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CASE STUDY OF THE SAHARAN DUST EFFECTS ON PM10 AND PM2.5 CONCENTRATIONS IN BUDAPEST IN MARCH 2022

ACHRAF QOR-EL-AINE – ANDRÁS BÉRES – GÁBOR GÉCZI

Abstract

The Earth's climatic system is greatly dependent on atmospheric mineral dust. Dust particles are regarded as one of the less well-known contributors to recent climatic changes, much like other aerosol constituents. Fifty to seventy percent of the world's budget for mineral dust comes from the Sahara Desert areas. These sources can produce dust-loaded air masses that can travel great distances and affect many parts of the world including Europe, the Middle East, North and South America. In March 2022 Europe faced two Saharan Dust storms (14-19 and 28-31), that affected many countries including Hungary. We used registered measurements of PM10 and PM2.5 concentrations from urban background air quality station in Budapest and MONARCH model to assess the effects of the two Saharan Dust storms on Budapest. As measured by daily average concentrations, PM10 and PM2.5 concentrations rose by 12 µg/m^3 and 10 µg/m^3 respectively during the first Saharan Dust event (SDE1), and by 14 µg/m^3 and 5 *µg/m3 during the Second Saharan Dust event (SDE2). While the effects of both SDEs on PM10 were nearly identical, SDE1 had a greater impact on PM2.5 concentrations than SDE2. Moreover, the dust load arriving to Budapest as estimated by the MONARCH model was higher in the SDE1 (1.26 g/m^3), and that was associated with high values of dust surface concentration and Dust optical depth (243.1 µg/m^3* and 0.71).
Keywords: *Saharan Dust Storms, PM10, PM2.5, MONARCH model, Budapest*

A SZAHARAI POR HATÁSA A PM10 ÉS PM2,5 KONCENTRÁCIÓKRA BUDAPESTEN, ESETTANULMÁNY 2022 MÁRCIUSÁBAN

Összefoglalás

Földünk klimatikus viszonyai erősen függenek az atmoszferikus ásványi por tartalomtól. Ezeket a szemcséket, más aeroszolok részecskékhez hasonlóan nem tekintik az éghajlatváltozást jelentős befolyásoló tényezőjének. Az ásványi por közel 50-70%-a a Szaharából származik.

Ezek a források porral teli légtömegeket termelhetnek, amelyek nagy távolságokat tehetnek meg és a világ számos részét érintik, beleértve Európát, a Közel-Keletet, Észak- és Dél-Amerikát. 2022 márciusában Európa két szaharai porviharral nézett szembe (14-19 és 28-31 között), amelyek számos országot, köztük Magyarországot is érintették. Egy budapesti levegőminőségi állomáson regisztrált PM10 és PM2.5 eredményeket és a MONARCH modellt használtuk a két szaharai porvihar Budapestre gyakorolt hatásának felmérésére. A napi átlag koncentrációval mérve a PM10 és PM2.5 koncentráció 12 µg/m3-rel, illetve 10 µg/m3-rel nőtt az első szaharai poresemény (SDE1) során, illetve 14 µg/m3-rel és 5 µg/m3-rel a második időszakban (SDE2). Megállapítható, hogy a PM10 koncentrációra közel azonos hatása a volt *mindkét SDE eseménynek, ugyanakkor az SDE1 nagyobb mértékben növelte a PM2,5 koncentrációt, mint az SDE2. Továbbá a MONARCH modellel becsült, Budapestre érkező*

porterhelés magasabb volt az SDE1-ben (1,26 g/m3), ami a por felületi koncentrációjának és a por optikai mélységének magas értékeivel (243,1 µg/m3 és 0,71) társult.
Kulcsszavak: *szaharai porviharok, PM10, PM2.5, MONARCH modell, Budapest*
JEL kód: *Q53*

Introduction

The dust absorbs and reflects solar energy and fertilizes ocean ecosystems with iron and other minerals that plants and phytoplankton need to grow, playing a significant role in the climate and biological systems of Earth. The primary source of atmospheric particles, which also significantly affects climate, ecosystems, and air quality, is desert dust. The Sahara is the primary source of dust in the Northern Hemisphere, and it clearly affects multiple continents, from South America's fertilization to Europe's air quality. (PROSPERO et al., 2020; QOR-EL-AINE et al., 2021; WANG et al., 2020) In fact, dust is often carried in the Mediterranean basin region, but it can also appear in Europe at higher latitudes. (GKIKAS et al., 2018) Weather conditions that endorse effective northward transport in the troposphere are related to transportation. (BIBI et al., 2020) Strong seasonal winds carry more than 100 million tons of dust out of North Africa and away from the Sahara Desert each year. (YU et al., 2021) Strong, consistent winds from the south push Saharan dust northward toward Europe at least a few times per year. According to research by FRANCIS et al. (2022), over the past forty years, 78% of atmospheric rivers over northwestern Africa have resulted in extreme dust events over Europe. These "aerosol atmospheric rivers" have the potential to significantly influence global climate and air quality. (CHAKRABORTY et al., 2021) Moreover, dust mat affect also the formation of soil by deposition on land surface, it may be part in forming calcretes if dust contains high carbonate percentage. (GOUDIE – MIDDLETON, 2001) Additionally, SUCHODOLETZ et al. (2013) indicate a correlation between rising soil levels of Saharan dust and an increase in the amount of phosphorous that is available to plants. Therefore, the Saharan dust input affects soil fertility.

A significant factor in the effects of dust on human health is particle size. PM10 particles, which are respirable, are smaller than or equal to 10 microns. PM2.5, or particles smaller than 2.5 microns, may enter the bloodstream and cause serious problems. Asthma, tracheitis, pneumonia, aspergillosis, allergic rhinitis, and nonindustrial silicosis, also known as "desert lung" syndrome, can all be brought on by those-sized particles in the respiratory tract. (DERBYSHIRE, 2007) The distribution and deposition of dusty particles in the respiratory system depend greatly on the grain size and grain size distribution of the inhaled dust. The likelihood of deposition increases as the particle size decreases. However, there is a link between a higher mortality rate and larger inhaled particles (PM10-2.5). (MALLONE et al., 2011) Significant numbers of casualties during periods of high Sahara dust concentration in South Europe were caused by respiratory ailments, cardiovascular and vessel diseases, as well as strokes. (DÍAZ et al., 2012; PEREZ et al., 2012; REMOUNDAKI et al., 2011) The length of exposure to dust and the quantity or dose of dust are key determinants of the health risk. The amount of dust that is inhaled depends on the air concentration (measured in g/m3), the length of exposure, and the breathing rate, which is typically 0.38 m^3/h. The higher the dose, the longer the exposure, the higher the airborne dust concentration, and the smaller the inhaled particle size. (HSIEH – LIAO, 2013; OPP et al., 2021)

Many studies were performed to reveal many aspects of how the Saharan dust affects the PM concentrations and other environmental effects in the European countries (MICHELOT et al., 2015; SALVADOR et al., 2008, 2022), using different existing models that can provide a forecast of the Saharan dust, and an understanding of its different parameters. (BARNABA et al., 2022; DELEVA et al., 2021; DI TOMASO et al., 2022; MONTEIRO et al., 2022; ȚÎMPU et al., 2020)

The aim of this paper is to evaluate the effects of the two Saharan storms that were in March 2022, on the concentration of PM10 and PM2.5 in Budapest, Hungary using real measurement and quantifying the intensity of the Saharan storms using the Multiscale Online Nonhydrostatic AtmospheRe CHemistry model (MONARCH) developed at the Barcelona Supercomputing Center (BSC).

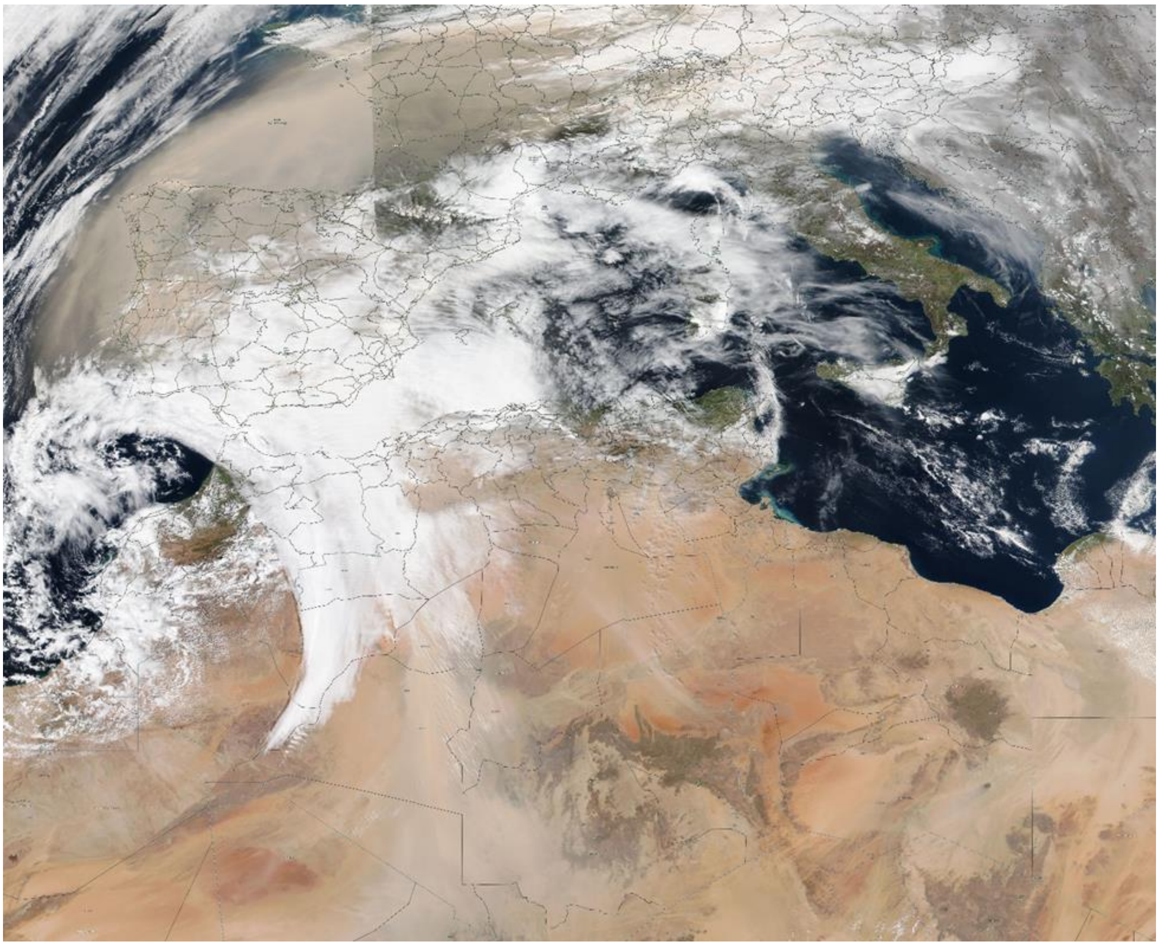

Figure 1. Suomi NPP / VIIRS true color image on the 15th of March 2022. Clouds appear in white and Saharan dust in pale yellow/brown
Source: NASA Worldview

Material and methods

In 2022, Europe suffered from two severe Saharan Dust Events (SDE) during March. Large storms in March 2022 sent clouds of Saharan dust to Europe. One of them also brought long-lasting, dusty, high-altitude cirrus clouds, which caused widespread cloud cover for more than a week, from Iberia to the Arctic. It was a rare kind of storm that researchers have only recently learned to comprehend. Its characteristics include icy clouds that are infused with dust, hence the name dust-infused baroclinic storm (DIBS). A DIBS entrained and lifted an atmospheric river of Saharan dust into the troposphere in the middle of March, attaining an altitude of 10 kilometers. Dust-infused, high-altitude cirrus clouds formed as a result of the dust acting as ice nucleation particles. They continued for almost a week, covering a sizable portion of Europe. On March 15, 2022 (SDE1), the first storm developed over north-central Europe and moved south through Poland, the Czech Republic, and Austria to the eastern Mediterranean (Figure 1). 13 days (28th March 2022-SDE2) after the first Saharan dust storm, another wave of Saharan dust hit the south of Europe a spread to reach the Eastern European countries.

To evaluate the effect of the Saharan dust load transported to Budapest Hungary, measurements of PM10 and PM2.5 from the Hungarian Air Quality Network platform (Országos Légszennyezettségi Mérőhálózat (OLM)) for Budapest Erzsébet tér air quality station, as well as Dust Load and Dust Surface Concentration (DSC) from the WMO Barcelona Dust Regional Center platform for the 3 dust storm events.

PM10 and PM2.5 concentrations in Budapest

PM10 and PM2.5 concentrations are always higher in winter and fall seasons due to the alternating variability of the weather conditions and the emission source.

The monitoring of PM10 with delicate temporal resolution began in 2007 at several locations in Budapest (525.1 km2, 1,775,000 inhabitants). The 12 stations that make up Budapest's network for monitoring air quality fall into one of three categories: traffic (four), industrial (three), and background (5). For our analysis, we chose the Gilice tér urban background station, which is typical weather and air quality monitoring station that provides PM10, and PM2.5 concentrations and in-depth meteorological observations with good data coverage. It is located in the Southern East part of Budapest. The Hungarian Meteorological Service's Marczell György Main Observatory is nearby this location. This air quality monitoring station is classified as suburban, with significant input from important sources in the greater Budapest region (Ferenczi et al., 2021).

Figure 2 shows the PM1 and PM2.5 in Gilice tér air quality station during March, the first 10 days of April, and May 2022. During March, the PM10 and PM2.5 concentrations are usually high, however, in March 2022 the PM10 concentration was below the daily EU limit value of 50 µg/m^3, alternating between 14 and 47 µg/m^3, and registering lower values in April and May.

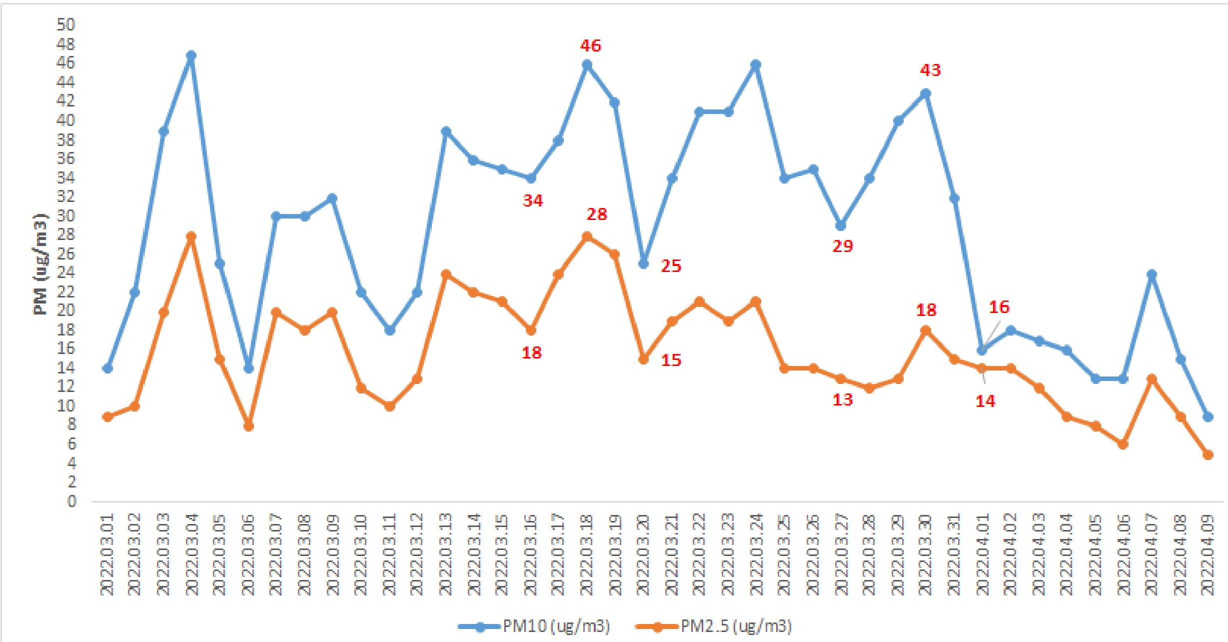

Figure 2. PM10, and PM2.5 concentrations (µg/m^3) in Gilice tér air quality station during March and the first 10 days of April 2022

WMO Barcelona Dust Regional Center products

In Northern Africa, the Middle East, and Europe, the World Meteorological Organization Barcelona Dust Regional Center directs research efforts and system operations for the WMO Sand and Dust Storms Warning Advisory and Assessment System (WMO SDS-WAS). The Center's main goal is to improve the ability of the countries to provide users with accurate and timely sand and dust storm forecasts, observations, and knowledge. Access to this data is essential for the creation of early warning systems and mitigation strategies. Additionally, it strengthens the global partnership between research, operational services, and user communities in response to the growing interest of stakeholders from various sectors.

Known as NMMB/BSC-CTM, the Multiscale Online Nonhydrostatic AtmospheRe CHemistry model (MONARCH) is a chemical weather forecasting system. The foundation of MONARCH, created at the Barcelona Supercomputing Center, is the online coupling of a complete aerosol-chemistry module with the meteorological Nonhydrostatic Multiscale Model on the B-grid (NMMB). The Barcelona Supercomputing Center received the NMMB model through a Memorandum of Understanding from the National Oceanic and Atmospheric Administration - Environmental Modeling Center (NOAA/EMC) on an AS IS basis, without any warranties or conditions of any kind. (KLOSE et al., 2021) The Barcelona Dust Forecast Center, the WMO SDS-WAS Regional Center for Northern Africa-Middle East-Europe (NA-ME-E) (https://sds-was.aemet.es/), and the International Cooperative for Aerosol Prediction (ICAP) produce daily dust forecasts using MONARCH. (SESSIONS et al., 2015; XIAN et al., 2019)

The amount of the solar beam that is absorbed by haze and dust is measured by the aerosol optical depth. In other words, dust, smoke, and pollution in the atmosphere can block sunlight by absorbing or scattering light. AOD informs us of the amount of direct sunlight that these aerosol particles keep from reaching the ground. It is an arbitrary number with no dimensions that describes how much aerosol is present in the vertical column of atmosphere. A value of 0.01 indicates an environment that is exceptionally clean, while a value of 0.4 indicates an environment that is extremely hazy. And, Dust Optical Depth (DOD) is the measure of the dust particles in the atmosphere, dust particles become so dense that the sun is blocked as DOD rises to 0.5, 1 and greater than 3.0. The storm's severity is indicated by the higher DOD values. (ASUTOSH et al., 2022; ECK et al., 1999). Dust Load is the mass of the dust suspended in the atmosphere, higher DL also indicate the intensity of the dust storm.

In this research, DOD, Dust Surface Concentration (DSC), and DL from the MONARCH model were extracted and evaluated for Budapest during the March SDEs.

Results

PM10 and PM2.5 concentrations during the Saharan dust events

The daily PM10 and PM2.5 concentrations increased in each Saharan dust event at a different percentage rate. During the first SDE in March 2022 (17th -20th), the daily PM10 and PM2.5 concentration jumped from 34 μg/m^3 and 18 μg/m^3 in 16th to 46 μg/m^3 and 28 μg/m^3 in the 18th and then start to decrease to reach 25 μg/m^3 and 15 μg/m3 in the 20th. For the second SDE in March 2022 (28th – 31st), the daily PM10 and PM2.5 concentration changed from 29 μg/m^3 and 13 μg/m^3 on the 27th to 43 μg/m^3 and 18 μg/m^3 on the 30th after which begin to decline to attain 16 μg/m^3 and 14 μg/m^3 in the 1st of April 2022.

Hourly PM10 and PM2.5 concentrations (Figure 3) provide details on how the hourly concentration changed with the SDE.

SDE1 was more intense than SDE2, as the effects were seen on the level of PM10 and PM2.5. The peak hourly concentration for PM10 was 86 μg/m^3 and 57 μg/m^3 for SDE1 and SDE2 respectively, while for PM2.5 it reached 51 μg/m^3 and 27 μg/m^3 as hourly concentration for SDE1 and SDE2 respectively.

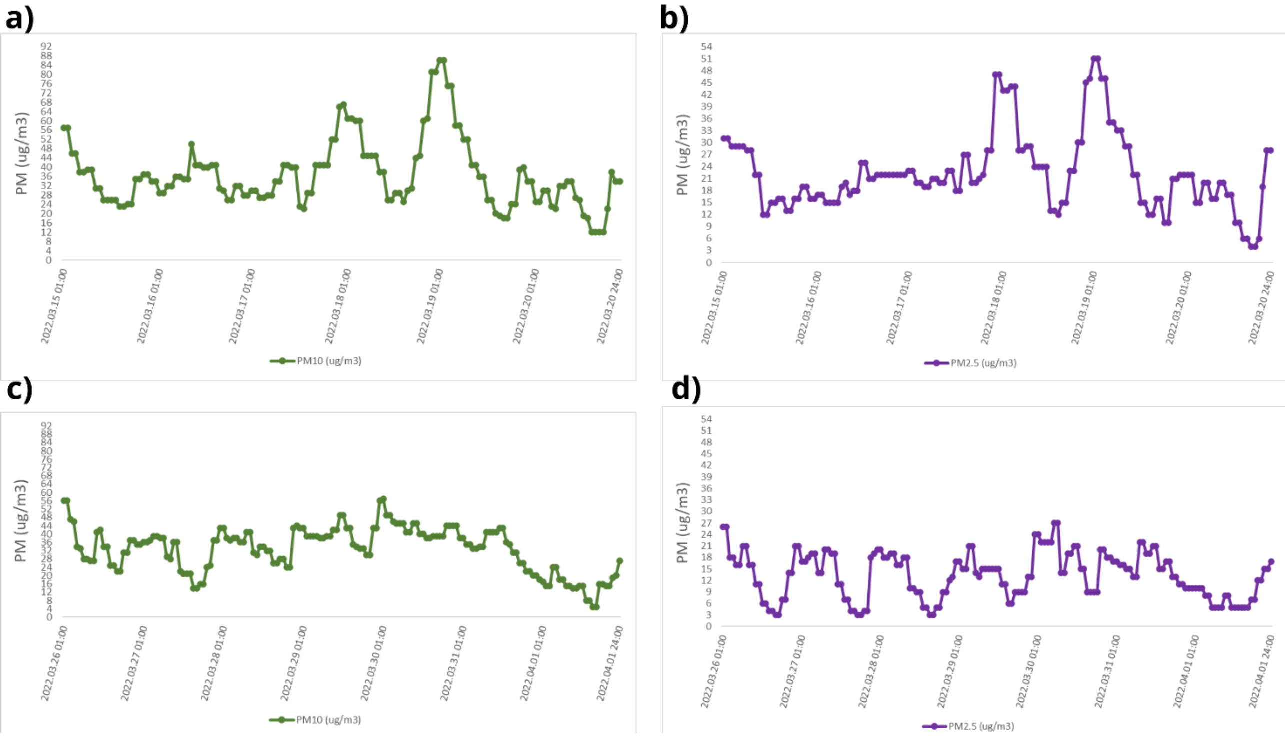

Figure 3. Hourly concentration of a) PM10 during SDE1, b) PM2.5 during SDE1, c) PM10 during SDE2, and d) PM2.5 during SDE2

About weather conditions, from 8 to 12 March 2022, the high temperature was between 7 and 10˚C, the wind direction from the North and Northeast direction, and the maximum wind speed was between 3.5 and 5m/s, and no precipitations were registered. There was a slight increase in the maximum temperature (between 8 and 15˚C) in the following days, while from the 15th of March wind pattern full of Saharan dust arrived by western winds and in-ground surface the wind speed didn't exceed 3.5m/s with no precipitations during SDE1.

The temperature continued to increase after SDE1, ranging from 16 and 21˚C as the maximum temperature, and start to decrease from the 31st of march and returns to the same levels that were at the beginning of March 2022, from the 2nd of April 2022 (between 5 and 9˚C). On the other hand, wind loaded with Saharan dust particles were transported by West-Southwest, Southwest, and South-Southwestern winds, and maximum wind speed on the ground surface ranged from 3 and 5m/s during the SDE2, and start to increase from the 1st of April 2022 to exceed 6m/s as maximum wind speed, and no precipitations occurred on those days.

DOD, DSC, and DL during the Saharan dust events

Figure 4 illustrates the changing of DSC, DOD, and DL during SDE1 and SDE2. The peak values registered during SDE1 are higher than during SDE2. 243.1 μg/m^3, 1.26 g/m^3, and 0.71 are the maximum reached during SDE1 for DSC, DL, and DOD respectively, while for SDE2 125.8 μg/m^3, 0.28 g/m^3, and 0.32 were registered for DSC, DL, and DOD respectively.

With increasing distance from the source, dust's grain size decreases. When transported over long distances, coarse particles typically do not exceed 20 µm because of their higher settling velocity. (DOES et al., 2016) MAHOWALD et al. (2014) hypothesized that because coarser particles tend to settle out more readily, dust in the high atmosphere is finer grained than dust that has been deposited. Seasonally, summertime is when Saharan dust is coarser than wintertime. The high DSC in both SDEs was triggered the increase of hourly PM10 and PM2.5 concentration. In addition, rise in the DL value was associated with the rise of DOD and DSC numbers also.

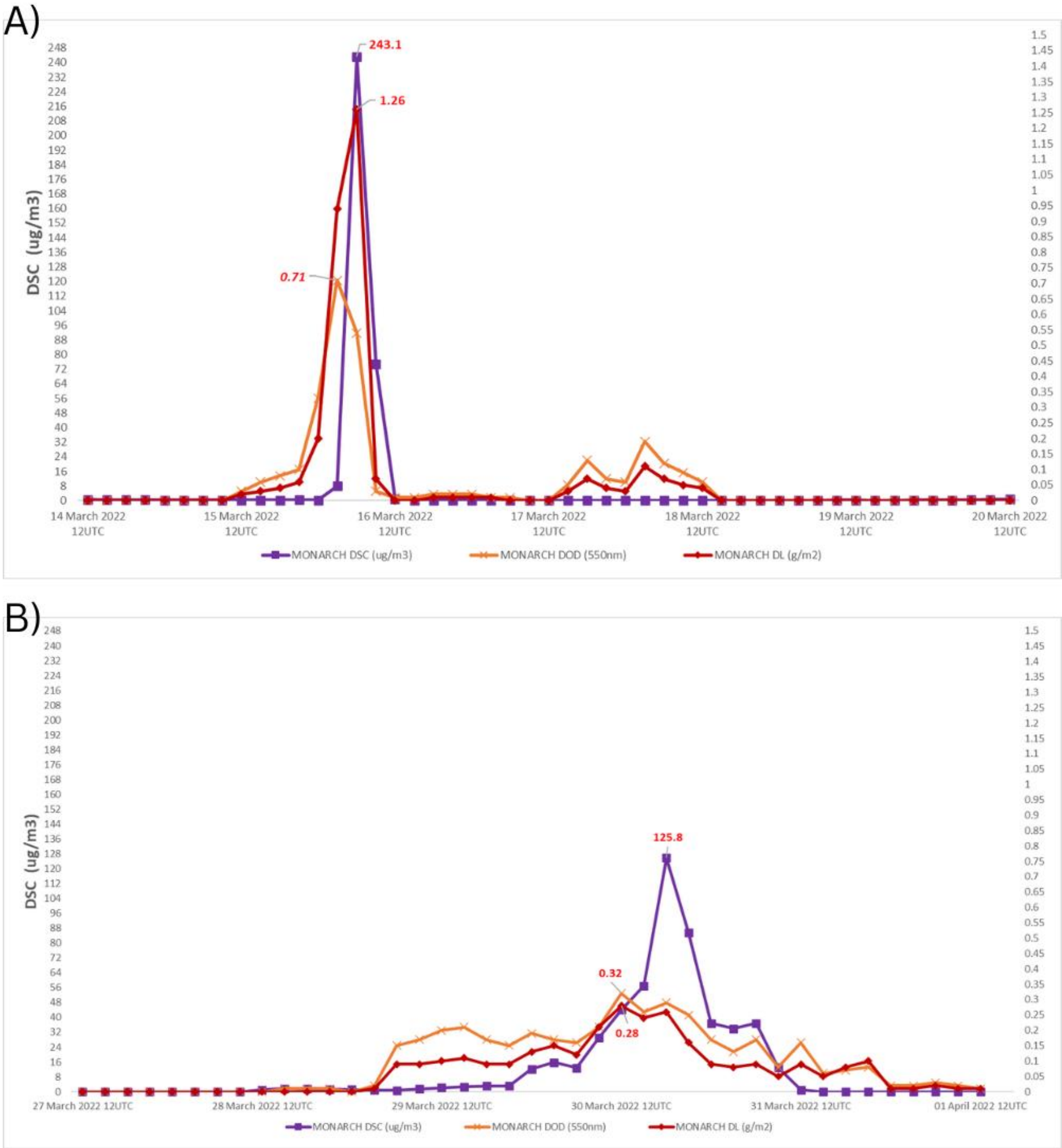

Figure 4. MONARCH DSC (µg/m3), DOD, and DL (g/m3) during A) SDE1, and B) SDE2

Conclusion

The Sahara is the main source of dust in the Northern Hemisphere, and it is obvious that it has an impact on many different continents, from the fertilization of South America to the air quality in Europe. The Saharan dust storms affects the PM concentrations depending on the intensity of the storm. During March 2022 SDEs, PM10 and PM2.5 concentrations in an urban background air quality station in Budapest increased by 12 μg/m^3 and 10 μg/m^3 respectively during SDE1, and 14 μg/m^3 and 5 μg/m^3 during SDE2 as daily average concentrations. in Both SDEs the effect on PM10 was almost the same, while SDE1 raised the PM2.5 concentrations more than SDE2. Furthermore, the MONARCH model estimated that the SDE1 had a higher DL arriving in Budapest (1.26 g/m^3), which was linked to high values of DSC and DOD (243.1 μg/m^3 and 0.71 respectively).

With the changing of the world climate, the intensity and the number of the Saharan dust storms episodes increase, and many model like MONARCH model are still improving to provide more accurate forecast and to analyse the dust effects on different meteorological and air quality parameters.

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Authors

Achraf QOR-EL-AINE
PhD student
Doctoral School of Mechanical Engineering, Hungarian University of Agriculture and Life Sciences,
H-2100 Gödöllő, Páter Károly str. 1.
qorelaine.achraf@gmail.com

Dr. András BÉRES
Head of Center
University Laboratory Center, Hungarian University of Agriculture and Life Sciences, H-2100 Gödöllő, Páter Károly str. 1.
beres.andras@uni-mate.hu

Dr. Gábor GÉCZI PhD.
associate professor
Institute of Environmental Science, Hungarian University of Agriculture and Life Sciences, H-2100 Gödöllő, Páter Károly str. 1.
geczi.gabor@uni-mate.hu