Bulgarian Journal of Meteorology and Hydrology

Национален институт по метеорология и хидрология

National Institute of Meteorology and Hydrology

Bul. J. Meteo & Hydro 29/ 2 (2025)

Methodology for assessment of desert dust contribution to PM_{10} exceedances in Bulgaria and identification of dust days

Emilia Georgieva*, Hristina Kirova and Anastasiya Stoycheva

National Institute of Meteorology and Hydrology,
Tsarigradsko shose 66, 1784 Sofia, Bulgaria

Abstract: In this work we outline the methodology, developed recently at NIMH, for identification and quantification of desert dust contribution to exceedances of daily limit values of PM_{10} in Bulgaria. The methodology is aligned with European Commission Guidelines from 2011 and recommendations published in the scientific literature after that. Accurately assessing and addressing exceedances attributable to natural sources remain challenging, especially in case of desert dust, because there are no regulatory measurements. The methodology integrates modelling results for dust concentrations to identify days with dust transport and applies statistical techniques to observed PM_{10} concentrations to estimate the dust contribution. The methodology is applicable to each station with PM_{10} observations and allows to access the exceedances due to dust. Here we discuss the sensitivity of the identification of the days to two versions of the Copernicus Atmosphere Monitoring Service regional air quality model (CAMS-ENS). The ensemble results of this system in two versions (analysis and interim reanalysis data) are investigated at 40 stations in the country for the year 2022. Differences in the identified days are presented as averaged over all stations and the whole year, but also for single stations and months. In general, interim model results provide by about 6% less number of days affected by dust.

Keywords: desert dust, particulate matter, exceedances, numerical model

1. INTRODUCTION

Dust storms are considered by the World Meteorological Organization (WMO) as significant extreme meteorological phenomena, since huge amount of airborne mineral particles have impact on the weather, the environment, and many socioeconomic

* emilia.georgieva@meteo.bg

sectors (Nickovic et al., 2025). Desert dust particles can be transported from hundreds to thousands of kilometers away from the sources and could have adverse effects on the air quality and human health in distant regions. Mineral dust particles arising in the atmosphere over desert areas are considered as primary aerosols of natural origins. They contribute to the mass of the particulate matter (PM) - a complex mixture of particles and liquid droplets having natural and anthropogenic origin.

The European air quality Directives (2008/50/EC and 2024/2881/EU) set limit values for key pollutants in order to protect human health and the environment. The current limit values for PM_{10} are the daily limit value (DLV) that should not exceed 50 μgm^{-3} more than 35 times in a year, and the annual mean value that should not exceed 40 μgm^{-3}. The new directive 2024/2881/EU introduces stricter air quality standards with an attainment date by 2030. For PM_{10} these new standards are DLV of 45 μgm^{-3}, not to be exceeded more than 18 times per calendar year, and the annual limit value of 20 μgm^{-3}. Both Directives gives the Member States the possibility to assess the non-attainment of limit values due to contribution from natural sources, including desert dust. Where the European Commission has been informed of an exceedance attributable to natural sources, that exceedance shall not be regarded as an exceedance for the purposes of the Directive.

A methodology for identification and quantification of desert dust contribution to PM_{10} exceedances of DLV in Bulgaria (ExEA, 2022) was elaborated at the National Institute of Meteorology and Hydrology (NIMH) upon request by the national Executive Environment Agency (ExEA). A review of existing approaches for identification and assessment of desert dust contribution to PM_{10} concentrations, as well as their applicability for Bulgaria, was conducted in (Georgieva et al., 2023).

The present study aims to present the methodology developed by NIMH and to discuss one of its main elements - the identification of days with desert dust at air quality stations, operated in the country by ExEA. The identified days are analyzed for the calendar year 2022 based on results from two different versions of the regional ensemble model at the Copernicus Air Quality Monitoring Service for Europe (CAMS-ENS) (CAMS, 2025).

2. THE METHODOLOGY

The methodology for subtraction of desert dust contribution in exceedances of PM_{10} DLV was developed at NIMH following the EC Guidelines (EC, 2011), known also as reference method, and the revised approach proposed and applied in Italy (Barnaba et al., 2017). The methodology can be applied to all ExA stations with PM_{10} measurements, regardless of their type.

The methodology consists of two stages: 1) identification of days influenced by the transport of desert dust for every ExEA station, and 2) quantification of the desert dust contribution to PM_{10} daily mean concentrations. The conceptual flowchart of the methodology with input and output information is shown in Figure 1.

At stage (1), results for the daily mean dust concentrations by the model CAMS-ENS are used. This modelling system was chosen for several reasons: a) ensemble approach of 11 state-of-the-art chemical transport models leading to overall better performance than a single model; b) assimilation of observational data; c) relatively high spatial resolution for trans-boundary transport processes (about 10 km); d) time resolution on hourly basis, allowing good estimates of daily mean values; e) available rolling archive for the last 3 years, with analysis and reanalysis data freely available. The parameter DUST (hourly dust concentrations at surface level from CAMS-ENS analysis) is extracted at the location of every ExEA station with PM_{10} measurements. Then the daily mean dust concentration is calculated. When the daily mean DUST concentration is above the threshold value of 5 μgm^{-3} the day for the stations is marked as influenced by desert dust. (Barnaba et al., 2017; Barnaba et al., 2022).

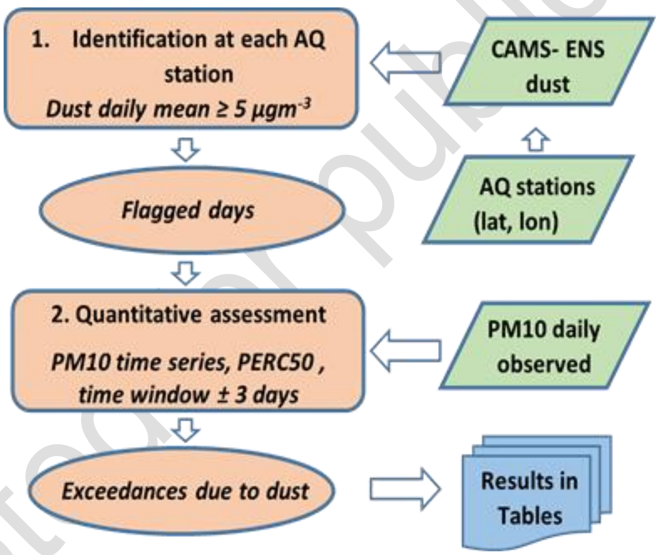

Fig. 1. Flow chart of the methodology: input information (in green) working blocks (brown) output information (blue)

At stage (2), the dust contribution is assessed for each identified day at a given station using a statistical method. The desert dust (DD) contribution for such a day is defined as the difference between the station-observed PM_{10} concentration and the concentration that would have occurred in the absence of DD ("background", or out–of–dust PM_{10} concentration). This "background" concentration is defined as the statistical parameter PERC50 - the 50th percentile (median) of measured PM_{10} over a time window of ±3 days, without counting the days affected by dust transport (Barnaba et al., 2017). The choice of PERC50, is more conservative than the 40th percentile in the reference method (EC, 2011). This means the PERC50 calculates a higher estimate on the "background" concentration, which results in lower values for the dust load. The time window is fixed at ±3 days after carrying out additional analyses, including autocorrelation functions, and sensitivity of PERC50 at different time window range. These additional analyses have showed that a time range of ±3 days for the PERC50 calculation leads to more conservative estimates of dust contribution compared to longer time windows.

3. IDENTIFICATION – SENSITIVITY OF RESULTS TO CAMS-ENS MODEL VERSIONS

We investigate the results of two versions of the modelling system CAMS-ENS for the number of identified days with dust transport. The first version (ENS) refers to the analysis data for dust concentrations by the operational CAMS-ENS model, the second version (IRA) refers to the interim reanalysis data. The reanalysis combines model data with observations provided by the European Environment Agency (EEA). CAMS produces two streams of reanalysis - an interim reanalysis based on the non-validated near-real-time observation data, and the validated reanalysis (VRA) that makes use of fully quality-controlled observations. IRA results are available for a whole year Y on May of year Y+1, while VRA results are ready in November year Y+2. As the reporting of ExEA to EEA is annually in September, only IRA data could be used.

We present the comparison between ENS and IRA results regarding the identified days influenced by desert dust in the 2022. The comparison is based on the model's extracts at the locations of 40 air quality stations in the country and on the respective daily mean dust concentrations. Models results were retrieved from CAMS atmosphere data store (CAMS, 2020; CAMS, 2021).

3.1. Comparison using averaged values over all stations

Figure 2a shows the time variation of daily mean dust concentrations averaged across 40 stations in the year 2022 for the two model versions ENS and IRA. In Figure 2b only data above the threshold of 5 μgm^{-3} are considered, thus also the number of stations is different. The last figure illustrates the differences in the identified dust-days.

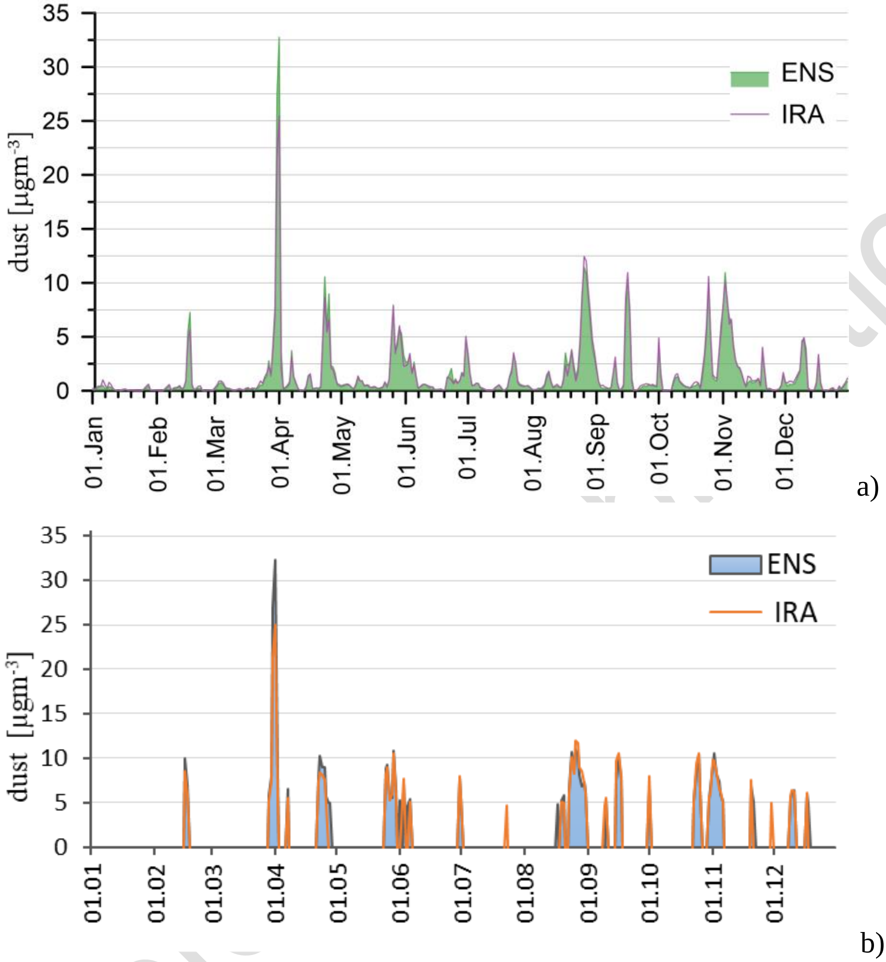

Fig. 2. Time series of daily mean dust concentrations (μgm^{-3}) in 2022 by ENS and IRA: a) averaged across 40 stations; b) averaged only for stations with values above 5 μgm^{-3}

Both modelling results are very close in terms of duration of events and dust concentrations. IRA results for the average dust concentrations are in general lower than the ENS results, especially for the days with higher average dust concentrations, as shown on the scatterplot in Figure 3. Table 1 shows some statistical metrics for the two data sets. IRA results have lower average dust concentrations by about 3% and lower spread of the data, the value of 0.965 for the correlation coefficient indicates high positive correlation.

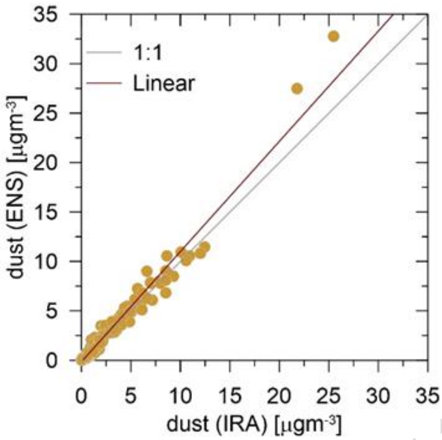

Fig 3. Scatter plot of daily mean dust concentrations (all values) averaged for 40 station for year 2022 from IRA and ENS data

Table 1 Statistics for the stations averaged daily mean concentrations by ENS and IRA (for values above 5 μgm^{-3}), stdev - standard deviation, nmb - normalized mean bias, r – correlation.

	mean [μgm^{-3}]	median [μgm^{-3}]	Max daily [μgm^{-3}]	stdev [μgm^{-3}]	nmb [%]	r
ENS	9.9	8.47	43.95 on 01.04.	6.12	-3.03	0.965
IRA	9.6	8.17	37.12 on 01.04.	4.83		

While there are some differences in the duration of the events, Figure 2b also indicates that IRA results identify additional days (e.g. 23.07 and 30.11), with average dust concentrations very close to the threshold value for flagging the days as a “dust day”. In other periods (e.g. mid-August) IRA does not identify days as ENS. This latter case will be discussed in Section 3.3.

3.2. Comparison for identified days per season and month

The total number of days identified at all stations (“station-days”) by ENS and IRA is shown in Table 2, for the whole year 2022 and for different seasons. IRA results are marked by lower number of days with dust, and this is due mainly to the lower number of such days in winter and in spring. The highest number of dust days was estimated by both models for the autumn and spring. The greatest difference is in spring, when IRA results indicated 45 stations-days less.

Table 2 Number of days identified as influenced by desert dust at all stations – on annual and seasonal basis (the abbreviations denote months in the season)

No. of days with dust	Year 2022	Winter DJF	Spring MAM	Summer JJA	Autumn SN
ENS	1200	105	382	274	439
IRA	1121	78	337	270	436

The distribution of the stations-days as part of all identified days, Figure 4, shows a difference of 3% more days by IRA in autumn.

The comparison for identified station-days by month, Figure 5, shows that August and November are the months with highest number of such days for both model versions. These two months account for about 36% of all station-days for ENS and about 39% for IRA. The only month without any "dust day" is January.

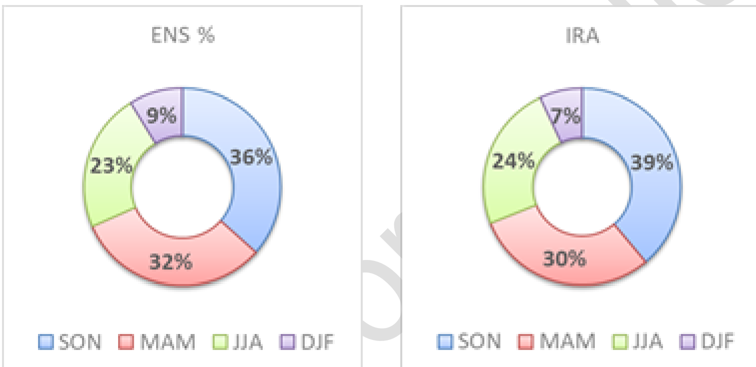

Fig. 4. Seasonal distribution of desert dust–affected station-days in 2022

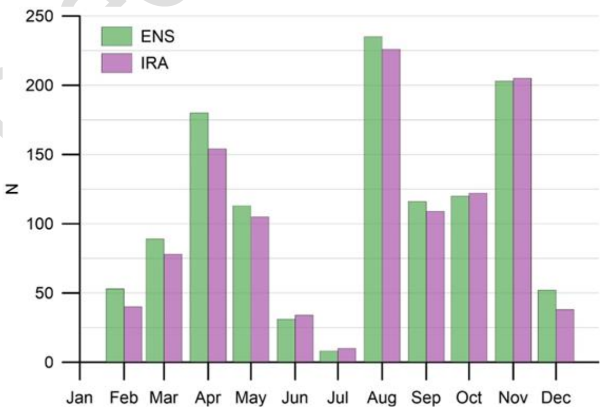

Fig. 5. Number of identified station-days by month– results by ENS and IRA

3.3. Comparison for single stations

Figure 6 shows the dust days in 2022, identified at each station based on ENS and IRA results. The highest number of dust days is noted for two stations in southern Bulgaria – the regional background station BG0053R Rozhen, with identified days 42 (ENS) and 39 (IRA), and the urban background station BG0077A Smolyan with identified days 44 (ENS) and 40 (IRA). The lowest number of desert dust was estimated for the station BG0081A Vidin - 16 days by both models. This suggests that dust intrusions with concentrations above 5 μgm^{-3} were more frequent from southern directions.

The intensity of the dust intrusions, expressed by the maximum daily mean concentrations at the single stations in Figure 7, varies among the stations. The highest values are for Burgas (BG0056A and BG0063A) with model estimated dust concentrations of more than 40 μgm^{-3} (ENS) and around 35 μgm^{-3} (IRA).

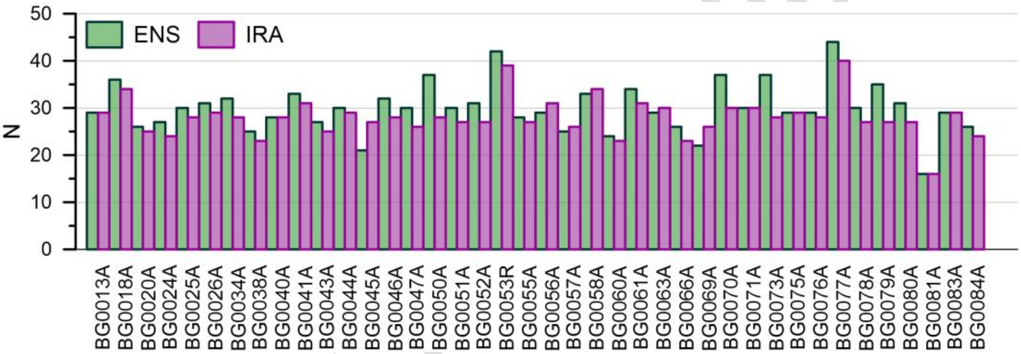

Fig. 6. Number of identified dust days at each station by ENS and IRA

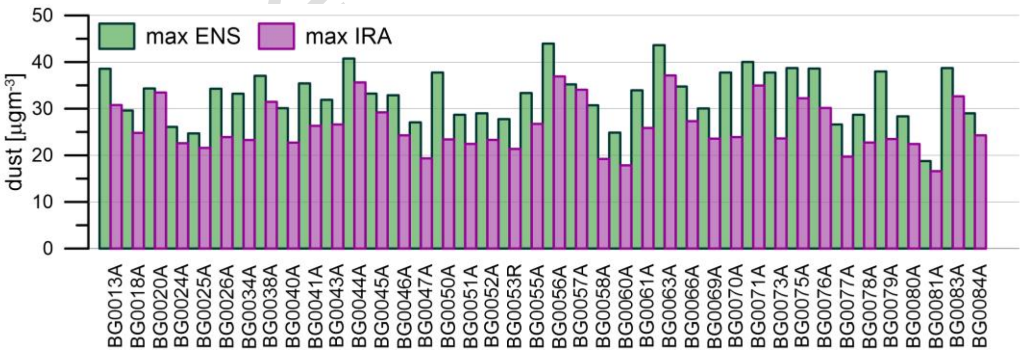

Fig. 7. Maximum of dust daily mean concentrations per station by ENS and IRA

The spatial distribution of the difference of the dust days identified by ENS and IRA at the 40 air quality stations in 2022 is shown in Figure 8.

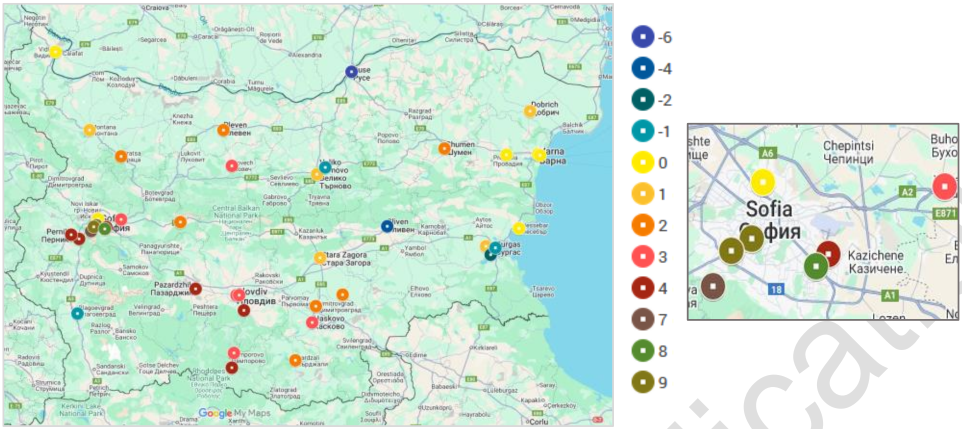

Fig. 8. Spatial distribution of the difference (ENS-IRA) in the number of identified dust days per station in 2022

Negative values in the legend indicate that IRA estimated days are more than the days identified by ENS, while positive values indicate higher number of dust days by ENS. The most notable differences are for the region of Sofia, where ENS estimated about 7 - 9 dust days more than IRA, and for some stations in the eastern part of the country (Sliven and Ruse) where IRA estimated 4-6 more dust days than ENS.

The difference in the dust days on monthly basis is shown as heat map in Figure 9.

Up to the month of May, the differences are mainly positive, indicating that ENS dust days are higher in number than by IRA. In the period from June to October the differences are mainly negative indicating higher number of days by IRA. August is the month with most significant differences, both positive and negative. Figure 2 shows that the identified days in August are in the second half of the month, with a more significant event during the days 25 - 28.08.

Station Name	Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Devnya Izvorite	BG0013A								-2			1	1
Kardzhali S.Klad	BG0018A		1		1			1	-1				
V.Tarnovo	BG0020A				1								
Gara Yana	BG0024A		2		1					1	-1		
Pirdop	BG0025A			1							1		
Galabovo	BG0026A			1									1
Dolni Voden	BG0034A		1	2	1	1					-1		
Shumen	BG0038A				1								1
Sofia Nadezhda	BG0040A				1						-1		
Dimitrovgrad Rak	BG0041A			1					-1		1	1	
Vratsa	BG0043A									1		1	
Burgas DEzerovo	BG0044A		1		1		-1						
Ruse Vazrazhdane	BG0045A					-1			-2			-2	-1
Pernik Tsarkva	BG0046A				2	1		-1	2				
Pazardzhik	BG0047A		2	1		1							
Sofia Hipodruma	BG0050A			1	2	1	1	-1	3	1			1
Plovdiv Kamenitsa	BG0051A		1	1		1							
Sofia Druzhba	BG0052A				1	1			1	1			
Rozhen*	BG0053R		1		2				-1		1		
StZagora Zelen klin	BG0055A												1
Burgas M. Rudnik	BG0056A						-1				-1		
Gorna Oryahovitsa	BG0057A			-1	1							-1	
Blagoevgrad	BG0058A					-1	1		2	-1	-1	-1	
Montana	BG0060A		1			-1				1	-1	1	
Haskovo	BG0061A		1		1						1	-1	1
Burgas DOAS	BG0063A						-1						
Lovech	BG0066A			1				1	1				
Sliven	BG0069A				-1				-2		1	-2	
Sofia Kopitoto *	BG0070A			1	2	1	1	-1	3		-1		1
Nesebar	BG0071A						-1		-1			1	1
Sofia Pavlovo	BG0073A			1	2	1	1	-1	3	1			1
Varna A.Kanchev	BG0075A				1		-1				-1		1
Dobrich H.Asparuh	BG0076A				1				-1				1
Smolyan Biblioteka	BG0077A		1		2		-1		-1		1		2
Plovdiv Trakia	BG0078A		1	1		1							
Sofia Mladost	BG0079A				1	1			4	1			1
Pernik Center	BG0080A				1	1			2				
Vidin	BG0081A												
Varna Chaika	BG0083A				1		-1				-1		1
Pleven P. Evtimiy	BG0084A									1	1		

Fig. 9. Difference (ENS-IRA) of number of identified dust days per station and per month, empty cells indicate no difference

3.3. Differences in identified days for Sofia stations in August

The analysis of the synoptic situations in August (Bulletin NIMH, 2022) and modelling results by CAMS-ENS indicates two periods with desert dust transport towards the country. The first one is linked to dust loaded air masses from Northern Africa, the episode started in the central Mediterranean around 15.08. and then with westerly and southwesterly flows the air masses reached the country around 17.08. The second episode started around 23.08., when dust was transported with easterly flow from regions east of the Black Sea. The intrusion had duration of several days and impacted mainly the eastern part of the country. While for Sofia the second episode was marked by both model versions, the first episode was characterized by differences in the flagged days as affected by dust.

As shown in Figure 9, ENS identified more dust days (3 - 4 additional days) in August for Sofia stations than IRA. ENS flagged August 17 and 19 - 20 as dust days for stations BG0050, BG0052, BG0070, BG0073, and BG0079 because daily mean dust concentrations (5 - 6 μgm^{-3}) were slightly above the detection threshold, while IRA concentrations for these days were lower (~4 μgm^{-3}) and thus not flagged.

The observed daily mean PM_{10} concentrations for these stations in the period 16 - 21. 08 are shown in Figure 10. At the rural background station BG0070A (peak Kopitoto), there is an increase in the observed PM_{10} values on 17.08. (suggesting a dust day, as estimated by ENS), and low values on 19.08. (suggesting non-dust day, as estimated by IRA). Thus, the exceedance in observed PM_{10} at BG0070A on 17.08. could be due to desert dust (ENS), but would be missed by IRA results. For the remaining stations in Sofia (BG0050A, BG0052A, BG0073A and BG0079A), no exceedances of the DLV was observed.

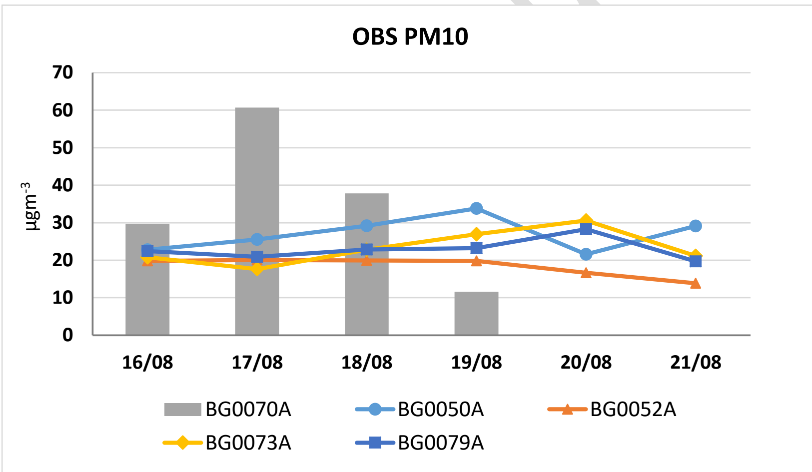

Fig. 10. Observed PM_{10} concentrations (μgm^{-3}) at Sofia stations during 16-21.08.2022; For station BG0070A – bars: grey (ENS) and brown (IRA), for remaining stations: color lines

The dust concentrations by ENS and IRA estimated at the stations (Figure 11) indicate differences. For example, at BG0070A (peak Kopitoto) only ENS marks the days 17, 19-20.08. as affected by desert dust. As observations are missing for the two days 19-20.08., it is difficult to interpret, without additional information, which model version is correct. For the remaining station, ERA and IRA have also opposite results relative to the dust or non-dust days on 17, 19-20.08.

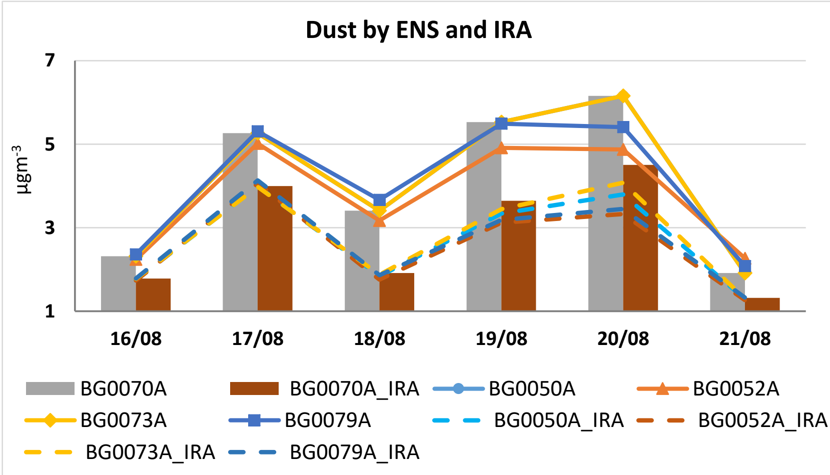

Fig. 11. Dust concentrations (µgm^{-3}) by ENS and IRA at Sofia stations during 16-21.08.2022; Bars for station BG0070A (peak Kopitoto) - grey (ENS) and brown (IRA); lines for the remaining stations – solid lines (ENS), dashed lines (IRA)

Additional information could be provided by other data sources, e.g. $PM_{2.5}$ observations. For the station BG0050A (Sofia Hipodruma), where both $PM_{2.5}$ and PM_{10} measurement data are available, the ratio of $PM_{2.5}$ to PM_{10} could provide indication if the days 17, 19-20.08. are affected by desert dust. For a dust day this ratio should be much smaller, 0.3-0.5 (Querol et al., 2019; Conte et al., 2020). This ratio at BG0050A has values for the mentioned days of 0.42, 0.5 and 0.77, while the monthly average is 0.49. Thus, only for the day 17.08. there is an indication for dust transport at BG0050A, as indicated only by ENS. For 19-20.08. IRA flags for non-dust days at the urban Sofia stations seem to provide better estimates than the dust flags by ENS.

Another indication for dust transport may come from the data for the aerosol optical depth (AOD), measured at the AERONET (AErosol RObotі NETwork) (Holben et al., 1998) station Sofia_IEBAS. AOD is an integral characteristic for all types of aerosol in the entire atmospheric column. For days with desert dust the AOD increases, while the Angstrom Exponent decreases, and the coarse aerosol prevails over the fine aerosol fractions (Basart et al, 2009; Evgenieva et al., 2022). All these parameters, estimated following prescribed retrieval and calculation procedures, are freely available at the AERONET site (https://aeronet.gsfc.nasa.gov/).

At station Sofia_IEBAS data for August 2022 are available for the days from 1 to 12, and from 15 to 19.08. From the identified dust days by ENS there only two dates 17 and 19.08. For both dates the joint analysis of different parameters does not provide firm evidence of dust event. Mean daily AOD at 500 nm was rather low (0.168 and 0.245, respectively for 17 and 19.08), the Angstrom exponent (440-870 nm) was rather high (1.66 and 0.938) and the fine aerosol fraction was prevailing over the coarse one. The sources for the aerosol content on 17.08. were discussed by Evgenieva at el. (2024) based on various data. The authors concluded that on this day the main reason for higher aerosol content in Sofia is biomass burning from forest fires, with contribution from marine aerosols and some desert dust particles.

The analysis of in-situ measurements (PM at the ExEA stations in Sofia, and the aerosol parameters from the AERONET station Sofia_IEBAS) indicate that IRA results seem to be more realistic, so that the days 17, 19 - 20. 08. 2022 at Sofia stations have not to be treated as affected by dust events.

4. CONCLUSIONS

The identification of days, for which desert dust transport might increase PM_{10} concentrations so that daily limit values are exceeded, is an important first stage of the methodology developed at NIMH in support to ExEA on reporting exceedances due to natural sources. At present the methodology makes use of the dust concentrations provided by the European air quality modelling system CAMS-ENS in its analysis data. Results from the interim reanalysis (IRA) of this system have been analyzed using the same threshold value for daily mean dust concentration (5 μgm^{-3}) to flag a day as a "dust day".

The comparison between ENS and IRA at 40 stations in 2022 showed that IRA estimates lower surface dust concentrations and the total number of dust days is lower by approximately 6%. However, on monthly basis IRA results are not always lower than the days by ENS. For example, the number of dust days by IRA across all stations in June, October and November was slightly higher. At individual stations, the differences varied - from a reduction of up to 6 days per year to an increase of up to 9 days per year.

Dust contribution in PM_{10} concentrations is not a parameter routinely measured. It can be assessed based on specific measurements and analysis of the PM chemical composition. Therefore, a direct evaluation of the ability of modelling systems to reproduce dust concentrations is not straightforward. Speciation data for the year 2022 are not available at stations in the country. Some additional in situ observations ($PM_{2.5}$ and AERONET data) in Sofia were used to interpret the differences in August, the month for which ENS estimated 3-4 more dust-days. The analysis suggest that IRA results provide better estimates for the dust-days.

It should be noted, that for the purposes of deducting exceedances it is important to have on a specific day not only a flag for a dust day, but also higher observed PM_{10} concentrations. The discussion about how the differences in identified days influence the deduction of exceedances at the air quality stations will be subject of further studies.

ACKNOWLEDGEMENTS

This study was carried out within the project "Identification of periods with desert dust transport in Bulgaria – a comparative analysis of different methods" (2023-2026), included in the NIMH research plan.

REFERENCES

Barnaba, F., Bolignano, A., Di Liberto, L., Morelli, M., Lucarelli, F., Nava, S., Perrino, C., Canepari, S., Basart, S., Costabile, F., Dionisi, D. (2017), Desert dust contribution to PM_{10} loads in Italy: methods and recommendations addressing the relevant European Commission Guidelines in support to the Air Quality Directive 2008/50, Atmos. Environ., 161, 288–305. https://doi.org/10.1016/j.atmosenv.2017.04.038

Barnaba, F., Alvan Romero, N., Bolignano, A., Basart, S., Renzi, M., and Stafoggia, M. (2022) Multiannual assessment of the desert dust impact on air quality in Italy combining PM_{10} data with physics-based and geostatistical models, Environ Int., 163, 107204, https://doi.org/10.1016/j.envint.2022.107204

Basart, S., Pérez, C., Cuevas, E., Baldasano, J. M., and Gobbi, G. P. (2009), Aerosol characterization in Northern Africa, Northeastern Atlantic, Mediterranean Basin and Middle East from direct-sun AERONET observations, Atmos. Chem. Phys., 9, 8265–8282, https://doi.org/10.5194/acp-9-8265-2009, 2009.

Bulletin NIMH (2022) Monthly hydro-meteorological bulletin for the month of August 2022, issued by NIMH, ISSN 2815-2743, available at: https://bulletins.cfd.meteo.bg/

CAMS (2025) Documentation on the CAMS regional air quality forecast and analysis production system, available at: https://confluence.ecmwf.int/display/CKB/CAMS+Regional%3A+European+air+quality+analysis+and+forecast+data+documentation

CAMS (2020) CAMS European air quality forecasts. Copernicus Atmosphere Monitoring Service (CAMS) Atmosphere Data Store, DOI: 10.24381/a4005cee https://ads.atmosphere.copernicus.eu/datasets/cams-europe-air-quality-forecasts (Accessed on 09-01-2026)

CAMS (2021) CAMS European air quality reanalyses. Copernicus Atmosphere Monitoring Service (CAMS) Atmosphere Data Store, Ensemble data, DOI: 10.24381/7cc0465a https://ads.atmosphere.copernicus.eu/datasets/cams-europe-air-quality-reanalyses (Accessed on 09-01-2026)

Conte, M., Merico, E., Cesaria, D., Dinoi, A., Grasso, F.M., Donateo, A., Guascito, M.R., Contini, D. 2020, Long-term characterization of African dust advection in south-eastern Italy: Influence on fine and coarse particle concentrations, size distributions, and carbon content. Atmos. Res. 233, 104690, https://doi.org/10.1016/j.atmosres.2019.104690

EC (2011), European Commission Staff Working paper, Establishing Guidelines for Demonstration and Subtraction of Exceedances Attributable to Natural Sources under the Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe. https://data.consilium.europa.eu/doc/document/ST%206771%202011%20INIT/EN/pdf

ExEA (2022) Methodology for assessment of exceedances of the daily limit value of PM_{10} in Bulgaria due to emissions from natural sources – desert dust (in Bulgarian) , available at https://www.eea.government.bg/bg/legislation/air/Metodika_pustinen_prah1.pdf

Evgenieva, T., Gurdev, L., Toncheva, E., and Dreischuh, T. (2022), Optical and Microphysical Properties of the Aerosol Field over Sofia, Bulgaria, Based on AERONET Sun-Photometer Measurements. Atmosphere, 13, 884, https://doi.org/10.3390/atmos13060884

Evgenieva, T., Vakareeva, E., Gurdev, L. and Dreischu T. (2024), Identification of Saharan-Dust intrusions over Sofia, Bulgaria, using near-ground PM_{10} and $PM_{2.5}$ mass concentration Measurements. Aerosol Air Qual. Res. 24, 230304, https://doi.org/10.4209/aaqr.230304

Georgieva, E., Kirova, H., and Stoycheva, A. (2023), Impact of desert dust transport on fine particulate matter (PM_{10}) concentrations – methods for assessment and applicability for Bulgaria, Bul. J. Meteo & Hydro 27/1, 54-75, (in Bulgarian) , available at http://meteorology.meteo.bg/global-change/bjmh_online_en.html

Holben, B.N., Eck, T.F., Slutsker, I., Tanre, D., Buis, J.P., Setzer, A., Vermote, E., Reagan, J.A., Kaufman, Y.J., Nakajima, T., et al. (1998), AERONET—A federated instrument network and data archive for aerosol characterization, Rem. Sens. Environ, 66, 1–16.

Nickovic, S., Vukovic Vimic, A., Tong, D., and Basart, S. (2025), Guidelines on Sand and Dust Storm Mitigation, GAW Report No. 305, World Meteorological Organization, 112 p.

Querol, X., Pérez, N., Reche, C., Ealo, M., Ripoll, A., Tur, J., Pandolfi, M., Pey, J., Salvador, P., Moreno, T., and Alastuey, A. (2019), African dust and air quality over Spain: Is it only dust that matters?, Science of The Total Environment, 686, 737-752, https://doi.org/10.1016/j.scitotenv.2019.05.349.