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Article

Saharan Dust Contributions to PM_{10} Levels in Hungary

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Abstract: There are meteorological situations when huge amounts of Saharan dust are transported from Africa to Europe. These natural dust events may have a significant impact on particulate matter concentrations at monitoring sites. This phenomenon affects mainly the countries in Southern Europe; however, some strong advections can bring Saharan dust to higher latitudes too. The number of Saharan dust events in the Carpathian Basin is believed to increase due to the changing patterns in the atmospheric circulation over the Northern Hemisphere's mid-latitudes. The jet stream becomes more meandering if the temperature difference between the Arctic areas and the lower latitudes decreases. This favours the northward transport of the North African dust. The European regulation makes it possible to subtract the concentration of Saharan-originated aerosol from the measured PM_{10} concentration. This manuscript describes the methodology used by the HungaroMet to calculate the amount of natural dust contributing to measured PM_{10} concentrations.

Keywords: Saharan dust events; Carpathian Basin; PM_{10} dust fraction

1. Introduction

Mineral dust emissions from arid and semiarid regions are crucial to the Earth's atmospheric dynamics and have extensive effects on climate, air quality, and ecosystems [1], as well as on photovoltaic energy generation [2]. The primary source areas for dust are situated in the subtropical latitudes of the Northern Hemisphere, stretching from the West coast of North Africa and the Middle East to Central and South Asia, reaching as far as China [3]. Among these regions, North African dust hotspots, particularly in the Sahara Desert, make a significant contribution to the global mineral dust budget. Air masses rich in dust from these hotspots can be transported over long distances [4], extending thousands of kilometres across continents and oceans. These dust plumes are frequently carried by atmospheric circulation patterns, such as the Saharan Air Layer, and can affect distant areas, including North and South America, Europe, and the Middle East. Although this phenomenon primarily impacts countries in Southern Europe, strong advection events can also transport Saharan dust to higher latitudes [5]. Dust outbreaks can notably elevate ambient PM levels recorded by air quality monitoring networks [6–8]. This is especially relevant in Southern Europe but in the last decade, it has occurred more often in the area of the Carpathian Basin [9].

Air quality monitoring networks play a crucial role in assessing and managing ambient air pollution levels [10]. However, dust outbreaks present challenges for air quality in general and for human health in particular, as they can lead to abrupt spikes in PM concentrations that exceed regulatory standards and guidelines. Monitoring stations may register temporary breaches in PM levels during dust events [11,12], triggering alerts and necessitating immediate response measures to mitigate health risks and inform the public about potential hazards associated with poor air quality conditions.

The 2008 ambient air quality directive (2008/50/CE European directive) [13] sets limits for concentrations of major air pollutants in ambient air. The daily limit value for PM_{10} is currently 50 $\mu g/m^3$ (which can be exceeded up to 35 times a year). Each country of the European Union has reporting obligations. The Commission may start

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infringement procedures against countries that fail to meet the requirements of air quality. In several locations in Hungary, there are exceedances of the limit values of PM_{10}. The main source of particulate matter pollution in Hungary is residential heating [14]. The highest concentrations occur during the heating season. Besides the anthropogenic emissions, the meteorological situation and the activity of natural sources also contribute to the evolution of the PM_{10} concentrations over a year. The purpose of quantifying the natural contribution to PM_{10} is to keep only those exceedances that are under the control of the country.

There are meteorological situations when huge amounts of Saharan dust are transported from Africa to Europe. The number of Saharan dust events in the Carpathian Basin is believed to increase due to the changing patterns in the atmospheric circulation over the Northern Hemisphere's mid-latitudes [15]. The jet stream becomes more meandering if the temperature difference between the Arctic areas and the lower latitudes decreases. This favours the northward transport of the North African dust [9]. The crustal load within PM_{10} generally corresponds to the amount of dust during an episode. However, measurements of the chemical composition of PM_{10}, especially crustal components (Ca, Mg, Fe, Si, K), are sparse. Estimating the amount of desert dust based on different techniques (using measured or modelled concentrations) is therefore a beneficial task when subtracting the natural contribution from the PM_{10} values. The FAIRMODE (https://fairmode.jrc.ec.europa.eu/ accessed on 15 July 2024) community was launched in 2007 to facilitate cooperation and exchange of experience between air quality modelling experts. FAIRMODE is divided into working groups dealing with different areas of modelling, such as assessment, source apportionment, planning, and emissions. FAIRMODE aims to promote harmonised air quality modelling across Europe. The common CAMS (Copernicus Atmosphere Monitoring Service)—FAIRMODE (Forum for Air Quality Modeling in Europe) WG8 (Working Group 8) exercise was a collaborative effort aimed at enhancing the use of CAMS dust modelling products. The primary focus of the joint dust exercise was on understanding and managing natural contributions to air quality exceedances, particularly in the context of the Ambient Air Quality Directive. The first objective of the exercise was to establish best practices for utilising CAMS dust modelling products in the assessment of natural contributions to air quality exceedances. The second objective was to prepare recommendations for the inclusion of reference to CAMS dust products in a possible revision of the air quality directives guidelines for the deduction of natural contributions to exceedances.

Calculating the dust contribution to air quality measurements is essential for accurately assessing exceedances of air quality standards, particularly for particulate matter (PM) concentrations. Various methods can be employed to estimate the contribution of natural dust to air quality measurements. Each method has its strengths and limitations, and the choice of method depends on the specific context and available data. Studies on the impact of Saharan dust on PM_{10} concentrations in the Mediterranean countries have a longer history, as this is the region most affected by dust advection [16,17]. In general, it can be said that measurement-based methods are most commonly used to separate desert dust loads within PM_{10}. The European Commission has prepared a document with recommendations for identifying desert dust storm episodes and quantifying the dust load [18]. This method serves as a reference for the EU policy and is based on a previous extensive study by Escudero and colleagues [19]. The methodology consists of using different model results (dust simulations from chemical transport models, HYSPLIT backward trajectories) and meteorological information (satellite images, sea-level distribution maps) to select the episode situations, and then applying a statistical methodology to quantify the amount of dust using PM_{10} time series measured at regional background stations. This method relies on calculating the 30-day moving 40th percentile value (or 50th percentile value as in the EU recommendation) of the PM_{10} values after excluding the data corresponding to the dust episode days. This 40th percentile value, as a regional background, can be subtracted from the daily PM_{10} concentration measured at monitoring sites during the dust period to obtain the dust load at the given site. The method is sensitive to the selection of episode days, the length of the window, the threshold for the percentile calculation, and the choice of the regional background site. The chosen site should also be representative of the atmospheric transport process valid at the other concerned sites. This methodology, recommended by the European Commission, has been used in several studies. Querol and colleagues [17] evaluated the impact of natural dust on $PM_{2.5}$ and PM_{10} concentrations across Spain during 2001–2016. Cuspilici and colleagues [7] studied how Saharan dust storm events affected the number of daily PM_{10} exceedances over Sicily between 2013 and 2015. Lotrecchiano and colleagues [20] also used the EU method for quantifying the amount of dust at two stations in the Campania region (Italy), pointing out that in urban environments, the calculation of the $PM_{2.5}/PM_{10}$ ratio is a good indicator of the presence of Saharan dust in the atmosphere. Tel Aviv University has also developed a method based on PM_{10} measurements to determine the amount of desert dust within PM_{10}. According to their method, an episode situation is caused by desert dust when the half-hour PM_{10} average is above 100 $\mu g/m^3$, this level is maintained for at least 3 h and the maximum concentration measured is above 180 $\mu g/m^3$ [21]. The dust contribution is calculated as the difference between the average PM_{10} for the full time period and the average PM_{10} without the half-hours of the dust storm. This method works with hourly measurements and thus has the potential to mistakenly interpret PM increments from local dust sources as dust events. Viana and colleagues [22] compared the Tel Aviv University method with the European Commission method and with the results of a Positive Matrix Factorisation (PMF) receptor model at three monitoring sites in Spain. They found that the results of the Tel Aviv University method and the European Commission method were in relatively good agreement (R^2 = 0.58) and that the PMF dust contribution was relatively high. In addition to the PMF modelling technique, which calculates the contribution of different sources to total PM_{10} concentrations, there are other models that can quantify the amount of dust during an episode situation. Gonzalez-Calvo and colleagues [23] estimated the concentrations of Saharan dust in the Canary Islands through the use of artificial neural networks. One of the most widely used regional dust models in the Mediterranean is DREAM [24]. It calculates the total dust amount for the entire atmospheric column and the total dust concentration in the first model layer. Petroselli and colleagues [16] analysed the decadal trends in the Saharan dust transport at a rural regional background station. They used the EU methodology, the results of the DREAM model and a method specifically developed for Central Italy (DIAPASON) [25,26]. By integrating multiple approaches, a more comprehensive and reliable assessment of dust contributions can be achieved, which is essential for effective air quality management and regulatory compliance.

The present study aims to describe the methodology used by the Hungarian Meteorological Service to calculate the amount of natural dust contributing to measured PM_{10} concentrations. We aim to produce time series at the monitoring stations that are free from natural contributions and can be reported within the framework of the ambient air quality directive.

2. Materials and Methods

2.1. Air Quality Monitoring Data

The PM_{10} data that are used in this analysis are based on data from the Air Quality Monitoring Network of Hungary. The Monitoring Network is a comprehensive system established to detect air quality across Hungary. The network has been managed by HungaroMet, Hungarian Meteorological Service since 2024. The network aims to provide accurate and up-to-date information on the levels of various pollutants in the air, contributing to environmental protection and public health in Hungary. The network comprises several monitoring stations considered well-placed throughout the country. These stations are equipped with advanced instruments that continuously measure the concentrations of key air pollutants, including PM_{10} and $PM_{2.5}$, O_3, SO_2, NO_2 and CO. Calibration procedures and measurements of standards are used for air data quality control. The instruments and measurement methods fulfil the requirements of the EU standards. The monitoring stations collect data continuously, which are then transmitted to the central database. These data are processed and analysed to assess air quality levels, identify trends, and detect any exceedances of air quality standards. The information is made available to the public through various platforms (https://legszennyezettseg.met.hu/ accessed on 15 July 2024).

There are currently 26 sites in Hungary that provide PM_{10} measurements for international reporting. Figure 1 shows the location of the PM_{10} stations of the Hungarian Air Quality Monitoring Network. The colour of the dots indicates the station types. Unfortunately, chemical composition measurements of PM_{10} are not performed at these stations, which does not allow for a direct comparison of the dust fraction with measurements.

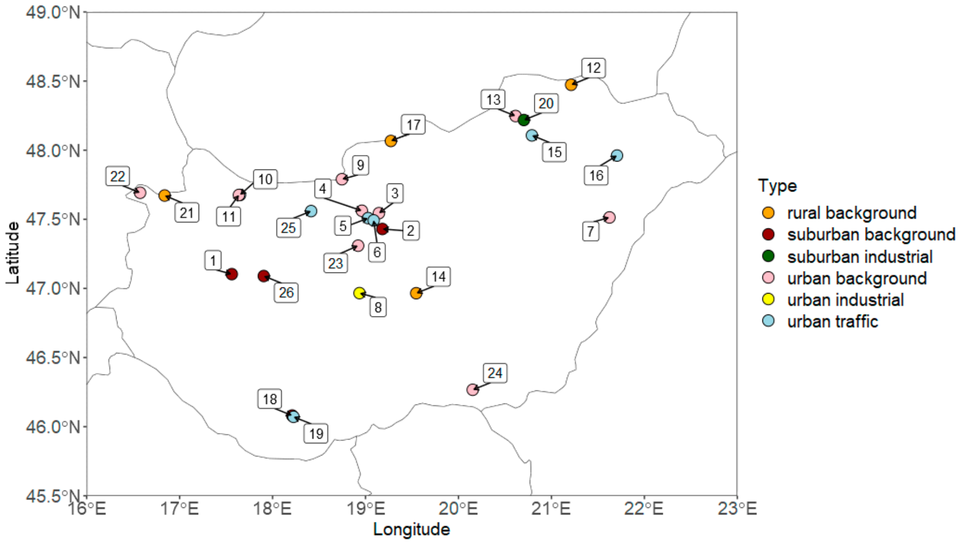


Figure 1. PM_{10} stations in Hungaryz: 1—Ajka, 2—Budapest Gilice tér, 3—Budapest Kőrakás park, 4—Budapest Pesthidegkút, 5—Budapest Széna tér, 6—Budapest Teleki tér, 7—Debrecen Kalotaszeg tér, 8—Dunaújváros, 9—Esztergom, 10—Győr 2 Ifjúság, 11—Győr 1 Szent István, 12—Hernádszurdok, 13—Kazincbarcika, 14—K-puszta, 15—Miskolc Búza tér, 16—Nyíregyháza, 17—Nyírjes, 18—Pécs Boszorkány u., 19—Pécs Szabadság u., 20—Sajószentpéter, 21—Sarród, 22—Sopron, 23—Százhalombatta Búzavirág tér, 24—Szeged 2 Rózsa u., 25—Tatabánya Ságvári u., 26—Veszprém.

2.2. CAMS Model Results

The main database for calculating the natural dust contribution to the measured PM_{10} concentrations is the CAMS European Interim Reanalysis data [27]. This dataset provides annual air quality reanalyses for Europe based on both unvalidated (interim) and validated observations for the European domain at the spatial resolution of 0.1 degrees. The production is currently based on an ensemble of eleven air quality models with data assimilation systems across Europe. A median ensemble is calculated from individual outputs since ensemble products yield on average better performance than the individual model products. The spread between the eleven models can be used to provide an estimate of the analysis uncertainty. An interim reanalysis is provided each year for the year before based on the unvalidated near-real-time observation data stream that has not undergone full quality control by the data providers yet. Once the fully quality-controlled observations are available from the data provider, typically with an additional delay of about 1 year, a final validated annual reanalysis is provided. Both reanalyses are available at hourly time steps at different levels.

This gridded dataset contains reliable information to describe the air quality situation in Europe over a year. We can easily access and download the reanalysis data from the Atmosphere Data Store. For our work, we need the hourly concentration data of the particulate matter < 10 µm (PM_{10}) and the PM_{10} dust fraction variables for a whole year. We selected the year 2022 to develop the methodology. The dataset has a 0.1° × 0.1° (approximately 10 km × 10 km) horizontal resolution and although the concentrations are given at different height levels, we only retrieved the surface data. We have chosen the time series of dust fraction and PM_{10} at the nearest grid cell to each monitoring site.

2.3. The Formula for Calculating the Dust Contribution to Measurements

The dust fraction within the PM_{10} is available in the CAMS Interim Reanalysis datasets. However, this value comes from modelled data (an ensemble of models), and we would like to deduct the natural part from the PM_{10} measurements. The dust reanalysis information approximates the real amount of dust in the atmosphere. It is possible that there is a bias in the CAMS model calculations, so it is not recommended to subtract the "raw" dust reanalysis concentration from the measurements. We assume that the same bias applies to the dust fraction within PM_{10} as to the total PM_{10} concentration. We correct the CAMS dust component for bias and use this corrected value for deducting the natural Saharan dust contribution from the observed PM_{10} concentrations.

We work with the daily average concentrations of dust fraction and PM_{10} reanalysis and measured data. We correct the CAMS dust fraction with the following formula:

$$CorrectedDust = \left(\frac{ReanalysisDust}{ReanalysisPM_{10}}\right) \times ObservedPM_{10}$$

This formula indicates that the direction of bias between the corrected dust data and the reanalysis dust data aligns with the direction of bias between the measured PM_{10} and the reanalysis PM_{10} data. The correction is made on the daily average dust concentrations for the whole year. However, we only deduct this corrected dust value from the PM_{10} daily averages on the days of the dust episodes we have found in 2022, to have time series of PM_{10} without the natural contribution.

Considering the sensitivity of our method, the results depend on the accuracy of the CAMS data. The annual air quality reanalysis data (interim) is based on unvalidated observations; therefore, the validated reanalysis can provide more accurate information on PM_{10} levels. Not only the observations but also the model characteristics have an effect on the accuracy of the PM_{10} and PM_{10} dust fraction data. The different models in the CAMS system determine the amount of dust within the PM_{10} variously. Some of them include only the natural windblown dust, others also the traffic resuspension and agricultural dust. This makes it difficult to identify the portion of dust that came from the Sahara or other deserted areas. The results of this method are also influenced by the selection of the temporal resolution for the correction of the modelled dust values. The hourly PM_{10} values are more sensitive to the influence of local sources, therefore the correction of the dust fraction based on hourly PM_{10} data could be excessive. In the correction formula, the difference between the observed and modelled PM_{10} daily average is divided by the modelled average. The difference could also be normalised by the observation, but this would cause lower dust concentrations as the observed PM_{10} values are higher than the modelled values. Nevertheless, the expression is multiplied by the modelled dust fraction, so the correct way is to normalise the difference by the modelled PM_{10}.

2.4. Experiences with the EU Methodology

The purpose of this paragraph is to present our main findings regarding the EU methodology. K-puszta is the only rural background station that could be considered as a regional background site adequate for the EU methodology as it has the highest spatial representativeness and does not reside over a complex terrain. The background concentration was calculated as the 30 days moving 50th percentile from the PM_{10} measurements. The calculated dust loads were overall higher than the dust concentrations obtained from our CAMS-based method at K-puszta. There were some days (mostly during the episode in March), during which the measured daily average PM_{10} was lower than the calculated background concentration. This can happen when the wrong percentile is chosen to calculate the background pollution of PM_{10} at the site, or if the dust days are not defined correctly. Thus, a sensitivity analysis is needed to find the best percentile value for the application of the EU methodology in the case of Hungary. However, the lower percentile value could lead to a higher dust load. In the future, chemical composition measurements are needed to validate our results. Considering the timing of the dust events, the maximum of the dust load quantified with the EU methodology did not coincide with the maximum PM_{10} value at other measurement sites. This highlights that more background stations are needed to provide the dust load accurately in time for different parts of the country.

The methodology presented in this article resolves the time-shift issue emerging from estimating the dust load at various sites from one background site in case of the EU methodology. The dust fraction data are formed by the modelled atmospheric transportation and are valid over a given grid cell, at a given time. For each station, the dust value is determined from the data of the grid cell closest to it. Due to the different sampling heights of the stations, the dust load calculated using the EU method may be higher than the daily PM_{10} average. In contrast, our correction method ensures that there are no negative concentrations after the deduction of the dust value.

3. Results

3.1. Selection of Dust Episodes

As a first step, the CAMS dust reanalysis data were examined to search for periods when dust plumes could reach Hungary in 2022. It was assumed that Saharan dust storm events reaching Hungary would be less intense and shorter in duration than those in Mediterranean countries, as the dust plume would have to travel a long distance to reach the higher latitudes. Because of the known underestimation of PM_{10} by the CAMS ensemble model, the modelled dust fraction was also considered to be underestimated. According to the chemical composition data provided by the CAMS policy support service, the ratio of dust within the daily average PM_{10} values in the concentration class of 30–40 $\mu g/m^3$ was 7% in 2022, which is equivalent to 2 $\mu g/m^3$. For these reasons, the 2 $\mu g/m^3$ value was chosen to be a threshold above which the frequent occurrences of the hourly dust values may indicate an episode situation. Days with a high number of hourly occurrences of dust (concentration above 2 $\mu g/m^3$) have been selected for the analysis (Figure 2). Daily averaged dust reanalysis maps for these high-dust days were used to follow dust plumes over Europe and assess whether they reached Hungary. In Figure 3, there are maps with daily dust reanalysis averages over Europe. The figure shows the evolution of the dust plume coming from the southeast in August 2022. With the help of the bar charts and the visualisation of daily dust averages on maps, we could select six dust episodes in 2022 that Hungary was affected by. (Dust episodes: 24–31 March, 25 June–3 July, 20–23 July, 18–21 August, 24–29 August, 21 October–5 November).

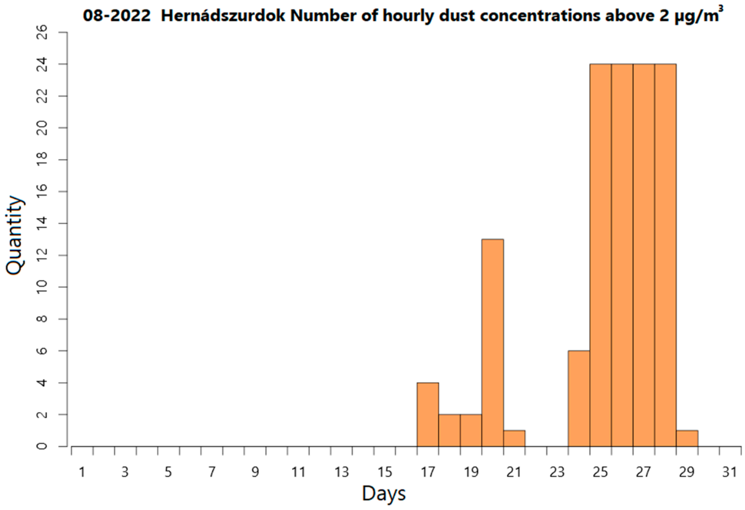


Figure 2. Bar chart with the number of hourly dust reanalysis concentrations above 2 $\mu g/m^3$ at Hernádszurdok in August 2022.

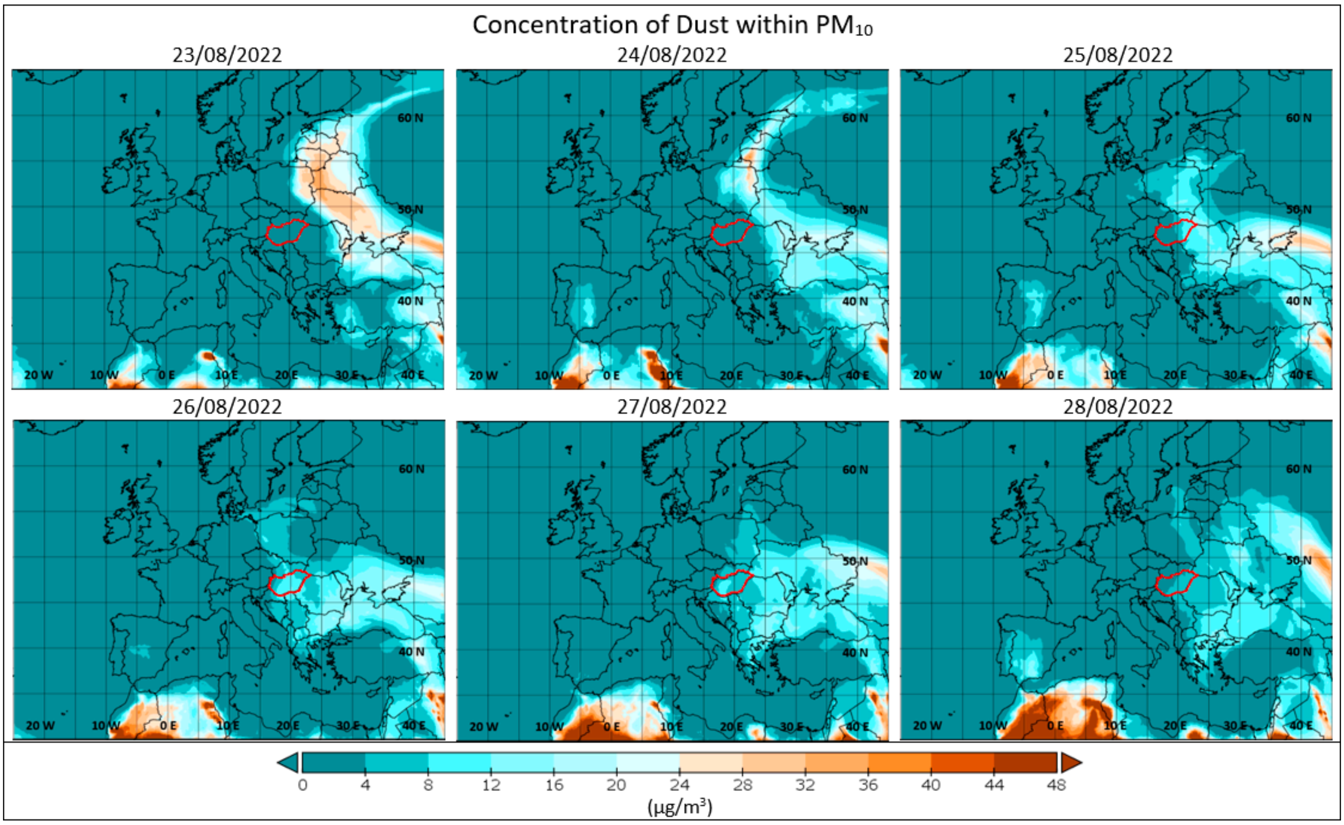


Figure 3. The change in daily average dust concentrations (CAMS reanalysis) over Europe, 23–28 August 2022. Hungary is circled in red.

Figure 4 shows an example of the dust deduction on a graph. During the dust episode of 24–29 August, the daily measured concentrations (yellow line) and the CAMS dust reanalysis averages (green line) had a peak, which indicates the presence of natural dust in the air. After the deduction of the corrected dust values the new PM_{10} measurements decreased by 18 µg/m^3 on 25 August.

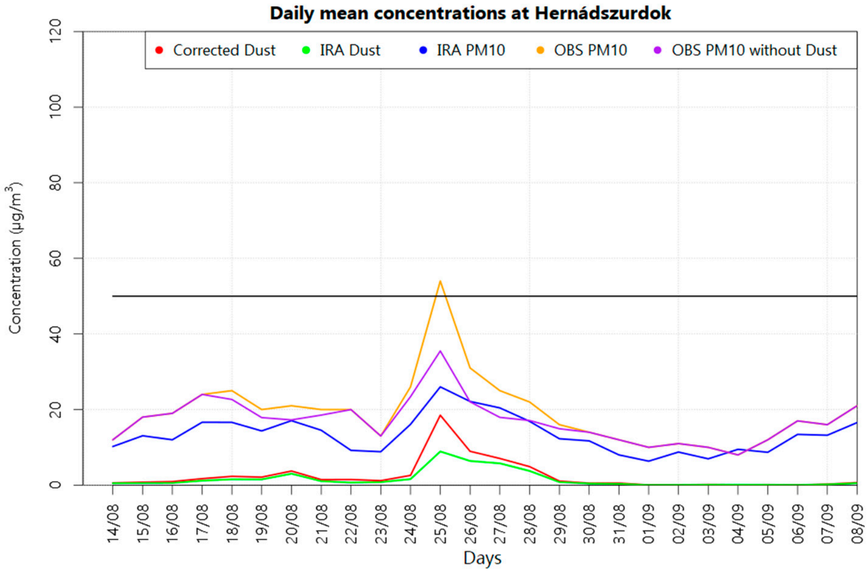
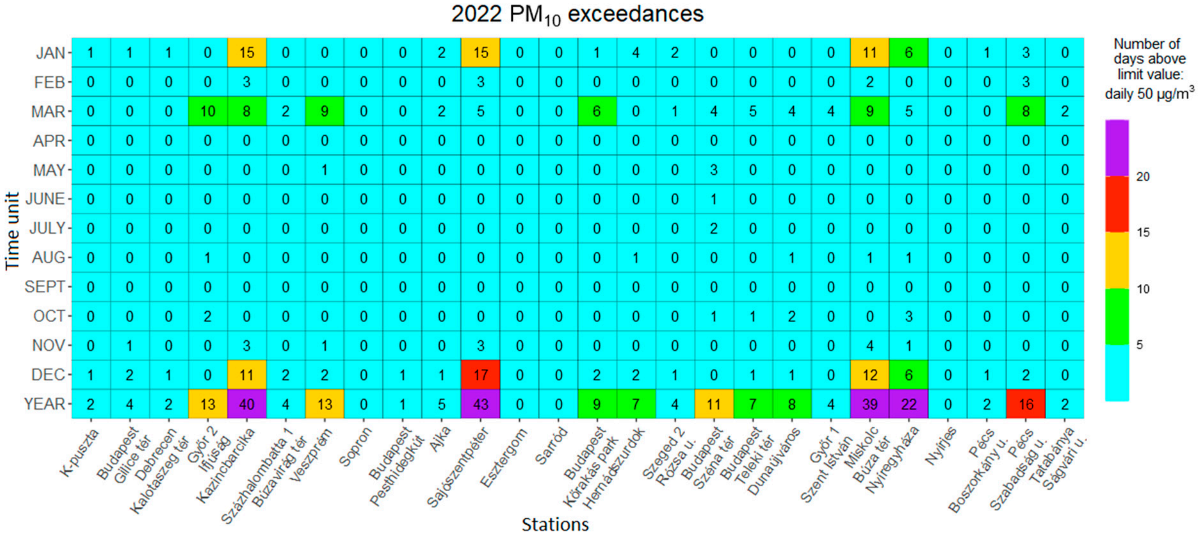


Figure 4. The daily concentrations of the CAMS dust fraction (green) and PM_{10} (blue), the corrected dust (red), the measured PM_{10} (yellow) and the PM_{10} without natural contribution (purple) at Hernádszurdok (the black line indicates the 50 µg/m^3 limit value), 14 August–8 September 2022.

3.2. The Achieved Changes in the PM_{10} Concentrations

Figure 5 shows the number of exceedances of the daily 50 µg/m^3 limit value at the PM_{10} stations. There are exceedances in each month in the first 12 rows, and the last row summarises the occurrences for the whole year.



	K-puszta	Budapest Gilice tér	Debrecen Kalotaszeg tér	Győr 2 Ifjúság	Kazincbarcika	Százhalombatta 1 Búzavirág tér	Veszprém	Sopron	Budapest Pesthidegkút	Ajka	Sajószentpéter	Esztergom	Sarród	Budapest Kőrakás park	Hernádszurdok	Szeged 2 Rózsa u.	Budapest Széna tér	Budapest Teleki tér	Dunaújváros	Győr 1 Szent István	Miskolc Búza tér	Nyíregyháza	Nyírjes	Pécs Boszorkány u.	Pécs Szabadság u.	Tatabánya Ságvári u.
JAN	1	1	1	0	15	0	0	0	0	2	15	0	0	1	4	2	0	0	0	0	11	6	0	1	3	0
FEB	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0
MAR	0	0	0	10	8	2	9	0	0	2	5	0	0	6	0	1	4	5	4	4	9	5	0	0	8	2
APR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
JUNE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
JULY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
AUG	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	0	0	0	0
SEPT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OCT	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	3	0	0	0	0
NOV	0	1	0	0	3	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0
DEC	1	2	1	0	11	2	2	0	1	1	17	0	0	2	2	1	0	1	1	0	12	6	0	1	2	0
YEAR	2	4	2	13	40	4	13	0	1	5	43	0	0	9	7	4	11	7	8	4	39	22	0	2	16	2

Figure 5. Number of PM_{10} exceedances at the monitoring sites in 2022.

The area with the most particulate matter pollution is the northeastern part of the country. The number of exceedances there is often above the target value (35). Therefore, it is important to find a way to define the natural contribution and to deduct it from the daily PM_{10} averages before reporting the number of exceedances to the EU.

In Table 1, we see the changes in the monthly averages of the PM_{10} measurements due to the deduction of the natural dust from the daily averages. The biggest changes occurred in August and in October.

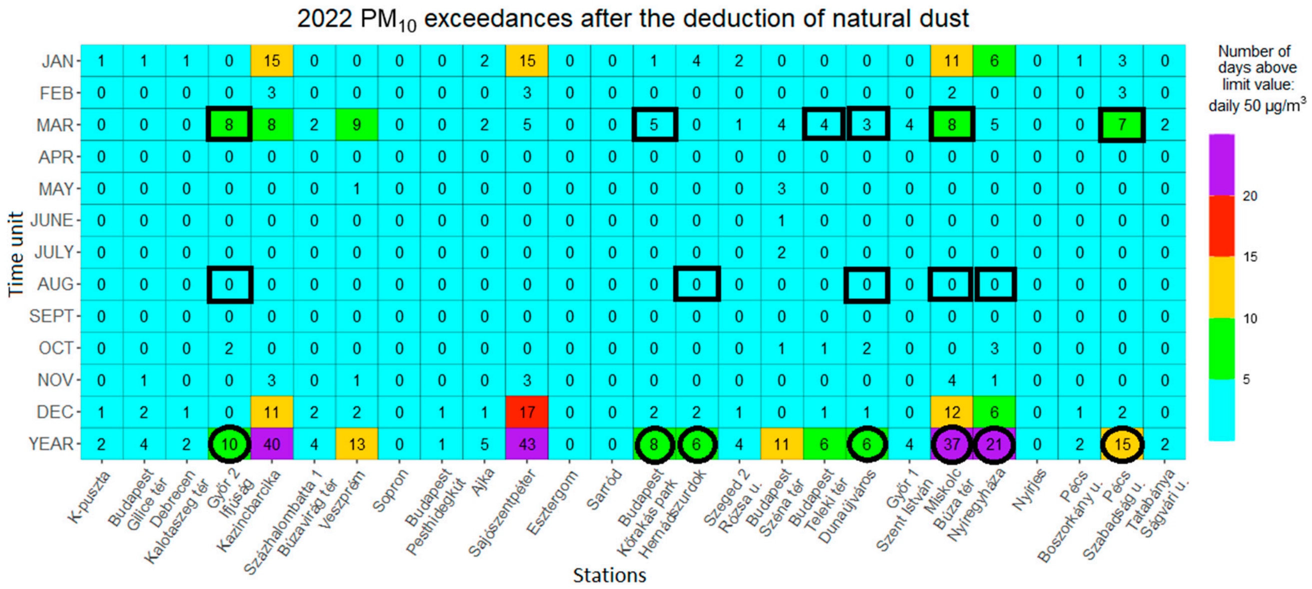
Table 1. Changes in monthly averages at monitoring sites in March, June, July, August, October and November.

Values in µg/m^3	MAR	JUNE	JULY	AUG	OCT	NOV
Ajka	−0.71	−0.58	−0.40	−1.51	−1.84	−0.76
Budapest Gilice	−0.70	−0.64	−0.80	−1.77	−0.02	–
Budapest Kőrakás park	−0.89	−0.63	−0.67	−1.33	−1.70	−0.66
Budapest Pesthidegkút	−0.71	−0.62	−0.67	−1.43	−1.14	−0.59
Budapest Széna tér	−0.96	−0.18	−0.96	−1.15	−1.39	−0.53
Budapest Teleki tér	−0.88	−0.86	−0.87	−1.41	−1.36	−0.61
Debrecen Kalotaszeg	−0.65	−0.38	−0.79	−1.92	−0.85	−1.03
Dunaújváros	−0.83	−0.79	−0.88	−2.32	−1.92	−0.96
Esztergom	−0.59	−0.40	−0.36	−1.50	−0.95	−0.40
Győr 1 Szent István	−0.73	–	−0.58	–	−1.38	−0.63
Győr 2 Ifjúság	−0.72	−0.51	−0.42	−1.86	−0.92	–
Hernádszurdok	−0.51	−0.29	−0.59	−1.70	−0.66	−0.79
Kazincbarcika	−0.74	−0.36	−0.73	−2.24	−1.02	−1.08

Table 1. *Cont.*

Values in µg/m^3	MAR	JUNE	JULY	AUG	OCT	NOV
K-puszta	−0.76	−0.56	−0.69	−1.63	−1.48	−0.92
Miskolc Búza tér	−0.85	−0.52	−0.99	−2.00	−1.12	−0.99
Nyíregyháza	−0.92	−0.42	−0.98	−2.58	−1.13	−1.21
Nyírjes	−0.76	−0.30	−0.41	−1.11	−0.63	−0.45
Pécs Boszorkány u.	−0.70	−0.89	−0.80	−2.48	−1.60	−0.90
Pécs Szabadság u.	−0.93	−1.16	−0.71	−1.61	−1.63	−1.04
Sajószentpéter	−0.64	−0.46	−0.82	−1.40	−1.28	−1.07
Sarród	−2.43	−0.45	−0.13	−1.09	−1.16	−0.40
Sopron	−0.61	–	–	−1.08	−1.00	–
Százhalombatta	−0.71	−0.29	−0.66	−1.46	−1.66	−0.74
Szeged 2 Rózsa u.	−0.51	−0.76	−0.96	−2.14	−1.12	−0.39
Tatabánya Ságvári u.	−0.62	−0.44	−0.33	–	−1.38	−0.58
Veszprém	−0.70	−0.54	−0.39	−1.99	−1.00	−0.31

We also saw changes in the number of the exceedances of the daily 50 µg/m^3 limit value at some stations. In Figure 6, we see the number of exceedances in 2022 after the deduction of the natural dust. The changes in the monthly number of exceedances are highlighted with black squares, and the changes in the annual occurrences are highlighted with black circles. In August, we could fully eliminate the exceedances that occurred. The exceedances decreased also in March, at Győr 2 Ifjúság station with 2 days, at Budapest Kőrakás Park, Budapest Teleki, Dunaújváros, Hernádszurdok, Miskolc Búza tér, Nyíregyháza and Pécs Szabadság u. stations with 1 day. However, the annual number of exceedances is still above the 35 target value at Kazincbarcika, Sajószentpéter and Miskolc Búza tér.



Time unit	K-puszta	Budapest Gilice tér	Debrecen Kalotaszeg tér	Győr 2 Ifjúság	Kazincbarcika	Százhalombatta 1 Búzavirág tér	Veszprém	Sopron	Budapest Pesthidegkút	Ajka	Sajószentpéter	Esztergom	Sarród	Budapest Kőrakás park	Hernádszurdok	Szeged 2 Rózsa u.	Budapest Széna tér	Budapest Teleki tér	Dunaújváros	Győr 1 Szent István	Miskolc Búza tér	Nyíregyháza	Nyírjes	Pécs Boszorkány u.	Pécs Szabadság u.	Tatabánya Ságvári u.
JAN	1	1	1	0	15	0	0	0	0	2	15	0	0	1	4	2	0	0	0	0	11	6	0	1	3	0
FEB	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	0	0	0	3	0
MAR	0	0	0	8	8	2	9	0	0	2	5	0	0	5	0	1	4	4	3	4	8	5	0	0	7	2
APR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MAY	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
JUNE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
JULY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
AUG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEPT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
OCT	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	3	0	0	0	0
NOV	0	1	0	0	3	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0
DEC	1	2	1	0	11	2	2	0	1	1	17	0	0	2	2	1	0	1	1	0	12	6	0	1	2	0
YEAR	2	4	2	10	40	4	13	0	1	5	43	0	0	8	6	4	11	6	6	4	37	21	0	2	15	2

Figure 6. Number of exceedances at the monitoring sites in 2022 after the deduction of the natural dust. The squares highlight the changes in the monthly number and the circles the changes in the annual number of exceedances.

4. Conclusions

North African dust hotspots in the Sahara Desert significantly contribute to the global mineral dust budget, with implications extending far beyond their geographical boundaries. The long-distance transport of dust-laden air masses originating from these hotspots influences climate, air quality, and ecosystems in remote regions across the globe. Understanding the dynamics of North African dust emissions and their impacts is crucial for addressing environmental challenges, promoting sustainable development, and safeguarding human health in a globally interconnected world.

Dust outbreaks significantly influence ambient PM levels recorded in air quality monitoring networks, posing challenges for public health and environmental management. These events underscore the importance of proactive measures to mitigate the impacts of dust pollution on air quality and safeguard vulnerable populations from exposure to elevated concentrations of PM.

The CAMS Interim Reanalysis data includes concentrations of PM_{10} and dust fraction within PM_{10}. We chose the ensemble median information of these two variables to work with. We wanted to deduct the natural contributions from the PM_{10} concentrations. Since there might be a bias in the calculations of the dust fraction, the correction of the dust concentrations is needed before we do the deduction. During dust events, mineral dust represents a large fraction of PM_{10} mass concentration [28]. It was therefore assumed that the same BIAS could be applied to dust fraction as to PM_{10} in case of the episode situation. In the future, this assumption could be validated with chemical speciation measurements at Hungarian monitoring sites. At each station, based on the bias between the reanalysis and measured PM_{10} daily averages, we corrected the CAMS dust fraction daily values. With this method, we believe that the corrected dust concentration is closer to reality. We deduct this corrected dust daily average from the daily average of the PM_{10} concentration.

The dust fraction data from the reanalysis database helps to identify episodes of Saharan dust reaching Hungary. There are also other sources of information that show that Saharan dust is in the air over Hungary, like satellite products. Furthermore, the study of backward trajectories can be important too.

We see from the results that the contribution of natural dust to the measured PM_{10} daily average concentrations can be significant. Moreover, in 2022 we found 12 exceedances (daily PM_{10} concentrations above 50 $\mu g/m^3$), which probably would not have occurred without the natural contribution.

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Data Availability Statement: The PM_{10} and PM_{10} dust fraction reanalysis data used in this study are available at Copernicus Atmosphere Monitoring Service (CAMS) Atmosphere Data Store (ADS) (https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-europe-air-quality-reanalyses?tab=form, last access 23 April 2023); and the PM_{10} observation data are published by HungaroMet (https://legszennyezettseg.met.hu/, last access 15 July 2024).

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