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SOME CHARACTERISTICS OF CONVECTIVE PHENOMENA IN THE AREA OF "MIHAIL KOGĂLNICEANU" INTERNATIONAL AIRPORT CONSTANȚA, IN THE PERIOD 2003 – 2022

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ABSTRACT

This study investigates the thermodynamic and environmental conditions associated with convective activity in the vicinity of ”Mihail Kogălniceanu” International Airport in Constanța, Romania, using a combination of ERA5 reanalysis data, radiosonde-derived instability indices, radar observations and multiannual severe-weather reports. Frequency-based analyses of CAPE, CIN, KI and TT for the April-September period (2003-2022) reveal a warm-season environment characterized by moderate to high convective potential, with a maximum CAPE and a minimum CIN occurring predominantly in June-August and during the early afternoon hours. Despite this thermodynamic predisposition, the observed number of cases of thunderstorms, rain showers, hail and squalls remains comparatively low, reflecting the strong moderating influence of the Black Sea, which reduces lapse rates and limits deep convection. The climatological analysis of local phenomena confirms the coastal suppression: thunderstorms, hail and squalls occur infrequently, with marked inter-annual variability but low multiannual averages. A detailed case study on 31 July 2022 illustrates that intense convective systems can still develop when synoptic forcing and thermodynamic profiles align. Radar data documented a multicellular storm producing high reflectivity, elevated VIL values and significant hail signatures, consistent with ESWD ground reports. Overall, the combined results highlight the contrast between the region's thermodynamic potential for convection and the relatively low occurrence of severe weather, emphasizing the decisive role of coastal boundary-layer processes in shaping convective outcomes.

Keywords: *Convective phenomena; Air-instability indices; Airport operation area; Radar, Upper air soundings.*

1. INTRODUCTION

Convective weather phenomena, such as heavy precipitation, hail, thunderstorms and strong winds are of particular importance in researching their influence and impact on airport operations and air-flights. Understanding the environmental factors that lead to convective development is therefore essential for maintaining safe and efficient airport activity. Accurate assessments of atmospheric instability, particularly through indices such as CAPE, LI or KI, allow forecasters and operational teams to anticipate hazardous conditions before they directly impact flight operations.

For airports located in regions prone to rapid convection evolution, continuous monitoring and analysis become even more critical. By correlating instability parameters with observations of storm occurrence and intensity, airport authorities can better evaluate operational risks and optimize delay management. Atmospheric instability refers to the tendency of air parcels in the atmosphere to continue rising when they are lifted. It is a key ingredient for cloud development, thunderstorms and severe weather. Convection occurs due to the uneven heating of the underlying surface, leading to strong upward motions. To better understand these processes, meteorologists use various instability indices, such as CAPE (Convective Available Potential Energy), the SWEAT index (Severe Weather Threat Index), LI (Lifted Index), K-index (KI), TT (Total Totals Index), SI (Showalter Index) and CIN (Convective Inhibition).

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Such quantitative indices allow the estimation of the risk and intensity of storm formation. Their effectiveness in forecasting convective phenomena has been demonstrated by numerous researchers, including Haklander and Delden (2003), Manzato (2005), Maier (2011), Haidu and Tudose (2014) Istrate et al. (2015, 2021), Sfică et al. (2015), Beteringhe et. al. (2025). These indices typically combine measurements of thermal and moisture characteristics of air parcels in the lower and mid-troposphere, providing estimates on the atmosphere's potential to generate convective phenomena. Many of these indices were specifically developed to improve the forecasting of thunderstorms and severe weather events.

The meteorological and climatic risks for aircraft operations and flights on the Mihail Kogălniceanu Airport in Constanța have been studied by Florea Dan (2004). In this respect, he studied the heavy atmospheric precipitation, which causes difficulties in aircraft navigation by reducing visibility, and then he further analysed the types of precipitation and their effects on the runway.

Some research works focusing on atmospheric risk phenomena in relation to aviation at European level, include specific topics highlighting the most effective methods for forecasting atmospheric phenomena, climate modelling concerning the development of convective storms, mesoscale convective systems and their impact on airports, early warning systems for meteorological events, and the use of radar and satellite data for climate predictability (Schultz et al., 2018; Guijo-Rubio et al., 2019; Kirschenstein et al., 2019; Taszarek et al., 2020; Jardines et al., 2021; Zatula et al., 2021).

At international level, several studies have highlighted the impact of atmospheric risk phenomena on airports in the United States (Liu et al., 2019; Niță et al., 2024), China (Chen și Wan, 2019; Wan et al. 2021), Brazil (Franca et al., 2018) and Australia (Roux et al., 2021).

2. DATA AND METHODS

2.1. Study area

The study area refers to the ”Mihail Kogălniceanu” International Airport, lying at a 26 km' distance to the North-Northwest off Constanța's city centre, within the commune of Mihail Kogălniceanu, in Constanța county (**Fig. 1 C**). It has initially been built in 1955 as an air force base but in 1960, it was opened to civil air traffic. In 2023, the number of passengers has drastically increased as compared to previous years and, therefore, a series of infrastructure modernization works were being initiated on the airport.

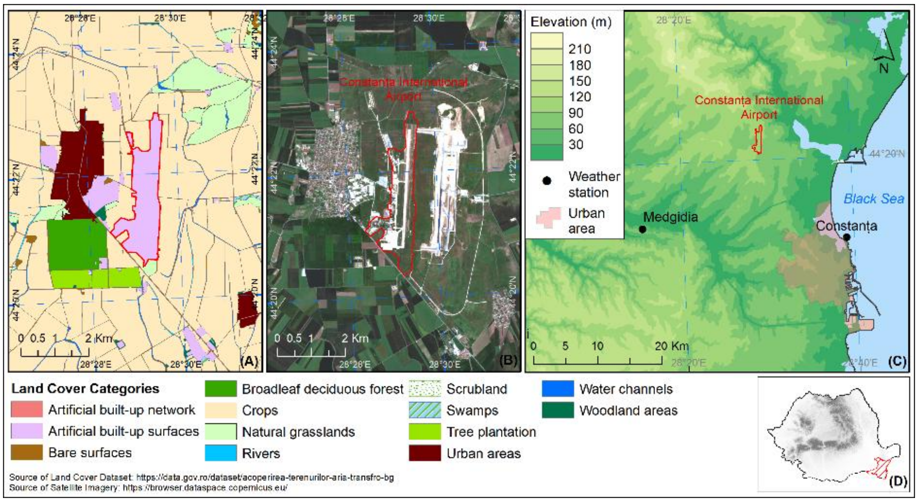


Fig. 1. The location of the ”Mihail Kogălniceanu” International Airport in the proximity of Constanța city, alongside the land-use map of the area

The map of the ”Mihail Kogălniceanu” International Airport and its surroundings illustrate a combination of hypsometric features and land-use patterns that play an important role in shaping the local meteorological conditions. Hypsometrically, the airport is located on a relatively elevated plateau, with altitudes generally ranging from 50 to 120 meters **(Fig. 1 B)**. The mildly undulating topography facilitates air drainage and local circulations, while the absence of steep relief ensures that orographic lifting keeps minimal. Toward the Black Sea coastline, the terrain gradually descends, contributing to the development of sea-land breeze systems that strongly influence the thermal and moisture structure of the boundary-layer in the region.

Land use in the vicinity of the airport is dominated by agricultural areas which generally support strong daytime heating and can enhance low-level turbulent mixing. These open surfaces favour the development of convective thermals under sufficient insolation, although the proximity of the Black Sea frequently moderates overall instability. Patches of urbanized land and artificial built-up surfaces, seen to the west and southwest of the airport area, can introduce localized heat island effects, potentially reinforce vertical mixing and enhance small-scale convergence boundaries, which may serve as triggering mechanism for shallow convection **(Fig. 1 A)**.

2.2. Materials and Methods

In this study we used daily meteorological records from the Constanța weather station (Latitude: 44.21°N, Longitude: 28.29°E, Elevation: 10 m) over the 2003 – 2022 period, because it is the closest station to the study area – ”Mihail Kogălniceanu” International Airport. The meteorological data from the station included: the number of days with rain showers and the number of days with some convection-associated meteorological phenomena (hail, thunderstorms, squalls).

To properly understand the source of the data and the way it was collected, it is essential to define each meteorological element considered in the study. According to the National Meteorological Administration, a **squall** is characterized by a sudden and sharp increase in wind speed lasting for a short period, often accompanied by an equally rapid change in wind direction. More than that, a squall is also associated with the sudden increase in air pressure and relative humidity and the decrease in air temperature (Institutul de Meteorologie și Hidrologie, 1974). A **thunderstorm** is identified by one or more atmospheric electrical discharges, manifested as a brief and intense flash light (lightning) or a low rumbling sound (thunder). The phenomenon is classified as a thunderstorm even if only thunder is heard and the lightning is not visible. **Hail** refers to precipitation composed of ice particles, either transparent or partially to fully opaque, generally spherical or irregular in shape, with diameters typically ranging from 5 to 50 mm. **Rain showers** are defined by sudden onset and rapid cessation, as well as quick and sometimes intense fluctuations in precipitation rate. They are generally short in duration and can produce either substantial amounts of rainfall or very small quantities (Institutul de Meteorologie și Hidrologie, 1974). In addition, rain showers occur when Cumulonimbus clouds are involved. Then, we compared the data on convective phenomena with the analysis of instability indices in the airport area, in order to understand the way in which the atmospheric instability identified in the study area correlates with the occurrence and intensity of convective phenomena observed at the Constanța weather station. Thus, this comparison allows for the validation of instability analyses using direct observation of the convective phenomena; the assessment of the extent to which high instability values actually translate into convective development within the study area and the improvement of meteorological interpretation by correlating the atmospheric predisposition to convection with the phenomena observed in reality.

The occurrence of convective phenomena was examined through the frequency distribution of several key instability indices - CAPE (Convective Available Potential Energy), K-index, TT (Total Totals), and CIN (Convective Inhibition). The frequency of these indices within predefined classes provides valuable information on the likelihood and the intensity of convective processes that may affect the operational area of the ”Mihail Kogălniceanu” International Airport in Constanța (**Table 1**). For this purpose, ERA5 reanalysis data provided by the European Centre for Medium-Range Weather Forecast (ECMWF) were used. These data provide physically consistent climate fields at hourly resolution and a horizontal spatial resolution of 0.25° × 0.25°, allowing a detailed representation of atmospheric conditions over south-eastern Romania. The datasets were retrieved from Copernicus Climate Data Store (www.cds.climate.copernicus.eu). Because convection varies on a daily basis, as a function of surface heating and moisture availability, hourly data at 00, 06, 12 and 18 UTC were extracted for the months of April to September over the 2003-2022 period. These summer months were specifically selected to capture the warm-season conditions under which convective activity is most likely to occur in this region.

Table 1

The instability indices based on ERA5 reanalysis data.

Parameters	Formulas	Values
CAPE – Convective available potential energy (Moncrieff and Miller, 1967; Doswell and Rassmussen, 1994	$CAPE = \int_{z_f}^{z_n} g(\frac{T_{vp} - T_{venv}}{T_{venv}})dz$	0 = Stable 0 – 1000 = Marginally unstable 1000 – 2500 = Moderately unstable 2500 – 3500 = Very unstable > 3500 = Extremely unstable
KI – K-index (George, 1960) (SUA)	$K = (T_{850} - T_{500}) + T_{d850} - (T_{700} - T_{d700})$	< 20 = No thunderstorms 20 – 25 = Isolated thunderstorms 25 – 30 = Widely scattered thunderstorms 30 – 35 = Scattered thunderstorms. > 35 = Numerous thunderstorms
TT – Total totals index (Miller, 1967; Darkow, 1968)	TT = VT + CT VT = T_{850}- T_{500} CT = T_{d850} – T_{500}	< 45 = Thunderstorms not likely 45 – 50 = Thunderstorms likely 50 – 55 = Widely scattered severe thunderstorms > 55 = Scattered severe thunderstorms more likely
CIN – Convective inhibition (Colby, 1984; Glickman, 2000)	$CIN = -\int_{z_{bottom}}^{z_{top}} g(\frac{T_{vp} - T_{venv}}{T_{venv}})dz$	0 – 50 = Weak inhibition 50 – 200 = Moderate inhibition > 200 = Strong inhibition

To extract the above-mentioned data from the ERA5 netCDF files, we firstly vectorized the airport boundary within Google Earth. Then, we projected the resulted kml file to fit the same coordinate system as the netCDF files. We further used the *terra* r-package within the R programming language (R Core Team, 2025) and the RStudio Integrated Development Environment (IDE) to extract the values of the raster layers contained by the netCDF files. The data extraction we made represents the mean of the pixels intersecting the airport area (the reprojected kml polygon). Further, the post-processing of the index's values, including frequency analysis, was made also by means of R programming language. To build the frequency graphs we used the Python programming language.

Table 2

Instability indices based on data from upper-air soundings from Bucharest-Băneasa and from the www.rawinsonde.com/ERA5_Europe website, with ERA5 data.

Parameters	Formulas	Values
SWEAT index – Severe Weather Threat Index (Binder, 1970; Miller, 1972)	$SWEAT = 12T_{d850} + 20(TTI - 49) + 2f_{850} + f_{500} + 125(s + 0.2)$	150 – 300 = Potential for moderate thunderstorms > 300 = Potential for severe thunderstorms > 400 = Potential for tornadoes
LI - Lifted index (Galway, 1956)	$LI = T_{500} - T_{p500}$	> 2 = Stable 2 to 0 = Weak unstable 0 to -3 = Marginally unstable -3 to-6 = Moderately unstable -6 to -9 = Very unstable < -9 = Extremely unstable
SI – Showalter index (Showalter, 1953)	$SI = T_{500} - T_{p850}$	> 0 = Stable 0 to -3 = Moderately unstable -4 to -6 = Very unstable < -6 = Extremely unstable
KO index (Europe) (Deutsches Wetterdienst)	$KO = (\theta_{ä}500 + \theta_{ä}700) - (\theta_{ä}850 + \theta_{ä}1000)/2$	> 6 = No thunderstorms 2 – 6 = Thunderstorms possible < 2 = Thunderstorms likely

In addition, the conditions of atmospheric instability that could influence the occurrence and development of convective phenomena at ”Mihail Kogălniceanu” International Airport in Constanța, were also inferred from the synoptic maps (showing the configuration of the surface air pressure field and the geopotential map at 500 hPa) provided by the Global Forecast System archive (www.wetter3.de), as well as by the maps of air instability indices such as CAPE, Lifted Index, and KO-index (www.wetter3.de). Upper-air soundings (thermodynamic skew-T log P diagrams) from Bucharest-Băneasa station (www.weather.uwyo.edu) were also used, alongside with extra data from www.rawinsonde.com/ERA5_Europe/, where the forecasted values of instability indices are also available – CAPE, SWEAT index, LI, K-index, TT, SI and CIN (**Table 2**).

Moreover, the characteristics of the convective phenomena on July 31, 2022, were highlighted by using the radar images of the convective cells as viewed by the WSR Doppler radar in Medgidia, part of the National Meteorological Administration (NMA) network.

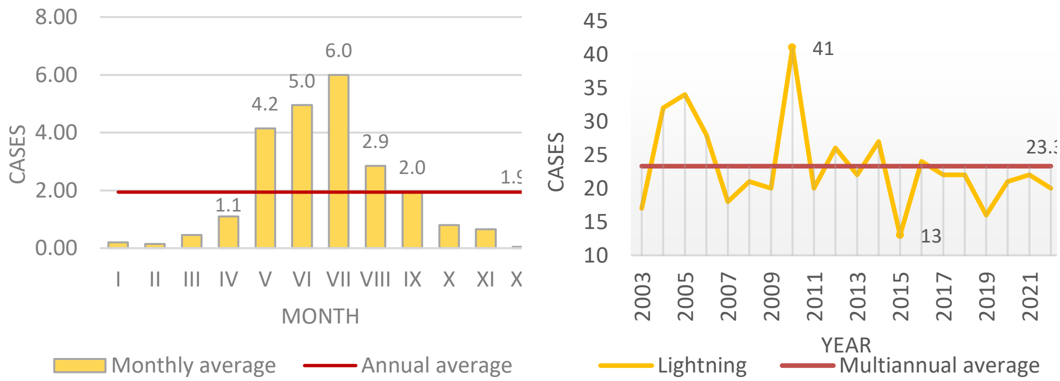
3. RESULTS

The atmospheric instability conditions influencing the formation and development of convective storms within the operational area of the ”Mihail Kogălniceanu” International Airport in Constanța were assessed by correlating meteorological observations from the Constanța weather station with instability index data calculated for the airport area. This approach provides a more accurate representation of local convective potential, as it captures both the regional weather patterns and the specific characteristics of the airport environment.

3.1. Analysis of significant meteorological phenomena

3.1.1. Lightning

From 2003 to 2022, the highest mean monthly number of thunderstorms cases at the Constanța meteorological station usually occurs in July (6 cases) and the lowest in April (1.1 cases) (**Fig. 2 A**), with an annual average value of 1.9 lightning cases. Additionally, the multiannual analysis revealed a peak in thunderstorm activity in 2010 (with 41 lightning cases) and a minimum in 2015 (13 cases) (**Fig. 2 B**), provided that the multi-annual mean value keeps around 23.3 lightning cases. The lower number of lightning cases at the Constanța meteorological station is mainly due to the climatically moderating influence of the Black Sea on the nearby shores as it lowers air-temperatures through increased humidity levels, thereby reducing atmospheric instability. Additionally, the sea breezes have a significant impact on air circulation patterns as they alter the distribution of updrafts and downdrafts, thus decreasing the frequency of severe convective phenomena such as storms.

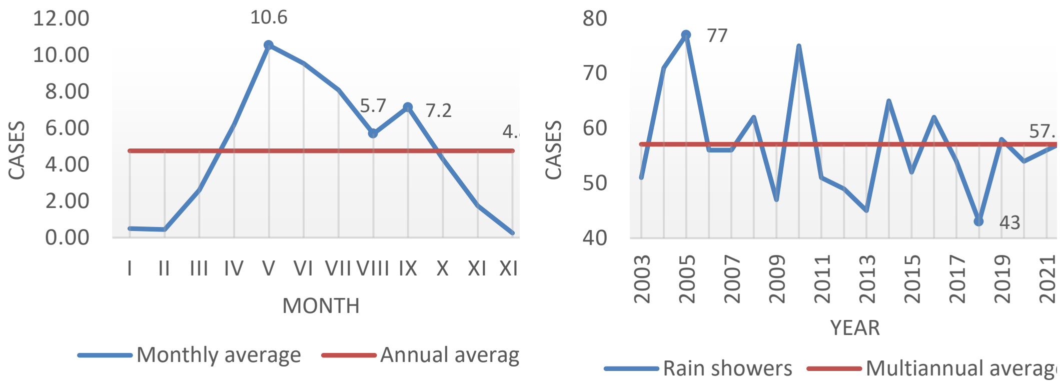


(A) **(B)**

Fig. 2. The monthly mean number of lightning cases (**A**) and the multiannual number of lightning cases (**B**) at the Constanța meteorological station from 2003 to 2022, data source: NMA.

3.1.2. Rain showers

At the Constanța meteorological station (**Fig. 3 A**), the monthly mean number of rain shower cases display two peaks: a first one from April to May, reaching a maximum of 10.6 cases, and a second period of increase from August to September, with 7.2 cases. Interestingly, the lowest value was recorded in August (5.7 cases), due to the higher air-temperatures in August, favourable to a more stable atmosphere, as warm, dry air reduces the instability needed for convective storm development. In contrast, the increased number of showers in September may be due to the seasonal changes that favour atmospheric instability. The annual mean number of rain showers from 2003 to 2022 was 4.8 cases. As for the multiannual number of rain shower cases, a maximum number of 77 cases has been recorded in 2005 and a minimum number of 43 cases in 2018 (**Fig. 3 B**).

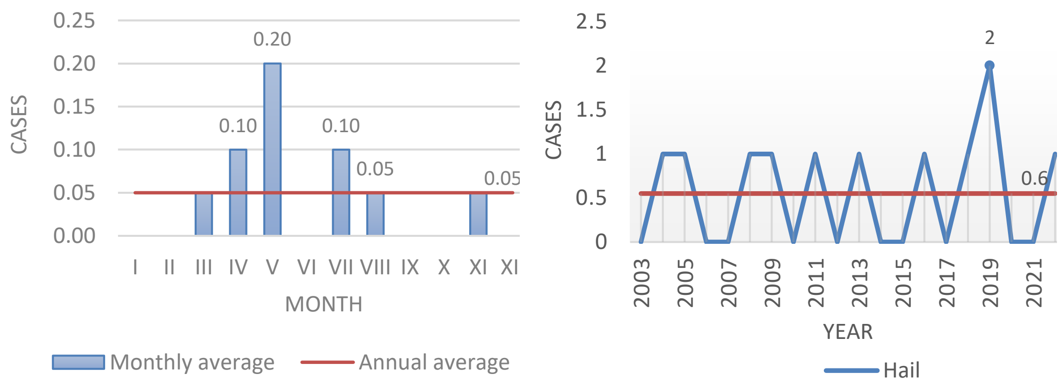


(A) **(B)**

Fig. 3. The monthly mean number of rain showers cases (A) and the multiannual number of rain showers cases (B) at the Constanța meteorological station from 2003 to 2022, data source: NMA.

3.1.3. Hail

The monthly mean number of hail cases at the Constanța meteorological station is generally low but nevertheless two significant increases and two notable decreases are evident. The first spike occurs in May (with a maximum of 0.2 cases), and the second one in April and July (with 0.1 cases) (**Fig. 4 A**). The two decreases occurred in June and September, both with 0 cases. The annual mean number of hail cases for the entire 2003-2022 period was 0.05 cases, while the multiannual number of hail cases shows a maximum of 2 cases in 2019 and a minimum of 0 cases in 2003, 2006, 2010, 2012, 2014, 2015, 2017, 2020 and 2021. In the remaining years, there has been recorded only one hail case for each year (**Fig. 4 B**). As hailstorms are more likely to occur in areas with high atmospheric instability and as in coastal regions the 0°C isotherm usually rises up to higher altitudes than in other parts of the country, hail gets less frequent onto the ground in the coastal region.

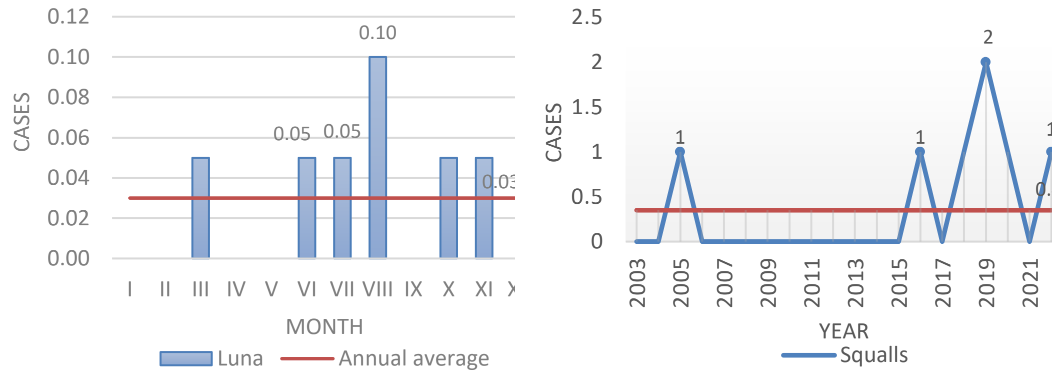


(A) **(B)**

Fig. 4. The monthly mean number of hail cases (A) and the multiannual number of hail cases (B) at the Constanța meteorological station from 2003 to 2022, data source: NMA.

3.1.4. Squalls

At the Constanța meteorological station, the monthly mean number of squall cases increases in August (0.1 cases) and decreases in September, with 0 cases recorded (**Fig. 5 A**). The annual mean value for the entire 2003–2022 period was 0.03 cases. As for the multiannual number of squall cases from 2003 to 2022, one can notice that a peak of 2 cases occurred in 2019, with other years recording one case each (2005, 2016, 2022). No squall was recorded in the remaining years (**Fig. 5 B**). As we have previously stated, Constanța's location near the Black Sea greatly inhibits the occurrence and development of convective processes, leading to more stable atmosphere conditions and a very low number of squalls in the study area.



(A) **(B)**

Fig. 5. The monthly mean number of squalls cases (A) and the multiannual number of squalls cases (B) at the Constanța meteorological station from 2003 to 2022, data source: NMA.

3.2. Analysis of instability indices

In order to assess the thermodynamic state of the atmosphere in the area of interest, we illustrated the frequency distribution of CAPE, CIN, KI and TT values, grouped by classes and analysed at different hours (00, 06, 12, 18 UTC), for the April-September period at "Mihail Kogălniceanu" International Airport (Constanța), during 2003-2022. The results reveal a pronounced seasonal cycle, accompanied by well-defined diurnal variability.

During April and early May, **CAPE** values remain predominantly low, with the 0 and 0-1000 J kg^{-1} classes being dominant **(Fig. 6 A)**. These conditions reflect a generally stable atmosphere, with limited convective potential. Beginning in June, the frequency of CAPE increases significantly, and the 0-1000 J kg^{-1} interval becomes predominant, although moderate CAPE values (1000-2500 J kg^{-1}) are also recorded **(Fig. 6 A)**. In July and August, the convective potential reaches its maximum, with the 1000-2500 J kg^{-1} category being more common. Occasional episodes of high CAPE (2500-3000 J kg^{-1}) are observed, and values above 3500 J kg^{-1} occur rarely. By September, the atmosphere becomes progressively more stable, which is reflected in the increasing frequency of low CAPE values. Diurnally, CAPE peaks consistently around 12 UTC and 18 UTC, underscoring the influence of daytime heating and the accumulation of buoyant energy.

In terms of **CIN**, April is characterized by relatively high frequencies in the 0-50 J kg^{-1} class and moderate values in the 50-200 J kg^{-1} class, indicating a slightly stable environment at the beginning of the season. Values exceeding 200 J kg^{-1} occur frequently, suggesting strong convective inhibition associated with cooler and more stable spring air masses. In May, CIN decreases visibly, and the 0-50 J kg^{-1} category becomes dominant as lower-tropospheric temperatures increase. Convective inhibition continues to weaken in June and July, and values above 200 J kg^{-1} become significantly less common, corresponding to an environment more favourable for convective development **(Fig. 6 B)**. In August, a slight increase in the 50-200 J kg^{-1} interval suggests a balance between enhanced warm-season instability and the intermittent episodes of subsident or dry air reinforcing the CIN layer.

By September, values above 200 J kg^{-1} reappear more often due to the progressive cooling of the lower troposphere.

At 00 UTC and 06 UTC, CIN is generally higher compared to daytime hours, with a greater presence of the 50-200 J kg^{-1} and >200 J kg^{-1} classes **(Fig. 6 B)**. This reflects nocturnal stabilization of the boundary layer through radiative cooling.

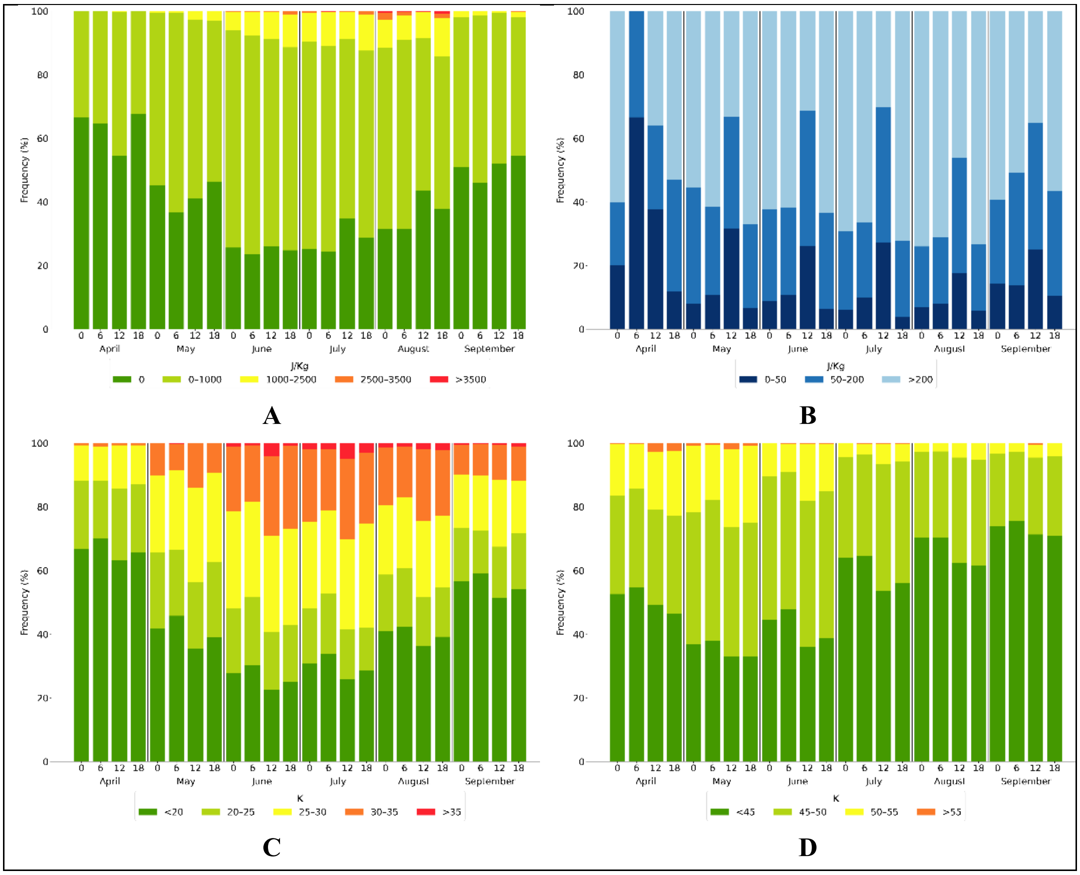


Fig. 6. The frequency distribution of CAPE **(A)**, CIN **(B)**, KI **(C)** and TT **(D)** values, grouped by classes at 00:00, 06:00, 12:00, and 18:00 UTC, for the "Mihail Kogălniceanu" International Airport (Constanța), during 2003-2022, data source: ERA5 data, www.cds.climate.copernicus.eu

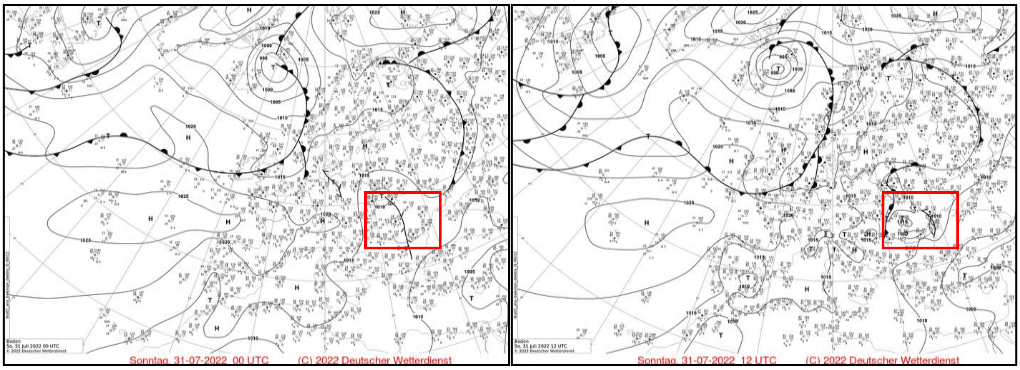
The **K-index** is an indicator of atmospheric instability and the likelihood of convective precipitation. Higher values are associated with an increased risk of organized convection. In April, low values (<20 K) dominate across all hours **(Fig. 6 C)**, indicative of a stable atmosphere and a low probability of organized convection. Moderate values (20-25 K and 25-30 K) increase significantly in May, especially at 12 UTC and 18 UTC, marking the transition to the warm season, when moisture advection in the lower troposphere becomes more pronounced. In June, the seasonal maximum becomes evident, characterized by dominant frequencies in the 25-30 K interval and increasingly frequent occurrences of 30-35 K values. This indicates a high probability of convective development, including showers and summertime thunderstorms. July exhibits a shift toward higher classes, with the 30-35 K values widespread at all hours and occasional values exceeding 35 K, signalling pronounced instability. August continues to show a strongly convective profile, similar to July but slightly more balanced, while in September, the frequencies of moderate and high KI values decrease progressively, and the <20 K class becomes dominant again during morning and nighttime hours, reflecting the establishment of a more stable thermal regime.

Total Totals is a classical indicator of thunderstorm potential and reflects a clear warm-season evolution. Low values (<45 K) dominate in April, especially at 00 UTC and 06 UTC, reflecting a stable atmosphere typical of early warm-season conditions **(Fig. 6 D)**. By contrast, moderate values (45-50 K) appear regularly during the midday and afternoon hours (12-18 UTC), indicating a slight increase in diurnal instability. In May, the distribution becomes more balanced as 45-50 K and 50-55 K values increase at 12 UTC and 18 UTC, signalling a heightened likelihood of convective showers and lightning activity. TT reaches a pronounced convective level in June, with 45-50 K values frequent at all hours and 50-55 K values dominant at 12 UTC and 18 UTC. July exhibits one of the strongest convective signatures, with 50-55 K values particularly common during the daytime hours and occasional occurrences of TT >55 K, indicative of severe instability. August maintains a similar profile, with high frequencies of 45-50 K and 50-55 K, though slightly reduces compared to July due to moderate increase in atmospheric stability. In September, TT values decrease once again, with the <45 K interval dominating at 00 UTC and 06 UTC, consistent with the seasonal transition toward a more stable thermodynamic environment.

3.3. Case study: Weather conditions in the area of the ”Mihail Kogălniceanu” International Airport on the 31st July 2022

3.3.1. Synoptic conditions

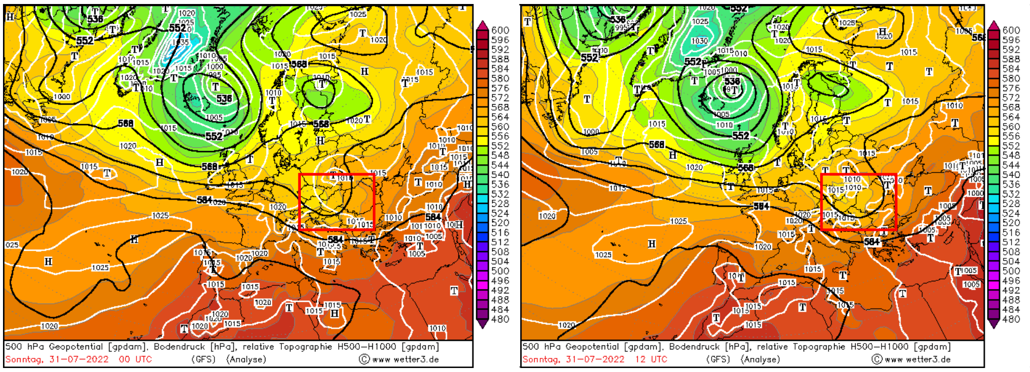
At continental scale, an active low-pressure area was present over Iceland (**Fig. 7**), with a short-wave trough extending eastwards, over much of the Scandinavian Peninsula. Concurrently, the expansion of the Azores ridge over the western regions of Europe was notable and its eastwards extent, in conjunction with the Iceland’s cyclone, facilitated the transport of polar maritime air over the central and south-eastern regions of the continent. Thus, the synoptic context was ideal for a massive zonal circulation over much of the European continent, particularly in the upper layers of the troposphere (**Fig. 7**).



(A) **(B)**

Fig. 7. The configuration of the surface air-pressure field on 31.07.2022, at 00 UTC (A) and 12 UTC (B), data source: www1.wetter3.de.

The surface pressure centers could largely be associated with those at the 500 hPa geopotential level, so not only the presence of the low-pressure area located over Iceland but also the eastward extension of the Azores high and the presence of the short-wave trough over Central Europe and the Scandinavian region could easily be identified (**Fig. 8**). Additionally, the expansion of this low-pressure area towards the central and south-eastern regions of Europe acted as a source of cold air aloft, creating ideal conditions for the initiation of convective processes, especially with warm, moisture-rich air in the lower troposphere. For the territory of Romania, the periphery of the mentioned depressionary area was of particular importance, as it resulted in the formation of a low-pressure area.



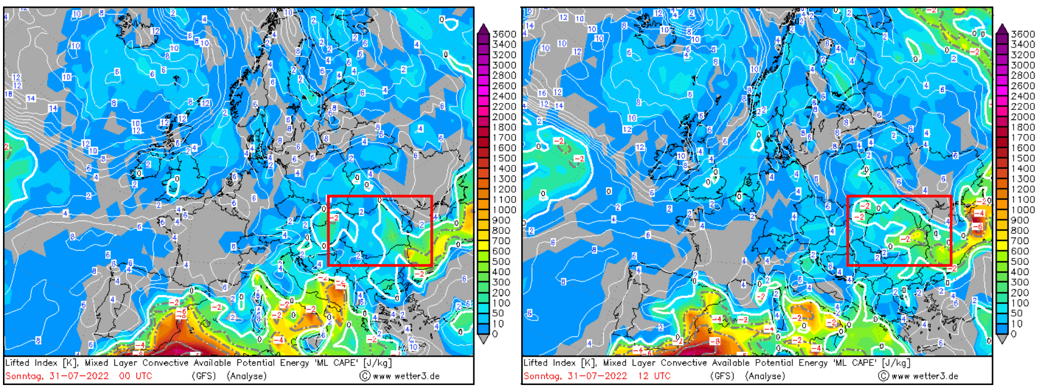
(A) (B)

Fig. 8. The geopotential map at 500 hPa on 31.07.2022, at 00 UTC (A) and 12 UTC (B), data source: www1.wetter3.de.

The presence of the upper-lever trough induces positive vorticity advection and large-scale ascent **(Fig. 8).** The synoptic configuration typically enhances convective potential, facilitates the decrease of inhibition during daytime and contributes to development of deep convection. As a result, such trough passages over or near Romania are commonly associated with episodes of heavy rainfall, thunderstorms and locally severe convective weather during the warm season (Dobri et al., 2017).

3.3.2. Air-instability indices

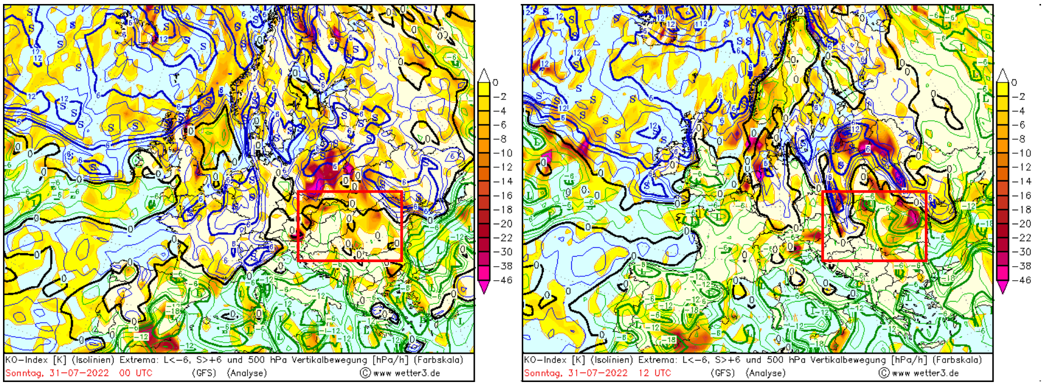
The **Lifted Index and CAPE** values for the south-eastern regions of Romania, including the area of interest, showed a gradual increase from 00 UTC to 12 UTC on July 31, 2022 (**Fig. 9 A and B**). At 00 UTC, the Lifted Index was 0 K but it decreased to -2 K by 12 UTC, thus indicating a marginally unstable atmosphere. A similar trend was observed for CAPE values which increased from 300 J/kg at 00 UTC to 800–900 J/kg by 12 UTC, also indicating a marginally unstable atmosphere, concordant with the Lifted Index values.



(A) (B)

Fig. 9. The spatial distribution of Lifted Index and CAPE on 31.07.2022, at 00 UTC (A) and 12 UTC (B), data source: www1.wetter3.de.

The values of the KO index (**Fig. 10 A and B**) show an increase from 0 K at 00 UTC to -6 K at 12 UTC, indicating a strong convective potential. In addition, the vertical ascent values at the 500 hPa level decrease to -20 hPa/h, pointing to high-intensity upward air-currents, which could lead to the development of severe convective storms.



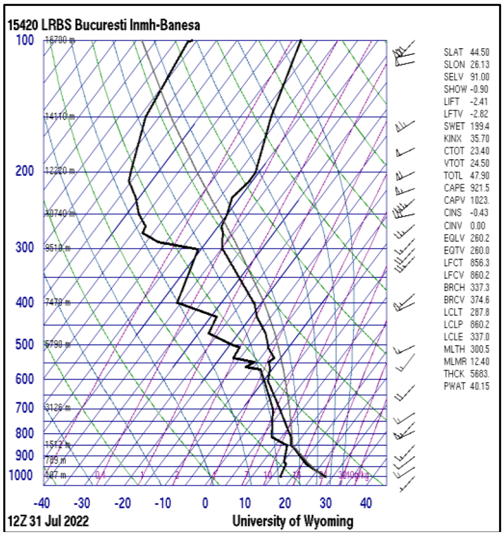
(A) **(B)**

Fig. 10. The spatial distribution of KO-index and the vertical ascent to the level of 500hPa on 31.07.2022, at 00 UTC (A) and 12 UTC (B), data source: www1.wetter3.de.

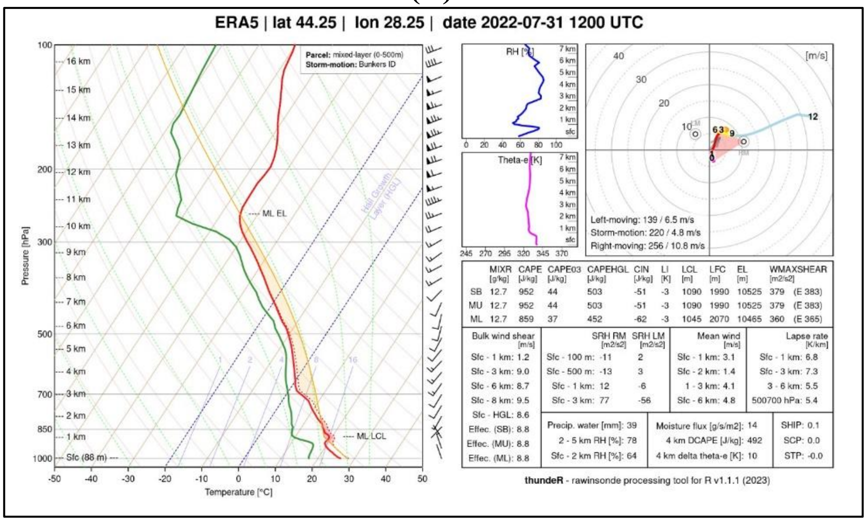
However, in order to analyse and compare the radiosonde data generated by ERA5 with the real ones, we had to refer to the Bucharest-Băneasa meteorological station, as it is the only one in Romania running real-time aerological observations. So, we compared the upper-air sounding at 12 UTC from the Bucharest-Băneasa weather station with the 12 UTC sounding generated by the ERA5 reanalysis data for the Constanța area (**Fig. 11 A and B**). Consequently, the analysis of the skew-T-log P diagram from the Bucharest-Băneasa meteorological station indicates a CAPE value of 921.5 J/kg, while the CAPEV value (based on the virtual temperature) is 1023 J/kg (**Fig. 11 A and Table 3**), thus suggesting a marginally unstable atmosphere. In parallel, the ERA5 radiosonde data indicate similar CAPE values to those from Bucharest-Băneasa: both SB-CAPE (surface-based parcel) and MU-CAPE (most-unstable parcel) maintaining at 952 J/kg, and the ML-CAPE (mixed-layer parcel) at 859 J/kg (**Fig. 11 B and Table 3**). These values actually correlate with those obtained from the analysis of the Lifted Index and CAPE maps, which are based on GFS data (**Fig. 9**).

Provided that these convective phenomena manifested mainly in the afternoon, the MU-CAPE value is no more as significant as the SB-CAPE and ML-CAPE values, which seem more appropriate for daytime convection. Under specific conditions, an intense convection cannot be supported by a surface air-layer but rather from a higher-altitude air-layer, which often occurs at night, when a thermal inversion is present just above the ground surface or on the cold side of a warm surface front, where MU-CAPE is more applicable (Craven et al., 2002). Since the mean-layer parcel provides a more accurate estimate of the height up to which the base of a convective cloud might develop, it is reasonable to conclude that the ML-CAPE value is a far better indicator of potential buoyancy as compared to the SB-CAPE value, especially in a well-mixed boundary layer. Furthermore, the moisture content in the lower troposphere was very high (**Fig. 11**) and, therefore, a significant difference between the air parcel temperature and the dew point can be observed in the mid-troposphere (500 hPa), thus creating ideal conditions for winds to reach squall speeds.

Regarding the Lifted Index, it recorded values of -2.41 K (LIFT) and -2.82 K for LFTV (based on virtual temperature) at the Bucharest-Băneasa radio-sounding, while the thermodynamic diagram based on ERA5 reanalysis data displayed a value of -3 K for all the three air parcels of reference: SB-LI, MU-LI, and ML-LI (**Fig. 11 A and B and Table 3**). The values obtained from the two radio-soundings are close, suggesting a marginally unstable convective potential, as also shown by the spatial distribution of Lifted Index values (**Fig. 9**). Initially, the Lifted Index was developed as a predictor for local severe storm forecasting in the United States, where Dennis et al. (1967) and Lyons (1964) suggested that low Lifted Index values are associated with hail occurrences in western South Dakota. Then, in 1968, Musil and Dennis used the Lifted Index alongside with other parameters to forecast hailstorms in western Nebraska. Also, in 2014 Haidu and Tudose showed that the LI is a good indicator for identifying convective storms that produce torrential rainfall, triggered either by convective or frontal lifting. Moreover, the correlation between the CAPE and the Lifted Index values point to favourable conditions for hail events in the area.



(A)



(B)

Fig. 11. The thermodynamic skew-T – log P diagram, alongside the meteorological parameters and the instability indices for the București-Băneasa meteorological station **(A)** (12 UTC) and based on ERA 5 data for the Constanța Airport **(B)** (12 UTC), on 31 July 2023, data source: www.weather.uwyo.edu; www.rawinsonde.com.

The Showalter Index values indicate a moderately unstable atmosphere, according to the radiosounding data from Bucharest-Băneasa (-0.90 K – SHOW), but a stable atmosphere according to the aerological diagram based on ERA5 data (1.67 K) (**Fig. 11 A and Table 3**). The Showalter Index is a static thermodynamic measure allowing a rapid assessment of the likelihood of thunderstorms, as inferred in the concept of potential (convective) instability (Showalter, 1953). However, its applicability is limited to mountainous regions and becomes ineffective in extremely dry air conditions, as it relies solely on the value at 850 mb to represent low-level moisture and temperature. However, although Carson (1954) demonstrated a good correlation between radiosonde data and precipitation amounts during the summer showers in Miami, Showalter (1953) suggested that values of +3 or lower can typically be linked to the occurrence of showers and possibly thunderstorms. The likelihood of thunderstorms increases as the values of the corresponding index decrease from +1 to -2, with severe thunderstorms possibly developing at values of -3 and below.

The SWEAT index recorded values of 199.4 units (SWET) for the Bucharest-Băneasa radio-sounding and of 112.95 units for the ERA5 sounding data, thus indicating a potential for moderate convective storms. Miller et al. (1972) emphasize that the index could best serve as an indicator of the potential for severe storms to develop, provided that a triggering mechanism lifts the air and utilizes this potential. However, one limitation of this index is that it uses data only from the 850 hPa and 500 hPa levels.

Table 3

The values of air-instability indices based on the sounding data at the București- Băneasa meteorological station and from ERA5 dataset, on 31 July 2022, for the "Mihail Kogălniceanu" International Airport Constanța

Indices	Radio sounding București-Băneasa	ERA5 data
CAPE	921.5 J/kg 1023 J/kg -CAPV	1436 J/kg – SB-CAPE, MU-CAPE 1286 J/kg – ML-CAPE
Lifted index	-2.41 K -2.82 K - LFTV	-3 K – SB-LI, MU-LI, ML-LI
SI	-0.90 K - SHOW	1.67 K
SWEAT index	199.4 - SWET	112.95
KI	35.70 K - KINX	30.98 K
TT	47.90 K (TOTL)	44.81 K
CIN	-0.42 J/kg 0 J/kg - CINV	-52 J/kg – SB-CIN, MU-CIN -62 J/kg – ML-CIN

Data source: www.weather.uwyo.edu.

The K-index recorded a value of 35.70 K (KINX) for the Bucharest-Băneasa radio-sounding data (**Fig. 11 A and Table 3**) and a value of 30.98 K (**Table 3**) for the ERA5 radio-sounding data, pointing to some probable scattered thunderstorms. The results from both radio-soundings seem quite similar, highlighting highly-probable storm conditions in both cases. Thus, the K-index has proven to be the most effective indicator in forecasting rain showers and less severe storms, but poorly indicative of severe storm conditions (Peppler, 1988). However, although the KI values may be indicative of storm occurrence, they greatly vary depending on the season and geographic location, proving to be much more relevant in the United States, during the summer months. In Europe, the KO index is used by The German Weather Bureau because it better integrated the effect of humidity as compared to other existing instability indices.

The Total Totals index recorded a value of 47.90 K (TOTL) in the Bucharest-Băneasa radiosonde (**Fig. 11 A and Table 3**) and a value of 44.81 K for the ERA5 reanalysis data, implying that thunderstorms are likely to occur within the operational area of ”Mihail Kogălniceanu” International Airport in Constanța (**Table 3**).

The Convective Inhibition index reached a value of -0.46 J/kg (CINS), while the CINV (based on virtual temperature) was 0 J/kg (**Fig. 11 A and Table 3**) at the Bucharest-Băneasa meteorological station. In comparison, the ERA5 radio-sounding data indicated a higher convective inhibition than at the Bucharest-Băneasa station, with SB-CIN and MU-CIN both at -52 J/kg, and ML-CIN at -62 J/kg (**Fig. 11 B and Table 3**). The lower CIN values suggest a moderately stable atmosphere; though both the radiative and dynamic factors on July 31, 2022 allowed convective processes to develop in the study area. When used alongside with CAPE, CIN provides useful insight on the potential of convective storms to develop, as shown by Beteringhe et al. (2025) in their study.

3.3.3. Radar images

To further investigate on the convective processes at ”Mihail Kogălniceanu” International Airport in Constanța, we correlated the data on the instability indices obtained from the two radio-sounding sources (Bucharest-Băneasa and ERA5 reanalysis data) with the radar images of the convective cells that developed in the area of Mihail Kogălniceanu (marked with a black border on the images below) on July 31, 2022. The convective cells started to become evident on the south-eastern areas of the

Mihail Kogălniceanu International Airport in Constanța at 2:53 p.m. (**Fig. 12**). They moved from the SE to the NW, and after surpassing the airport's perimeter, they headed northwards.

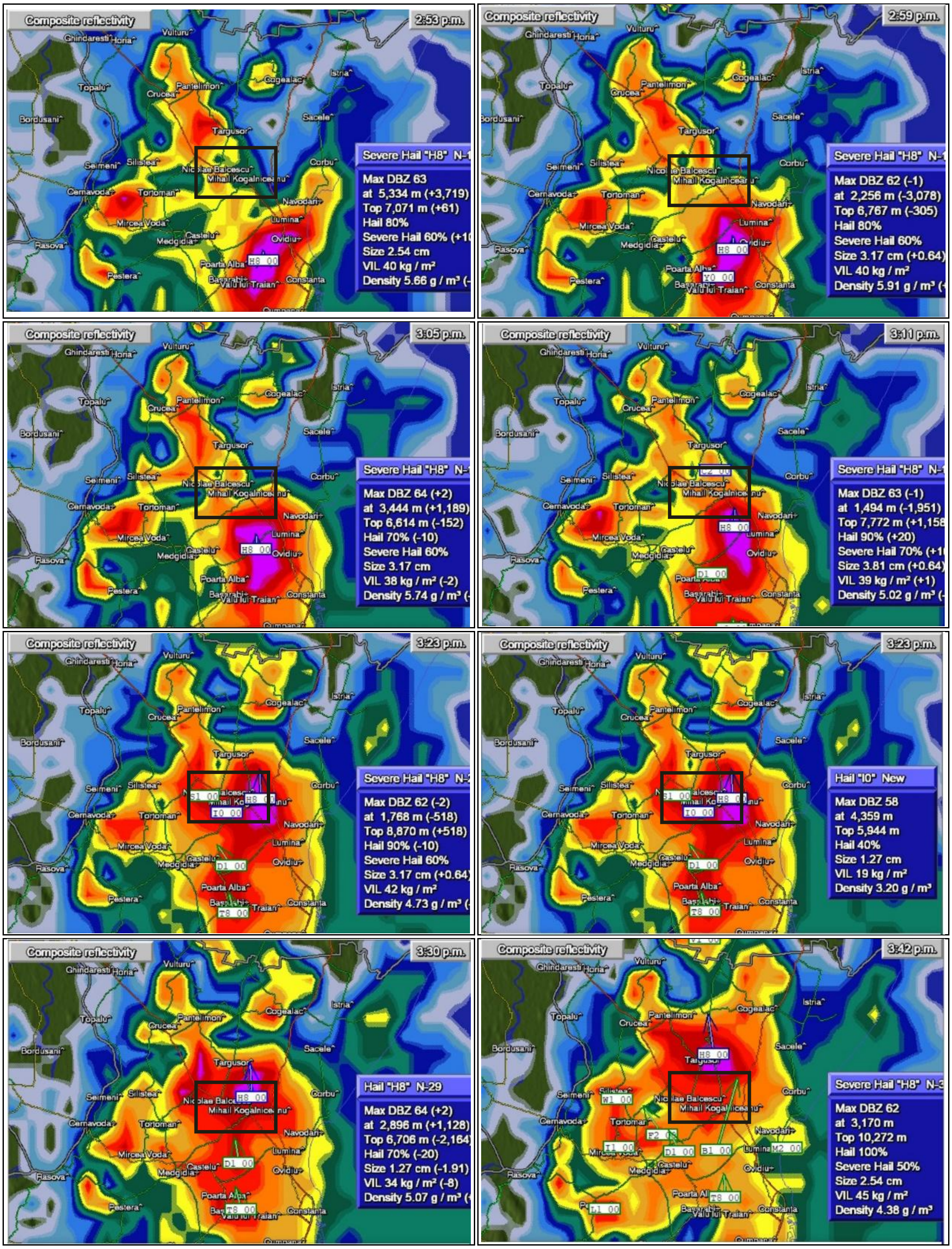


Fig. 12. Radar images of convective cells by the OmiWxTrac application in the operational area of the "Mihail Kogălniceanu" International Airport Constanța, on 31 July 2022, data source: NMA.

At 2:53 p.m., **cell H8** could be observed with several significant characteristics: an 80% probability for hail to occur and a 50% probability for severe hail to occur, with hail sizes up to 2.54 cm in diameter, provided that the radar reflectivity reached 63 dbZ and the cloud height rose to 7,010 m (**Fig. 12**). The cell was well-developed, as indicated by the high reflectivity, knowing that values above 55 dbZ are typically associated with hail in the cloud (Schuster et al., 2006; Kunz and Puskeiler, 2010). At 2:59 p.m., another cell (**Y8**) appeared (**Fig 12**), pointing to the multicellular nature of the system moving towards the "Mihail Kogălniceanu" International Airport in Constanța. Additionally, cell **H8** showed an increase in its convective parameters: hail sizes of 3.17 cm and a 60% probability for severe hail to occur. By 3:11 p.m., cell **H8** continued to grow and give birth to new accompanying convective cells, nearer to the airport. Thus, although reflectivity kept at 63 dbZ, hail increased to 3.81 cm inside the cloud, the probability of hail occurrence rose to 90%, the probability of severe hail increased to 70%, and the cloud top reached 7,772 m. Additionally, VIL (Vertical Integrated Liquid) recorded a value of 39 kg/m² (**Fig. 12**). This parameter is used in weather forecasting to estimate the water content inside the cloud, particularly in storm clouds. High VIL values are generally associated with severe storms and hail (Amburn and Wolf, 1997; Witt et al., 1998). Elevated VIL values, combined with high CAPE, indicate a very unstable atmosphere, favourable for severe storms to develop, especially inside highly-convective Cumulonimbus clouds.

At 3:23 p.m., cell **H8** was right over the perimeter of "Mihail Kogălniceanu" International Airport in Constanța, directly affecting the area (**Fig. 12**). Although its convective parameters have slightly diminished, the cell still remained vigorous enough. Additionally, the newly formed cell I0 was already exhibiting high values for most convective parameters: reflectivity of 53 dbZ, hail size of 1.27 cm, with a 40% probability of storm occurrence, and a VIL of 19 kg/m² (moderate VIL – moderate storms).

Starting at 3:30 p.m., cell **H8** continued its movement northwards, past the area of "Mihail Kogălniceanu" International Airport in Constanța, while displaying a decrease in all convective characteristics. However, at 3:42 p.m., there appeared a significant convective increase, with reflectivity rising back to 62 dbZ, hail size growing to 2.54 cm, the probability of hail occurrence increasing to 100% and the probability of severe hail to 50%, the cloud height mounting up to 10,272 m, and a VIL reaching as high as 45 kg/m² (high VIL – severe storms) (**Fig. 12**). Additionally, new green cells formed to the southern periphery of the main cell (H8), indicating a multicellular system.

The onset of convective activity in the area of Mihail Kogălniceanu International Airport in Constanța as reflected by the radar images perfectly coincides with the information derived from the analysis of instability indices from the two sounding diagrams (București-Băneasa radio-sounding and ERA5 reanalysis data). Their corresponding values suggested favourable conditions for the development of convective storms, with heavy rainfall, strong gusts and hail, in the area, as also shown by the radar images (**Fig. 12**).

The intensity of the convective phenomena was further supported by reports published in the European Severe Weather Database (ESWD), all classified with QC1 confidence level. The convective cell responsible for the severe wind and heavy rainfall observed near Valu lui Traian is the same system that subsequently propagated toward the study airport area, while the hail event reported at Topraisar is likewise attributable to this convective structure.

4. DISCUSSION

The analysis of convective weather reports at the Constanța meteorological station reveals a clear attenuation of severe convective activity along the Black Sea coast, consistent across all investigating phenomena. Thunderstorm frequency shows a pronounced seasonal cycle, with a peak in July and a minimum in April, while multiannual variability indicates years with markedly enhanced (2010) or suppressed (2015) lightning activity. This pattern reflects the moderating influence of the Black Sea, which lowers near-surface air temperatures and increases humidity, thereby reducing lapse rates and inhibiting deep convection. A similar coastal imprint is visible in the distribution of rain showers, which exhibit seasonal maxima – one in late spring and another in early autumn – suggesting that transitional seasons provide more favourable instability compared to midsummer, when warm and relatively dry air masses promote atmospheric stability. Hail and squalls occur only rarely, with most years recording zero or one event. This scarcity is consistent with the elevated 0°C isotherm height in coastal environments and overall reduction of strong updrafts needed for hail formation and severe wind gust. Altogether, these findings underscore that the proximity to the Black Sea exerts a persistent stabilizing effect on the boundary layer, substantially limiting the development of intense convective phenomena in Constanța region.

The observed seasonal and diurnal patterns in CAPE, CIN, KI and TT are consistent with thermodynamic evolution of the lower troposphere in coastal south-eastern Romania. The pronounced increase in CAPE during June-August, combined with sustained weakening of CIN during the same interval, highlights the role of strong surface heating and enhanced low-level moisture supply in promoting convective development. The systematic diurnal peaks in CAPE at 12 and 18 UTC further support this interpretation and align with previous studies documenting the timing of convective initiation over the western Black Sea coastal region.

The behaviour of CIN provides additional insight into boundary-layer processes influencing convection. Elevated CIN during night-time and early-morning hours, particularly during spring and late summer, correspond to stronger nocturnal radiative cooling and reduced turbulent mixing. Conversely, the marked decline in CIN during midday in summer underscores the effectiveness of surface heating in eroding inhibition and facilitating convective initiation when sufficient moisture is present.

The seasonal evolution of KI and TT corroborates these findings: both indices exhibit their strongest convective signatures in June and July, with frequent occurrences of values associated with significant thunderstorm potential. Occasional KI >35 K and TT >55 K highlight the presence of days with pronounced instability capable of supporting organized convective systems, even in a coastal environment typically characterized by mesoscale circulations that modulate convective development. Overall, the combined thermodynamic indicators portray a consistent picture of a warm season characterized by moderate to high convective potential, particularly in midsummer, modulated by strong diurnal forcing and seasonal changes in low-level moisture availability. When interpreted alongside the low observed frequency of thunderstorms, hail and squalls, these results highlight the decisive role of coastal boundary-layer processes in constraining convective outcomes and provide a comprehensive framework for forecasting local convective behaviour in the airport area.

The convective episode of 31 July 2022 provides an illustrative example of how high instability conditions, as indicated by both radiosonde-derived and ERA5-based instability indices, can translate into the rapid development of severe convective cells near the ”Mihail Kogălniceanu” International Airport. Despite the general climatological tendency for the Black Sea to suppress the occurrence of intense convection in the Constanța region, this case demonstrates that under sufficiently favourable thermodynamic conditions, vigorous multicellular systems can still develop and impact the coastal area. Radar observations clearly captured the lifecycle of a well-organized convective system, with cell **H8** exhibiting substantial reflectivity values (>60 dBZ), large VIL signatures and hail-size estimates exceeding 3 cm. The system's multicellular structure – visible through the emergence of successive cells such as **Y8** and **I0** – highlights a sustained inflow environment capable of supporting repeated updraft regeneration. The temporal evolution of the radar convective metrics underscores the dynamic behaviour of the storm as it crossed the airport area. Notably, the intensification observed after 3:42 p., following an initial weakening phase, is characteristic of multicellular convective system, which often undergo cycles of decay and regeneration. This behaviour is consistent with instability conditions indicated by high CAPE and reduces CIN during the afternoon hours, conditions that are frequently conducive to convective redevelopment.

The research conducted allowed the deduction of time series for atmospheric instability indices, providing a solid basis for analysing convective variability in the vicinity of the investigated airport. We suggest that future studies should include a frequency analysis of these indices, using the probabilistic methodology proposed by I. Haidu (2002). Such an approach would aim to quantify the risk associated with the occurrence of exceptional convection and its potential impact on air navigation.

5. CONCLUSIONS

This study highlights the importance of air-instability indices in evaluating the formation and development of convective storms in the area of the ”Mihail Kogălniceanu” International Airport in Constanța. The analysis of daily meteorological parameters from 2003 to 2022 (number of days with rain showers, hail, lightning and squalls) emphasized the general characteristics of convective phenomena in the study area, where the thermoregulatory role of the Black Sea is evident, as it moderates air-temperatures in the region during summer and contributes to atmospheric stability, thereby reducing the intensity of convective events. The average number of cases with severe weather phenomena indicate a predominance of thunderstorms in July (6 cases), rain showers in May (10.6 cases), hail in May (0.2 cases) and squalls in August (0.1 cases).

The frequency-based assessment of the instability indices (CAPE, CIN, KI and TT) over the ”Mihail Kogălniceanu” International Airport area provides a coherent picture of the thermodynamic environment that characterizes the western Black Sea region. The results indicate that, although moderate to high convective potential frequently develops during warm season – particularly in June, July and August - the actual occurrence of severe convective phenomena remains comparatively low. The contrast reflects the persistent moderating influence of the Black Sea, which reduces lapse rates, enhances boundary-layer stability.

The observed diurnal cycle, with CAPE maxima and CIN minima at midday and the early afternoon, confirms that daytime heating is the primary driver of convective potential in this area. KI and TT frequencies further highlight the presence of environments occasionally supportive of organized convection.

Regarding the case study from July 31, 2022, at ”Mihail Kogălniceanu” International Airport in Constanța, the overall synoptic context showed favourable conditions for convective processes to develop in the area. Thus, the Lifted Index and CAPE values for Romania’s south-eastern parts were indicating a "marginally unstable" atmosphere, based on both data from the Bucharest-Băneasa radio-soundings and the ERA5 reanalysis data, as well as from the maps showing the distribution of the index values by means of GFS data (www.wetter3.de). The Showalter, SWEAT, and Total Totals indices derived from both radiosonde sources indicated a favourable atmosphere for the formation and development of convective storms. Additionally, the K-index suggested scattered thunderstorms, while the KO index indicated strong convective potential.

Regarding CIN, the values derived from the Bucharest-Băneasa soundings showed a low inhibition, while the ERA5 data indicated a moderate inhibition. Elevated CIN values would normally indicate a moderately stable atmosphere but the specific radiative and dynamic factors contributed to the development of a strong convective activity at Mihail Kogălniceanu International Airport in Constanța, on July 31, 2022, as was confirmed by the radar images displaying the convective cells from that day.

The analysis of the radar images from July 31, 2022 confirms that the initial values calculated for various instability indices were indicating optimal conditions for convective phenomena to occur that day. Consequently, a series of convective cells developed over the operational area of ”Mihail Kogălniceanu” International Airport in Constanța, displaying high convective parameter values: reflectivity of 63 dbZ, hail up to 3.81 cm in diameter, a 90% probability of hail and a 70% probability of severe hail, with cloud tops reaching as high as 7,772 m. Although the main convective cell showed a decrease in its convective characteristics, after moving past the airport perimeter, it continued to be fuelled by a warm air inflow and kept on growing, by forming additional cells to its southern ends. The onset of convective activity in the area of ”Mihail Kogălniceanu” International Airport in Constanța fully corresponds with the values of the instability indices derived from the data provided by the two upper air-soundings (Bucharest-Băneasa and ERA5 reanalysis data) that were taken into consideration.

The radar-derived convective signatures were validated by ESWD reports, as observed hail and severe weather occurrences matched the storm characteristics indicated by radar data.

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Web resources:

ECMWF - The European Centre for Medium-Range Weather Forecasts: www.cds.climate.copernicus.eu. (20.10.2024)

European Severe Weather Database (ESWD): https://www.essl.org/cms/european-severe-weather-database/ (18.11.2025)

Global Forecast System archive: www.wetter3.de (20.10.2024)

National Meteorological Administration: www.meteoromania.ro (10.10.2024)

University of Wyoming. College of Engineering: www.weather.uwyo.edu/upperair/sounding.html (20.10.2024)

ThundeR rawinsonde package: www.rawinsonde.com/ERA5_Europe/ (27.10.2024)