheric circulation. Therefore, future studies should investigate these atmospheric circulation principles to enhance comprehension of the observed temporal patterns of convective events across various regions.

The monthly distribution of weather variables associated with convective events indicates that June is the "extreme" month, featuring the highest values. Hourly distribution emphasizes that the highest frequency of convective events occurred in the afternoon (12–18 UTC interval), while the lowest occurred during the 00–06 UTC interval.

Meanwhile, trend analysis in TCU, CB, and TS reveals a tendency toward a higher frequency of convective events in Romania, and results related to +SH and GR indicate a high variability across Romania. However, these results should be interpreted with caution, as the time series only spans 11 years. Furthermore, while the 11-year interval may not capture long-term trends, it can still provide valuable insights into short-term variations and patterns in convective events. By analyzing trends over this period, we can identify potential patterns or anomalies that may warrant further investigation. Additionally, the inclusion of multiple climatic data sources can help corroborate and strengthen the findings of our analysis. This interdisciplinary approach enhances the robustness of our conclusions and opens avenues for future research collaborations.

While acknowledging the limitations of the 11-year dataset, we believe that the findings presented in this analysis offer valuable contributions to the scientific understanding of convective events in Romania and lay the groundwork for further exploration using longer-term datasets and interdisciplinary approaches. These results could be particularly useful for planning flights, air force missions, etc. With rising temperatures and the intensification of climate change, we can expect that convective events will be more frequent and of higher intensity. Additionally, the convective season may extend, impacting off-season periods. This study can also contribute to the development and application of principles in strategies for sustainable development and aid in future studies related to convective events.

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