Long Range Transport Analysis Based on Eastern Atmospheric Circulation and Its Impact to the Dust Event over Moldavia, Romania in August 2022

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Article

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Abstract: During the second half of August 2022, a dust intrusion event occurred, when dust that originated from the dry regions of Kalmyk steppe and the Precaspian plain was transported over the eastern region of Romania. The dry soil in these regions was the result of the severe drought over a long period of time, accentuated by early heat waves in May and June 2022. The dust event was captured by MODIS images. Smoke trains originating from fires in the north of the Azov were also detected, but these did not reach Romania. Optical parametres from AERONET was used to confirm the dust event. To determine the trajectory of the particles, the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model was used in this paper. The Ensemble median model was used to highlight the presence and concentration of dust in eastern part of Romania. Aerosols were detected between 0 and 4 km, according to radar and ceilometer data of the REXDAN cloud remote sensing facility in Galați, Romania. This dust intrusion event was the result of the dominant easterly circulation caused by the extension of East European High to the northeast of the continent, which transported the dust towards eastern part of Romania for more than 2 days. Moreover, the torrential rains between August 22nd and 24th did not clear the atmosphere of dust, since the intense easterly circulation kept carrying the dust into the Moldavian area.

Keywords: dust transport; air pollution; eastern atmospheric circulation; aerosols

1. Introduction

The drought of 2022 in Europa was considered the worst in recent years by The European Commission Joint Research Center (EC-JRC) and was intensified in August, according to the European Drought Observatory (EDO) of the Copernicus Emergency Management Service (CEMS) [1]. In areas with dry and scattered vegetation, wind erosion can easily occur, leading to the transportation of dust over long distances. The Kalmyk steppe is located in the arid belt of the Russian Federation, where desertification is fully manifested (up to 80%) [2]. Depending on synoptic conditions, dust particles can be transported over long distances and can accumulate at ground level and at high altitudes. Moreover, dust particles can remain in the lower troposphere for several days. Studies related to the transport of Saharan dust to Europe are numerous [3–6], but only few have considered dust particles of Asian origin [7].

A study by Joseph M. Prospero et al in 2002 [8], showed that the highest concentrations of dust in summer are observed in Europe and the Middle East in the late spring. While peak dust activity

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occurs in the cold semester at low latitudes the highest dust concentrations are transported in summer and spring at medium and high latitudes [8]. Thus, for the latitude of Romania, the lowest dust activities are in autumn and winter. Prospero's work from 2002, identified the sector between the Caspian Sea and the Aral Lake as one of the most important global sources of dust, with persistent dust activity. Although dust can be transported from this region throughout the year, the most intense periods are from May to August.

The thermodynamics and dynamical characteristics of the atmosphere or various meteorological events can influence pollution events. Weather conditions can facilitate or reduce the transport, dispersion, diffusion, preservation, modification and transformation of pollutants [9]. For example, continental anticyclones are associated with pollution, while cyclones are associated with dispersion [10]. Dust particles have a direct impact on health, the environment and climate. Dust particles can absorb and reflect radiation, influencing air temperature and altering clouds properties [11]. Romania, due to its geographical position, is one of the countries where the atmosphere can be infused with dust particles of Asian origin. However, the African continent is the main global source of dust observed in Romania [12].

We show here that the dust detected in the lower atmosphere of Romania at the end of August in 2022 originated from another source. Weather and meteorological data, together with remote sensing observations, will be analyzed to identify the role played in the dust event observed in the eastern part of Romania on August 22nd and 23rd, 2022, especially since eastern circulation events are atypical for this region during summer. We will identify weather conditions that may have favored both the transportation and the persistence of dust in the eastern region of Romania at the end of August.

2. Materials and Methods

The area where the dust event was observed on August 22nd -23rd is Moldavia, in the eastern part of Romania (Figure 1). We used synoptic maps of the middle troposphere and ground level from the ECMWF (European Center for Medium-Range Weather Forecasts) and GFS (Global Forecast System) models, to help us describe the mesosynoptic conditions during the 2 days of the dust event. The dust event was also captured by the MODIS (Moderate Resolution Imaging Spectroradiometer) images, which provide data with good spatial resolution in 36 spectral bands ranging in wavelength from 0.4 μm to 14.4 μm [13]. MODIS products have a spatial resolution of 250 m, 500 m, 1 km. Channels with wavelengths between 0.4 μm and 2.1 μm are used to characterize aerosols. The spatial resolution for producing daily level aerosol optical thickness is 10 km x 10 km [14].

The origin of the dust event was initially considered to be of Saharan origin [15]. However, using the HYSPLIT model and the GDAS- U.S. NOAA database [16], in this paper we show that the dust event between 22nd and 24th August 2022 observed in the Moldavian troposphere originates in the arid regions of the Kalmyk steppe (the Caspian region) most likely because of an intense circulation from east. A preliminary analysis of the dust event August 23/24, 2022 has already been shown by Apetroaie et al. [17].

Radar and ceilometer data provided by the REXDAN cloud remote sensing facility in Galati, Romania (SE of Moldavia, 45°26`07.1" N, 28°02`13.8" E), confirmed the presence of aerosols between 0 and 4 km [18]. This data can be accessed and viewed by accessing the monitoring point in Galati from the CloudNet data portal [18]. AERONET observations are complementary to these types of analyses (both qualitative and quantitative analyses). The Kishinev (about 100 km from Iasi), Moldova monitoring point (47.00° N; 28.82° E) was chosen because it contains enough data to achieve a statistical correlation to determine the predominant type of aerosols for the considered period.

Inversion products based on the level 1.5 inversion data (version 3) with AOD values (at 440 nm) greater than 0.2 were used. According to the commonly accepted clustering method in literature, the Absorption Ångström Exponent (AAE) and Scattering Ångström Exponent (SAE) were calculated using the 440 nm and 675 nm wavelengths. These optical parameters values were used to determine the type of aerosols [19–25].

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We used European ensemble dust-model to analyze the dust event, which brings together the performance of each individual model based on the nine air quality forecast models [26]. The European ensemble model uses the median value of each model, thus minimizing the uncertainty. It collects a series of pollutants regulated by the EU, such as PM10 and PM2.5 fine particles matter, sulfur dioxide, ozone, nitrogen dioxide, which are regularly validated by in situ observations [27].

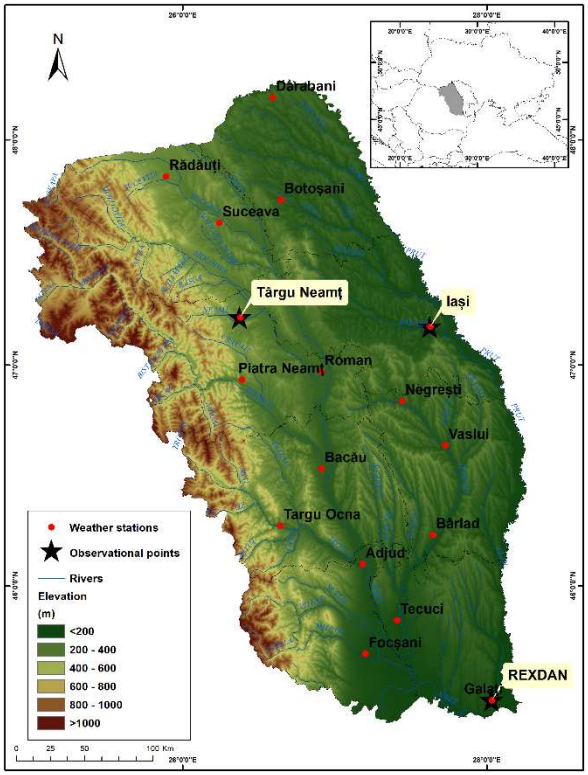

Figure 1. Map of the studied area.

3. Mesoscale Context

3.1. Ground Level

The Eastern European High was present in NE Europe in the analyzed period. Its ridge gradually extended over the northeast of Romania, which ensured a continuous flow of air from the east. For Romania, August is considered the warmest and sunniest month of the year, characterized by a greater stability of masses [28]. This is due to the change of baric centers, respectively, the extension of Azores High's ridge over Eastern Europe. The stability of this region in August is generally ensured by the formation of a high pressure belt, resulting from the union of the Azores High's ridge and the Eastern European High' ridge, to which tropical air from the north of Africa is added [28].

However, the atmosphere was configured differently at the end of August 2022. The activity of the Azores ridge in this part of Europe was reduced, to which the presence of a low-pressure field in the Mediterranean Sea basin and the Middle East region was added (Figure 2). Thus, pollutants transported from the east were trapped in the eastern part of Romanian, where the air was warm and humid, due to the flow of moisture brought from the Mediterranean basin. This ultimately represented a reservoir of atmospheric instability on the night of 23/24 August [18].

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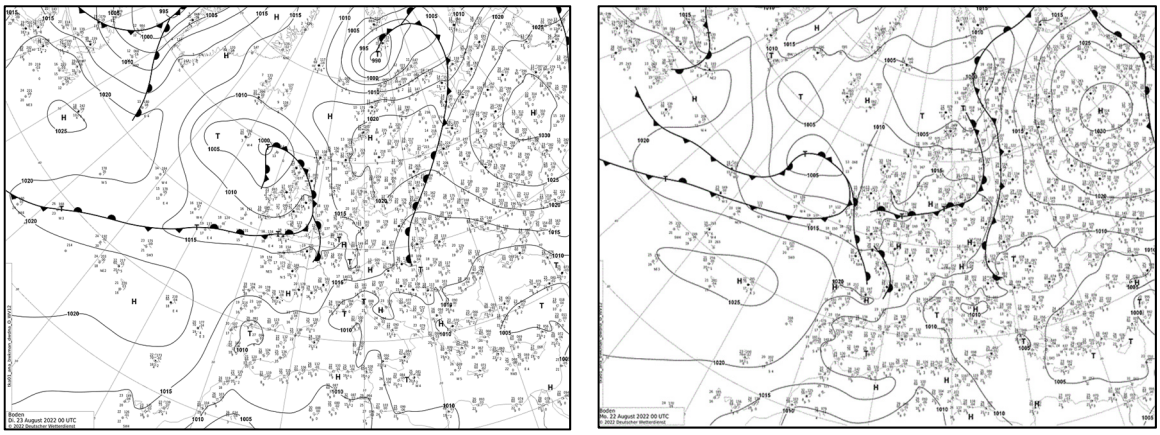


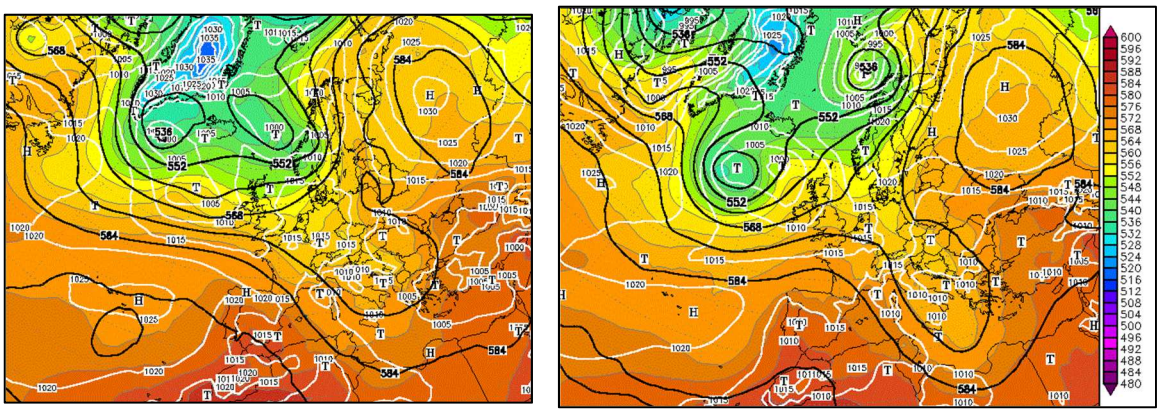
(**a**) (**b**)

Figure 2. Synoptic maps at ground level (black lines represents isobars (hPa) for 23rd (**a**) and 22nd (**b**) of August, 2022 [29].

3.2. Middle Troposphere and 850 hPa Level

Starting with 20th of August, a well-individualized geopotential nucleus was present in the middle troposphere of the northern part of the continent. Gradually, a middle troposphere trough extended from this nucleus, which deepened over time. On August 23rd, it reached the eastern basin of the Mediterranean Sea, west of the Balkan Peninsula (Figure 3).

The eastern part of Romania was on the ascending side of this trough, which maintained a flow of moisture and heat from the Mediterranean Sea. As the trough deepened, atmospheric instability began to manifest. Dust particles offered a large reservoir for new condensation nuclei which led to consistent amounts of precipitation, and in the end, contributed to the atmospheric instability [30].



(**a**) (**b**)

Figure 3. Synoptic maps at 500 hPa level, for August 22nd (**a**) and 23rd (**b**) 2022 (black lines represents isohypses (gpdam) and white lines represents isobars (hPa) at ground level) [28].

3.3. Streamlines and Wind Direction

At 500 hPa the atmospheric circulation was southerly, due to the positioning of an altitude nucleus west of the Balkan Peninsula, for both 22nd and 23rd of August 2022 (Figure 4). The Eastern part of Romania is located on the extending side of the geopotential trough and was fed with moisture and heat from the Mediterranean Sea basin. This altitude nucleus fluctuates and slightly changes its position. Following, the altitude nucleus deepens its valley on 23rd of August. The circulation is thus the result of the presence of this nucleus formed in the Mediterranean Sea.

At the ground level the atmospheric circulation, in the analyzed region, was exclusively easterly, as a result of the activity of the East European Anticyclone in this part of Europe, whose ridge was

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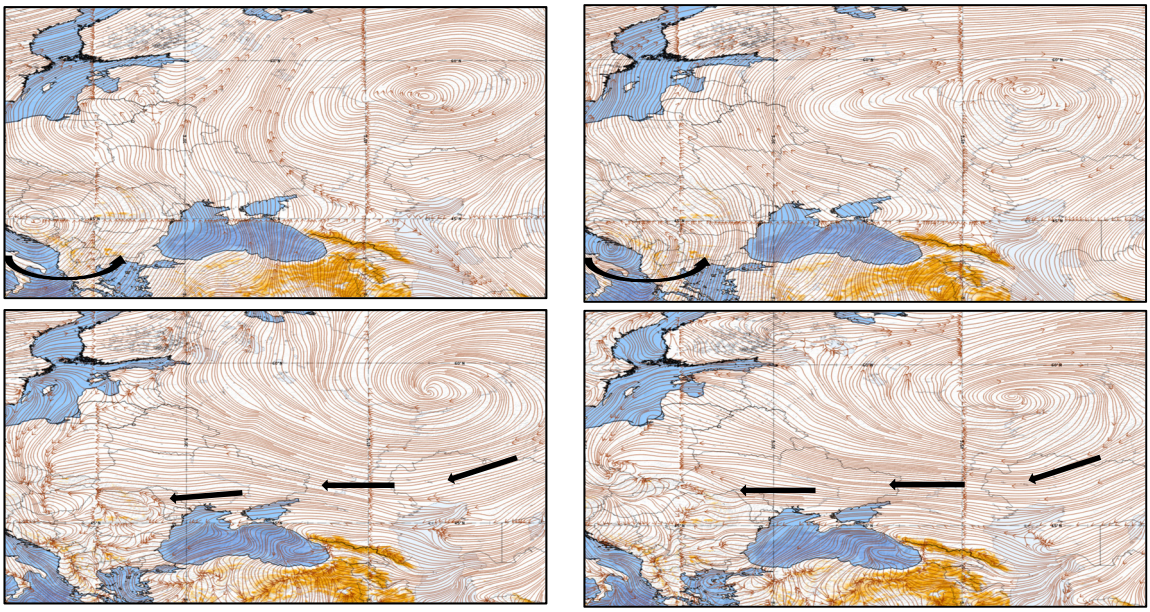
extended only to the extra-Carpathian region. The streamlines in Figure 4 describe the intense easterly circulation from the ground surface that ensured the continuous transport of air masses from the east. As a result of the stability given by the downward movements, in the eastern half of the analyzed region, atmospheric instability did not manifest itself. Instead, in the western area, orographic instability dictated the weather aspect.



(**a**) (**b**)

Figure 4. Streamlines for (**a**) August 22nd, 2022 (500 hPa level- up, ground level- down) and (**b**) August 23rd, 2022 (500 hPa level- up, ground level- down).

The wind speed and wind shear is small (Figure 5) at low altitudes/ground level, due to the Eastern European High extending over the area of interest. At higher altitudes the wind direction is better defined. The easterly circulation is maintained up to 750 hPa. At higher altitudes, between 750 and 200 hPa, the wind speed increases and the gradually changes its direction, dictated by the geopotential nucleus in the Mediterranean Sea. Between 750 and 100 hPa, the wind blows from the predominantly southern sector. Up to 925 hPa the direction of the wind is rapidly changing.

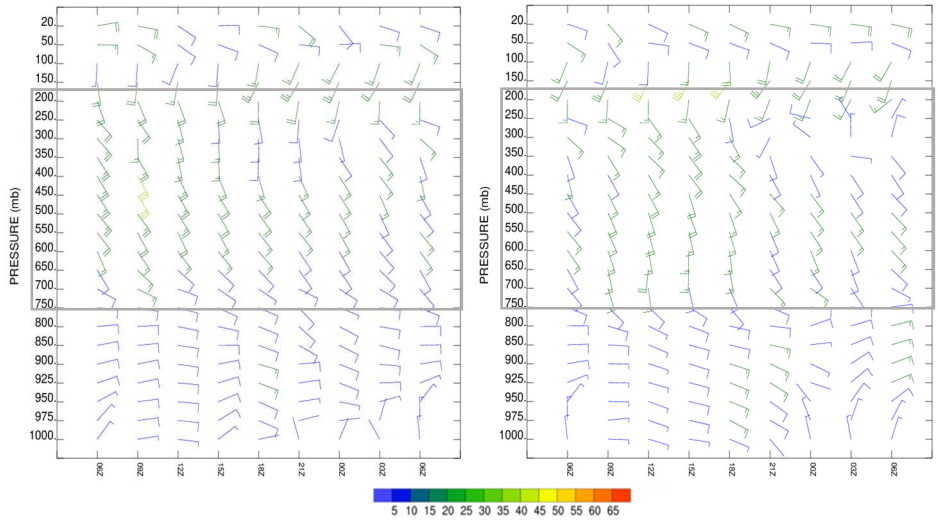


Figure 5. Vertical wind profile (wind bars – speed in m/s and direction) for August 22nd (**left**) and 23rd (**right**), 2022.

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4. Dust Event Analysis

4.1. Analysis of MODIS Satellite Images

On August 21st, satellite images show a high concentration of dust particles in the atmosphere, originating from the arid region around Caspian Sea affected by drought. Here the wind erosion was able to dislodge dust particles from the land depleted of water and vegetation. On August 22nd, the dust traveled further westward and was supplemented by particles from the north of the Black Sea, resulting in a cloud of dust detected north of the Sea of Azov on this date. Images show that fine particles continue to be displaced from the source, locality.

The Eastern Europe High (Figure 4) is the primary factor responsible for the presence of dust particles detected in the low atmosphere of Moldavia in this interval and it facilitated a continuous flow of air masses from the east.

On August 23rd, these particles are further transported to the west, invading the eastern Romania. The dust continues to be transported on August 24th, but at lower concentrations. The dust arrived in a region of humid and warm air supplied by the middle troposphere trough, generating a milky atmosphere that persisted in the east of Moldavia for over two days. This phenomenon would not have occurred at this particular time of the year without an intense movement of air masses from east to west, which also lasted for several days. Thus, dust of eastern origin has been transported towards the region of Moldavia.

The downward movement specific to anticyclones allowed the preservation of these particles in the lower troposphere during the analyzed interval. In this case, air masses remained above the earth for several days and were heated by it [31], which offered a favorable stable environment for locking the dust particles in this region.

Satellite images (Figure 6) show trains of smoke in the East European Plain, to the north and east of the Dnieper River. These were moving towards the west, driven by the atmospheric circulation imposed by the Eastern European Maximum. The fires that affected this area during the analyzed period resulted in a combination of smoke and dust being transported over long distances. In addition to anthropogenic causes, the large-scale fires were also facilitated by dry conditions, with lack of water in the soil or dry vegetation, all caused by the drought that affected Europe in 2022 [32].

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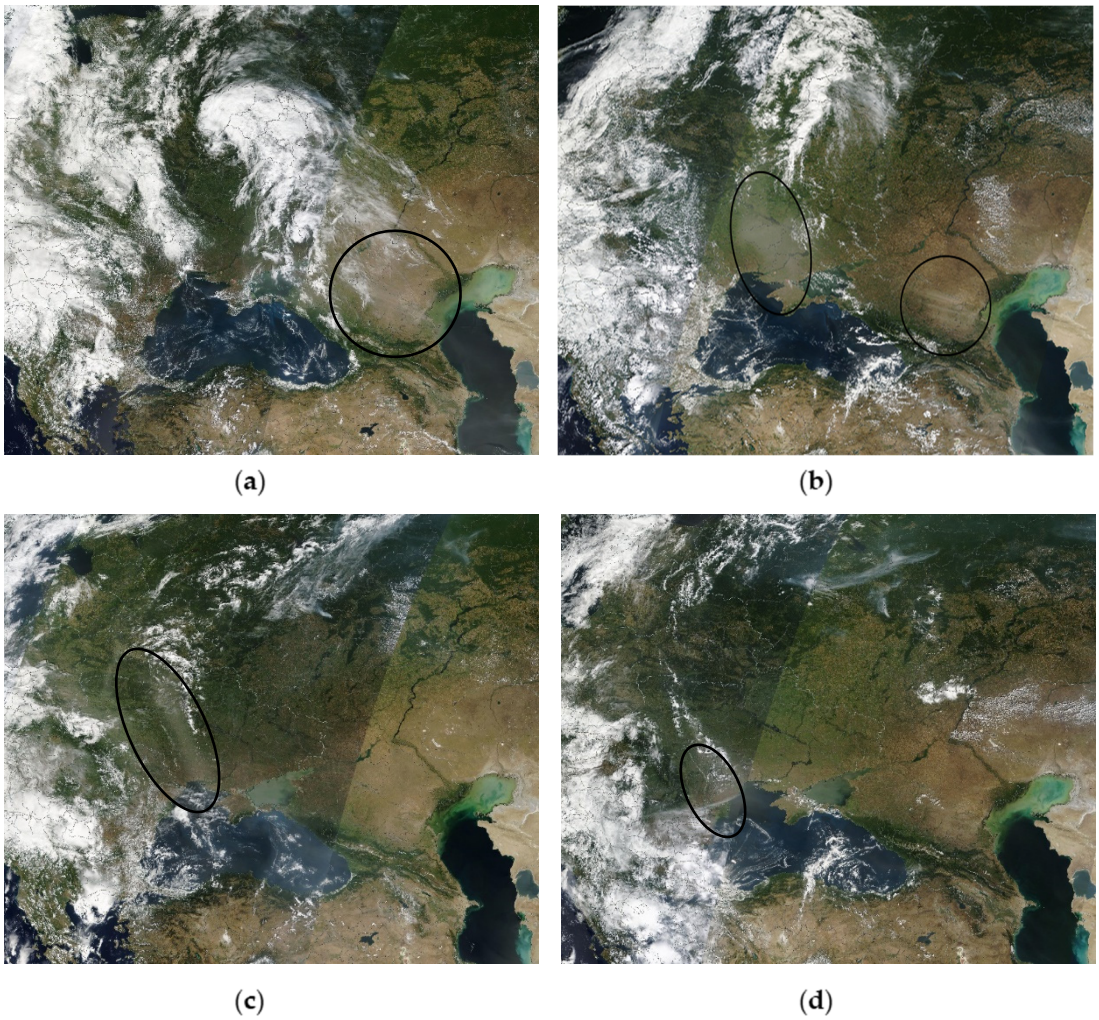

Figure 6. MODIS satellite images for August 21st (**a**), 22nd (**b**), 23rd (**c**) and 24th (**d**), 2022 (dust from the Russian steppes is highlighted inside the circles).

4.2. Analysis of Forecast Models and Reanalysis Data

4.2.1. MERRA Data

MERRA - 2 reanalysis data (Figure 7) show that high concentrations of dust particles are located north and west of the Black Sea, originating in these dry steppes [33]. These particles were transported over long distances, reaching the atmosphere of Romania mainly on 23rd of August, when the particles flooded the atmosphere of the eastern part of Europe, reaching as far as Germany and Poland, but also the Baltic countries. The highest concentrations, over 180 μg/m^3, were mainly detected in the east of Romania, without crossing the Carpathian arc to the west. The flow of particles was continuous during the analyzed period. On August 22nd the dust had the highest concentrations (over 300 μg/m^3), were concentrated in Ukraine, in the Dnieper basin and the East European Plain. Later, on August 23rd dust moved over the eastern part of Romania, the Republic of Moldova and the Northern Countries - Eastern Europe, with slightly lower concentrations.

The dust transportation continued throughout August 23rd and was slightly reduced on August 24th, when dust was slowly transported towards the north. The orographic barrier represented by the Carpathian chain prevented the dust particles from circulating further, to the west. Therefore, the eastern Romania was the most affected by this natural episode of dust transport.

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The atmosphere of the Mediterranean Sea remained free of dust particles, which, together with the atmospheric circulation that prevailed over Eastern Europe and the European part of Asia at that time, supports the idea that the dust event in Romania is of Asian and not Saharan origin.

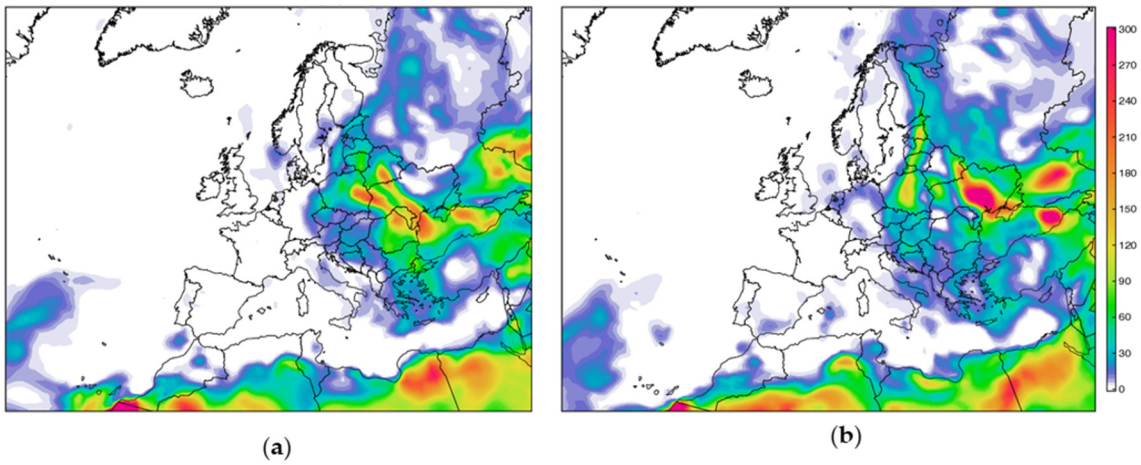

Figure 7. Dust surface mass (μg/m³) for August 22nd (**a**) and 23rd (**b**), 2022 (Modern - Era Retrospective Analysis for Research and Application, Version 2).

4.2.2. European Ensemble Model

The August 2022 dust event was accurately predicted by the models. The ensemble model, which incorporates several forecast models [34], signaled the presence of dust in the eastern half of Europe, with the highest concentrations in the Black Sea basin, eastern Romania and the Republic of Moldova, western Ukraine, Poland, the Baltic States and Belarus. However, for August 22nd (Figure 8), lower concentrations of dust were forecasted for the eastern region of Romania. The Eastern European High ensured the transport of dust that reached higher concentrations the following day. According to the model, the average dust concentration for August 22nd, was below 50 μg/m³.

The model accurately captured the distribution of the dust cloud in the Eastern part of the Carpathians. For 23rd of August the model predicted average concentrations of over 200 μg/m³ in the eastern region of Romania. This is not surprising, since we have shown that transportation was intensified on this particular day. Based on the model, it was estimated that the dust from the lower levels might have originated from Asia.

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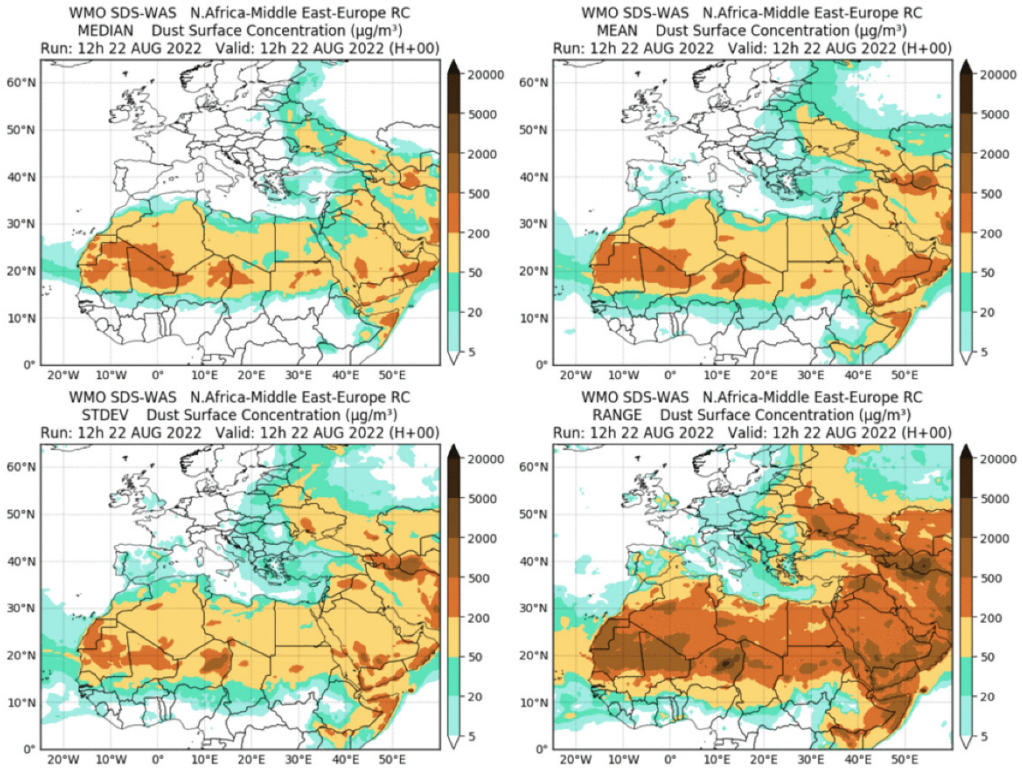
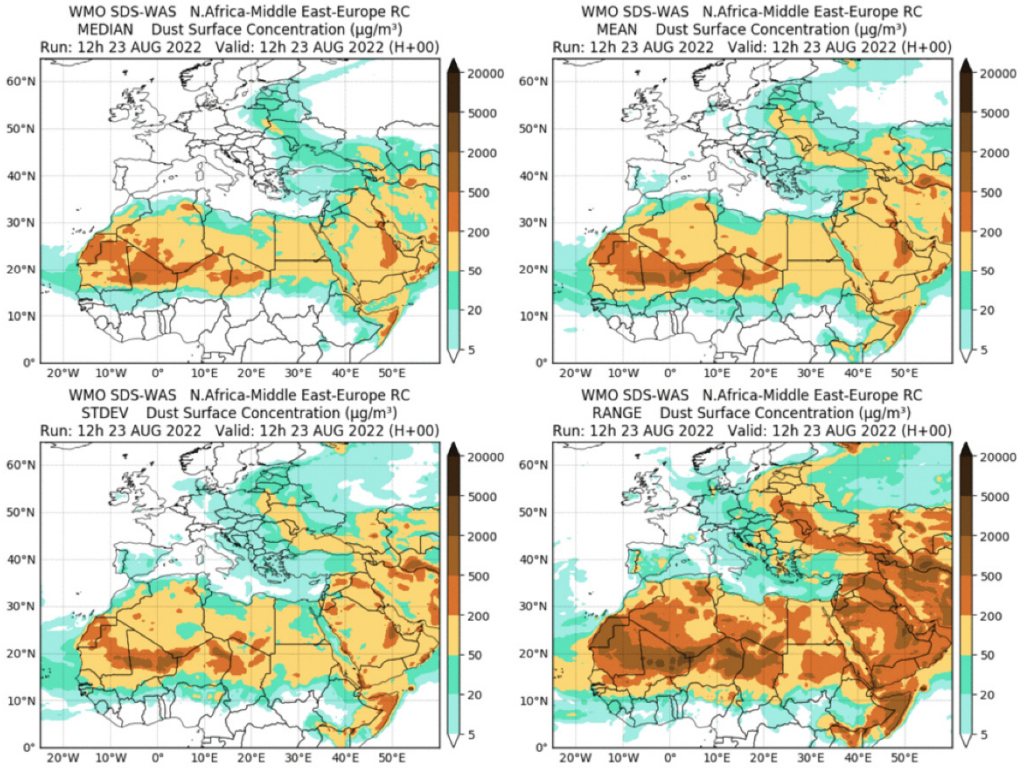


(a)



(b)

Figure 8. European ensemble model-dust surface concentration (µg/m³) for August 22nd (a) and 23rd (b), 2022 (Run 12h) - median (upper left), mean (upper right), stdev (bottom left), range (bottom right).

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4.3. Backward Trajectories Analysis

In order to identify the origin of the dust present in the atmosphere of Moldova on August 23rd, we analyzed the back trajectories of the particles (Figures 9–11), for three observation points, respectively Târgu Neamț (47°12'9"N 26°21'31"E) and Iași (47° 9' 6.2'' N, 27° 35' 16'' E) observation points shown in Figure 1. The points of 500 and 1500 meters were chosen as reference altitudes in the analysis, in order to highlight the relief characteristics of the region. In order to analyze the situation in the free atmosphere, but also to have a clear vertical image, the altitude of 5000 m was also selected. Backward trajectories for 72 hours show that the particles originated from the Asian continent.

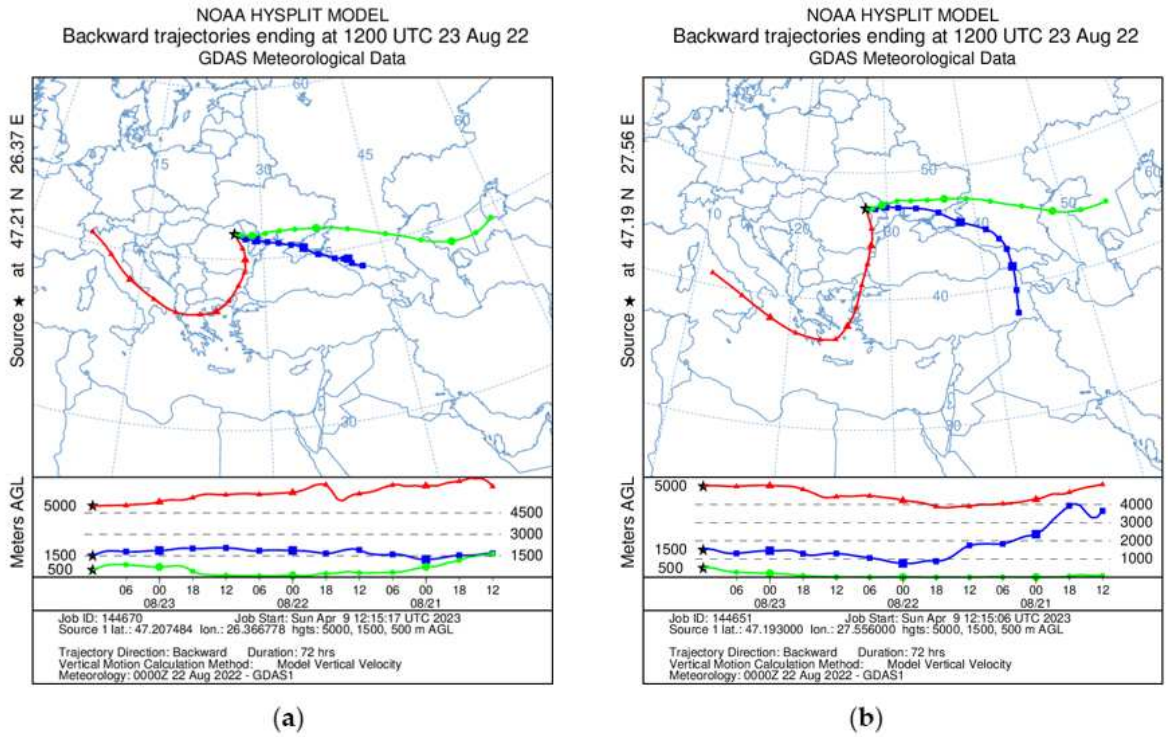

Figure 9. Backward trajectories for August 23rd, 2022- Duration: 72 hours (**a**- for Târgu Neamț observation point, **b**- for Iași observation point).

HYSPLIT shows that particles arriving at Târgu Neamț station particle are detected on August 21st at 12 UTC, at an altitude of 1500 meters, originating from the region beyond the Caspian Sea, specifically from the dry region of the Turan Plain. On August 22nd, at 12 UTC, particles moved north of the Azov Sea passing through the region of the Donesk Plateau, and on Augus23rd the particle reached the point of interest, at an altitude of approximately 500 m. Thus, particles in the lower troposphere originate from the Asian continent.

At the same altitude, of 1500 m, in the eastern region of Romania, the dust has a clear trajectory from the east as well but starting in the Kalmyk steppe. For the Iași observation point the HYSPLIT results are similar.

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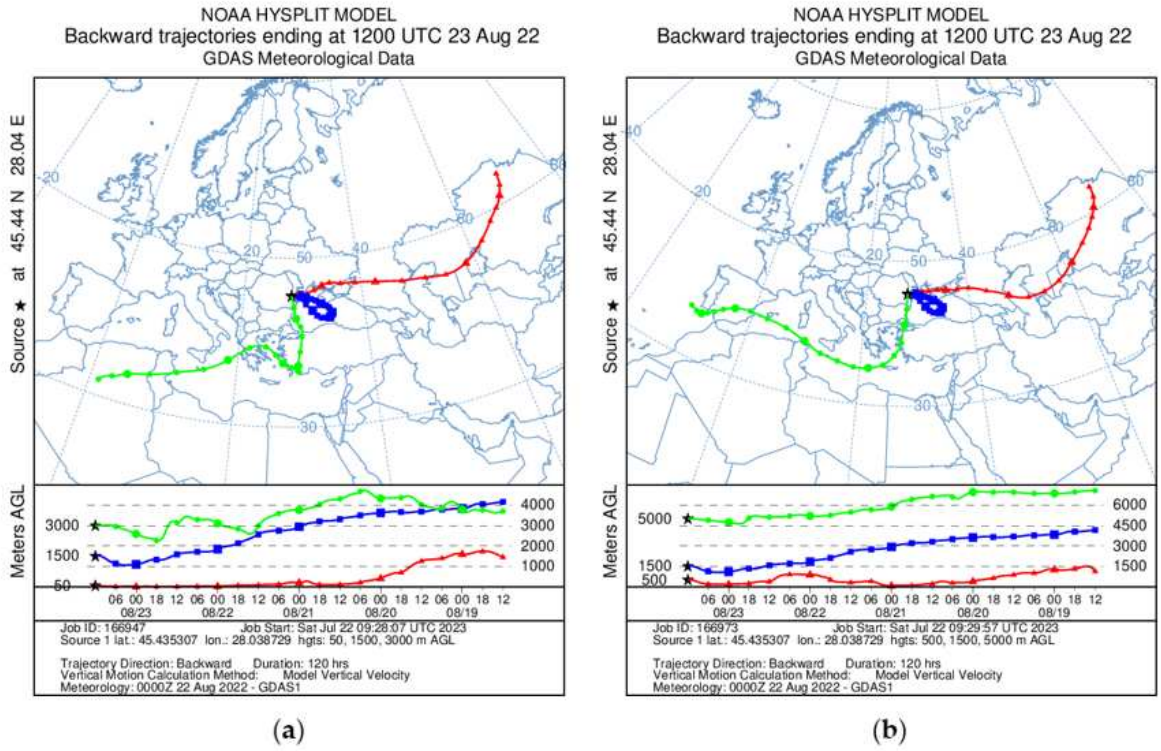

Figure 10. Backward trajectories for 23rd of August, 2022- Duration: 120 hours (**a**- REXDAN- Galați observation point, **b**- REXDAN- Galați observation point).

Precisely to demonstrate the stratification of different types of dust (Saharan dust, respectively dust from the Russian steppes), we chose to investigate the layers from 50m, a1500m and 3000m. It can be easily observed that dust of eastern origin reaches above the observation point, at low altitudes. The one that would have origins from the Sahara, does not mix and is maintained at high altitudes (over 3000 m). Moreover, the stratification is not perfect in Moldavia region, because of the complex movements in the atmosphere, as we said above, instead, the influence of each type of dust can be observed, depending on its origin, on various levels.

The situation is different at higher altitudes: at 5000 m, the particles are of European origin. On August 21st at 12 UTC, the particle travels from the Swiss Alps area, from an altitude over 4000 m. On August 22nd, the particles were in the region of the Aegean Sea, catching dust particles from the Mediterranean Sea in their path, which are probably of Saharan origin.

On August 23rd, the particles reach the atmosphere of Moldavia at an altitude of 5000 m. It should be mentioned that these particles are well defined in altitude. The dust particles in the low atmosphere in eastern Romania have their origin in the arid regions of Asia, while at over 4000 m, the particles have a southern origin, from the Sahara. These layers are very well defined and do not mix.

The situation seems to change slightly when extending the travel time of particles to 120-hours (Figure 8). The dust at low altitudes originates in the south of the Western Siberian Plain, from an altitude of over 3000 meters, on August 19 at 12 UTC. On August 20th, the particles are entrained from an altitude below 3000 m, beyond the Caspian Sea, from the Turan Plain region. However, it is difficult to say, based only on HYSPLIT, where from was the dust picked up. Thus, one can only infer that the dust event has Asian origin.

On August 22nd, the particles travel north of the Black Sea, in the eastern part of Ukraine, where the particles are drawn from an altitude of 500 m. On August 23rd, particles reach the eastern region of Romania at an altitude of 500m. On August 23rd, particles can be seen mixing at an altitude of about 2000 m, north of the Sea of Azov.

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According to the HYSPLIT, dust particles from high altitudes, if existing, were carried from the Western Europe on 22nd August, probably picking up some particles when sweeping the region of the Dalmatian coast of the Adriatic Sea, at an altitude of approximately 5000 m.

It is also the moment when, possibly, the dust is mixed with that of the Sahara. In the region of eastern Romania, the dust thus travels from the south, arriving here on August 23rd. And this time, it can be observed that the dust that flooded the low atmosphere of the eastern region of Romania is of Asian origin and not of Saharan origin. Even there are easy concentrations of Saharan dust at an altitude of over 5000 m, it was not transported to the lower layers of the atmosphere.

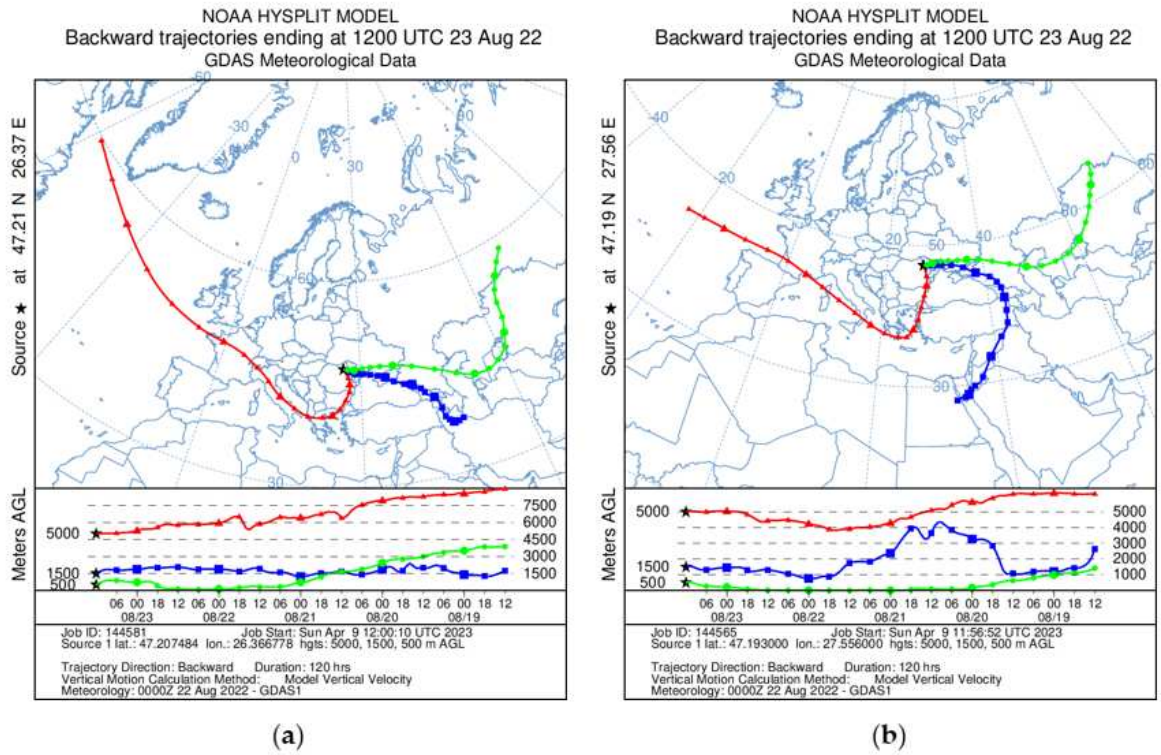

Figure 11. Backward trajectories for 23rd of August, 2022- Duration: 120 hours (**a**- for Târgu Neamț observation point, **b**- for Iași observation point).

For the observation point from Iasi, a difference is noted. It seems that the origin of the dust from the altitude of 1500 is a southern one, from the African continent in the Eastern Desert of Egypt. These particles travel through the Middle East. However, it can be observed that on August 21st, this dust of Saharan origin is located at an altitude of over 4000 m altitude and does not mix with the dust from low altitudes that arrived in the eastern region of Romania on August 23rd.

Overall, the dust event can be attributed to the easterly circulation, from Asia. At higher altitudes, over 5000 m altitude, dust may originate from the Dalmatian coast. However, the two major layers, at low and high altitudes, do not mix. The atmosphere in eastern Romania was therefore loaded with particles of Asian origin and there was no mixing with the particles from other origins at different altitudes.

4.4. Air Quality Analysis

Analyzing the air quality bulletins from different points in eastern Romania, made available by the Ministry of the Environment National Agency for Environmental Protection (ANPM) [35], it can be stated that the dust episode analyzed was not a polluted one, considering that no fine particles of PM2.5 were detected, and those of PM10 did not exceed the harmful threshold for human health [36].

According to Air Quality, LAW no. 104 of June 15, 2011, the daily limit value of PM10 particles for the protection of human health is 50 μg/m^3, with 35 overtakings allowed per year [37], and the

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annual limit value for the protection of human health is 40 μg/m³. In the case of PM2.5 particles, the annual limit value is 20 μg [38].

The analyzed examples show that for Neamț county (Figure 12), on 23rd of August, 2022, the air quality was "good" for NT2 and NT3 stations, and "acceptable" for NT1. For Bacau county (Figure 13) for all observation points (BC1, BC2, BC3), the air quality was "acceptable". The same situation was in Botosani and Vaslui counties (Figures 14 and 15).

Nr. crt.	Cod stație	Zona	Indice general de calitatea aerului zilnic						Obs.
			1 Bun	2 Acceptabil	3 Moderat	4 Rău	5 Foarte rău	6 Extrem de rău	
1.	NT 1 - FU	Piatra Neamț							
2.	NT 2 - I	Roman							
3.	NT 3 - I	Taşca							

Figure 12. Bulletin of air quality in Neamț county - general air quality index for 23rd of August, 2022 (1 - good, 2- acceptable, 3- moderate, 4- bad, 5- very bad, 6- extremely bad).

Nr. crt.	Cod stație	Zona	Indice general de calitate a aerului zilnic						Observații
			1 BUN	2 ACCEPTABIL	3 MODERAT	4 RĂU	5 FOARTE RĂU	6 EXTREM DE RĂU	
1	BC 1	Războieni, nr. 11, Bacău							
2	BC 2	Izvoare, nr.1 bis, Bacău							
3	BC 3	Cauciucului nr.1, Onești							

Figure 13. Bulletin of air quality in Bacău county - general air quality index for 23rd of August, 2022 (1 - good, 2- acceptable, 3- moderate, 4- bad, 5- very bad, 6- extremely bad).

Nr. crt.	Cod stație	Zona	Indice general de calitatea aerului zilnic						Obs.
			1 Bun	2 Acceptabil	3 Moderat	4 Rău	5 Foarte rău	6 Extrem de rău	
1.	BT-1	b-dul M. Eminescu, nr.44							Indice dat de O3

Figure 14. Bulletin of air quality in Botoșani county - general air quality index for 23rd of August, 2022 (1 - good, 2- acceptable, 3- moderate, 4- bad, 5- very bad, 6- extremely bad).

Nr. Crt	Cod statie	Zona	Indice general de calitatea aerului zilnic						Obs.
			1 BUN	2 ACCEPTABIL	3 MODERAT	4 RĂU	5 FOARTE RĂU	6 EXTREM DE RĂU	
1.	VS 1	Vaslui-FU							(*)
2.	VS 2	Husi-FU							(**)

Figure 15. Bulletin of air quality in Vaslui county - general air quality index for 23rd of August, 2022 (1 - good, 2- acceptable, 3- moderate, 4- bad, 5- very bad, 6- extremely bad).

4.5. Dust Event from AERONET—Observations

Aerosol population measured by AERONET over Moldova for August 2022, in general, are dominated by the occurrence of the elemental carbon (EC) and organic carbon (OC) mixture (fine mode particles) in the 34%, (see EC/OC mixture from Figure 16 - a).

Cazacu et al. [23] investigates how aerosol data from the – Iasi_LOASL AERONET site (47.19 ° N, 27.55 ° E) compare with the data from Moldova site (Kishinev: 47.00° N; 28.82° E) for one year (May 2012 – May 2013). Similar trends of the optical parameters were observed, thus data from Moldova site can be considered representative for the dust event. Additionally, Sîca et al. [24] and Timpu at al., [25] already reported that the EC/OC mixture type dominates for the Iasi site, as can also be seen in the figure below for Moldova site, also.

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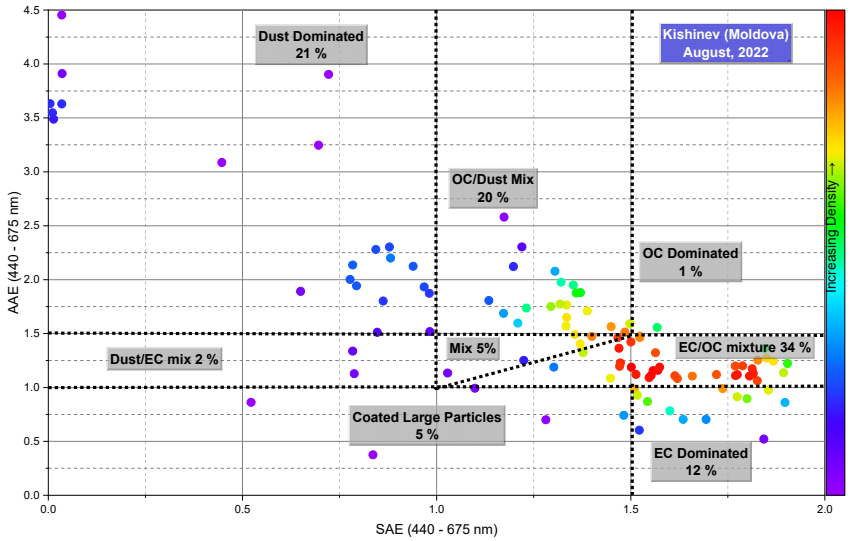
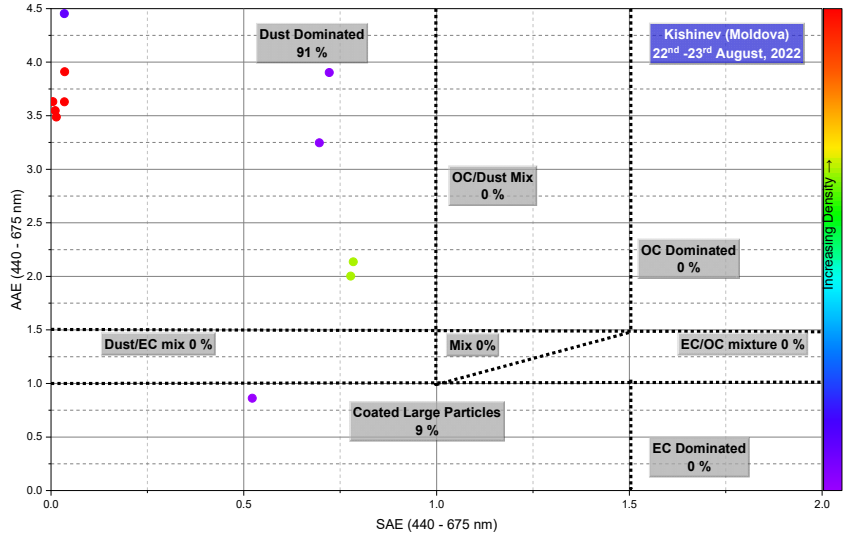
The fine mode particles, categorized as "EC dominated" in Figure 16 - a, indicate that 12% of the aerosol comes from biomass burning or soot particle types. Categories of aerosol types as: "OC dominated", "Mix", "Coated large particles" and "Dust/EC mix" are not important for our study, since they are present in a fairly small percentage of less than 5%. The other two remaining categories that may described the dust are "OC/Dust Mix" and "Dust Dominated, in a percentage of approximately 20%.

The "OC/Dust" mixture indicates that part of aerosols is of combustion/biomass burning origin, although their source is not straightforward, since no fires were signaled during that period. However, during the dust event period, i.e. August 22nd -23rd, "Dust Dominated" type makes more than 90% of the aerosol (Figure 16 - b). Due to clouds and precipitation, inversion products cannot be generated to be included in the level 1.5 inversion data (version 3) at the Moldova site on August 24th 2022.



(**a**)



(**b**)

Figure 16. Absorption Ångström Exponent [AAE at 440–675 nm] vs Scattering Ångström Exponent [SAE at 440–675 nm] in the number density plot from Moldova (Kishinev) monitoring site (**a**) [August of 2022] (**b**) [August 22nd -23rd, 2022].

4.6. Radar and Ceilometer Data

Cloud radar and ceilometer data provided by REXDAN cloud remote sensing facility in Galati, SE of Romania, revealed a consistent layer of dust between 0 and 4000 m altitude [17,18]. Figure 17

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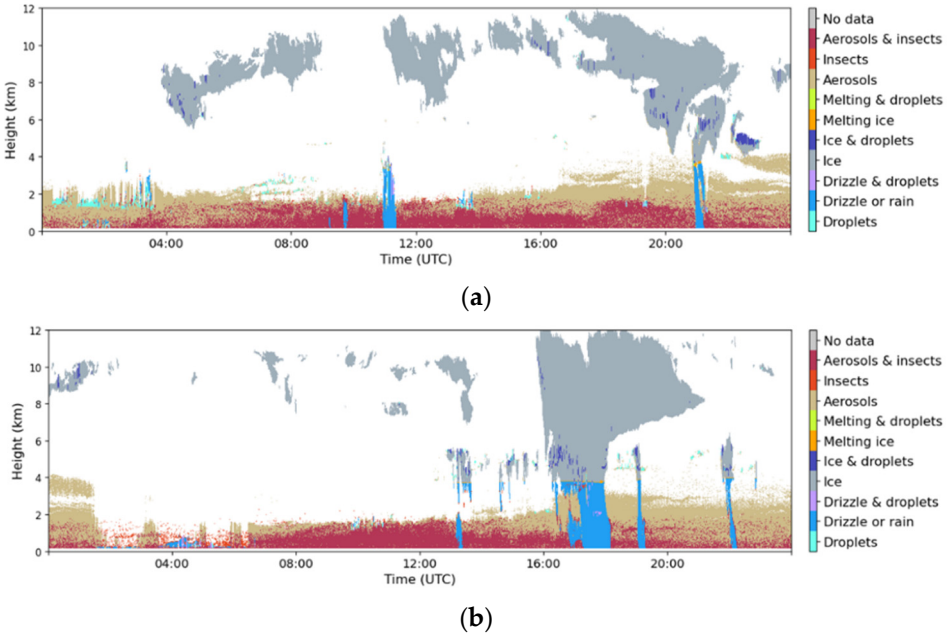
shows that on August 22nd some showers occurred between 10.00 and 12.00 LT and around 21.00 LT [18]. However, the combined radar and lidar data show that dust particles (i.e. aerosols, shown with light brown in Figure 17) persisted in the atmosphere even after these short showers.



(**a**)

(**b**)

Figure 17. Combined results of radar and lidar data for August 22nd (**a**) and 23rd (**b**) (Cloudnet image from UGAL – REXDAN).

On August 23rd, when the atmospheric instability increased, a significant torrential rain was observed in the afternoon, between approximately 17.00 and 18.00, probably as a result of the deepening of the high-altitude trough. However, large quantities of aerosol continued to be detected in the atmosphere, confirming the continuous flow of dust from the East, facilitated by the presence of the East European Maximum which directed the dust towards the eastern region of Romania.

5. Conclusion

A dust event observed during the third decade of August 2022 in the eatsren part of Romania was investigated using both model and observational data. Usually, transportation of dust from Sahara is the main source of dust events in Europe, occurring in southerly circulation conditions, resulting from deepening of cyclones in the Mediterranean Sea.

However, this particular case observed in August 22nd - 24this linked to another important source of dust, i.e. the arid regions of Asia. Due to favorable synoptic conditions of easterly circulation resulting form the persistence of the East European High in the Russian Plain, dust was present in the atmosphere for more than two days in the eastern region of Romania. On the night of 23/24 August, 2022, the atmosphere became instable due to the advancement of a high-altitude trough whose ascending part reached the eastern part of Romania. The torrential rains, potentiated by the presence of a depression area in the Mediterranean basin correlated with a deep altitude trough, did not clean the atmosphere of dust. Satellite images have captured smoke trains, but smoke was not detected in the Romanian atmosphere.

Based on HYSPLIT generated backward trajectories, the origin of dust in the lower troposphere is of Asian origin, up to at least 1500 m. The AERONET data showed the presence of dust. Additionally, the presence of other types of pollutants such as various types of combustion/biomasses burning, urban and industrial pollution contributed to the optical parameters values as a characteristic of mixing between the intrusion events of both the Saharan dust from higher altitudes and of the dust from eastern origin dispersed in the low troposphere.

However, in the analyzed days, the optical parameters presented specific values of a dust event intense enough to allow us to neglect the influence of the other mentioned categories of pollutants on the optical parameters.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors without undue reservation.

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