

The relevance of air-instability indices in assessing the thermoconvective phenomena within the operation area of the "Traian Vuia" airport in Timișoara, on 10 July 2021

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Abstract: At present, we are witnessing progressive changes in the global climate, caused by both natural and anthropogenic factors. According to a 2019 IPCC (Intergovernmental Panel on Climate Change) report, ocean levels will rise drastically, storms will be more frequent, summers will be warmer, with frequent air-temperatures of 35°C. These high temperatures will lead to much more frequent manifestations of convective phenomena. The correlation between convective phenomena and airplane flights is important for identifying the conditions having a negative impact on aviation. In order to observe the factors that influence the occurrence and development of convective phenomena in the operation area of the "Traian Vuia" International Airport, Timișoara, an analysis of atmospheric instability was conducted based on some air-instability indices: CAPE (Convective Available Potential Energy), SWEAT index (Severe Weather Threat Index), LI (Lifted Index), K-index (KI), TT (Total Totals Index), SI (Showalter Index), CIN (Convective Inhibition), for July 10, 2021, a representative day in terms of the severity of convective processes. The analysis of the above-mentioned indices was further developed by means of the radar images from the WSR Doppler radar in Timișoara (source: the SMIN network of the Romanian National Meteorological Administration - NMA) and by the number of cases with convective phenomena recorded at the Timișoara meteorological station. This day (10 July 2021) was associated with high values of all air-instability indices, and with estimated hail sizes of 5.71 cm inside the clouds. The analyzed instability indices were extracted both from maps (including the CAPE and LI index), as well as through radiosonde data, measuring values of - 2...-7 K for the LI index (strong severity level), between 1,200 – 1,300 J/kg for CAPE (Szeged meteorological station and from GFS data from zyGrib program) and 1,900 J/kg based on ERA5 dataset (moderate instability), values lower than +1 K for SI (increased atmospheric instability), values indicating the occurrence of convective storms in the area for SWEAT index and values that indicate high probability of scattered convective storms for KI and TT indices.

1. Introduction

The main atmospheric risk phenomena that primarily affect airport operations are: wind gust speed, horizontal visibility, turbulence, icing, heavy precipitation, thunderstorms, as well as electrical phenomena and snowfalls. These often lead to flight diversions to other airports, increased holding times in the air for landing maneuvers, take-off delays and additional workload for pilots and air traffic controllers. According to a report by EUROCONTROL (2019), in 2018, 25% of total flight delays in Europe were caused by severe weather conditions.

At international level, a series of studies have analyzed the relationship between atmospheric risk phenomena and aviation. The most important topics being addressed included flight delays caused by severe weather (Pejovic et al., 2009; Kreuz et al., 2012; Schultz et al., 2018; Liu et al., 2019; Garcia-Heras et al., 2021), the use of forecasting models in the study of weather phenomena (Mahapatra et al., 1983; Buzdugan et al., 2020; Jardines et al., 2021), and the impact of atmospheric phenomena on aviation (Makela et al., 2013; Cao et al., 2014; Pumpel, 2016; Gultepe et al., 2019; Araany and Łaszyca, 2020; Taszarek et al., 2020; Kirschenstein et al., 2020; Wan et al., 2021; Zatula et al., 2021; Voskaki et al., 2023).

Various research works in Romania have mainly analyzed the favorable conditions for the formation and development of convective phenomena over airport areas, as well as their impact from a climatological and meteorological perspective (Gheorghe, 1993; Piticar et al., 2024). Most studies have focused on airports in the proximity of Bucharest city (Băneasa and Otopeni), thus highlighting favorable synoptic conditions for heavy precipitation (Cristodor and Darie, 1963), the occurrence of fog (Șorodoc and Cristodor, 1965), the formation of Cumulonimbus clouds and thunderstorms (Grama, 1969), along with reduced horizontal visibility (Buzdugan et al., 2018), and general meteorological risks (Păunescu, 2007; Șchiopu, 2015).

The studies focusing on the impact of meteorological risk phenomena on aviation in eastern Romania's airports (Suceava, Iași, and Bacău) are fewer in number. Their main topics were mainly related to climate risks in airport areas (Pintilie, 2015), favorable meteorological conditions for fog formation (Grama, 1965) and specific synoptic conditions for the occurrence of risk phenomena (Ranga and Vasenciuc, 1980).

In Romania's central region, the meteorological parameters and phenomena affecting the operational areas of Cluj-Napoca, Brașov, and Sibiu airports have represented the main subject of several studies (Șerbu et al., 1985; Kiraly, 2003; Raicu, 2011). Conversely, in Romania's western region, research in this respect has been more limited, with only two studies focusing on the influence of radiation fog on airport operations at Timișoara Airport (Chertic et al., 1964) and weather hazards (Mărăzan et al., 2021).

The day of **July 10, 2021**, was selected for analysis due to the occurrence of severe convective weather phenomena in Timiș County, including heavy rainfall, hail, and strong wind gusts. The storm that developed on this day caused significant material damage and disrupted urban infrastructure, while radar imagery revealed the presence of intense convective cells in the vicinity of the "Traian Vuia" International Airport in Timișoara. The analysis of atmospheric soundings, instability indices and radar data, aims to assess the predictive potential for such phenomena in the airport area.

Additionally, understanding the evolution and forecast accuracy of such severe phenomena is critical for airport operations, including flight safety, scheduling, and ground logistics, all of which can be heavily impacted by convective storms.

2. Materials and Methods

2.1 Study area

The study area is represented by the "Traian Vuia" International Airport in Timișoara, Timiș county, which is located at a distance of 12 km North-East from the city center (Figure 1). It is the third airport in Romania in terms of its number of passengers (Table 1). Since 1964, it has been operating as a civil airport; only military air flights have been operated until then.

The Timiș county is located in the western part of Romania and is bounded to the North-West by Hungary, to the West by Serbia, to the North by Arad County, to the East by Hunedoara County and to the South by Caraș-Severin County (Figure 1). The "Traian Vuia" International Airport in Timișoara is located in a plain area characterized by slightly elevated relief forms, lying between the Lipova Hills and the Timiș Plain: with the latter extending to the west of the airport area and hardly exceeding 170 meters in altitude (Timiș, Monografie, JP).

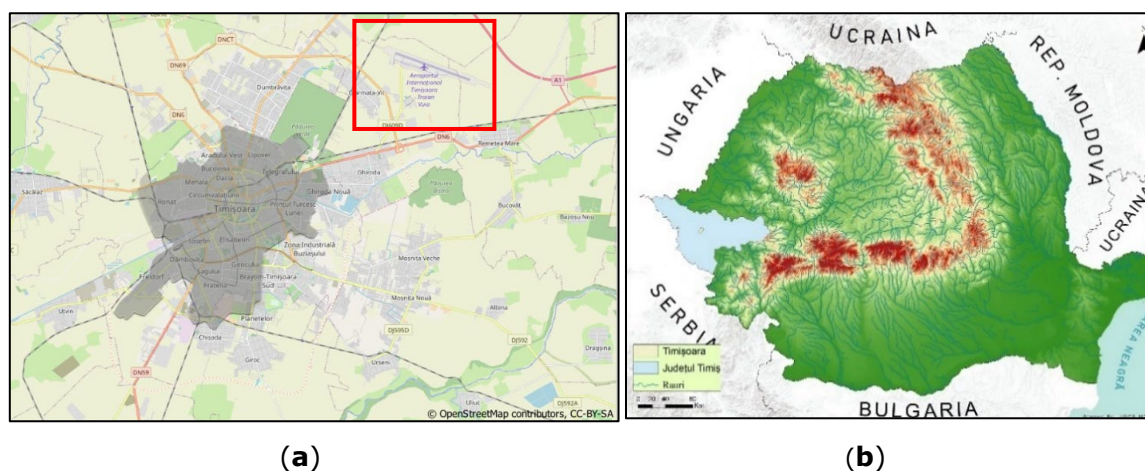


Figure 1: (a) The location of the "Traian Vuia" International Airport (marked by a red square on the map) in the proximity of Timișoara city; (b) The location of Timiș county, data source: OpenStreetMap, ArcGis

Table 1: Characteristics of the "Traian Vuia" International Airport, Timișoara, data source: www.aerotim.ro

No	Technical characteristics	
1.	Runway	1 (direction 11/29 – 3500 x 45 m)/ asphalt
2.	Processing capacity	1500 passengers /hour
3.	Terminals	3
4.	Destinations	36
5.	Passengers (2021)	630.000

2.2. Database

In this study, daily data from the archives of the National Meteorological Administration were used to analyze the meteorological conditions associated with convective phenomena at the "Traian Vuia" International Airport, Timișoara, over the 2003 – 2022 period. The data provided by the Timișoara meteorological station included: the daily average air temperature, daily maximum air temperature, daily rainfall amounts, daily gust wind speed, recorded cases of rain showers and other specific meteorological phenomena (hail, lightnings, squalls).

As for the 10th July 2021, synoptic maps (presenting the configuration of the surface air-pressure field and the geopotential map at 500 hPa) were used from the

Global Forecast System archive (www.wetter3.de), as well as maps of air-instability indices CAPE and Lifted Index (www.wetter3.de), in order to observe the factors that influence the formation and development of the thermoconvective phenomena in the area of the "Traian Vuia" International Airport. In order to analyze the values of the instability indices - CAPE (Convective Available Potential Energy), SWEAT index (Severe Weather Threat Index), LI (Lifted Index), K-index (KI), TT (Total Totals Index), SI (Showalter Index), CIN (Convective Inhibition), upper-air soundings (thermodynamic diagrams skew-T – log P) were also analyzed: both from Szeged – Hungary (www.weather.uwyo.edu) and from the ZyGrib - a visualization weather program with GFS data (GRIB files from NOAA – www.weather.noaa.gov) as well as from www.rawinsonde.com/ERA5_Europe, which were also later added.

In addition, the evolution of convective phenomena on 10 July 2021 was completed by the analysis of radar images on the developing convective cells, by using data from the WSR Doppler radar in Timișoara (source: the SMIN network of the Romanian National Meteorological Administration - NMA).

3. Results and discussion

The present study outlines the characteristics of the main convective phenomena in the operational area of the "Traian Vuia" International Airport, Timișoara, by analyzing daily average air temperature, daily maximum air temperature, daily amount of atmospheric precipitation, daily gust wind speed and the recorded cases of rain showers, hail, lightnings, squalls and strong wind.

3.1. Meteorological parameters

In this chapter, we made a brief analysis of the main meteorological parameters essential for the formation and development of convective phenomena. Then, in Chapter 3.2, section (c), we compared the day of July 10, 2021, with the mean and maximum parameter values analyzed in this section, to highlight why that specific day was so meteorologically extraordinary.

The daily average values of air temperature at the Timișoara meteorological station recorded a maximum of 23.9°C in July and a minimum of 0.2°C in January over the entire period of observation (2003-2022) (Figure 2). By analyzing the daily average values of maximum air temperatures at the Timișoara meteorological station during the 2003-2022 period, it can be observed that the maximum value (30.5°C) occurs in July, and the minimum value (4.1°C) in January (Figure 2 right). The territory of Timiș county is characterized by a mid-latitude climate with oceanic and mediterranean influences provided that the orographic barrier role of the Carpathian Mountains often leads to the blocking of cold air masses from the North and the North-East (Timis, Monografie, JP).

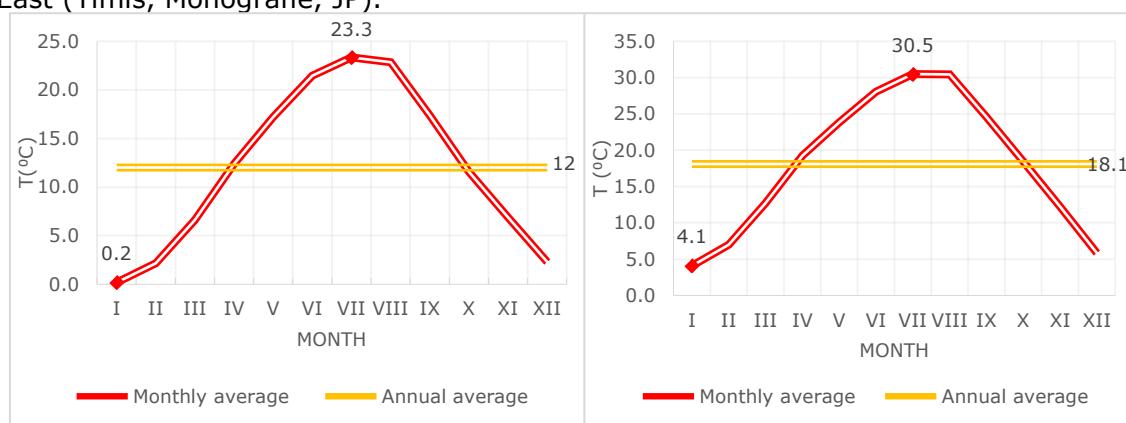


Figure 2. The annual variation regime of daily average air temperatures ($^{\circ}\text{C}$) (left) and the annual variation of daily maximum air temperatures ($^{\circ}\text{C}$) (right) (Data source: National Meteorological Administration)

The rainiest period is represented by the months of April to June, when the rainfall amounts increase, and the driest one, by the months of January to March, when the rainfall amount decreases. The maximum value of rainfall amounts recorded at the Timișoara meteorological station, was 72.2 mm (June), while the lowest one was 37.5 mm (March) (Figure 3). Due to the location of the Timișoara county in the western part of Romania and consequently, in the direct path of the oceanic air masses, the rainfall amounts are higher and more uniformly distributed in time as compared to other areas. However, due to the strong radiative heating of the ground and the subsequent development of thermal convection, higher rainfall amounts usually occur during the warmer period of the year.

The daily average values of wind gust speed at the Timișoara meteorological station, during the 2003-2022 period are generally increasing from March (7.7 m/s) until June, when the maximum value is being reached (8.2 m/s). This increase is then followed by a gradual and continuous decrease until the end of the year, with the minimum value usually being recorded in January (5.9 m/s) (Figure 3).

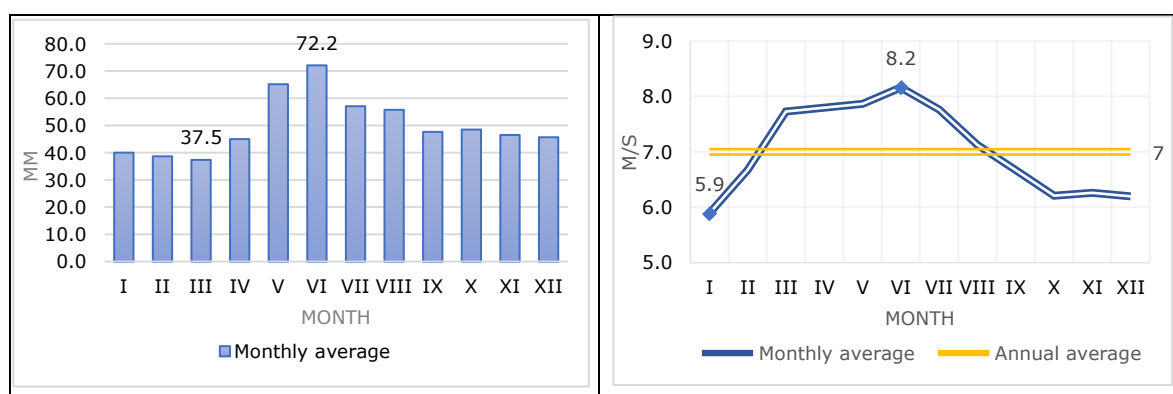


Figure 3. The annual variation of daily average rainfall amounts (mm) (left) and annual variation of daily average wind gust speed (m/s) (right) (Data source: National Meteorological Administration)

3.2. The case study of 10 July 2021 on the "Traian Vuia" International Airport

a) Synoptic conditions

At continental level, the day of 10 July 2021 was characterized by the presence of an active low-pressure area over the Baltic Sea basin, which was associated with a stationary cold front, also influencing the geographical area of our country (marked by a red square on the map) (Figure 4).

The Romanian territory was under the influence of the anterior part of the cold atmospheric front, thus creating conditions for the development of local convective clouds, associated with prefrontal instability. Meanwhile, active high-pressure formations were also significant over central and southern Europe, so that the coupling

between the existing high-pressure and low-pressure formations favored a transport of warm, tropical air over most of Europe (Figure 4).

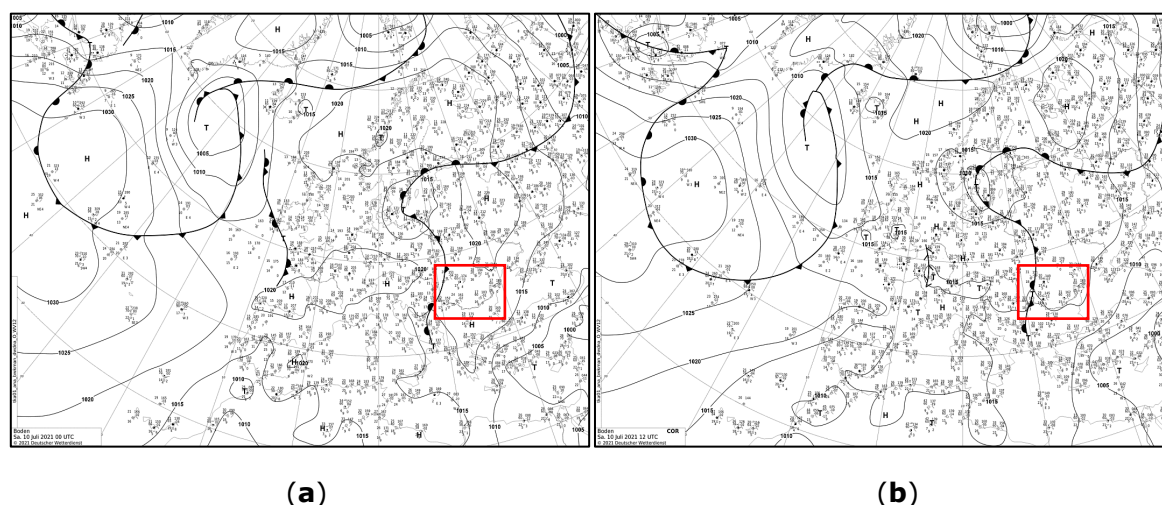


Figure 4: The configuration of the surface air-pressure field on 10.07.2021, at 00 UTC (a) and 12 UTC (b), data source: www1.wetter3.de.

The distribution of the respective high-pressure and low-pressure formations at the surface was paralleled by another similar one at the 500 hPa geopotential level. So, some low geopotential areas can be distinguished in the North and North-West of Europe, while some high-pressure areas were evident in the centre and South of Europe (Figure 7). Additionally, a warm air ridge is clearly observed at higher altitudes, in the middle layers of the troposphere, thus greatly influencing the extent and amplitude of convective phenomena over the Romanian territory (Figure 5).

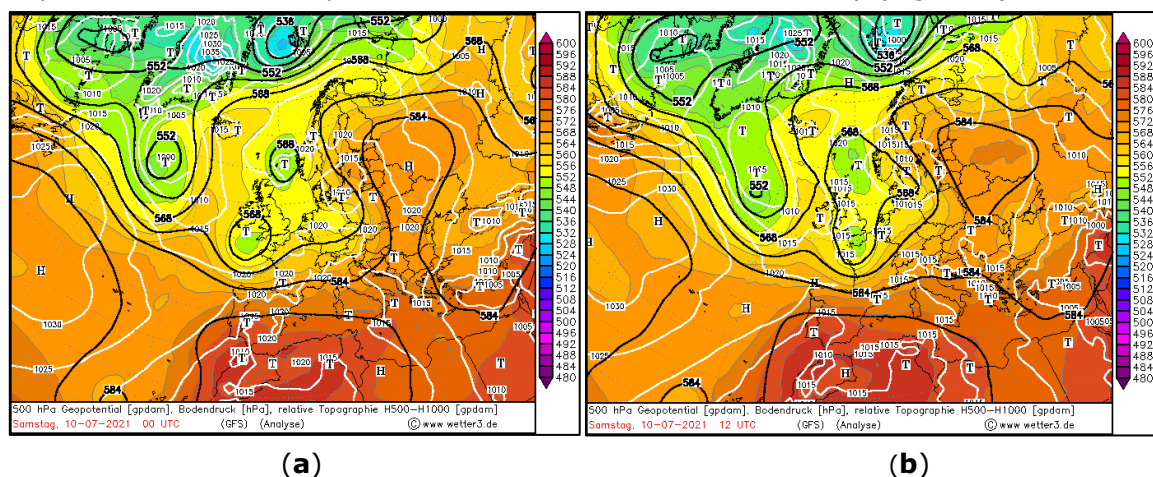


Figure 5: The geopotential map at 500 hPa on 10.07.2021, at 00 UTC (a) and 12 UTC (b), data source: www1.wetter3.de.

b) Instability indices

The values of the CAPE and Lifted Index for the north-western and western regions of Romania, increased twofold throughout the day. So, if on 10 July 2021, at 00 UTC, the value of the Lifted index reached -2 K in the western part of Romania, then at 12 UTC, it increased significantly to -4 K, thus indicating a highly unstable atmosphere (Figure 6).

Also, **CAPE** values increased from 600 J/kg (00 UTC) to 1,200 – 1,300 J/kg (12 UTC); the resulting high values leading to the development of extensive convective cloud formations, indicative of a moderately unstable atmosphere (Moncrieff and Miller, 1976).

Because there is no sounding station where aerological observations are made in real time in the western part of Romania, we used the upper air-sounding from the Szeged meteorological station (Hungary), which could be representative for the overlaying atmosphere of our airport of interest - "Traian Vuia" International Airport. In this respect, we selected the upper air-soundings from 12 UTC, when the highest values are usually being recorded. The resulting data from the Szeged radiosounding were then compared with those from the Zygrid forecast program, based on GFS data, as well as with the ERA5 sounding data, both obtained for the area where the airport is located in order to emphasize the relevance and complementarity of meteorological models and different other types of data used in forecasting the occurrence and development of convective phenomena.

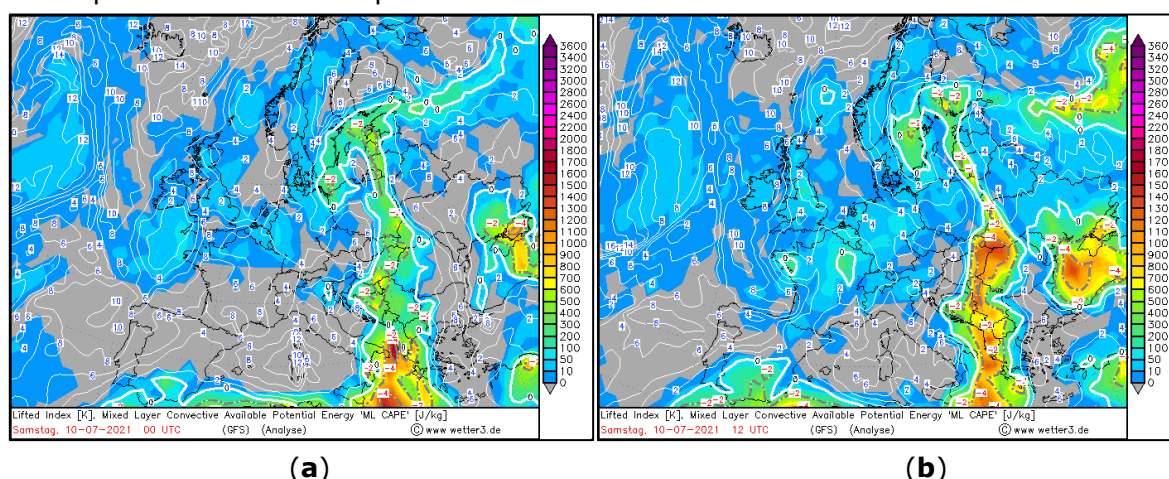


Figure 6: The spatial distribution of Lifted Index and CAPE (Convective Available Potential Energy) on 10.07.2021, at 00 UTC (a) and 12 UTC (b), data source: www1.wetter3.de.

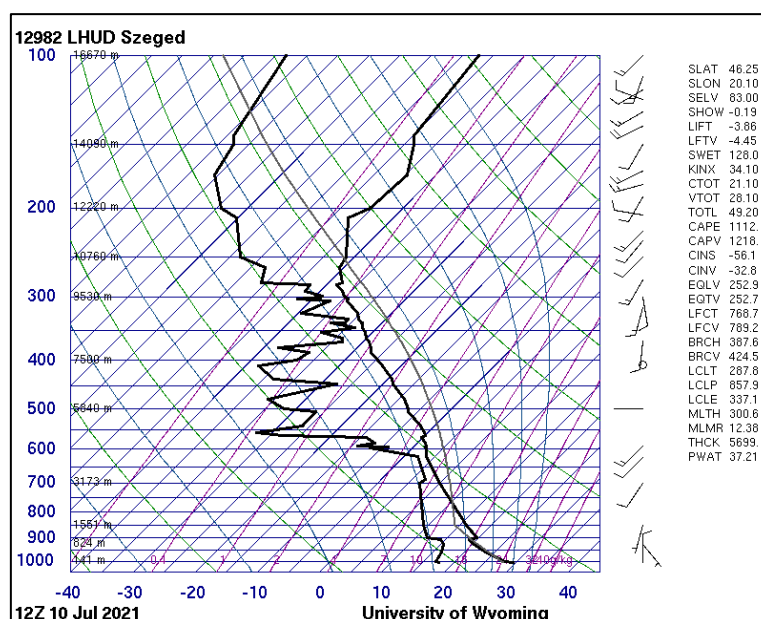
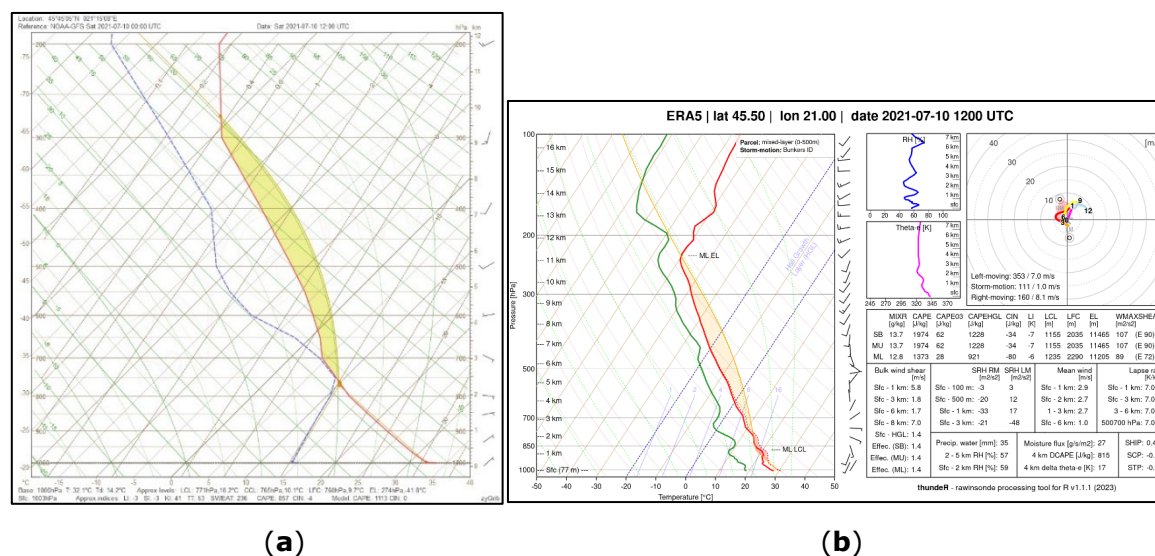


Figure 7: The thermodynamic skew-T – log P diagram, alongside the meteorological parameters and the instability indices for the Szeged (Hungary) meteorological station, on 10 July 2021, 12 UTC, data Source: www.weather.uwyo.edu/upperair/sounding.html

By analyzing the skew-T-log P diagram from the Szeged meteorological station (Hungary), it can be observed that the CAPE index recorded a value of 1,112 J/kg, and the CAPV (based on the virtual temperature) – 1,218 J/kg (Figure 7). Doswell and Rassmussen (1994) discuss on the importance of using the virtual temperature in the calculation of the CAPE index as it allows to differentiate between the density of a rising air-parcel and its environment, particularly at lower CAPE values.

In comparison, by using the sounding data from the Zygrib program (GFS data), the CAPE index is similar in value – 1,113 J/kg for the Szeged sounding (Figure 18a and Table 2). However, the sounding resulting from ERA5 data (Figure 8b and Table 2) indicates higher CAPE values: both SB-CAPE (surface-based parcel) and MU-CAPE (most-unstable parcel) of 1,974 J/kg and ML-CAPE (mixed-layer parcel) of 1,373 J/kg. It should be noted that SB-CAPE uses the total amount of potential energy available to an air-parcel at the ground level, MU-CAPE uses the total potential energy available for the most unstable air-parcel at the lowest level below the 300 hPa level and ML-CAPE uses the mean potential energy available to the lowest-lying air-parcel below the 100 hPa level (Prosser and Foster, 1966; Doswell et.al., 1982; Craven et.al., 2002). Although these values differ significantly either from the sounding data recorded at the Szeged meteorological station or from those developed by the Zygrib program (using GFS data), the ML-CAPE values fall within the range indicated by the spatial distribution map of the Lifted Index and CAPE, at 12 UTC (Figure 8). However, the reanalysis data (ERA5) better reflect the local conditions of air instability due to their much higher spatial resolution as compared to the sounding data.



Out of all the three values of CAPE index, which describe the state of the lifting air parcel, the ML-CAPE is more representative because it allows the estimation of the height of the convective cloud base in the mixed-layer parcel. For the boundary layer-based convection, it is better to use parameters from the mixed-layer parcel, even during the warm season (Craven et.al., 2002). The choice of the air parcel that is being lifted (surface-based layer, mixed-layer, most-unstable layer) can be more significant in the evolution of the convective phenomena, than simply relying on the high values of CAPE index only (Doswell and Rassmussen, 1994).

High CAPE values, together with strong updrafts, are indicators of hail formation within clouds. Hail size also depends on wind shear in the deep layer (DLS). Additionally, the occurrence of lightning is determined by CAPE and by equilibrium level temperatures below -10°C within the cloud (Taszarek et al., 2017; Sfîcă et al., 2023).

The **Lifted index (LI)** recorded values of -3.86 K (LIFT on Figure 12) and - 4.45 K for LFTV (based on the virtual temperature) at the Szeged meteorological station (Figure 12). As regards the forecasted soundings, the index reached a value of -3 K for the thermodynamic diagram generated by the Zygrib program (Figure 8a and Table 2) and values of -7 K for SB-LI (surface-based parcel) and MU-LI (most-unstable parcel) or -6 K for ML-LI (mixed-layer parcel), based on the ERA5 reanalysis data (Figure 8b and Table 2). This time, the values from the Szeged meteorological station and those derived from the Zygrib program are close to the values indicated by the spatial distribution map of the Lifted Index and CAPE, at 12 UTC (Figure 8), in contradiction to the ERA5 ones, which recorded double values (Figure 8b and Table 2).

Table 2: The values of air-instability indices based on the sounding data at the Szeged (Hungary) meteorological station, from the Zygrib program (GFS data) and from ERA5 dataset, on 10 July 2021, both at 12 UTC

Instability indices			
Indices	Radio sounding Szeged	Zygrib – GFS data	ERA5 data
CAPE	1112 J/kg 1218 J/kg -CAPV	1113 J/kg	1974 J/kg – SB-CAPE, MU-CAPE 1373 J/kg – ML-CAPE
Lifted index	-3.86 K -4.45 K - LFTV	-3 K	-7 K – SB-LI, MU-LI -6 K -ML-LI
SI	-0,19 K	-3 K	-2,21 K
SWEAT index	128	236	173
KI	34,10 K	41 K	30 K
TT	49,20 K	53 K	51 K
CIN	-56,1 J/kg -32,6 J/kg - CINV	-4 J/kg	-34 J/kg – SB-CIN, MU-CIN -80 J/kg – ML-CIN

The values of the Lifted index suggest a moderately-severe level of convective clouds for values between -3 and -5 K and a strongly-severe level for values greater than -6 K (Miller, 1972). On 10 July 2021, in the area of the "Traian Vuia" International Airport, Timișoara, the Lifted index reached a moderate level of severity, according to the Szeged and Zygrib soundings and a strong severity level, according to the ERA5 data. Since hailfalls were recorded in the study area at that time, Renne and Sinclair (1969) argue that the Lifted Index indicates higher instability on days with larger hail falls, which is also observed in this case. In practice, the Lifted index better predicts convection (Doswell and Rasmussen, 1994).

Regarding the **Showalter index (SI)**, it reached values of -0.19 K (SHOW on Figure 9) on the Szeged upper-air sounding; -3 K on the forecasted sounding from Zygrib program (Figure 10a and Table 2) and -2.21 K, by using ERA5 reanalysis data (Table 2).

The Showalter index indicates a very low atmosphere instability according to the Szeged radiosounding (-0.19 K) (Figure 9) and a moderate instability, according to the forecasted soundings from the Zygrib program (-3 K) (Figure 8a and Table 2) and ERA5 dataset (-2.21 K) (Table 2) (Showalter, 1953). Convective storms are more likely to occur if the SI records values below +1 K (Showalter, 1953), and this is exactly what has also been observed in the area of the "Traian Vuia" International Airport, Timișoara. Nevertheless, the values derived from the forecasted soundings (Zygrib and ERA5) are more similar, as compared to those recorded at Szeged.

The **SWEAT** index recorded values of 128 units – as derived from the Szeged radiosounding (Figure 9), 236 units – from the Zygrib program with GFS data (Figure 10a and Table 2) and 173 units – based on ERA5 dataset (Table 2), indicating possible convective storms in the area. The **Severe Weather Threat** index helps identify potential areas where air instability develops rapidly and is ideally used in forecasting severe thunderstorms (Miller, 1972). Even though the values of the SWEAT index did not exceed 300 units to indicate strong convective storms, as in the USA, due to Romania's climatic conditions and topography, the 10 July 2021 was characterized by severe convective phenomena (rain showers, hailfalls, lightning).

The **K-index (KI)** indicates a value of 34.10 K for the Szeged sounding (KINX on Figure 9), a value of 41 K on the sounding based on GFS data (Figure 8a and Table 2) and a value of 30 K according to ERA5 dataset (Table 2). The results recorded on the three radiosoundings do not indicate a significant difference between the values, thus emphasizing a high probability of thunderstorm occurrence in all three cases. For KI values between 30 and 35 K, widespread scattered convective storms are likely to occur and for values above 35 K, the likelihood that multiple convective storms may develop increases (Johnson, 1982).

Initially the K-index was used to forecast storms characterized by weak winds and no frontal or cyclonic influence (George, 1960), but later, Rodgers et al. (1984) used index values greater than 30 K to predict the development of Mesoscale Convective Complexes (MCCs). In the present study, we cannot fully agree to the development of a well-defined mesoscale system due to the presence of a weak wind shear (Figure 8b); instead, the situation is more characteristic of a multicellular system. The wind shear in the 0–3 km layer is a key parameter for distinguishing between severe thunderstorms and extremely severe thunderstorms that generate tornadoes (Taszarek et al., 2017).

The **TT index (Total Totals index)** recorded a value of 49.20 K at the Szeged meteorological station (TOTL on Figure 7), a value of 53 K on the sounding from the Zygrib program (Figure 8a and Table 2) and a value of 51 K based on ERA5 dataset (Table 2). The values are very similar, indicating that thunderstorms may occur in the area of "Traian Vuia" International Airport, Timișoara. Values between 44 and 50 K are associated with possible thunderstorms, while values between 51 and 55 K, with moderate thunderstorms (Miller, 1967).

Following the analysis of the skew-T-log P diagram from the Szeged meteorological station, it is observed that the **CIN index (convective inhibition)** reached a value of -56.1 J/kg (CINS on Figure 9), and the CINV (based on the virtual temperature), a value of -32.6 J/kg (Figure 9). In comparison, the radio-sounding from Zygrib program (by using GFS data) revealed a very low value of CIN: -4 J/kg (Figure 8a and Table 2), while the ERA5 reanalysis dataset recorded the following CIN values : both SB-CIN (surface-based parcel) and MU-CIN (most-unstable parcel) of -34 J/kg and ML-CIN (mixed-layer parcel) of -80 J/kg (Figure 8b and Table 2). According to Glickman (2000), values between 0 and -50 J/kg suggest weak convective inhibition and values between -50 and -200 J/kg, show a moderate inhibition. Similar to CAPE, the CIN values are much higher in the case of reanalysis data as compared to radiosonde data (Szeged). With higher CIN values, the environment is expected to be moderately stable, but daytime heating and dynamic factors can transform this inhibition trend of convection into potential energy for the development of Cumulonimbus clouds. This is also observed in the case of 10 July 2021, when the Cumulonimbus clouds had great vertical development. Both CAPE and CIN affect the frequency and intensity of atmospheric convection and convective precipitation (Chen et al., 2020).

The probability of thunderstorm occurrence cannot be accurately determined by using a single convective index. As shown in the present study, the most important conditions for convection are associated with latent instability (as characterized by

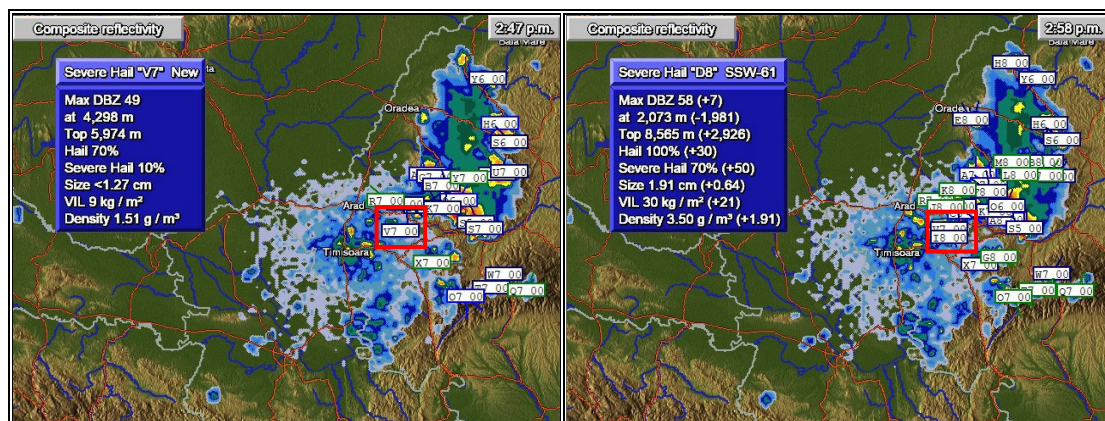
indices such as LI, CAPE, and SHOW), potential instability and indices that integrate both theoretical concepts (TT și K) (Kunz, 2007).

c) Radar images of convective cells

In order to correlate the information about air-instability indices with the occurrence of convective phenomena in the area of "Traian Vuia" International Airport, Timișoara, on 10 July 2021, we analyzed the convective cells that occurred in the perimeter of the airport, by using the radar images from the WSR Doppler radar in Timișoara (source: the SMIN network of the Romanian National Meteorological Administration-NMA). The airport's position is outlined with a red border on the radar images to identify the most significant convective cells for "Traian Vuia" International Airport.

On 10 July 2021, the convective activity in the area of the "Traian Vuia" International Airport started in the afternoon, when the first convective cells approached the operational area of the airport, at 2:47 PM (Figure 11). The general direction of the convective cells was from North-East to South-West, primarily impacting the study area. It is to be noticed that from that time, cell **V7** (Figure 11 and Table 4), located within the airport perimeter, exhibited high values for all of the most specific convective parameters, namely: hail with sizes of 1.27 cm, with a 70% probability of hail occurrence and a 10% probability of severe hail, a radar reflectivity of 49 dbZ and the top-height of the cloud at 5,974 m.

Throughout the day, increasingly dangerous convective cells formed, with ever growing convective parameters. Thus, at 2:58 PM, cell **D8** already presented higher values as compared to cell **V7** (Figure 11 and Table 4), hail with sizes of 1.91 cm, with a 100% probability of hail occurrence and a 70% probability of severe hail, a much higher reflectivity of 58 dbZ and a top-height of the cloud at 8,565 m, thus indicating the rapid development of the cell.



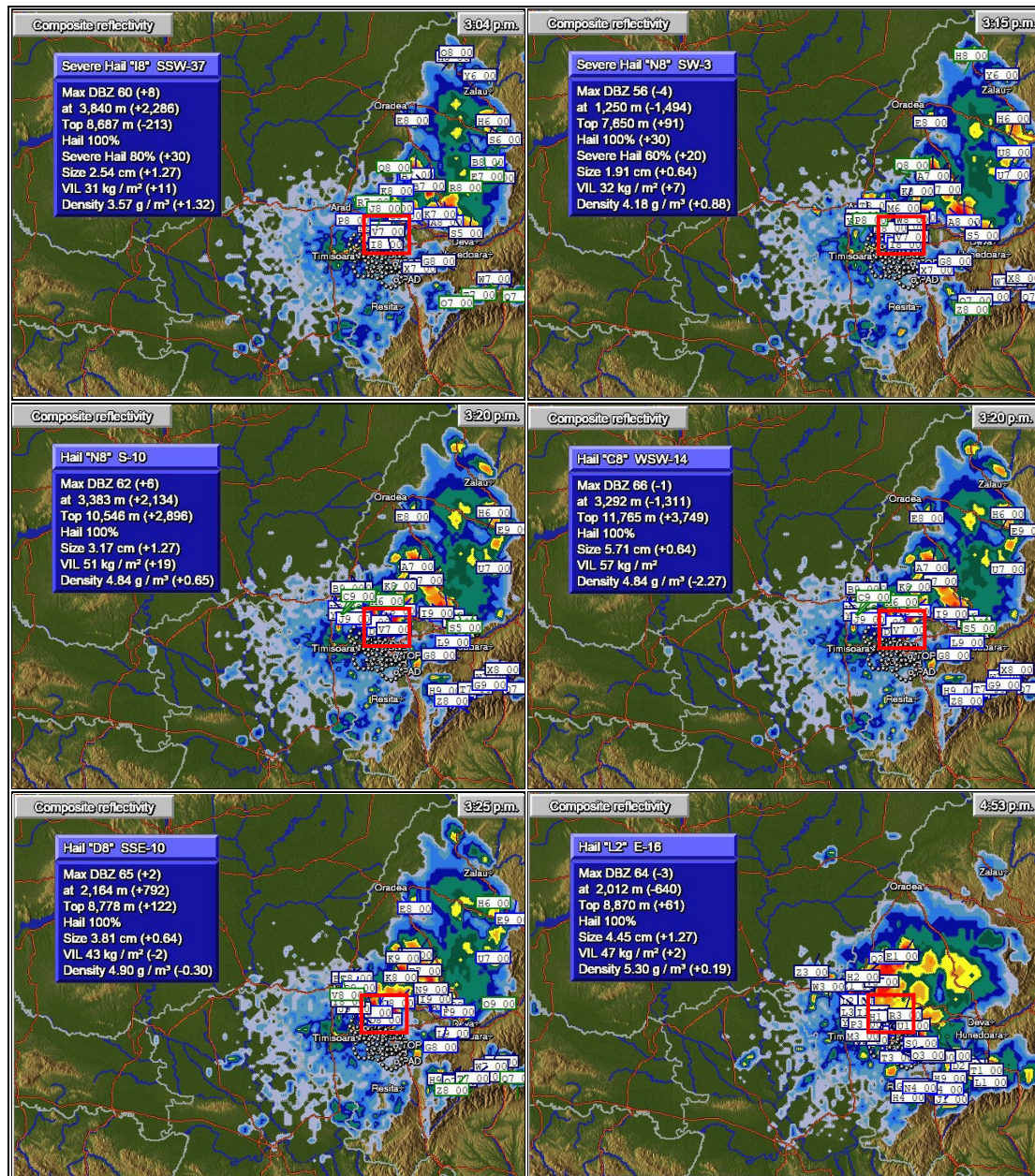


Figure 9: The use of radar data by the OmiWxTrac application in identifying the convective parameters within the operational area of the "Traian Vuia" International Airport, on 10 July 2021, data source: National Meteorological Administration, Romania

Mason (1971) discusses the values and thresholds of radar reflectivity, establishing a value of ≥ 55 dbZ as a useful indicator for hailfalls on the ground level. The beginning of the convective activity in the area of the "Traian Vuia" International Airport coincides with the time on the radiosoundings presented in the previous section, where the values of convective indices pointed to an increased probability of convective storm formation (Figures 7 and 8).

The convective parameters increase significantly within short time intervals (Figure 9). Within the airport perimeter, cell **18** (3:04 PM) indicates a hail size of 2.54 cm with a dbZ of 60 and a top-height of the cloud at 8,687 m. Also, cell **N8** evolves from a 56 dbZ (3:15 PM) to 62 dbZ (3:20 PM) and a hail size from 1.91 cm to 3.17 cm (Figure 11 and Table 4). The convective parameters with the highest values were recorded in cell

C8 (3:20 PM), with a hail size of 5.71 cm, a 100% probability of hail occurrence, a reflectivity of 66 dbZ and a cloud top-height of 11,765 m (Figure 11 and Table 4). These values reveal the extent of convective phenomena and, implicitly, of Cumulonimbus convective clouds. Radar images (Figure 11) highlight the initial formation of a single significant cell and subsequently, the development of a much-extended multicellular line. This can be observed through the radar reflectivity field. Moreover, it appears that the initial developed cells triggered a favorable circulation for the development of new cells on their left side (Figure 9, new green cells).

It is also observed that cell **D8** (3:25 PM) continued to evolve to a hail size of 3.81 cm, with a reflectivity of 65 dbZ and a cloud top-height of 8,778 m (Figure 11 and Table 4). Although convective parameters continued to increase, cloud systems did not develop as vigorously as before, thus highlighting a gradual decrease in convective activity. A final cell with significant features was observed in the airport area: cell **L2** (4:53 PM), with a hail size of 4.45 cm, a 100% hail probability, a reflectivity of 64 dbZ and a cloud top-height of 8,870 m (Figure 9 and Table 4). Then, gradually, the convective parameters began to decrease, and the magnitude of the convective phenomena was also lowered. Around 8:30 PM, the convective cells were located to the South of the airport area and the city of Timișoara.

Table 4: The characteristics of convective cells on 10 July 2021 at the "Traian Vuia" International Airport, Timișoara, data source: National Meteorological Administration, Romania

The characteristics of convective cells								
Name	V7	D8	I8	N8	C8	N8	D8	L2
Time	2:47 p.m	2:58 p.m	3:04 p.m	3:15 p.m	3:20 p.m	3:20 p.m	3:25 p.m	4:53 p.m
Probability of hail	70% and severe hail 10%	100% and severe hail 70%	100% and severe hail 80%	100% and severe hail 60%	100%	100%	100%	100%
Hail dimension	<1,27 cm	1,91 cm	2,54 cm	1,91 cm	5,71 cm	3,17	3,81	4,45
DBZ	49	58	60	56	66	62	65	64
Top-height of the cloud	5,974 m	8,565 m	8,687 m	7,650 m	11,765 m	10,546 m	8,778 m	8,870 m

Atmospheric instability manifested through downpours accompanied by electrical phenomena, intense winds and severe hailfalls. The radiative heating of the ground during the first half of the day favored the formation of local convective cells, and the high values of Convective Potential Energy (CAPE) (Figures 9 and 10) further led to even more extensive convective cloud developments – reaching a top-height of the cloud up to 11,765 m (Table 4). The air temperatures at the Timișoara meteorological station recorded an average value of 25.5°C and a maximum value of 34.4°C, characterizing an exceptionally warm weather pattern (Table 5).

To assess whether the values of air-instability indices and the radar-recorded data were relevant to the study area of the "Traian Vuia" International Airport in Timișoara, we had to compare them with both the daily data recorded on the same day - 10 July 2021, and with the monthly averages for each July month from the 2003-2022 period

(section. 3.1) and with the meteorological data from 10 July of each year recorded at the Timișoara meteorological station.

Table 5: Meteorological parameters for 10 July 2021 at the Timișoara meteorological station, data source: National Meteorological Administration, Romania

Parameters	10.07.2021
T average °C	25.5
T max °C	34.4
Precipitation (mm)	0.7
Lightnings (case)	1
Rain-showers (case)	1
Hail (case)	0
Storm (case)	0
Wind gust speed (m/s)	11

By comparing the data recorded on 10 July 2021 (Table 5) at the Timișoara meteorological station with the monthly average data from the entire 2003 - 2022 period (Table 6), obtained from the same station, it observes that the values on 10 July 2021 have exceeded almost all of the monthly average values recorded in July, except for the monthly average rainfall amounts, which totalled 57.2 mm and resulted by averaging all the daily amounts that have been recorded over the entire 2003-2022 period, in the month of July (Table 6).

Table 6: Average values of meteorological parameters recorded on the month of July, at the Timișoara meteorological station, for the 2003-2022 period, data source: National Meteorological Administration, Romania

Average values of meteorological parameters	
T average °C	23,3
T max °C	30,5
Precipitation (mm)	57,2
Wind gust speed (m/s)	7,8

As regards the highest daily values recorded on 10 July, during the 2003-2022 period, the years 2011 and 2013 stand out for their higher values of daily mean/average air temperature (29.6 °C), daily maximum temperature (37.3 °C), daily rainfall amounts (13.5 mm) and daily wind gust speed (18 m/s), as compared to 10 July 2021 (Table 7). Days with thunderstorms and rain showers were also recorded in 2003, 2004, 2005, 2012, 2013, 2014, 2018 (lightning cases) and 2003, 2005, 2007, 2013, 2014, 2018, 2022 (rain- shower cases) (Table 7). No data were recorded for hailstorm and storm cases for July 10 during the 2003 – 2022 period.

Although cases of rain showers and electrical phenomena and no cases of hail and storms have been recorded at the Timișoara meteorological station on 10 July 2021, the position of the meteorological station in correlation with the area where the severe phenomena took place can explain this anomaly, as sometimes, the area where convective phenomena appear and develop does not coincide with the position of the main meteorological station. Therefore, to better prospect on the occurrence of severe

convective phenomena, synoptic daily data, upper-air sounding data from meteorological stations, reanalyzed data and radar data with images of convective cells are all very useful.

Table 7: The highest values of meteorological parameters and the number of cases of bad-weather related phenomena recorded on the 10th of July during the 2003-2022 period, as compared to the 10th July 2021 at the Timișoara meteorological station, data source: National Meteorological Administration, Romania

Parameters	Values/ Years
T average °C	29,6 (2011)
T max °C	37,3 (2011)
Precipitation (mm)	13,5 (2013)
Wind gust speed (m/s)	18 (2013)
Lightnings (case)	2003, 2004, 2005, 2012, 2013, 2014, 2018
Rain-showers (case)	2003, 2005, 2007, 2013, 2014, 2018, 2022

4. Conclusions

The present study provides a very detailed analysis of the importance of instability indices in assessing convective phenomena in the area of the "Traian Vuia" International Airport in Timișoara. Thus, by analyzing the daily meteorological parameters from 2003 to 2022, the overall geographical and climatic characteristics of the study area and their importance in the occurrence of convective phenomena during the warm period of the year, were highlighted.

A first step in the analysis of the convective phenomena that occurred on 10 July 2021, in the area of the "Traian Vuia" International Airport in Timișoara, was to observe the synoptic context at continental level and see how it influenced the Romanian territory. Thus, a low-pressure area was active over the Baltic Sea basin, which had associated with a stationary cold front. Romania was located on its anterior part, accordingly leading to favorable conditions for the development of large convective clouds, specific to prefrontal air-instability.

Then, in the given context, it appeared that the values of some air-instability indices such as CAPE (Convective Available Potential Energy) and Lifted Index (from the maps of instability indices on www.wetter3.de) showed a significant increase during the day, from -2K (00 UTC) to -4K (12 UTC) for the Lifted index and from 600 J/kg (00 UTC) to 1,200-1,300 J/kg (12 UTC) for CAPE. By comparing the obtained values with those obtained from the radiosounding data in Szeged, Hungary (1,112 J/kg), a difference of 100 – 200 J/kg is noted, only the value based on virtual temperature (CAPV – 1,218 J/kg) being closer to those derived from the instability maps. In addition, the values from the radiosounding based on GFS data (Zygrib program) are similar to those at Szeged, but those from the ERA5 reanalyzed dataset are much higher (SB-CAPE and MU-CAPE: 1,974 J/kg and ML –CAPE: 1,373 J/kg). The occurrence of thunderstorms on 10 July 2021 was dependent on the higher values of CAPE. In general, by comparing the sounding data recorded at a meteorological station with the ERA5 reanalysis data, it becomes self-evident that the latter ones better emphasize the local conditions of air-instability, due to their much better spatial resolution. Additionally, it has been noted that reanalysis data better reflect the events on the ground.

Also, the Lifted index and CIN showed, as in the case of CAPE, higher values from the ERA5 reanalysis dataset (SB-LI and MU-LI: -7 K, ML-LI: -6 K for Lifted index; SB-CIN and MU-CIN: -34 J/kg, and ML-CIN: -80 J/kg for CIN). The higher Convective

Inhibition (CIN) values were expected to suppress the atmospheric convection. However, daytime heating of the ground and the dynamic factors have transformed this inhibition into potential energy, which further contributed to the development of Cumulonimbus clouds. This observation is consistent with what derives from the radar images as well. All the other air-instability indices (SWEAT index, SI, KI, TT), as reflected through the values obtained on 10 July 2021, have indicated the occurrence of convective storms in the airport area during that specific day. The SI (Showalter index) had values lower than +1 K, according to radio-soundings, pointing to increased atmospheric instability, and the SWEAT index (with values between 120 and 240 units) indicated the occurrence of convective storms in the area. The KI index (values between 30 – 40 K) indicated a high probability for scattered convective storms to occur and the TT (Total Totals index) (between 40 - 55 K) underscored the same tendency.

Following the analysis of air-instability indices, we concluded that, in order to understand how convective phenomena evolve and to assess their potential danger for the study area, it is better to use parameters from mixed-layer parcel (ML) and for nocturnal convection from most-unstable parcel (MU).

Finally, the values obtained from the analysis of air-instability indices were compared with the radar images from the WSR Doppler radar in Timișoara (source: the SMIN network of the Romanian National Meteorological Administration - NMA). Therefore, the information observed in the previous section was validated by the radar images reflecting the characteristics of the convective cells, in the area of the "Traian Vuia" International Airport in Timișoara. During the day of 10 July 2021, convective cells rapidly developed in the operational area of the airport. From a hail size of 1.27 cm inside the cloud (cell V7, 2:47 PM), hail pellets reached a maximum size of 5.71 cm for cell C8 at 3:20 PM. This cell showed a 100% probability of hail occurrence, a reflectivity of 66 dBZ and a top-height of the cloud at 11,765 m. In approximately 35 minutes, all parameters of the existing convective cells in the area increased significantly. It's worth adding that, while these cells were reaching maturity, new ones were being formed to their left side (west). So, in this area, atmospheric instability manifested through hailfalls, lightning and heavy rain showers. Then, convective parameters gradually began to decrease, and around 8:30 PM the convective cells were already extending to the southern part of the airport area. In the specific case of the rapid increasing of hail inside the Cumulonimbus cloud, the Lifted index proved to be very useful, its relatively high values indicating the actual convective developments.

In the final part of the study, the number of cases with convective phenomena that were recorded on 10 July 2021, at the Timișoara meteorological station, were analyzed to observe the relevance of air-instability indices in their occurrence. This analysis revealed the local character of the evolution and extent of convective phenomena in the area of "Traian Vuia" International Airport. Often, convective phenomena do not have the same magnitude in their development, and so, the data recorded at the meteorological stations may not always correspond to those observed in the field.

The study highlighted the importance of analyzing air-instability indices derived from radiosoundings, alongside with radar data, to accurately understand the synoptic context and conditions leading to the occurrence and development of convective phenomena in the area of "Traian Vuia" International Airport, in Timișoara.

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Author contributions:

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