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USAGE OF ATMOSPHERIC SOUNDING TO CHARACTERIZE THE METEOROLOGICAL EVENTS ON THE NIGHT OF 23/24 AUGUST, 2022

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Abstract. At the end of summer, the episode of atmospheric instability in the Moldavia region, is attributed to the predominantly eastern circulation, which directed air masses from the Asian continent to Romania. This context is the result of the presence of a high-pressure area, located in northern Siberia and extended to north-eastern Europe. Romania was located in the flow of the eastern circulation, behind the warm front.

The emersion of unforeseen factors, as was the case with the transport of dust from the dry regions of Asia, due to background of a circulation from the east, or the specificities of the relief, make it difficult to forecast the phenomena associated with instability. In this sense, atmospheric soundings are among the most used tools in forecasting atmospheric instability. In this sense, we used atmospheric soundings estimated by the GFS and ECMWF numerical forecast models to analyze the atmosphere vertically. Also, the cross-section profiles drawn in the EUMeTrain application showed the differences between the west and the east of Moldavia and described the vertical atmosphere in the analysed interval.

The evolution of the convective episode was described through satellite images. The forecast models anticipated the instability but did not estimate the amounts of cumulative precipitation. The increase in the amount of precipitation was, among other things, attributed to the existence in the atmosphere of Moldavia of dust particles that acted as condensation nuclei that increased the amount of precipitation. High concentrations of dust were also noticed after consistent rain showers, as explained by Cloudnet data processed.

The analysed case was one of the most representative instability episodes for summer of 2022 in Moldavia and played a decisive role in the soil water reserve.

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Here's how air quality and changes in the atmosphere have a major impact on the environment. The notable frequency of detected electrical discharges, was probably also the result of the presence in the atmosphere of suspended dust particles (due to a natural air pollution process), driven towards the Moldavia region.

Keywords: atmospheric soundings, forecasting, meteorology, environment, pollution.

1. Introduction

Distribution of baric formations over the European continent significantly influences August's general meteorological characteristics. The stability of the air masses in the European region this month, is attributed to the Azores anticyclonic ridge, which is advancing strongly on the continent, up to over Eastern Europe. Added to this context are the frequent penetrations of tropical air from the north of the African continent. Theoretically, August is the sunniest month of the year. The presence of an altitude nucleus, located in the eastern basin of the Mediterranean Sea, allowed moisture supply especially in the south and east of Romania, the Moldavia region being on the ascending side of the long-wave trough. The orographic convection, produced especially against the background of circulation from the east of the continent, led to the recording of significant amounts of water, especially in the mountain and submountain regions of Moldavia. The 24 hours fallen precipitation outlined an asymmetric panel for this region [1 – 3]. In the west, considerable amounts of water have fallen on extensive areas, compared to the situation in the east of the region, where precipitation was on limited areas and quantitatively weak Most of the time, severe meteorological manifestations associated with episodes of atmospheric instability are quite complex [4], also temporal and spatial predictability can sometimes become difficult [5, 6]. In the present paper, the description of the meteorological events on the night of 23/24 August 2022, was based on the Skew-T log-P diagrams, and on the impact of the unusual circulation of air masses at the continental level, on the Moldavia region [7].

2. Methods and Materials Used

For this paper we used ground-level and altitude synoptic maps from GFS (Global Forecast System) reanalysis data [8 – 11] and Deutscher Wetterdienst – Analysis and forecast charts EuropeDE [12], MODIS (Moderate Resolution Imaging Spectroradiometer) satellite data [13].

The paper is based on atmospheric soundings, selected for a number of stations in the Moldavian region, estimated by ECMWF [14] and GFS [15].

The vertical sections were made with the Cross-Sections tool, made available by IBL Weather Software Solutions- EUMeTrain – ePort [16], and the radar imagery was taken from the same source, from observations data section – OPERA Radar Europe (Operational Program for Exchange of Weather Radar Information). The estimation of the amounts of precipitation resulting from the episode of instability analyzed, was taken from Meteologix^{RO} website [17], ECMWF (European Centre for Medium-Range Weather Forecasts) model, and the actual amounts of accumulated precipitation were also taken from the same source, from observation data.

The cartographic representations expressing the presence of PM_{10} and $PM_{2.5}$ particles [18, 19] at the continental level were taken from the (CAMS) Copernicus Atmosphere Monitoring Service, ECMWF model [20].

The information about the amount of PM_{10} and $PM_{2.5}$ particles insignificant for human health was documented on the CalitateAer website [21].

Persistent aerosol layers between 0 and 4 km were identified in ACTRIS (Aerosol, Clouds and Trace Gases Research InfraStructure) Cloudnet images [22, 23]. The picture with the frequency and distribution of electrical discharges detected on the night of 23/24 August 2022, was taken from the Real Time Lightning and Thunderstorm Network [24].

The suggestive photo that captures the atmosphere loaded with dust particles was taken by one of this paper authors, on August the 24th 2022 at 15:51 UTC, in the area of Târgu Neamț city, Neamț County, on the banks of the Ozana River.

3. Synoptic Situation at European Level

The end of August places Europe in a synoptic context favoring severe weather events. In the north-west of the continent, a low-pressure field is well identified, whose trough extends to the south-east, favoring the development of a convergence line on its front side (Fig. 1). At the opposite pole, in the north-east of the continent, in the Russian Plain region, a vast anticyclonic field is located, with atmospheric pressure values up to 1030 mbar. Its activity plays an important role in directing atmospheric circulation, drawing air masses from the east towards the center of the continent.

The activity of the baric formation of low-pressure (Fig. 2) is directly related to the activity of the Jet Stream in the upper layers of the atmosphere, at 300 hPa level (Fig. 3), which produces a strong vertical wind shear. The line of convergence on the ground level takes shape, to a good extent, on the upward side of the jet stream, where have been estimated speeds of over 250 km/h.

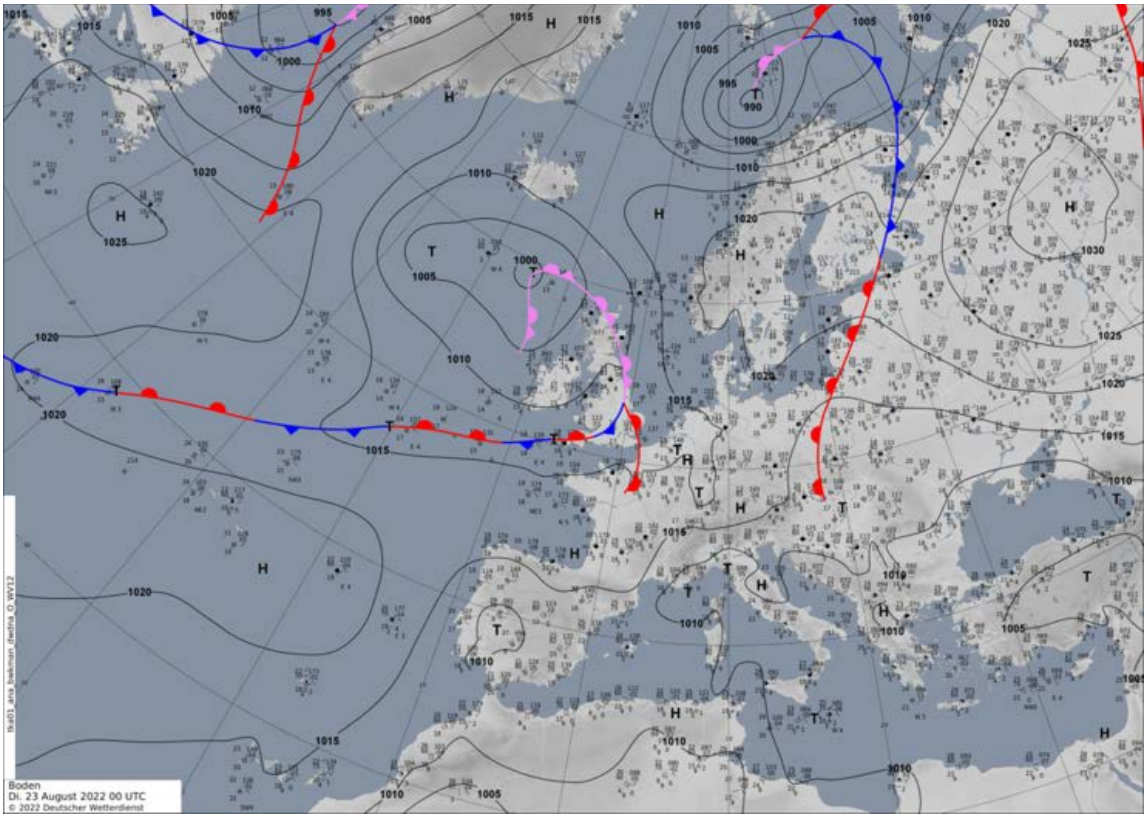


Fig. 1. Synoptic context at continental level for August the 23rd [5], the black isolines - lines that connect points with the same atmospheric pressure (isobars), T- field of low pressure (cyclone), H- field of high pressure (anticyclone)

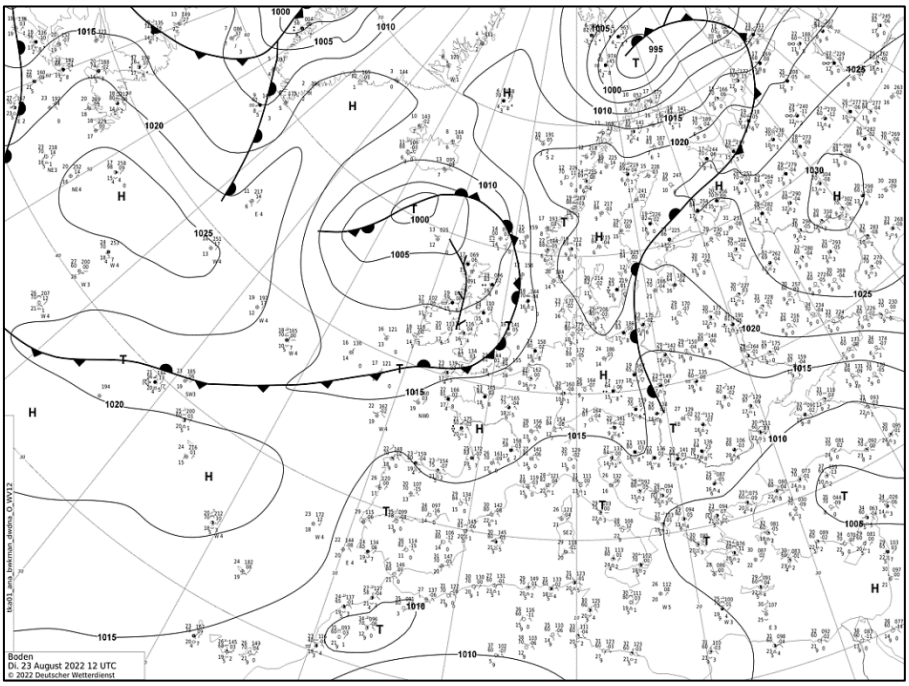


Fig. 2. Distribution of the main baric centers and atmospheric fronts on August the 23rd [3]

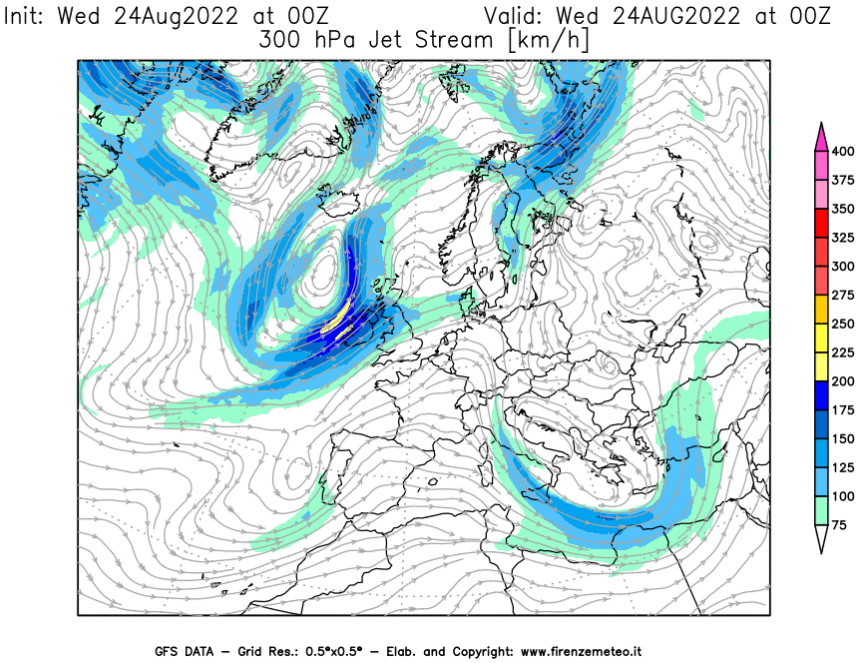


Fig. 3. Jet Stream activity on August the 24th [2]

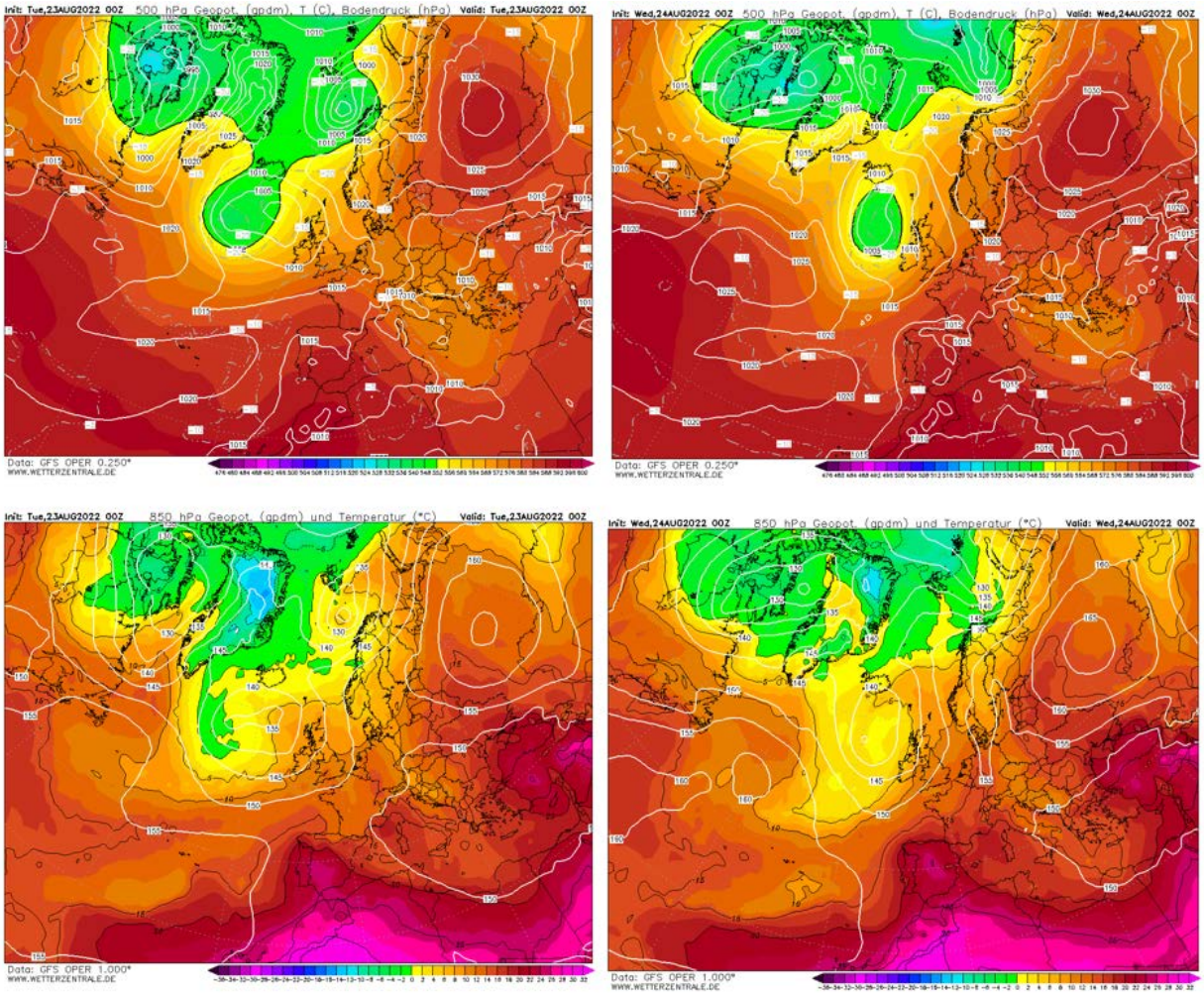


Fig. 4. 500 and 850 hPa geopotential level, for August the 23rd (left) and 24th (right) [4]

The low-pressure field at the ground level is correlated with a geopotential level at 500 hPa, which between August the 21st and 24th gradually changed its position and intensity, so that its long-wave trough penetrated to the west of the Balkan Peninsula (Fig. 4). It maintained an influx of warm and humid air from the Mediterranean Sea towards the Balkan Peninsula [25]. The atmospheric stability in the north-east of the continent ensured by the activity of the anticyclone and its ridge extended towards the east of Europe, is compensated by specific phenomena of instability in the north-west and south-east.

4. Synoptic Context for Romania

For the Moldavia region, the atmospheric pressure during the analyzed period was relatively high and slightly variable, as a result of the high-pressure field in the north-east of the continent. Its ridge expanded strongly, penetrating to the center of the country. The presence of the anticyclone in the Eastern European Plain region dictated the general circulation of air masses in this part of the continent. Air masses from the east were drawn towards Europe, with Moldavia implicitly in the path of this atypical circulation for the end of August.

The south of Moldavia is characterized by relatively low values of the atmospheric pressure, as a result of the activity of a low-pressure field in the region of the Mediterranean Sea.

Romania was in the warm sector of the described front, which crossed the east of the continent in the previous interval and which was responsible for the precipitation that fell on August the 22nd.

A geopotential cold nucleus took shape in north-western Europe at the end of August was responsible for episodes of accentuated atmospheric instability at the continental level. In relation to it, Moldavia was on the ascending side of the long-wave trough described by the geopotential nucleus. In this context, warm and humid air masses from the Mediterranean crossed southern Romania and were transported to the Moldavia region. The altitude nucleus is present throughout the tropospheric column, being best represented at 500 hPa level. The bottom of this depression can easily be seen at this level as well (Fig. 7). The baric formation crosses the continent from the north-west to the south-east, giving the atmosphere an unstable character, with violent manifestations of the weather at the end of August.

The severe manifestations of instability surprised the region of Moldavia, culminating with the episode of 23/24 August night. On extensive areas in the western region of Moldavia, especially in the mountainous and submontane areas, consistent amounts of water, frequent electrical discharges and hail were reported.

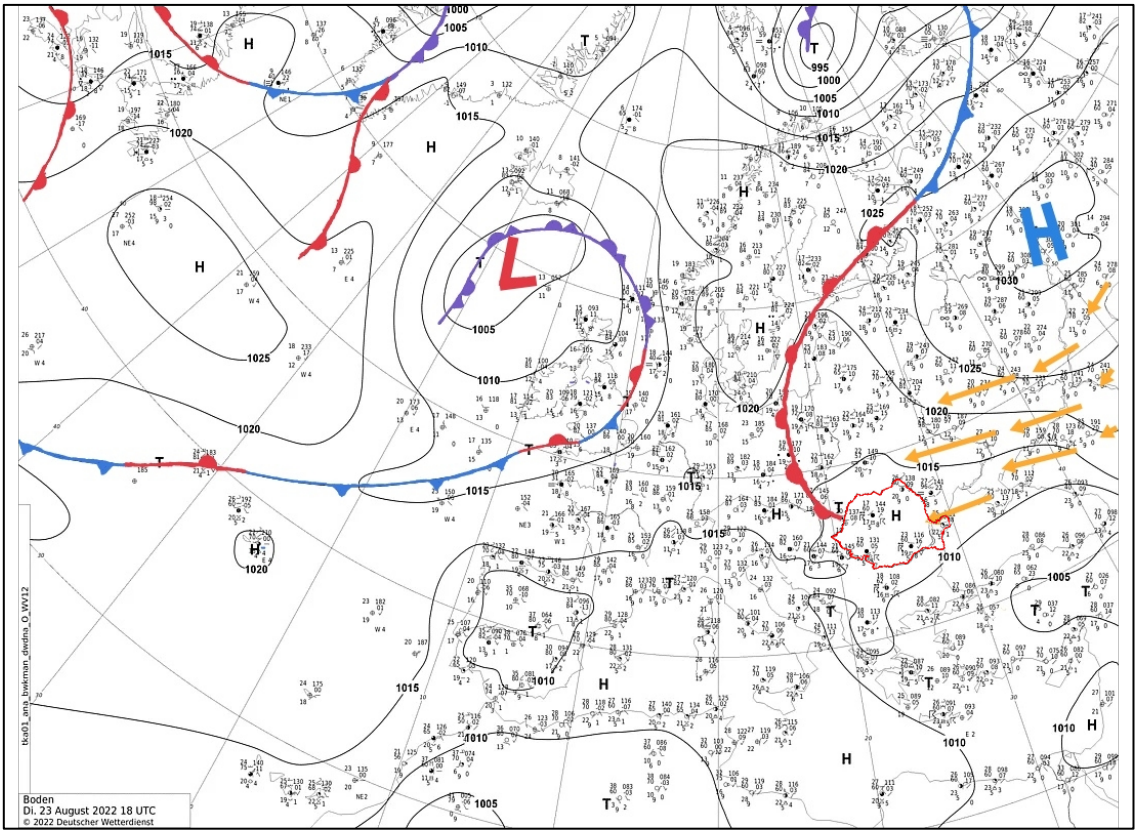


Fig. 5. Mean sea level pressure, August the 23rd – 18 UTC [3]

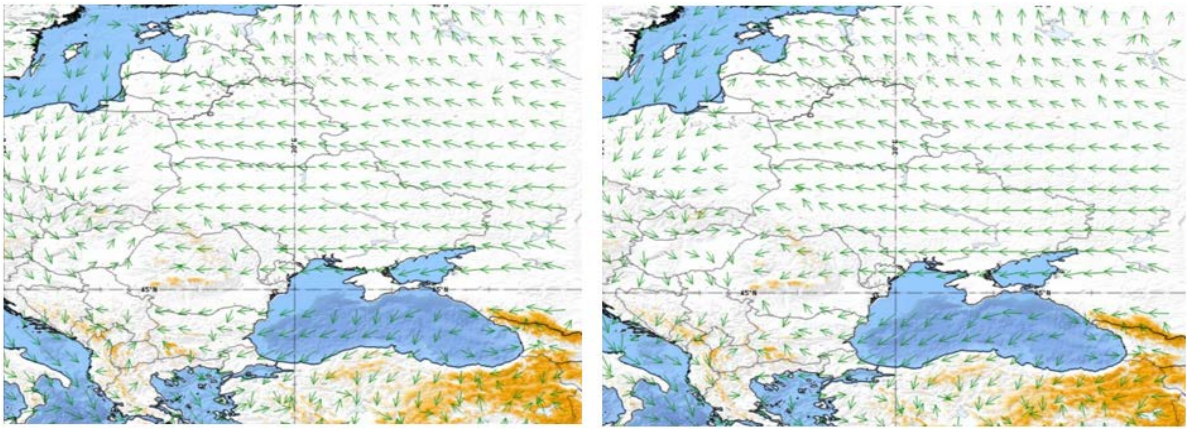


Fig. 6. Streamline direction for August the 23rd (left) and 24th (right) – ECMWF [7]

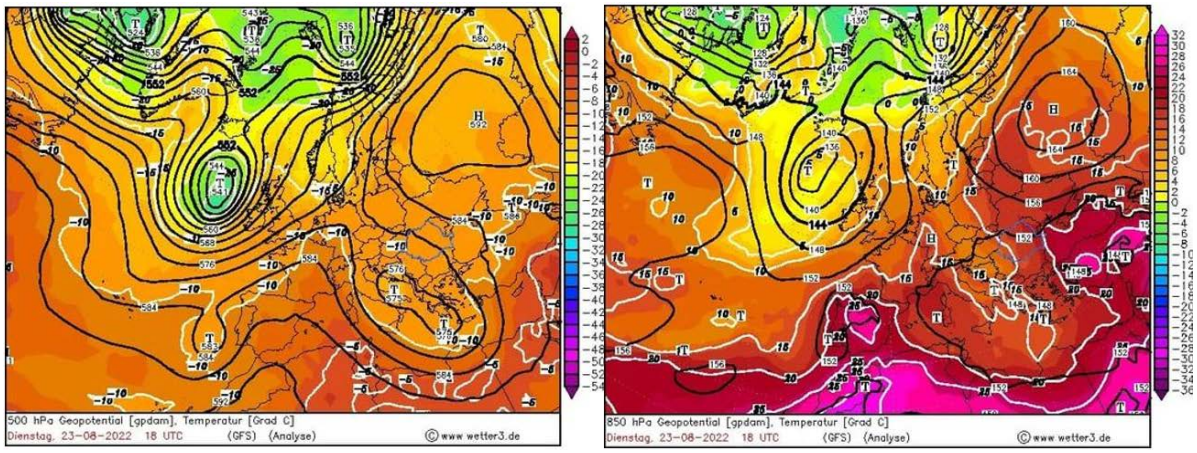


Fig. 7. Geopotential level at 500 and 850 hPa for August the 23rd at 18 UTC [3]

5. Characterization of the Weather Events of 23/24 August by Atmospheric Soundings Models (ECMWF and GFS Atmospheric Models)

5.1. Analysis of atmospheric soundings forecast for western Moldavia stations

Most of the time atmospheric soundings represent the most used tools for convective phenomena forecasting, as they describe the vertical profile of the atmosphere [26, 27]. Analyzing the atmospheric soundings (Fig. 8) for a number of stations in Moldavia, differences can be observed between the east and west of the region.

For the Suceava station, the model estimated values of over 80% for relative humidity on the ground level, and the lifted condensation level was estimated at 900 hPa (Table 1). A drier layer, located between 700 and 400 hPa, is preceded by a moist layer, between 300 and 200 hPa, above which the equilibrium level is individualized. The 0 degree isotherm is contoured at 650 hPa. From the 700 hPa level, the temperature of the air particle becomes higher than the temperature estimated by the profile.

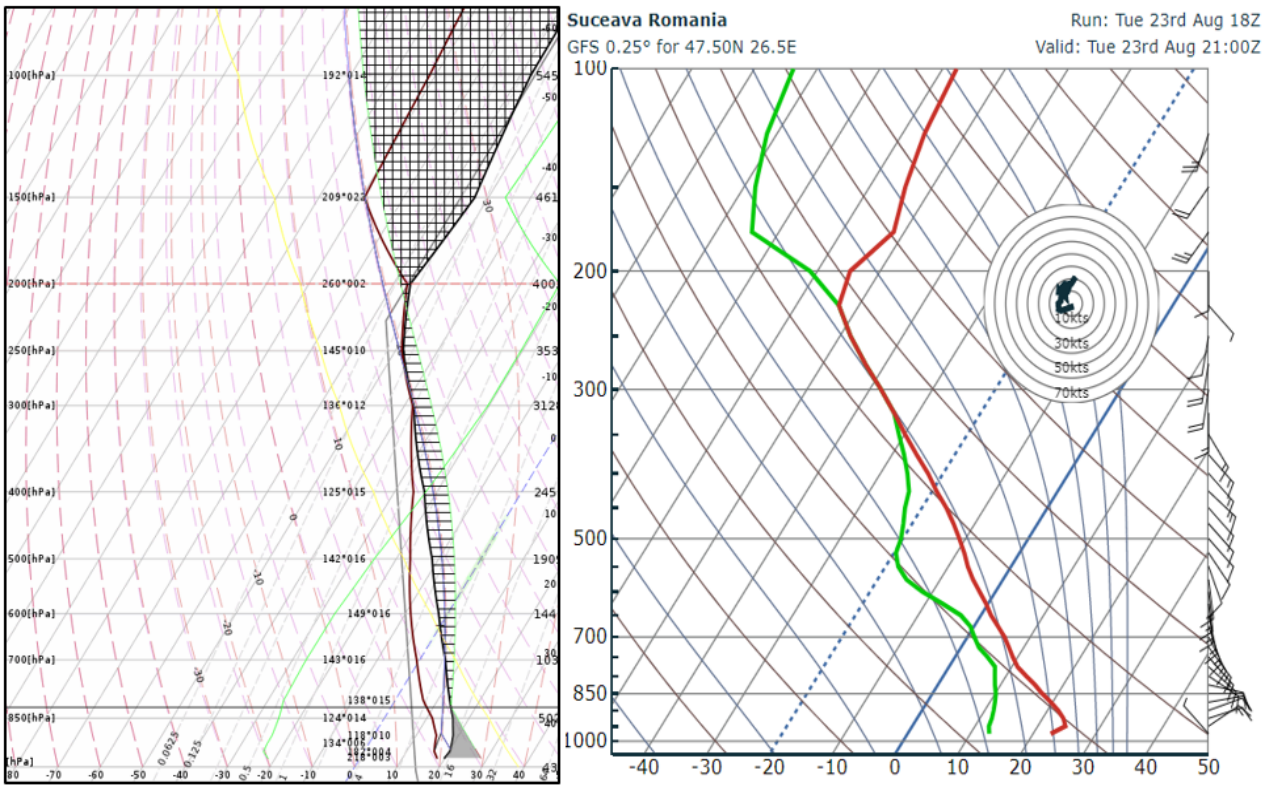


Fig. 8. Atmospheric soundings forecast for Suceava station
(ECMWF- left and GFS- right) [7, 8]

Table 1. Data extracted from the atmospheric soundings forecast – Suceava station (ECMWF Model 23.08.h12), H - vertical pressure in hPa, T - air temperature, Td - dew point temperature, Mix. R - mixing ratio, RH - relative humidity, wind direction in degrees, wind speed in m/s

H (hPa)	T (°C)	Td (°C)	Mix R. (g/kg)	RH (%)	W (°)	W (m/s)
950	18.3	16.1	12.07	87	305	2
850	15.8	11.3	9.9687	75	105	5
700	6.3	-0.9	5.1193	60	132	5
600	-3.2	-8.6	3.3671	66	23	6
500	-12.2	-15.9	2.21	74	130	6
400	-22.8	-27.1	1.0301	68	128	5
300	-37.6	-40.2	0.3804	77	109	6
250	-47.9	-49.6	0.1655	83	184	1
200	-56	-57.9	0.0765	79	208	5
150	-54.4	-77	0.0073	5	192	9
100	-58	-81	0.005	3	174	6

The atmospheric soundings (ECMWF model) for the Târgu Neamț station, based on the 12 UTC run, indicates high relative humidity values at 950 hPa- level. The lifted condensation level (LCL), respectively the base of the clouds, was estimated at 900 hPa, and starting with the altitude of 700 hPa, the temperature of the air parcel becomes higher than the temperature of the profile. The sounding estimated a high potential for ascent, with relatively high CAPE (Convective Available Potential Energy) values - 600 J/Kg. The 0 degree isotherm was described at about 630 hPa (Fig. 9).

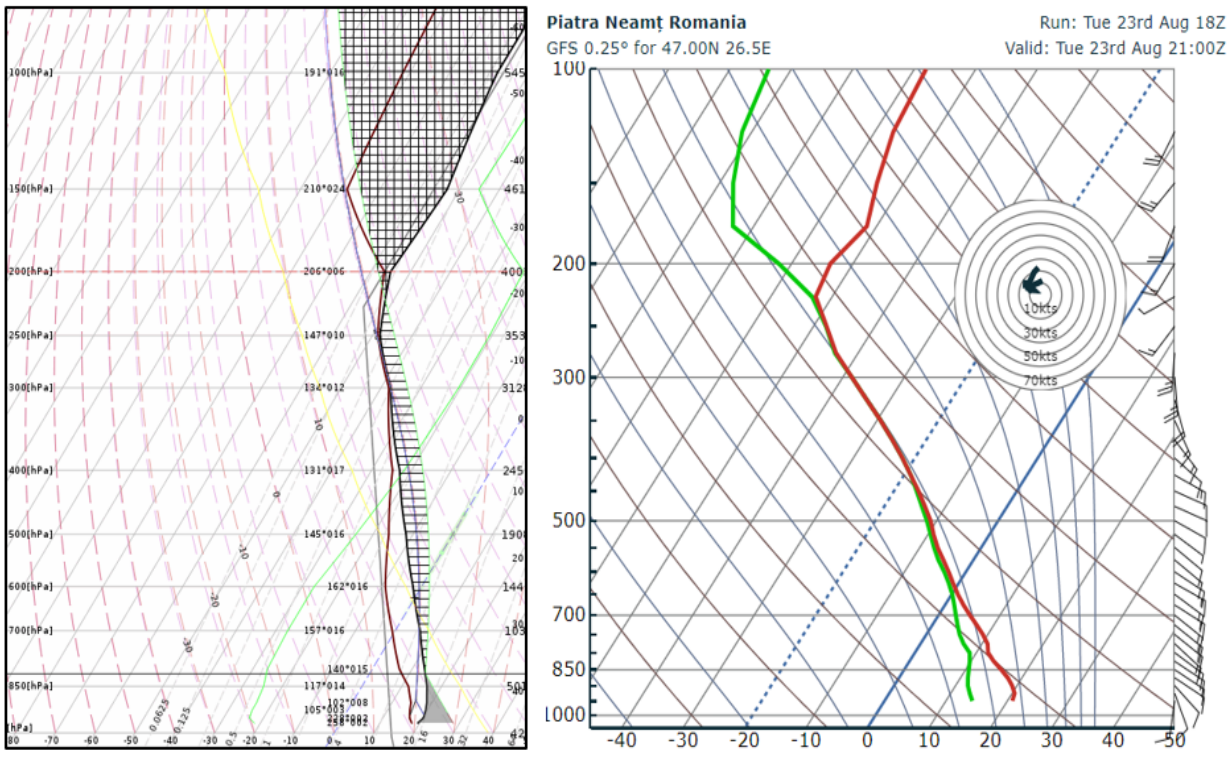


Fig. 9. Atmospheric soundings forecast for Târgu Neamț station (ECMWF- left and GFS- right) [7, 8]

In the immediately upper layers, between 850 and 500 hPa, a less humid sector was identified, with relative humidity values of 50%. Above it, the air gradually becomes saturated, so that between 300 and 250 hPa, the relative humidity is 100% (Table 2).

Low wind speeds, estimated at the surface and in close proximity to the ground level, are offset by high speeds, associated with significant wind shear, in altitude. If on the ground level the wind blows from the NW (319 degrees at 950 hPa), in altitude it obeys the dominant circulation of the atmosphere (E – SE) (Table 2).

Table 2. Data extracted from the atmospheric soundings forecast – Târgu Neamț station (ECMWF Model 23.08.h12), H - vertical pressure in hPa, T - air temperature, Td - dew point temperature, Mix. R - mixing ratio, RH - relative humidity, wind direction in degrees, wind speed in m/s

H (hPa)	T (°C)	Td (°C)	Mix R. (g/kg)	RH (%)	W (°)	W (m/s)
950	17.7	15.9	12	89	324	2
850	15.6	10.2	9.25	70	100	4
700	6	-0.9	5.15	61	133	4
600	-2.8	-7.9	3.5193	68	138	4
500	-12.5	-16.6	2.09	71	136	5
400	-22.8	-26	1.1417	75	135	6
300	-37.7	-39.2	0.4224	86	122	5
250	-48	-49	0.1794	89	157	3
200	-55.6	56.9	0.0871	86	188	5
150	-53.8	-76.6	0.0076	5	193	10
100	-58.5	-80.9	0.0058	4	186	8

For Bacău station, the atmospheric soundings indicated humidity values of over 90% on the ground surface, and at the altitude of 900 hPa the lifted condensation level was realized. The isotherm of 0 degrees at the level of 630 hPa and the base of the clouds at a relatively low altitude, facilitated isolated small hail falls (Fig. 10).

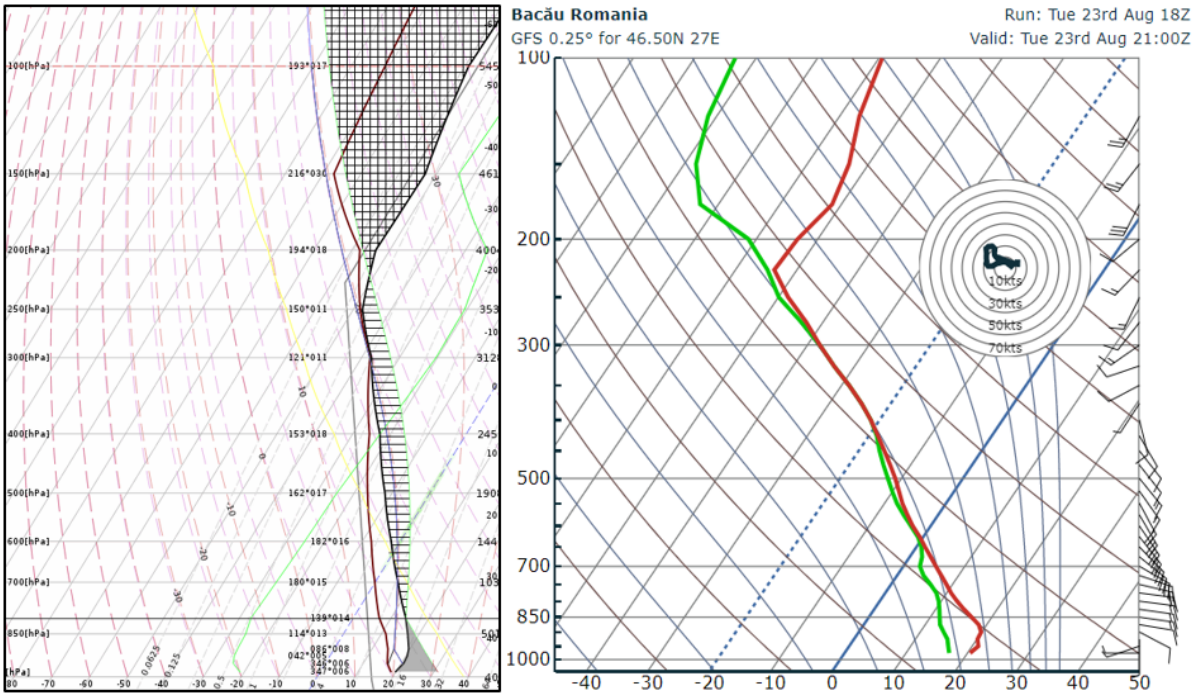


Fig. 10. Atmospheric soundings forecast for Bacău station (ECMWF- left and GFS- right) [7, 8]

According to sounding, from 700 hPa, the temperature of the air parcel becomes higher than the temperature estimated by the profile, and at 250 hPa the equilibrium level is reached. The profile indicates a high potential for convection, with high CAPE values (600 J/Kg). A less humid sector is individualized between 850 and 500 hPa. From 850 hPa, the relative humidity drops sharply below 70%, after which, up to 250 hPa, it gradually increases. At this level, the relative humidity is over 90%. Between 850 and 300 hPa, less moist air is trapped (Table 3).

Table 3. Data extracted from the atmospheric soundings forecast – Bacău (ECMWF Model 23.08.h12), H - vertical pressure in hPa, T - air temperature, Td - dew point temperature, Mix. R - mixing ratio, RH - relative humidity, wind direction in degrees, wind speed in m/s

H (hPa)	T (°C)	Td (°C)	Mix R. (g/kg)	RH (%)	W (°)	W (m/s)
950	18	17.1	12.59	95	313	2
850	15.8	10	9.12	68	86	4
700	5.6	0.5	5.72	69	142	4
600	-2.8	-7.3	3.67	71	157	4
500	-12.1	-18.2	1.82	60	152	5
400	-23	-26.3	1.2226	75	146	7
300	-37.4	40	0.38	77	112	6
250	-47.5	-48	0.1989	95	150	4
200	-54.4	-57.5	0.0804	69	192	7
150	-53.9	-77	0.0072	4	197	13
100	-58.9	-89.8	0.0058	4	189	10

If at the ground surface, the model estimates low wind speed values, at altitude the wind increases in intensity. After 950 hPa level, the wind suddenly changes direction and reorients according to the prevailing circulation in the atmosphere. If on the ground level the wind direction is from the NW, at altitude it acts from the predominantly south-east sector. Low wind shear from the ground level is compensated in altitude.

The atmospheric soundings for the Focșani station estimated values of over 80% for the relative humidity, in the immediate vicinity of the ground surface. At 900 hPa is individualized the lifted condensation level, and from 730 hPa the air parcel has higher temperature than that estimated by the profile (Fig. 11). Between 850 and 400 hPa, the relative humidity has relatively low values, but above this level, it exceeds 90%. At 250 hPa the equilibrium level is reached, so the model predicts considerable cloud heights. The potential for convection is high and the atmospheric soundings indicating high values for CAPE.

The wind increases in intensity from the ground level to the upper Troposphere, changing its direction abruptly: from NW to E and SE. Also, shear increases gradually in the upper layers (Table 4).

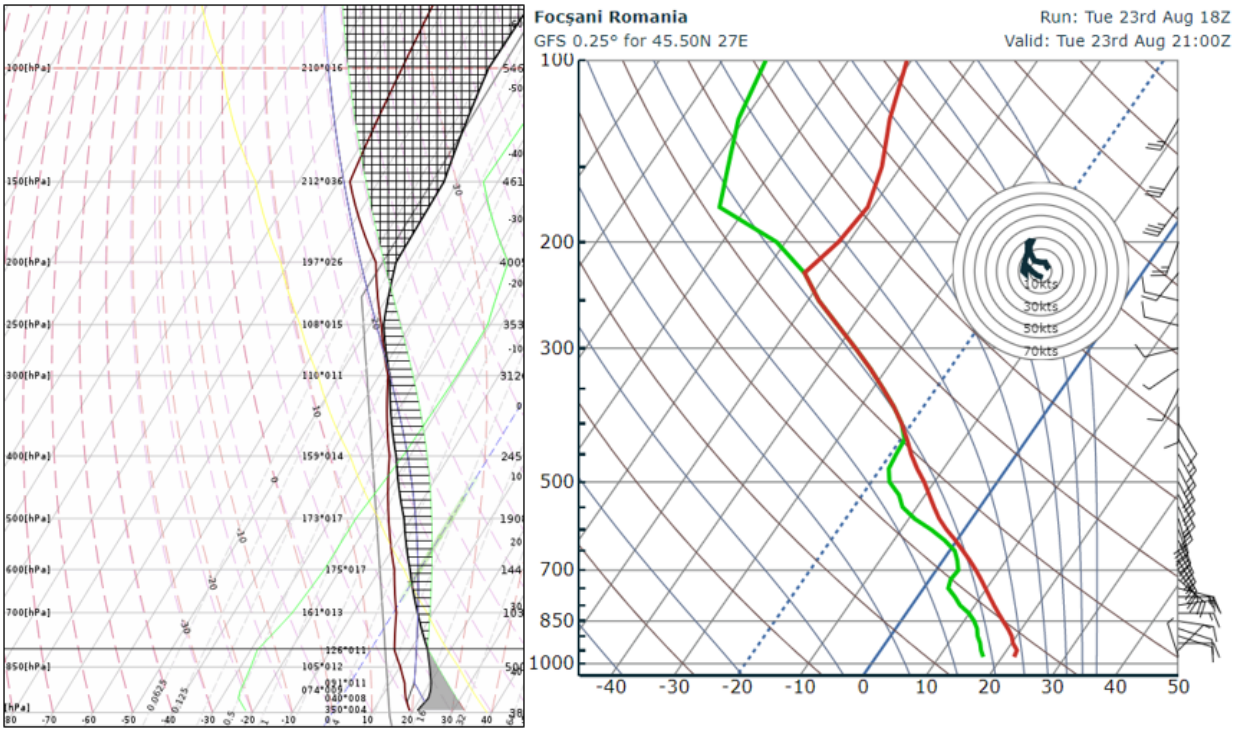


Fig. 11. Atmospheric soundings forecast for Focșani station (ECMWF- left and GFS- right) [7, 8]

Table 4. Data extracted from the atmospheric soundings forecast – Focșani station (ECMWF Model 23.08.h12), H – vertical pressure in hPa, T - air temperature, Td - dew point temperature, Mix. R - mixing ratio, RH - relative humidity, wind direction in degrees, wind speed in m/s

H (hPa)	T (°C)	Td (°C)	Mix R. (g/kg)	RH (%)	W (°)	W (m/s)
950	19.8	17.4	12.75	86	347	4
850	16.6	8.4	8.2364	56	72	5
700	5.8	1.9	6.3376	76	139	5
600	-2.3	-7.9	3.5296	66	142	5
500	-12.3	-18.6	1.76	59	139	6
400	-23.7	-25.9	1.1599	82	161	7
300	-38.7	-39.6	0.415	91	133	7
250	-46.9	-47.3	0.2145	96	146	7
200	-51.9	-61.5	0.0489	31	197	13
150	-54.6	-766.2	0.0082	5	204	14
100	-58.5	-81.2	0.0055	4	191	11

5.2. Analysis of atmospheric soundings forecast for eastern Moldavia stations

For the Botoșani station, the ECMWF model predicts high values for relative humidity at the ground surface, respectively 85%. Starting at the level of 850 hPa, the relative humidity begins to decrease gradually until 300 hPa, the level at which the relative humidity is above 90%. At this point, the equilibrium level is defined (Fig. 12). A layer of less moist air separates between 700 and 400 hPa. At 900 hPa, the lifted condensation level is estimated, and from 700 hPa the temperature of the air parcel becomes higher than the temperature of the profile.

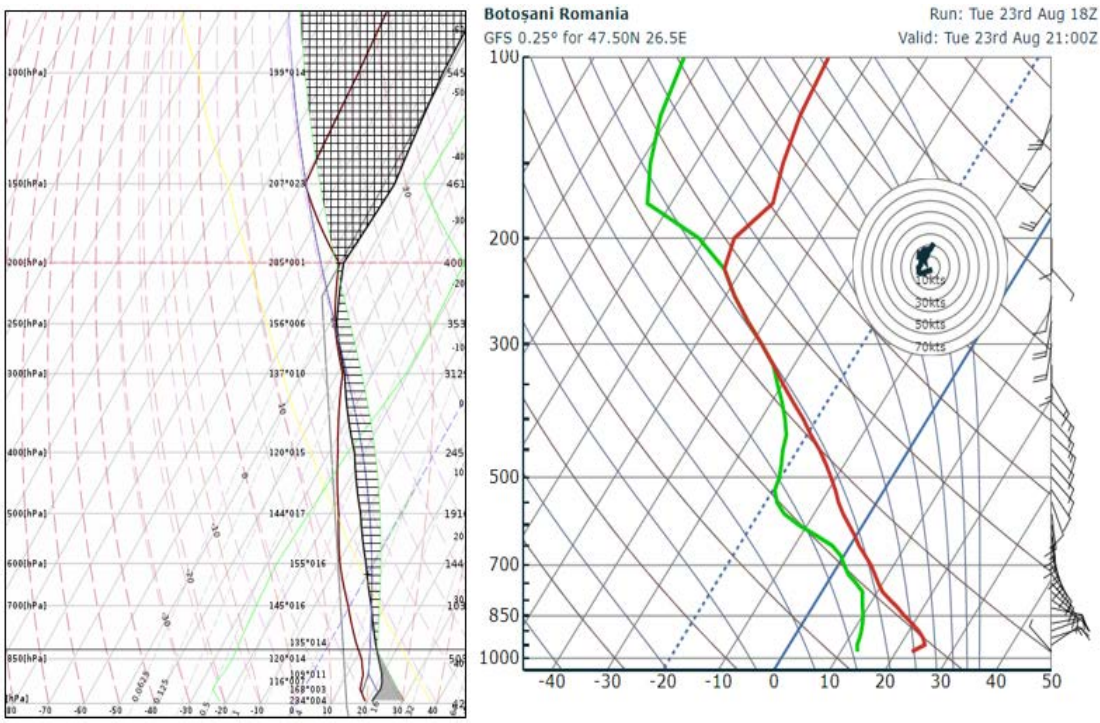


Fig. 12. Atmospheric soundings forecast for Botoșani station (ECMWF- left and GFS- right) [7, 8]

At the ground level, high relative humidity is not supported by high potential energy values for convection. The 0 degree isotherm is estimated at 650 hPa. On the ground surface, the wind is

oriented from the SW, then at altitude it reorients itself according to the general circulation of the atmosphere. Also, low ground level velocities are correlated with weak shear. In the upper layers, the shear intensifies and the wind speed increases gradually (Table 5).

Table 5. Data extracted from the atmospheric soundings forecast – Botoșani station (ECMWF Model 23.08.h12), H - vertical pressure in hPa, T - air temperature, Td - dew point temperature, Mix. R - mixing ratio, RH - relative humidity, wind direction in degrees, wind speed in m/s

H (hPa)	T (°C)	Td (°C)	Mix R. (g/kg)	RH (%)	W (°)	W (m/s)
950	21.3	18.5	13.8177	85	226	2
850	16.8	11.8	10.2775	73	119	7
700	5.8	-0.8	5.1841	63	146	8
600	-2.3	-9.6	3.0798	57	155	8
500	-11.5	-17.7	1.9081	60	144	8
400	-23	-27	0.9919	66	120	7
300	-37.9	38.5	0.4568	94	137	5
250	-48.5	-49.1	0.1776	93	157	3
200	-55.6	-57.9	0.0778	81	253	1
150	-53.6	-78.9	0.0053	3	207	11
100	-57.7	-81.4	0.0054	3	167	7

The forecasted atmospheric soundings for the Iași station estimates high values for relative humidity at ground level, over 90%. Above this moist layer held captive at the ground level, the relative humidity gradually decreases. At 900 hPa, the lifted condensation level is estimated, and at 700 hPa the temperature of the air parcel becomes higher than the temperature of the profile. At this point the level of free convection (LFC) is estimated. The air particle free ascends on the moist adiabat up to 300 hPa, at which point the equilibrium level is reached, and the 0 degree isotherm is located at 600 hPa (Fig. 13).

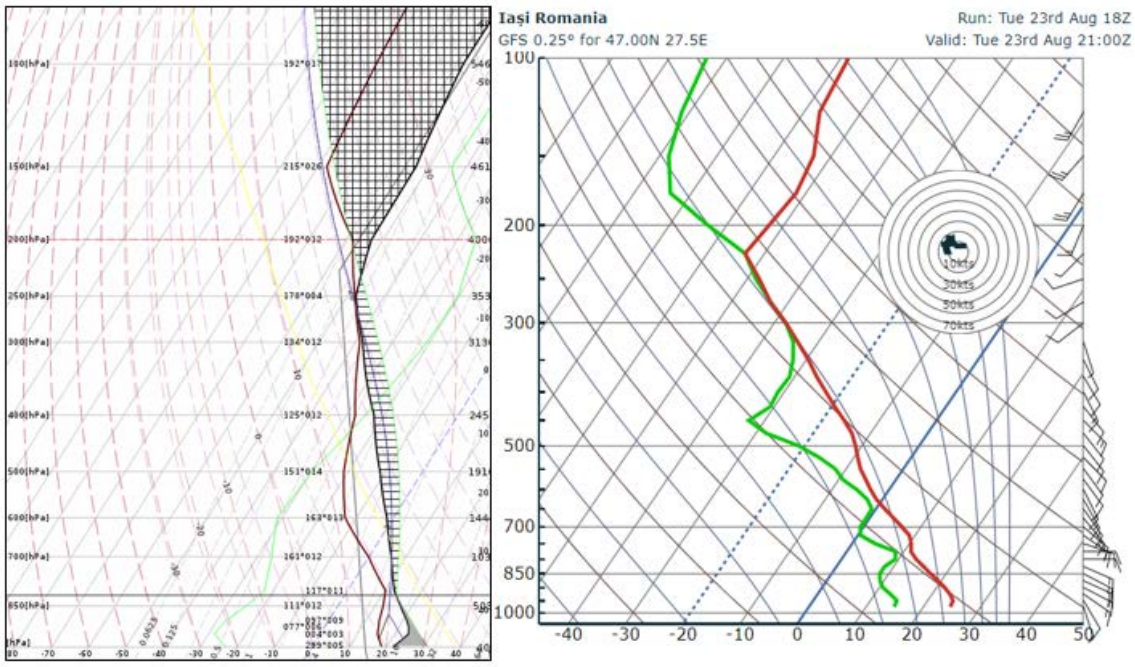


Fig. 13. Atmospheric soundings forecast for Iași station (ECMWF- left and GFS- right) [7, 8]

The model describes modest values for CAPE. On the ground surface, the potential energy values for convection tend to 0 J/Kg, increasing insignificantly in altitude.

The wind suddenly changes its direction: from the NW near the ground level, to the E and SE between 850 – 300 hPa. The wind increases slightly in intensity with altitude, as does the shear (Table 6).

Table 6. Data extracted from the atmospheric soundings forecast – Iași station (ECMWF Model 23.08.h12), H - vertical pressure in hPa, T - air temperature, Td - dew point temperature, Mix. R - mixing ratio, RH - relative humidity, wind direction in degrees, wind speed in m/s

H (hPa)	T (°C)	Td (°C)	Mix R. (g/kg)	RH (%)	W (°)	W (m/s)
950	18.5	17.4	12.6582	94	355	2
850	15.8	8.4	8.1638	62	0.68	5
700	6.4	-2.3	4.6727	54	143	3
600	-3	-8.6	3.3508	65	156	4
500	-11.7	-18.6	1.7471	56	140	6
400	-23.6	-30.1	0.7849	55	123	4
300	-37.8	-43.8	0.2603	53	0.93	4
250	-47.4	-49.9	0.1602	76	236	3
200	-54.2	-58.7	0.0703	60	208	8
150	-54.2	-75.9	0.0086	5	203	11
100	-58.5	-81.1	0.0057	4	190	8

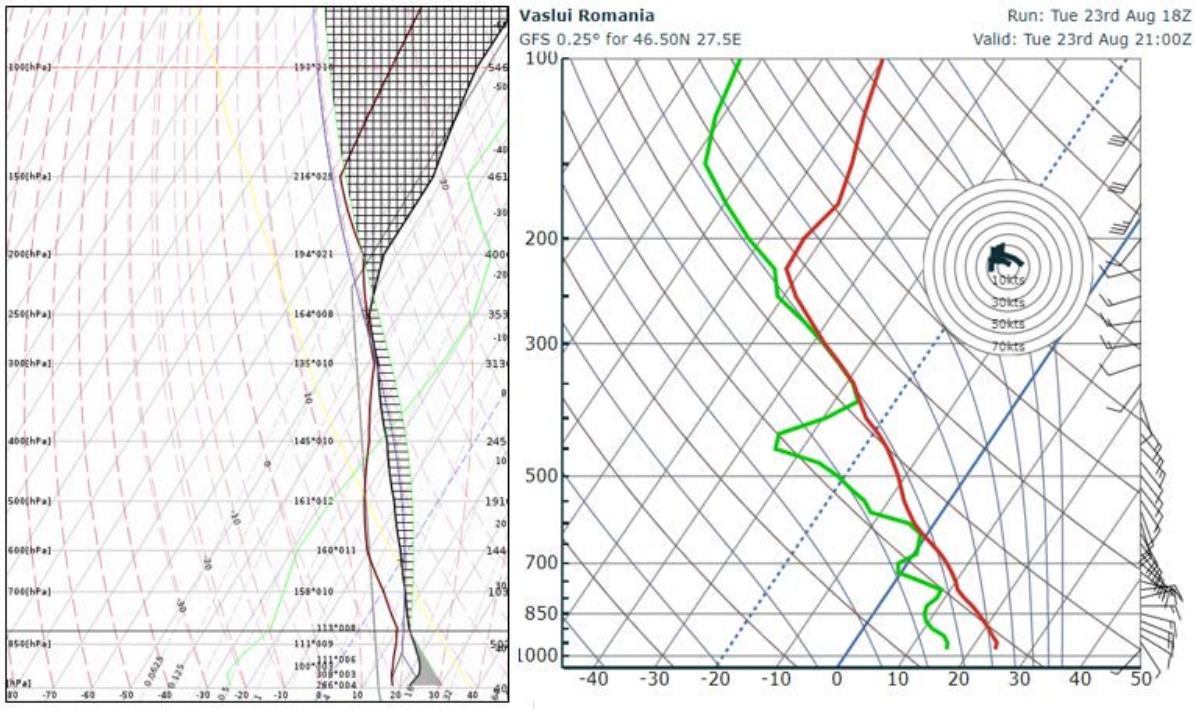


Fig. 14. Atmospheric soundings forecast for Vaslui station (ECMWF- left and GFS- right) [7, 8]

For the Vaslui station, the model estimated values of over 80% for relative humidity at the ground surface, but also at 250 hPa. Between these points, but also beyond 250 hPa, the relative

humidity decreases considerably (Table 7). At the level of 900 hPa, the model estimates the lifted condensation level, respectively the base of the clouds, and at 750 the level of free convection is outlined (Fig. 14). From this point, the air parcel ascends directly on the moist adiabatic, up to 300 hPa, where the equilibrium level is established. The 0 degree isotherm is described at 650 hPa. On almost the entire column, the wind is oriented according to the general circulation of the atmosphere, respectively from the E and SE, and the speeds are weak.

Table 7. Data extracted from the atmospheric soundings forecast – Vaslui station (ECMWF Model 23.08.h12), H - vertical pressure in hPa, T - air temperature, Td - dew point temperature, Mix. R - mixing ratio, RH - relative humidity, wind direction in degrees, wind speed in m/s

H (hPa)	T (°C)	Td (°C)	Mix R. (g/kg)	RH (%)	W (°)	W (m/s)
950	19.3	16.4	12.0419	85	0.5	2
850	16.2	8.7	8.3526	62	0.57	4
700	6.9	0	5.4558	61	142	2
600	-2.9	-8.2	3.4516	67	164	4
500	-12.1	-17.8	1.8859	62	146	5
400	-23.6	-28.9	0.8828	62	144	4
300	-38.3	-43.7	0.2683	57	109	4
250	-47.3	-48.4	0.1911	88	193	3
200	-53.7	-59	0.0671	53	205	10
150	-54.2	-75.9	0.0086	5	203	13
100	-59.1	-81.1	0.0056	4	189	8

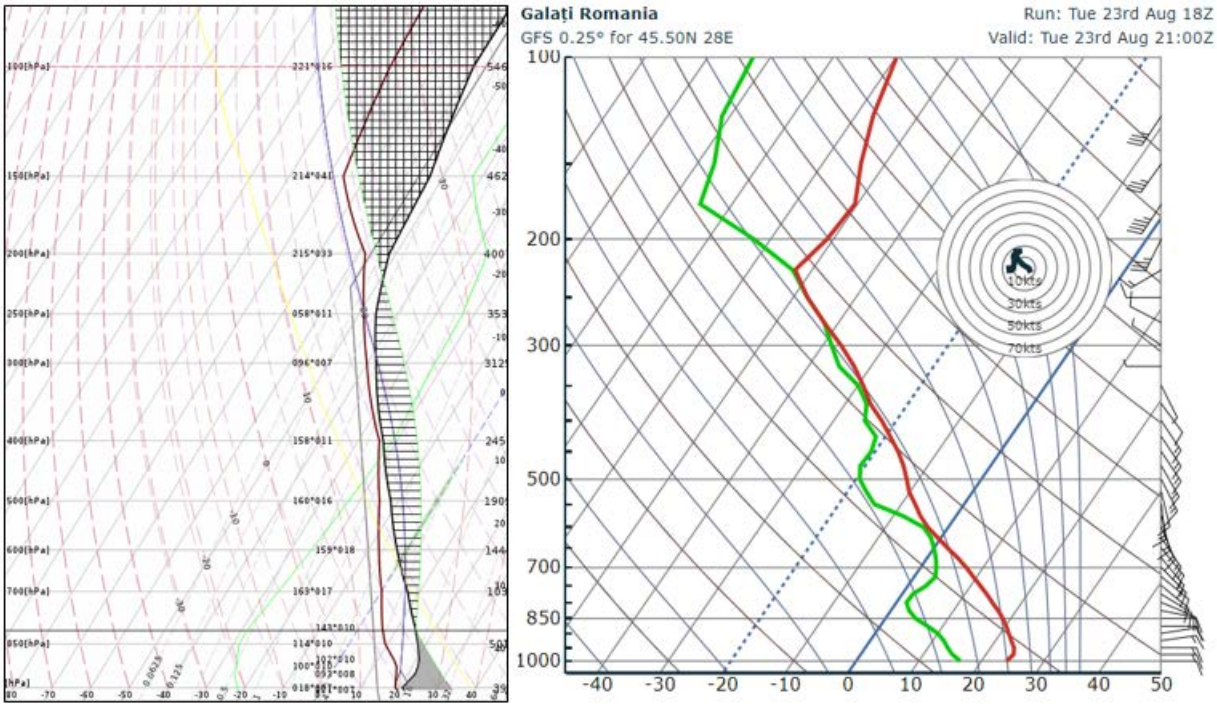


Fig. 15. Atmospheric soundings forecast for Galați station (ECMWF- left and GFS- right) [7, 8]

The atmospheric soundings for the Galati station estimated values of over 90% for the relative humidity at ground level. Similar to the soundings analyzed for the rest of the stations in eastern Moldavia, the relative humidity decreases up to the altitude of 300 hPa, from which point it increases, reaching 100 percent at 250 hPa (Table 8). At 900 hPa, the condensation level is outlined, and at 700 hPa, the air parcel rises on the moist adiabat up to 300 hPa, at which point the equilibrium level is extinguished. The potential energy for convection described by the model is modest in the lower layers and becomes moderate between 600 and 300 hPa (Fig. 15). On the ground level, the wind acts from the north-west sector, contrary to the general circulation, following that at altitude it will reorient itself and increase in intensity.

Table 8. Data extracted from the atmospheric soundings forecast – Galați station (ECMWF Model 23.08.h12), H - vertical pressure in hPa, T - air temperature, Td - dew point temperature, Mix. R - mixing ratio, RH - relative humidity, wind direction in degrees, wind speed in m/s

H (hPa)	T (°C)	Td (°C)	Mix R. (g/kg)	RH (%)	W (°)	W (m/s)
950	20	18.7	13.59	92	342	4
850	17.5	7.5	7.7011	52	54	6
700	6.7	2.7	6.6359	75	129	3
600	-2.7	-9	3.2525	62	135	6
500	-12.2	-21.5	1.3703	46	134	5
400	-23.5	-29.3	0.8455	59	172	9
300	-38.2	-39.1	0.4297	91	153	5
250	-46.4	-46.4	0.2363	100	160	7
200	-50.4	-62.7	0.0418	22	202	18
150	-54.6	-76.2	0.0082	5	214	16
100	-59.8	-81.1	0.0057	4	185	11

Comparing the atmospheric soundings for weather stations located at east of Siret, vertical differences can be observed. For the Botoșani and Iași stations, the GFS model based on the 18 UTC run, estimated modest values for the relative humidity at the ground surface. At 800 hPa, a moist layer takes shape, trapped between two drier layers. The lifting condensation level is estimated at 700 hPa, and the level of free condensation at 750 hPa. Also, the model estimated modest values for CAPE, respectively 173 J/Kg (on the ground surface - Botoșani) and 0 J/Kg (on the ground surface - Iași). The wind speed intensifies vertically, and the shear becomes moderate (Table 9).

At the level of 600 hPa, the isotherm of 0 degrees is estimated, and the equilibrium level is reached at 250 hPa. Vertically, the temperature of the air parcel is comparable to the estimated profile temperature.

Similarly, for Vaslui and Galați stations, the model predicted low values for relative humidity near the ground surface and up to the 700 hPa level. Above this level, at 650 hPa, the sounding estimates a moist layer, with 100% values of relative humidity. At 850 hPa, the lifted condensation level is estimated, and the level of free convection at 750 hPa. From this point, the air

parcel rises on the moist adiabat up to 400 hPa, at which point the equilibrium level is reached. The temperature of the air parcel is similar to the estimated profile temperature, so the model describes modest values for CAPE, both at the ground level and altitude.

At 650 hPa is located the 0 degree isotherm. On the ground surface, the wind is characterized by slight intensifications, weak shear in a predominantly north-westerly direction, then at altitude it intensifies and reorients itself according to the general circulation of the atmosphere.

Table 9. Data extracted from the atmospheric soundings forecast: 1 - Botoșani station, 2 - Iași station, 3 - Vaslui station, 4 - Galați station GFS atmospheric model 23.08.h21[8]; the K Index is related to the probability of occurrence of a thunderstorm: less than 20- none, 20 to 25- isolated thunderstorms, 26 to 30- widely scattered thunderstorms, 31 to 35- scattered thunderstorms, above 35- numerous thunderstorms; the lifted index (LI): positive number- stable, 0 to -4 marginal instability, -4 to -7- large instability, -8 or less- extreme instability; CAPE- Convective Available Potential Energy is the amount of fuel available to a developing thunderstorm.

1. H (km)	CAPE (J/Kg)	SHEAR (m/s)	INDICIES		2. H (km)	CAPE (J/Kg)	SHEAR (m/s)	INDICIES	
0 - 1	173	9	LI	0	0 - 1	0	7	LI	2
0 - 3	485	7	K	29	0 - 3	204	10	K	34
0 - 6	560	5			0 - 6	207	7		
3. H (km)	CAPE (J/Kg)	SHEAR (m/s)	INDICIES		4. H (km)	CAPE (J/Kg)	SHEAR (m/s)	INDICIES	
0 - 1	214	4	LI	-2	0 - 1	416	9	LI	-2
0 - 3	209	6	K	31	0 - 3	531	10	K	29
0 - 6	239	7			0 - 6	615	7		

6. Analysis of the Vertical Profile of the Atmosphere Using the Cross-Sections Tool

Analyzing the transversal profiles drawn from east to west, which express the divergence, convergence and vertical equivalent-potential temperature, several surfaces can be distinguished, having different characteristics. Two reference points were selected to capture both the differences between the east and west of the region, as well as the vertical ones (Fig. 16), during the maximum manifestation of the instability (21:00 and 00:00 UTC).

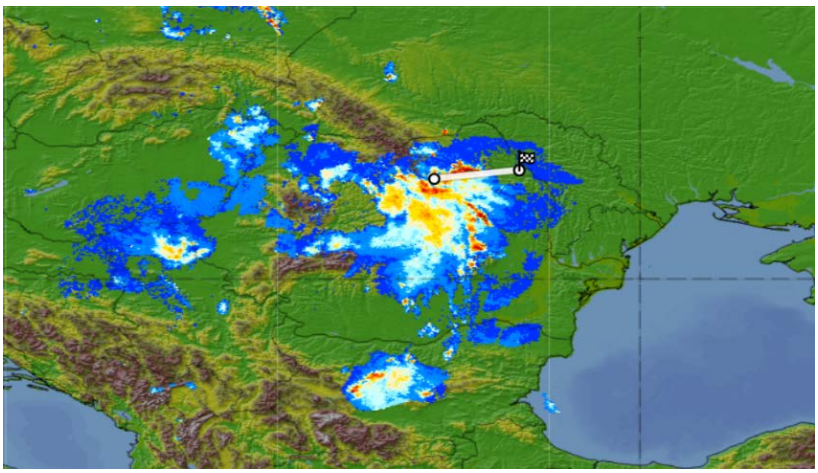


Fig. 16. Selected points for cross section – ECMWF [7]

At 21:00 UTC, from ground surface to 900 hPa, the model captured the most intense atmospheric activity. From east to west, a series of upward and downward movements can be highlighted. In the extreme west, representing the first point selected, a divergent movement of downward takes place at the ground surface. It is the mountainous region, where the specific phenomena of instability were fully manifested. It is preceded by an ascending movement, in the immediately following region, at the contact with the high region, where the air masses have converged, on the background of the atmospheric circulation. Vertically, in the adjacent layer, in the extreme east of the drawn profile, there is a movement of divergence and therefore of downward, which did not allow the moist air from the surface to continue its upward, keeping it captive, like a lid. For this reason, the east of the region was also the most protected from the intense instability phenomena, contrary to the pre-existing moisture near the ground surface. Also, between 900 and 800 hPa, the distance between the isentropes becomes more significant, but still maintains a more stable layer (Fig. 17).

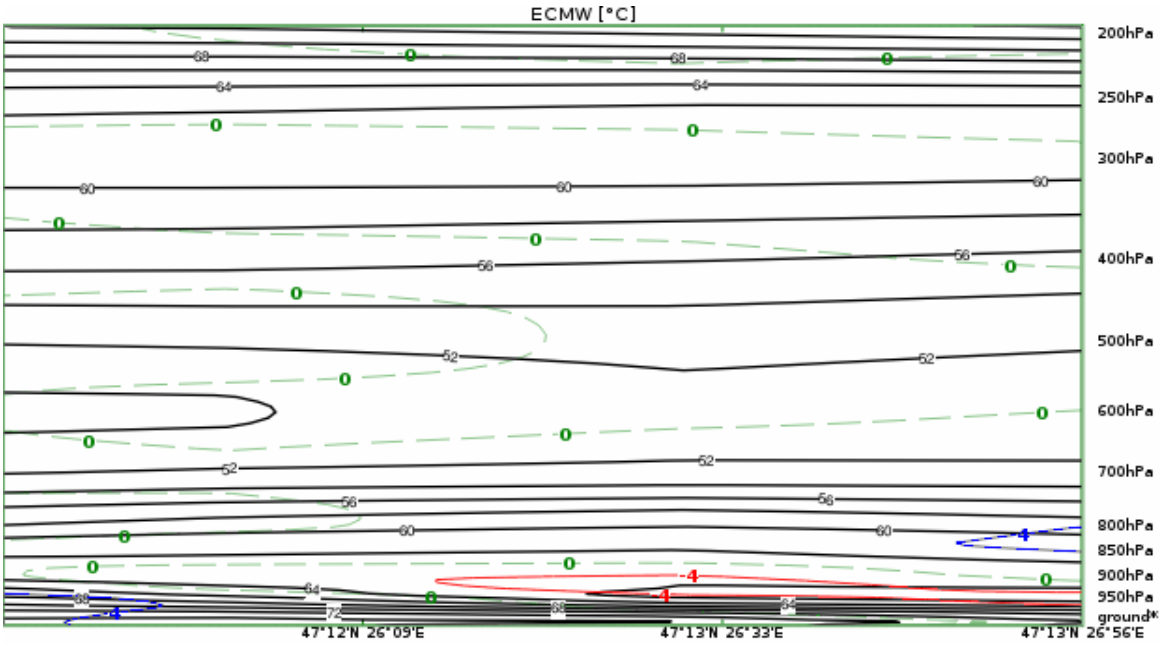


Fig. 17. Cross-sectional profile: equivalent-potential temperature and divergence (blue lines)/convergence (red lines) at 21 UTC [7]

Above this level, the distance between the isentropes begins to increase even more sharply, delimiting even a region of great instability, at 600 hPa, where the isentrope is almost closed, representing the very west of the region. This layer of instability in the atmosphere is therefore positioned above a stable layer. At the 250 hPa level, the Tropopause is separated, marked by a closeness of the isentropes and therefore by a great specific stability. The situation changes slightly at 00 UTC so that more instability is emerging between 900 and 500 hPa. At the ground level, a

region of convergence is evident, also at the contact with the high relief region, where the largest amounts of water were recorded. At 900 hPa, to the east of the section, a downward movement is delineated, below which the model estimates a weakly developed segment, relatively stable, with close isentropes. Between 800 and 500 hPa, the isentropes are at large distances or even closed between 700 and 500 hPa, a region of great instability. It should be noted, that this considerably unstable layer is positioned above a stable layer with descent movements. Between 400 and 200 hPa, the isentropes tend to narrow the space that delimits them, and at 250 hPa the presence of the Tropopause is highlighted (Fig. 18).

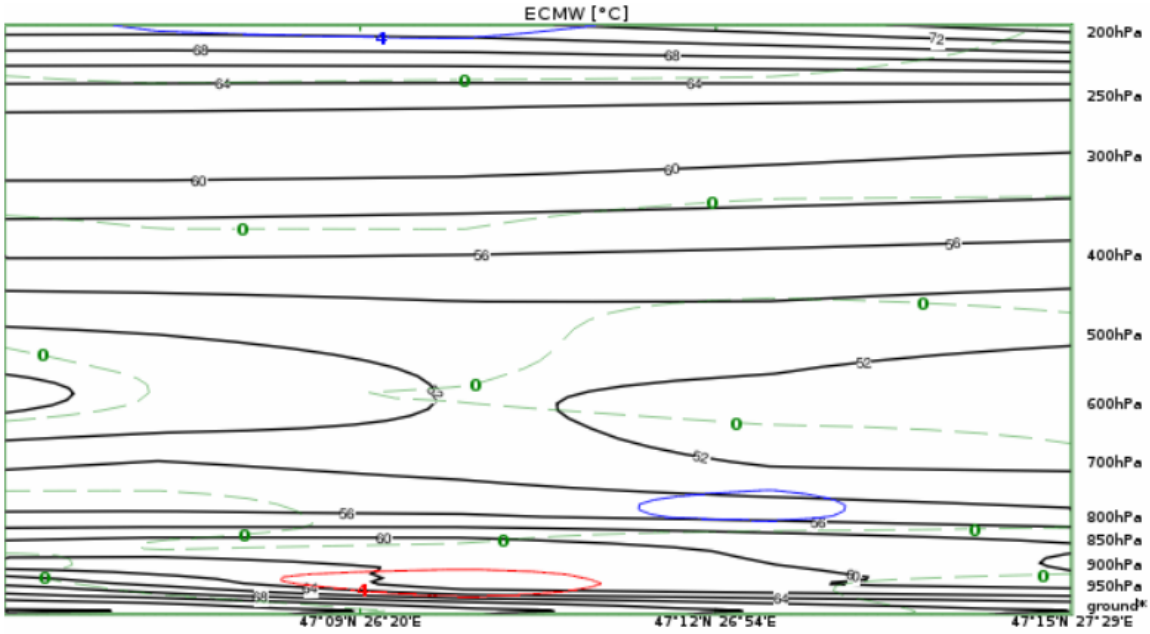


Fig. 18. Cross-sectional profile: equivalent-potential temperature and divergence (blue lines)/convergence (red lines) at 00 UTC [7]

Analyzing, for the same section, the potential equivalent temperature and relative humidity at 21:00 UTC, their differentiated vertical and horizontal distribution can be observed. A layer with relative humidity above 80% is concentrated at the ground surface. In the western part of the profile, high relative humidity is found up to the level of 800 hPa, while in the east of the profile, from 900 hPa, the relative humidity has modest values, below 60%. The moist air from the ground surface, in the east of the region, is therefore held captive under a layer poorer in moisture, having no other lifting mechanisms. It is also the region where the atmospheric precipitation was in reduced quantities and on small areas. The orographic force represented by the relief that gradually becomes higher from east to west, potentiated the upward and convergence of moist air in altitude, thus penetrating the adjacent, more stable and drier layer. Between 400 and 250 hPa, the model predicts a stable, moist layer with relative humidity values above 80%, sandwiched between two less moist layers (Fig. 19).

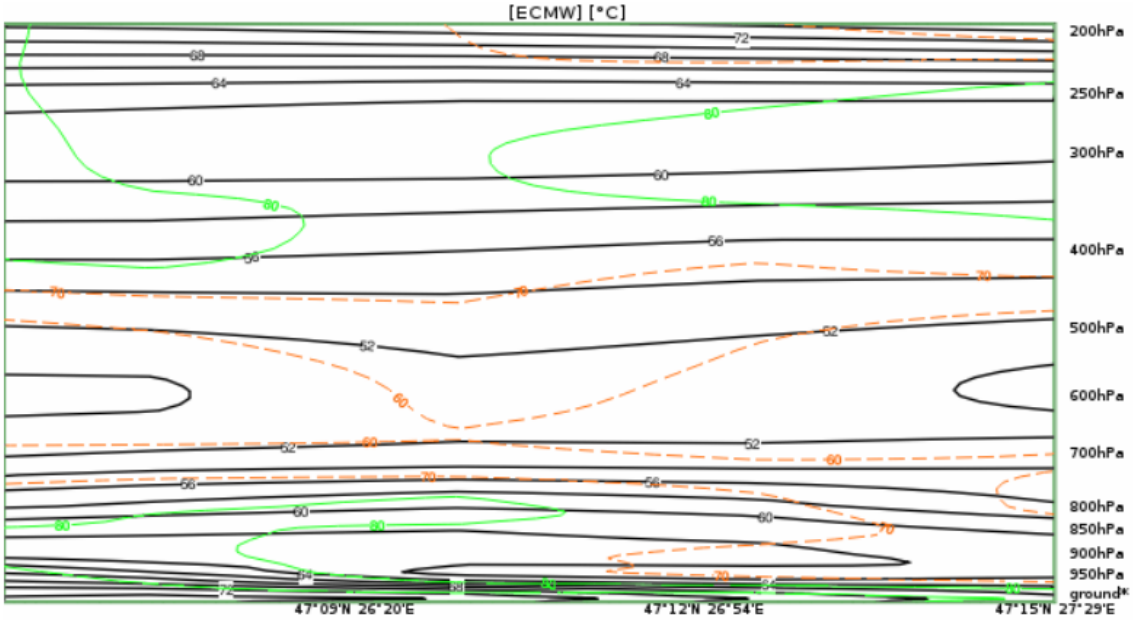


Fig. 19. Cross-sectional profile: potential-equivalent temperature and relative humidity at 21 UTC [7]

At 00 UTC, the situation changes so that the moisture in the near ground surface layer for the west of the profile remains high only up to 900 hPa. Above this layer, the relative humidity gradually decreases, even though at 500 hPa an unstable atmosphere is maintained, described by the nearly closed isentropes at large distances. However, from 400 hPa, the relative humidity starts to increase slightly (Fig. 20).

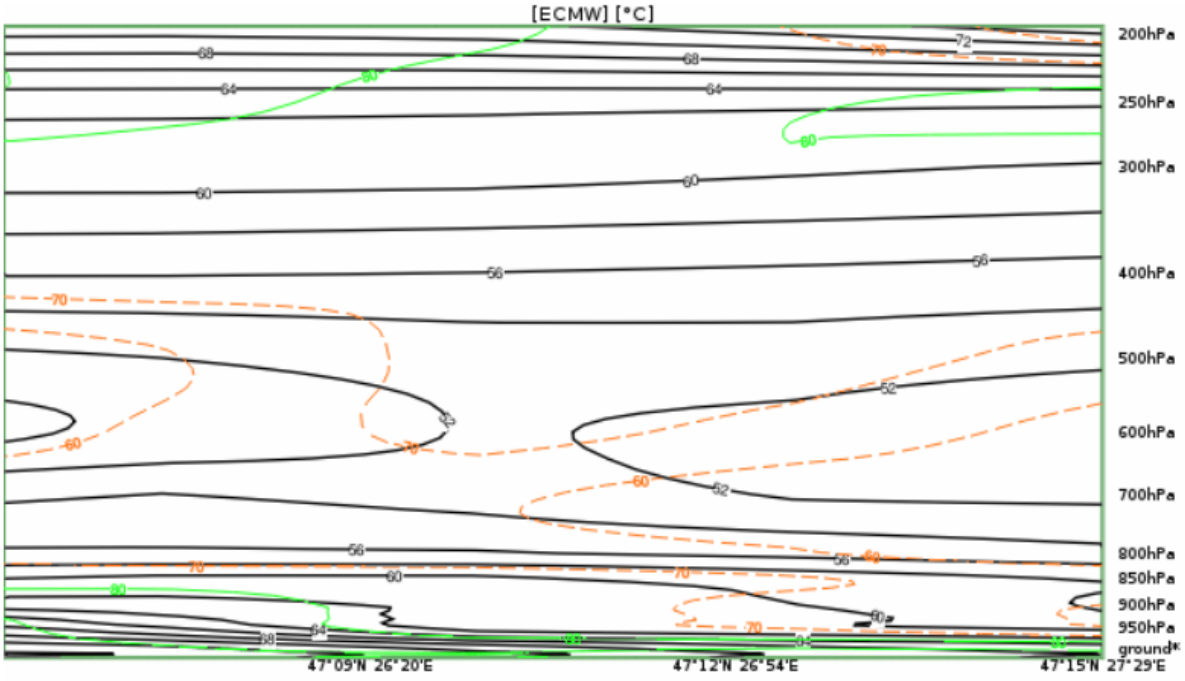


Fig. 20. Cross-sectional profile: potential-equivalent temperature and relative humidity at 00 UTC [7]

7. Analysis of Radar Images from August 23/24

On 23rd August, at 06 UTC, the first manifestations of atmospheric instability appeared in the west of the country, on background of the presence of an altitude trough in the eastern basin of the Mediterranean Sea, on whose ascending part Romania was positioned. Gradually, the area of instability expands, the cells sliding towards the north-east of the country. At 12 UTC, the first important cloudy developments appear in the west of Moldavia, at the contact with the Carpathian chain, then at 18 UTC they will develop in the south and south-west of the region. The instability is fully manifested in Moldavia at 21 UTC, when in the west of the region, still rising to the north, significant amounts of water accumulated and electrical discharges were reported with a notable frequency. Furthermore, the east of the region is safe from these severe manifestations. At 00 UTC, the instability persists with considerable energy, but it slides far north-ward and especially into the mountain area, where the storms converge, directed by the strong easterly circulation of the continent.

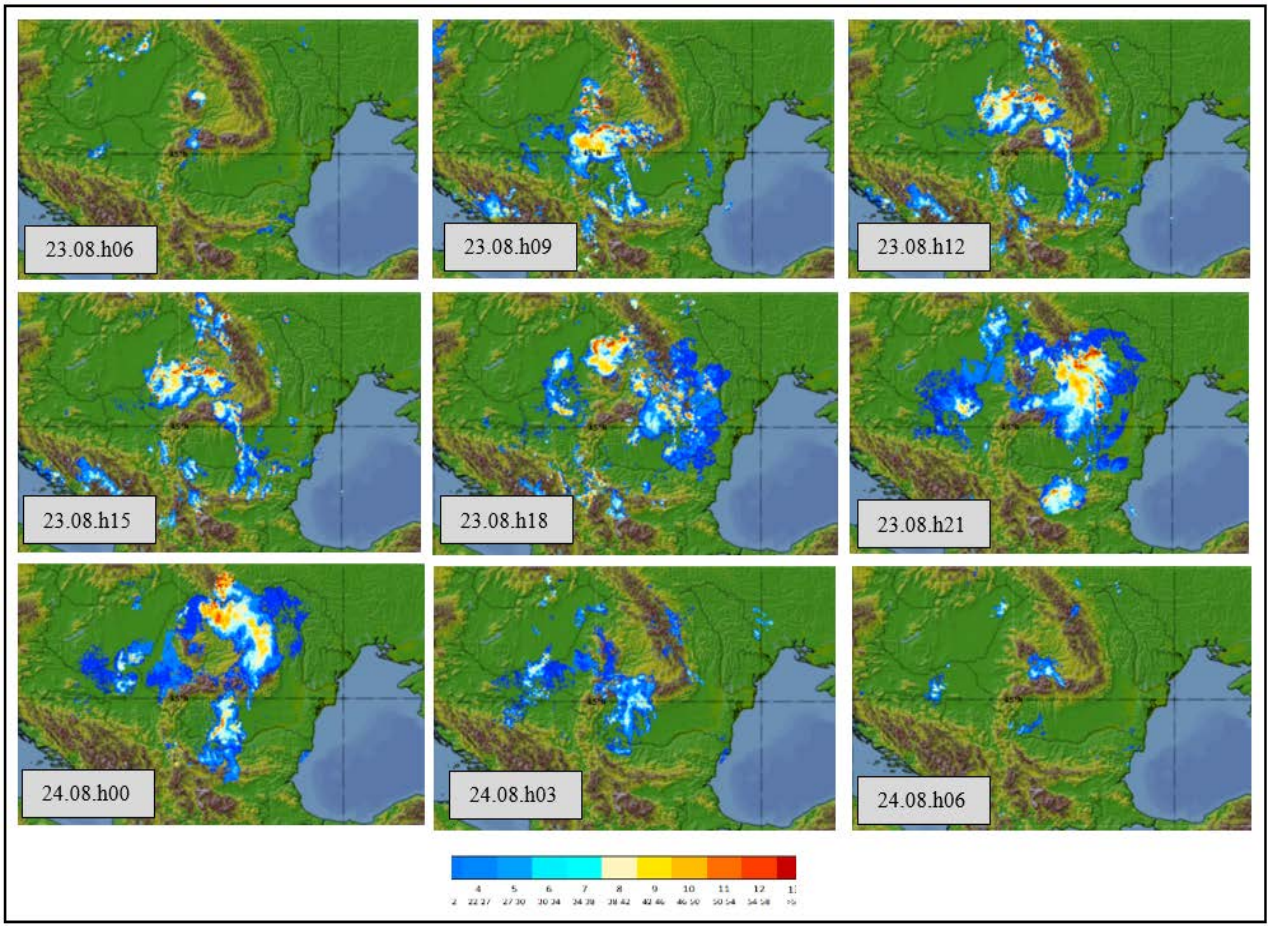


Fig. 21. Radar reflectivity captures 23/24 August, UTC time - Europe Radar [9]

8. Precipitation Distribution – Forecast and Diagnosis

On the night of 23/24 August, one of the most consistent episodes of atmospheric instability occurred in the warm season of 2022, for the region of Moldavia. This episode of instability, through the appreciable amounts of precipitation it left, removed the mountainous and submontane regions of Moldavia from the sphere of severe drought. Forecast models estimated between 25 and 30 l/m^2, on the west of Siret River, and to the east the estimated water quantities were 10...15 l/m^2 (ECMWF) (Fig. 22). These quantities were underestimated even by the most optimistic forecast models, because water quantities of 40...50 and even 80 l/m^2 were recorded on extensive areas.

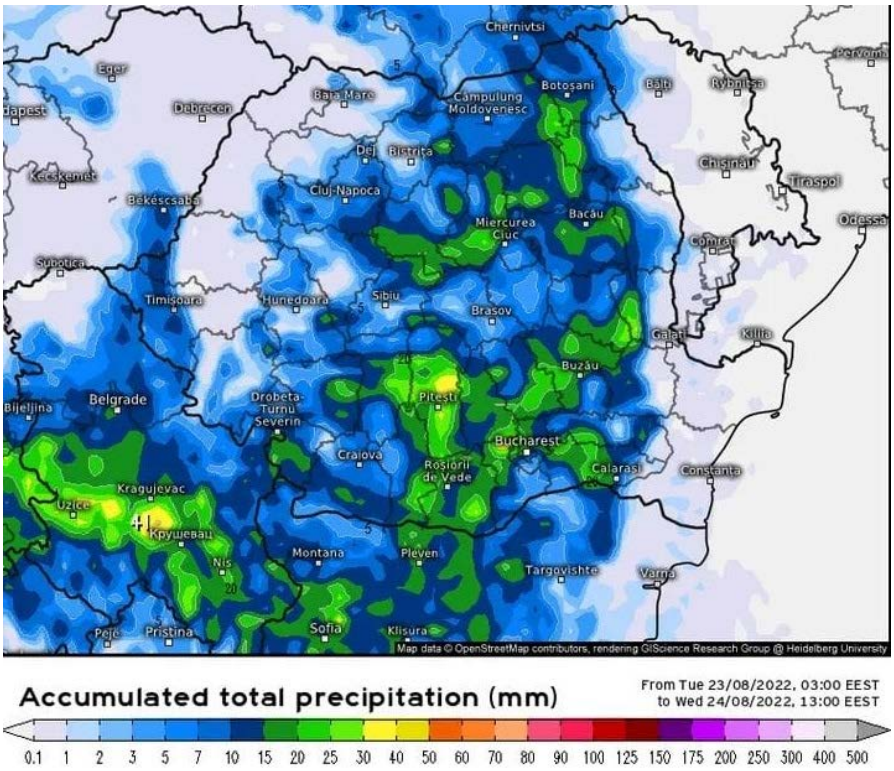


Fig. 22. 23/24 August - Estimated amounts of water in 24h - ECMWF model [10]

Gradually, atmospheric instability increased in Moldavia, starting in the evening hours, especially in the west and south of the region and manifested itself in torrential downpours and electrical discharges. The water quantities recorded (Fig. 23): Bacău county: Cremenea - 84.0 l/m^2, Helegiu - 77.5 l/m^2, P. Uz Dam - 66.7 l/m^2, Dofteana - 56.2 l/m^2, Borzești - 52.4 l/m^2, Onești - 49.6 l/m^2, Valea Uzului - 42.0 l/m^2, Haloș - 39.5 l/m^2, Lucăcești - 39.5 l/m^2, Scorțeni - 33.6 l/m^2, Ghimeș-Făget 32.5 l/m^2, Ferăstrău - 28.7 l/m^2, Comănești - 28.0 l/m^2, Asău - 28.0 l/m^2, Sulita - 23.5 l/m^2, Răcăciuni - 23.0 l/m^2, S.M. Târgu Ocna - 22.0 l/m^2, Dărmanesti - 21.1 l/m^2; Neamț County: Slobozia - 44.5 l/m^2, Ceahlău 39.2 l/m^2, Cuiejdi - 38.8 l/m^2, S.M. Târgu Neamț - 38.0 l/m^2, Păstrăveni - 29.0 l/m^2, Borlești

- 28.4 l/m^2, Magazia - 25.3 l/m^2, Filioara - 24.7 l/m^2, Luminis - 21.3 l/m^2, Pluton - 20.4 l/m^2; Suceava county: Frunzeni - 34.2 l/m^2, Straja - 33.0 l/m^2, Bogdănești - 31.6 l/m^2, Broșteni 29.2 l/m^2, Putna - 25.4 l/m^2, Frumosu - 24.3 l/m^2, Tupilati - 23.0 l/m^2, Stulpicani - 21.6 l/m^2, Panaci - 20.5 l/m^2; Vrancea county: Vrânceni - 50.3 l/m^2, Colacu - 39.5 l/m^2, Nereju - 36.7 l/m^2, Tulnici - 35.2 l/m^2, Lepșa - 32.7 l/m^2, Reghiu - 31.8 l/m^2, Ciuruc - 21.0 l/m^2; Galati county: Bălăbănești - 27.0 l/m^2. Hail was reported in Bacău and Neamț counties. The wind intensified associated with the shower rain, which temporarily had the appearance of squall (Vaslui county), and in the high mountain area, at night, the wind gusts reached 90...100 km/h.

The distribution in the territory shows that the precipitation was concentrated in the west of the region, especially in contact with the mountain area. Circulation from the east and the existence of the divergent movement between 800 and 900 hPa, did not facilitate significant falls of precipitation in the east of Moldavia. The unstable mass was directed to the west, where, forced to orographically lift, it left large quantities of water. Among these, the most significant were recorded in the counties of Bacău and Neamț.

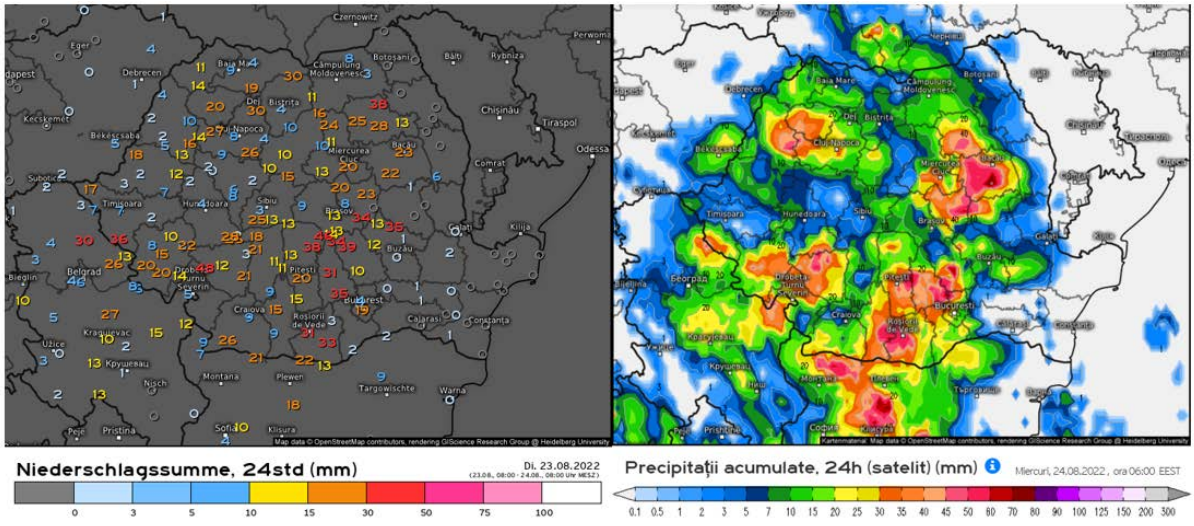


Fig. 23. 23/24 August - Amounts of water recorded in 24h: at stations on the left and interpolated values on the right – data from observations [10]

9. The Role of Dust Particles Entrained Towards the Moldavia Region, in the Evolution of the Convective Episode of August 23/24, 2022

To the north of the Black Sea, the currents transport dust particles entrained from the north of the Caucasus, as well as from the north of the Black Sea, regions strongly affected by drought, on an easterly circulation. These dust particles also reached the Moldavia region. The existing high humidity at the ground surface, the stability of the immediately upper layer, as well as the existence of a downward movement, facilitated the retention in the lower Troposphere of the region of fine

particles in suspension and led to a dust-laden atmosphere. If in the eastern part, the instability was inhibited by the downward movement of air from the altitude, in the west of Moldavia, precisely the presence of an upward movement, potentiated the development and manifestation of convection.

Additional dust particles existing in the area may be responsible for the large amounts of water in the carpathian and subcarpathian regions. It appears that the dust particles acted as condensation nuclei [28].

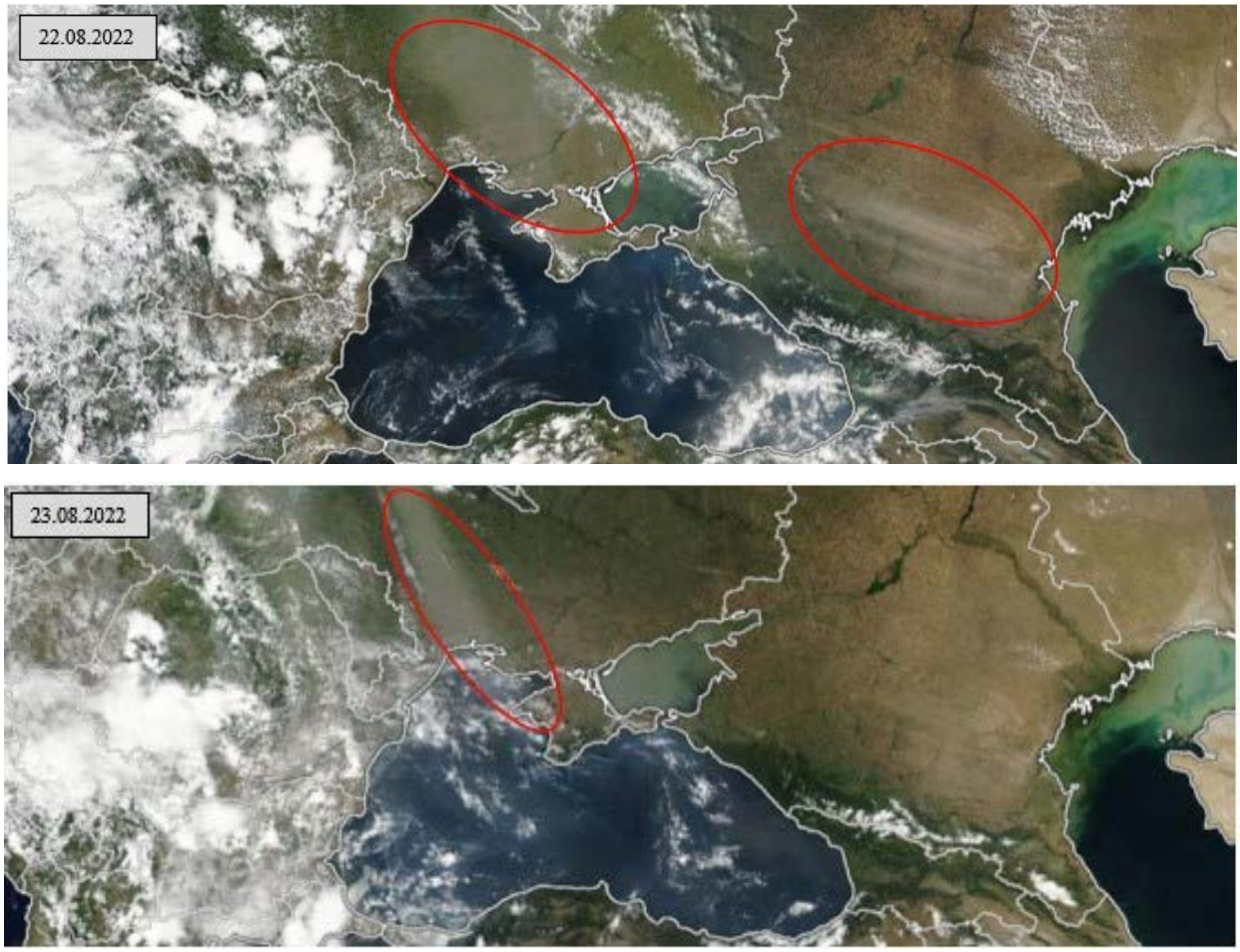


Fig. 24. Satellite images capturing dust in the lower atmosphere: 22nd and 23rd August – MODIS [6]

The presence and concentration of dust particles in the Moldavia region, for the analysed period, is also captured by the Copernicus Atmosphere Monitoring Service, ECMWF model. For August 23rd, the model estimated PM_{10} amounts of 20...30 μg/m^3 across the region. For August 24th, the model approximated the same amounts, but narrowly to the north of the region. According to the website CalitateAer website, in these days, the daily dose for human health was not exceeded. As for the concentration of $PM_{2.5}$ particles, really harmful to health, and the model did not capture such intrusions. In the case of $PM_{2.5}$ particles, the daily concentration not harmful to human health is 25 μg/m^3, representing the target value per year. It can be appreciated that the analysed situation does not

describe an episode of anthropogenic pollution, but can be categorized as a natural phenomenon, potentiated by the general circulation of the atmosphere. The increase in the concentration of PM_{10} was therefore not accompanied by increases in the concentration of $PM_{2.5}$.

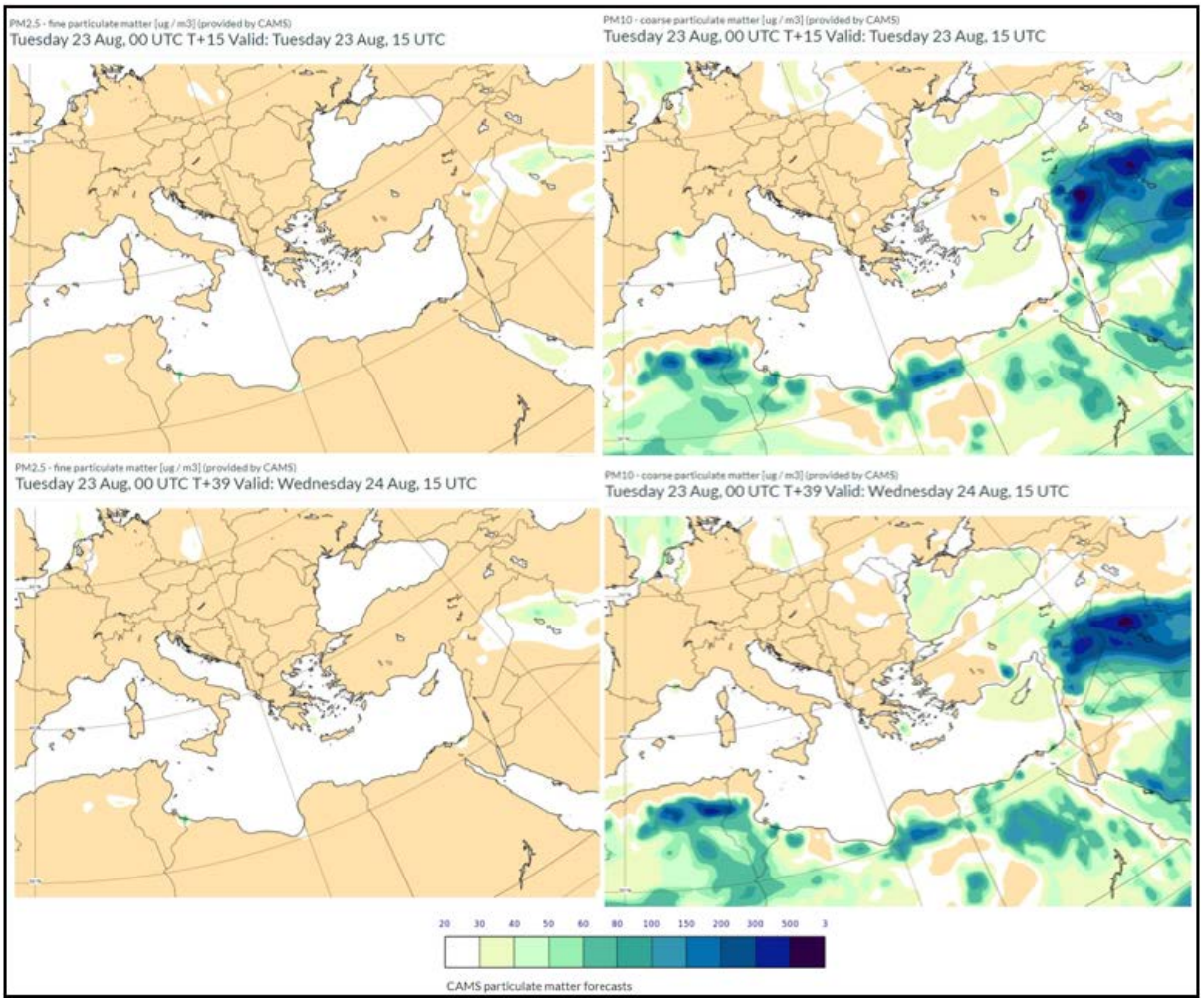


Fig. 25. PM_{10} and $PM_{2.5}$ particles estimated by CAMS, for 23rd and 24th August – ECMWF [11]

Normally, after a rain, especially a downpour, the atmosphere "cleanses", but in the present case, the suspended particles continued to persist, due to the easterly circulation. From the radar and ceilometer data, obtained courtesy of UGAL – REXDAN cloud remote sensing facility part of ACTRIS – RO (Aerosol, Clouds and Trace gases Research InfraStructure – Romania) and RADO (Romanian Atmospheric 3D research Observatory), persistent layers of aerosols, between 0 and 4 km (Fig. 26). The combined radar/lidar image supports our hypothesis, namely that we were dealing with a natural phenomenon, amplified by the general circulation of the atmosphere and not an episode of anthropogenic pollution.

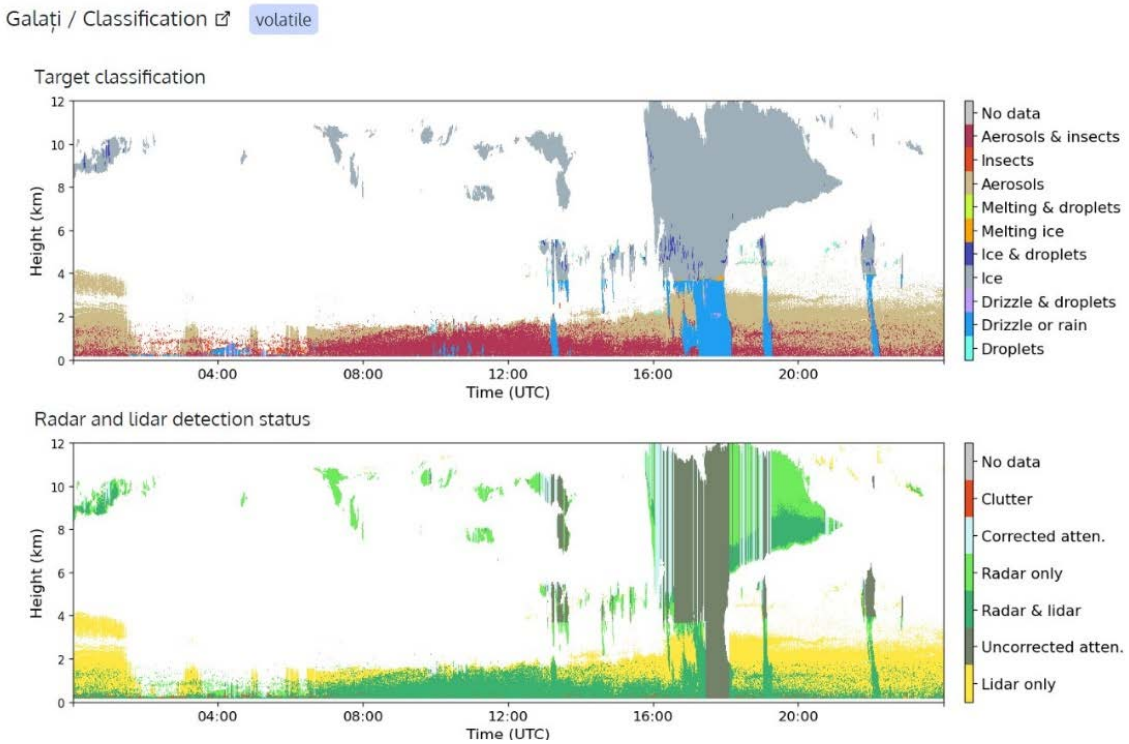


Fig. 26. Cloudnet image from UGAL – REXDAN, combining radar and lidar data [13]

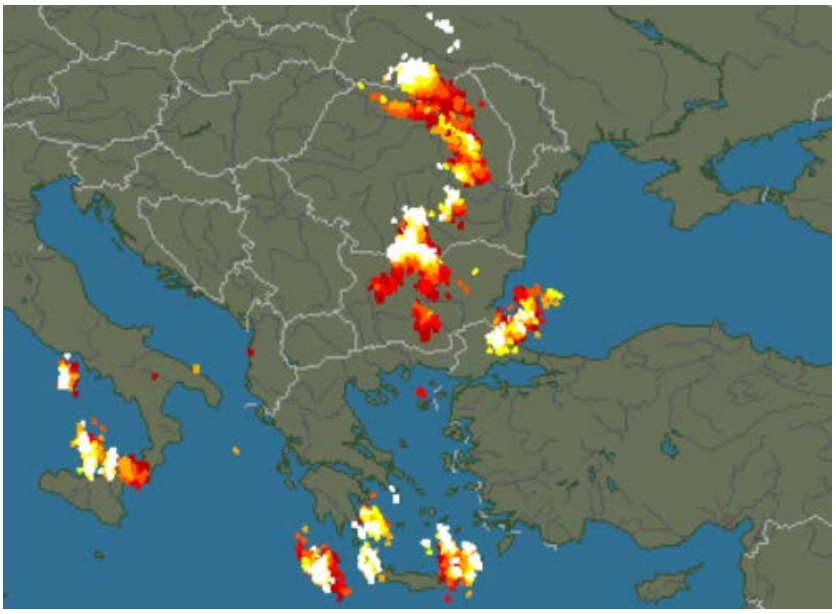


Fig. 27. Frequency and spatial distribution of detected electrical discharges,

on August the 24th 2022, h00 UTC [14]

The notable frequency of detected electric discharges was also due to the presence of suspended dust particles in the atmosphere (Fig. 27).



Fig. 28. The atmosphere loaded with dust particles, on August the 24th, 2022 at 15:51 UTC, in the area of the city of Târgu Neamț, Neamț county, on the banks of the Ozana river (photo: Adrian Timofte)

10. Conclusions

The convective episode that took place on the night of 23/24 August 2022, was one of the most representative episodes of atmospheric instability in this year's warm season. Produced in an inappropriate context for the end of August, the atmospheric instability manifested in the analyzed interval, had a decisive role on the water reserve in the soil, so that the west of Moldavia, from the contact with the mountain area, was removed from the moderate drought that affected the entire region. Atmospheric soundings thus represent important materials for capturing the specific phenomena of instability. Both the ECMWF and GFS model estimated, to a good extent, the convective potential and the intensity of the atmosphere in the analyzed evening. Both models captured the differences found between western and eastern Moldavia. Across the region, the models captured the moist layer at the land surface, with relative humidity values above 90%, preceded by a lower moisture layer between 850 and 500 hPa.

For the Târgu Neamț station, for example, the numerical forecast models, ECMWF and GFS predicted the cloud base at 900 hPa. Starting at the altitude of 700 hPa, was estimated the LFC. From

this point, the temperature of the air parcel becomes higher than the ambient temperature. The models also predicted the equilibrium level at 250 hPa and a high potential energy for convection. For the stations in eastern Moldavia, the models captured the downward of air from altitude and the inhibition of convection. For the Iasi and Botoșani stations, the surveys describe an hourglass shape that indicates the maintenance of a moist layer on the ground level and the divergent movement that broke up the cloud structures and prevented their development.

Although the models estimated water quantities of up to 30 l/m^2, in reality they were far exceeded. The addition of water can be attributed to the natural seeding of clouds with suspended particles, as a result of the detection in the Moldavia region of a significant supply of dust, transported on the eastern circulation. The high frequency of electrical discharges and the concentration of instability in the west of the region, at the contact with the mountain area, may be the result of the presence of these suspended particles in the atmosphere. It can be considered that the episode of instability that happened on the night of August 23/24, represented a classic pattern of orographic convection, on the background of circulation from the east.

Acknowledgments: The authors acknowledge the UGAL – REXDAN cloud remote sensing facility part of ACTRIS – RO (Aerosol, Clouds and Trace gases Research Infrastructure – Romania) for providing radiometer and ceilometer data used in this study. Also, the authors acknowledge the RADO (Romanian Atmospheric 3D research Observatory).

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REFERENCES

[1] Kirshbaum D.J., Adler B., Kalthoff N., Barthlott C., Serafin S., *Moist Orographic Convection: Physical Mechanisms and Links to Surface-Exchange Processes*, Atmosphere, 2018; 9(3):80, https://doi.org/10.3390/atmos9030080

[2] Silvestri L., Saraceni M. & Bongioannini Cerlini P., *Links between precipitation, circulation weather types and orography in central Italy*, International Journal of Climatology, 2022, 42(11), 5807–5825, https://doi.org/10.1002/joc.7563

[3] Heim C., Panosetti D., Schlemmer L., Leuenberger D. & Schär C., *The Influence of the Resolution of Orography on the Simulation of Orographic Moist Convection*, Monthly Weather Review, 2020, 148(6), 2391-2410.

[4] Hochman A., Marra F., Messori G., Pinto J.G., Raveh-Rubin S., Yosef Y. and Zittis G., *Extreme weather and societal impacts in the eastern Mediterranean*, Earth Syst. Dynam., 13, 749–777, https://doi.org/10.5194/esd-13-749-2022, 2022.

[5] Cai X., Cao H., Fang X., Sun J. and Yu Y., *A View for Atmospheric Unpredictability*, Front. Earth Sci. 9:686832 (2021), doi: 10.3389/feart.2021.686832

[6] Yano J.I., Ziemiański M.Z., Cullen M., Termonia P., Onvlee J. et al., *Scientific challenges of convective-scale numerical weather prediction*, Bulletin of the American Meteorological Society, American Meteorological Society, 2018, ff10.1175/BAMSD-17-0125.1ff. ffhal-02395934f

[7] Bartoszek K., *The main characteristics of atmospheric circulation over East-Central Europe from 1871 to 2010*, Meteorol Atmos Phys 129, 113–129 (2017), https://doi.org/10.1007/s00703-016-0455-z

[8] Modellzentrale Database, accessed on 03/09/2022, http://www.modellzentrale.de/

[9] Firenzemeteo Database, accessed on 03/09/2022, https://www.firenzemeteo.it/

[10] Wetter Database, accessed on 04/09/2022, https://www.wetter3.de

[11] Wetterzentrale Database, accessed on 01/09/2022, https://www.wetterzentrale.de/

[12] Wetter und Klima - Deutscher Wetterdienst, accessed on 02/09/2022, http://www.dwd.de/

[13] Zoom Earth, accessed on 05/09/2022, https://zoom.earth/maps/daily/

[14] European national meteorological services, trainers and operational forecasters, accessed on 03/09/2022, https://eumetrain.org/index.php/eport

[15] WxCharts Database, accessed on 08/09/2022, https://www.wxcharts.com/

[16] European national meteorological services, trainers and operational forecasters, accessed on 07/09/2022, http://www.eumetrain.org/

[17] Meteologix Database, accessed on 05/09/2022, https://meteologix.com/ro

[18] Hassan A., Ilyas S.Z., Agathopoulos S., Hussain S.M., Jalil A., Ahmed S. & Baqir Y., *Evaluation of adverse effects of particulate matter on human life.* Heliyon, 2021, 7(2), e05968, https://doi.org/10.1016/J.HELIYON.2021.E05968

[19] Kim K.H., Kabir E. & Kabir S., *A review on the human health impact of airborne particulate matter*, Environment International, 2015, 74, 136–143, https://doi.org/10.1016/J.ENVINT.2014.10.005

[20] Copernicus - Particulate matter forecasts Database, https://atmosphere.copernicus.eu/charts/cams/particulate-matter-forecasts

[21] National Air Quality Monitoring Network, accessed on 05/09/2022, https://www.calitateaer.ro/

[22] ACTRIS Cloudnet data portal, accessed on 05/09/2022, https://cloudnet.fmi.fi/search/visualizations

[23] Illingworth A.J., Hogan R.J., O'Connor E.J., Bouniol D., Brooks M.E., Delanoë J., Donovan D.P., Eastment J.D., Gaussiat N., Goddard J.W. et al., *Cloudnet: Continuous evaluation of cloud profiles in seven operational models using ground-based observations*, Bull. Am. Meteorol. Soc. 2007, 88, 883–898.

[24] https://www.blitzortung.org/, accessed on 05/09/2022

[25] Schicker I., Radanovics S. and Seibert P., *Origin and transport of Mediterranean moisture and air*, Atmos. Chem. Phys., 10, 5089–5105, 2010, https://doi.org/10.5194/acp-10-5089-2010

[26] Manzato A., *The Use of Sounding-Derived Indices for a Neural Network Short-Term Thunderstorm Forecast*, Weather and Forecasting, 2005, 20(6), 896-917.

[27] Manzato A. & Morgan G.J., *Evaluating the sounding instability with the Lifted Parcel Theory*. Atmospheric Research, 2003, 67–68, 455–473, https://doi.org/10.1016/S0169-8095(03)00059-0

[28] Gangane A., Pawar S.D., Gopalakrishnan V. and Saikrishnan K.C., *Effect of dust particles on lightning flash rate and polarity of dust storms over India*, Natural Hazards, 2022.