WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

WWRP WORLD WEATHER RESEARCH PROGRAMME

No. 6 – SEPTEMBER 2022

WMO AIRBORNE DUST BULLETIN

Overview of global airborne dust in 2021

The spatial distribution of the global surface concentration of mineral dust in 2021 (Figure 1) and its anomaly relative to climatologically mean values (1981–2010) (Figure 2) were derived based on the dust products from the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) (Gelaro et al., 2017). This is the latest atmospheric reanalysis version for the modern satellite era produced by the NASA Global Modeling and Assimilation Office (GMAO).

In general, the spatial distribution of the global surface concentration of mineral dust in 2021 was similar to that present in 2020 (*WMO Airborne Dust Bulletin, No. 5*), although some differences were found. The global average of annual mean dust surface concentrations in 2021 was 13.6 $\mu g\ m^{-3}$, which is slightly higher than that in 2020 (12.8 $\mu g\ m^{-3}$). This increase in 2021 has also been observed in several dust-active regions around the world, such as Central Asia, the Arabian Peninsula, the Iranian Plateau and north-western China. Spatially, the estimated peak annual mean dust surface

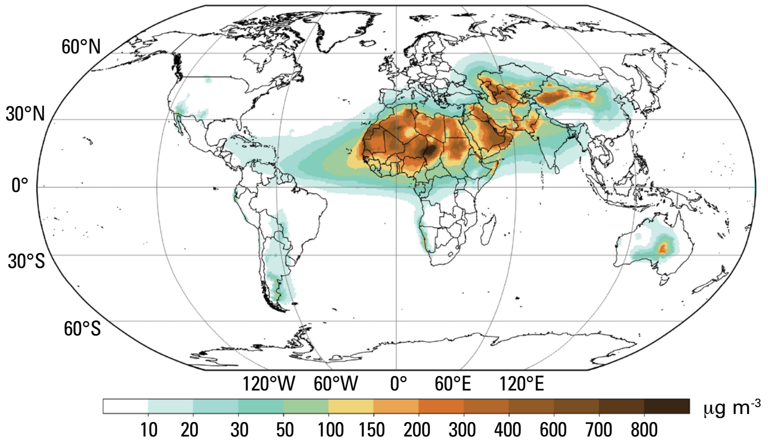


Figure 1. Annual mean surface concentration of mineral dust (in $\mu g\ m^{-3}$) in 2021 based on the NASA MERRA-2 reanalysis

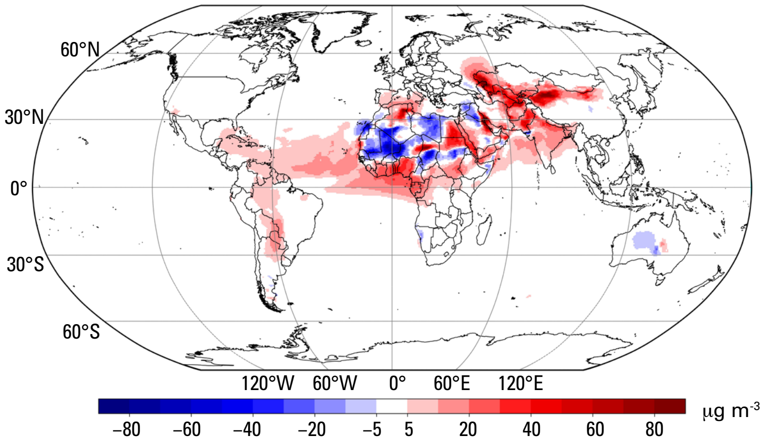


Figure 2. Anomaly of the annual mean surface dust concentration in 2021 relative to the 1981–2010 mean, based on the NASA MERRA-2 reanalysis

concentration (~1000–1300 $\mu g\ m^{-3}$) in 2021 was found in some areas of Chad in North-Central Africa. In the southern hemisphere, dust concentrations reached their highest level (~200 $\mu g\ m^{-3}$) in parts of central Australia and the west coast of South Africa. From these typical dust source areas (especially in North Africa, the Middle East, Central Asia and northern China), wind-driven dust was transported to the surrounding regions. These include the northern tropical Atlantic Ocean between West Africa and the Caribbean, South America, the Mediterranean Sea, the Arabian Sea, the Bay of Bengal, central-eastern China, the Korean Peninsula and Japan, demonstrating the significant impact of sand and dust storms (SDSs) on many regions of the world. In terms of the geographic area impacted, SDSs from dust sources in West Africa and north-west China had a slightly expanded impact area compared to 2020. Influenced by SDSs in 2021, trans-Atlantic transport of African dust invaded the entire Caribbean Sea region; East Asian dust aerosols from northern China reached the Bohai and Yellow Seas. These features were not seen in 2020.

In the most affected areas, the surface dust concentration in 2021 was higher than the climatological mean. Exceptions to this were parts of North Africa (including Mali, Mauritania, south-western Algeria, the western Sahara, Morocco, Libya, north-western Niger, southern Chad, central Sudan), Iraq, Syria and mid-west Australia (Figure 2). Hot spots with significantly higher dust concentrations included the northern tropical Atlantic Ocean between West Africa and the Caribbean, Central and South America, most of Central Africa, parts of Western Europe, the Red Sea, the Persian Gulf, Central Asia, Southern Asia, north-western China and central-northern China.

The three-dimensional (3D) distribution of the dust extinction coefficient (DEC) in the spring of 2021 (Figure 3) was extracted based on the Level-3 tropospheric aerosol profile product from the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) sensor onboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) satellite (Tackett et al., 2018; Gui et al., 2021). The DEC is a characteristic that determines how strongly dust absorbs or reflects radiation or light at a particular wavelength. The results presented here are the average values for both daytime and night-time under the “all-sky” condition. Satellite observations in the spring of 2021 successfully captured dust activity in the near-dust source regions in the northern hemisphere, and its spatial extent of influence was portrayed. Overall, CALIOP observations suggest that stronger DECs and a wider range of impacts were observed in March 2021 in most regions of the world (such as East Asia and the northern tropical Atlantic Ocean) than in the same period in 2020 (*WMO Airborne Dust Bulletin, No. 5*). From satellite observations, a dust belt similar to that of 2020 was identified, extending from the west coast of North Africa, spanning the entire Arabian Peninsula and Central and Southern Asia, to north-western China and its downstream area (east-central China and North-East Asia). In terms of uplifted height, the increased DEC (extinction > 0.1 km^{-1}) was mainly located at an altitude range of 1–4 km above mean sea level (a.s.l). The maximum lifting height of the dust plume layer (DEC > 0.001 km^{-1}) was around 6–10 km a.s.l, spanning the area between 10°S and 60°N, demonstrating the long-range transport of dust.

Major sand and dust events in 2021

Dust events in Europe, February 2021

In February 2021, Europe was affected by several intense Saharan dust intrusions which had a significant impact because of the high values of surface dust concentration and dry and wet deposition recorded. As a result of this phenomenon, values that exceeded the daily limit of particulate matter established by the European Union (EU) air quality regulations, with

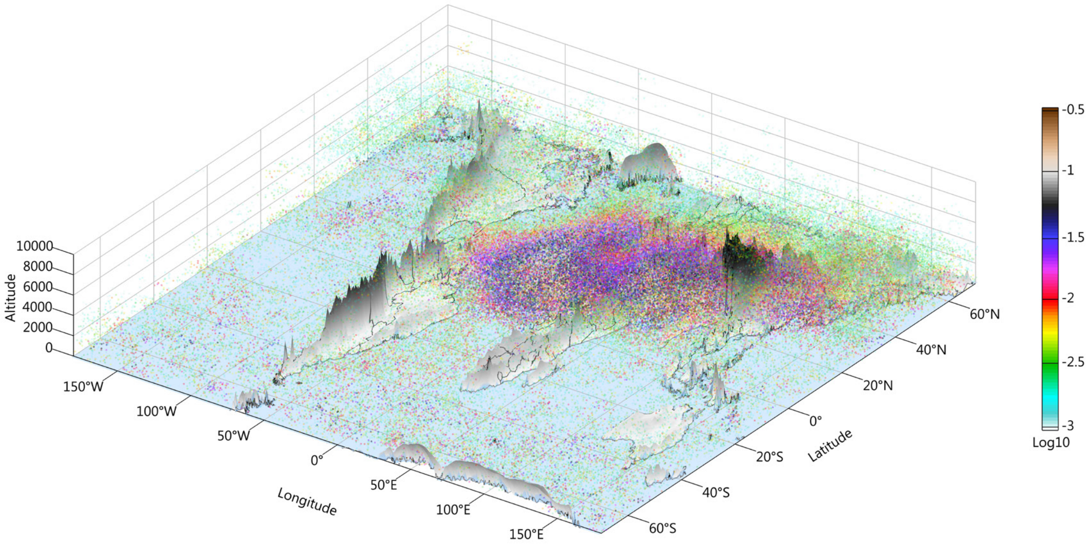


Figure 3. CALIOP-derived global three-dimensional particles map of the dust extinction coefficient (DEC) in the northern hemisphere spring of 2021. The colour scale is converted to log10 for improved visualization, corresponding to a minimum DEC of 0.001 and a maximum DEC of approximately 0.32.

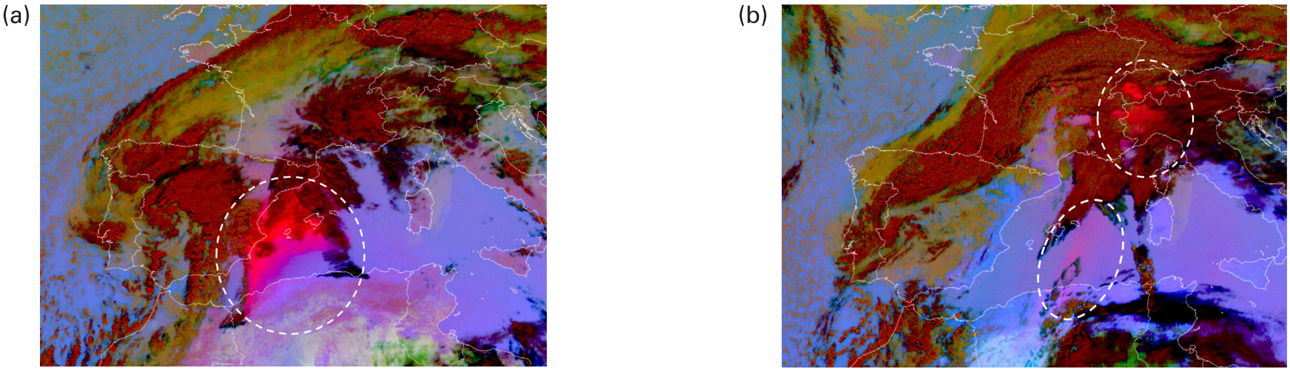


Figure 4. (a) RGB-Meteosat image, 5 Feb 2022 at 2130 hours; (b) RGB-Meteosat image, 6 Feb 2022 at 1130 hours. Dashed circle indicates the dust transport. (*Source:* EUMETSAT)

Figure 5. (a) MONARCH (Run: 4 Feb 2021) 5 Feb 2022 at 2100 hours; (b) MONARCH (Run: 4 Feb 2021) 6 Feb 2021 at 1200 hours (*Source:* Barcelona Dust Regional Center)

diameters of 10 micrometres and smaller (PM_{10}), were detected throughout Europe. This increase in dust particles in the atmosphere led to the EU daily limit value for particulate matter for the protection of human health ($PM_{10} = 50\ \mu g\ m^{-3}$) being exceeded in a large part of the European continent. The World Health Organization (WHO) updated this limit to 45 $\mu g\ m^{-3}$ in its latest *Global Air Quality Guidelines*, published in September, 2021 (https://apps.who.int/iris/handle/10665/345329).

The first dust event of the month started on 5 February in northern Algeria. On the same day, the dust particles were transported through the atmosphere to the south-east of Spain. This dust event was monitored by the RGB-Meteosat, which generated satellite images (Figure 4(a) and 4(b) where dust particles are represented by the colour pink). Over the next few days, the dust plume moved on to southern and central Europe (Figure 5(a) and 5(b)), turning the sky yellow, coating buildings and cars with Saharan dust and even covering snow on the Pyrenees and Alps mountain ranges (see Figure 6(a)). Although partially covered by clouds, the satellite was able to detect the dust mass on its way over the Mediterranean towards Europe and also over the Alpine region. The thickness of the deposited dust layer can be seen in the vertical profile of the snow cover (Figure 6(b)). Mineral dust deposited over snow cover changes its radiative emission properties and albedo, leading to a faster melting and snow evolution.

Figure 6. (a) Jura Mountains (*Source:* Lu Ren, WMO); (b) Snow profile at Refugio Ángel Orús in Huesca in the Pyrenees (*Source:* AEMET meteoglosario (weather glossary))

The centre of the dust plume with maximum concentrations travelled at around 2 500 m and the plume thickness was between 500 m and 5 000 m. The dust concentration vertical distribution predicted by the MONARCH model is shown in the cross-section in Figure 7. This cross-section shows the maximum concentration over the Pyrenees, spreading over Europe and the Alps regions. The inset map shows the dust load.

Furthermore, high PM_{10} levels were recorded in many locations, with different values depending on the altitude of the station, but far exceeding the European daily limit value for particulate matter mentioned above. Several dust intrusions with a significant and long impact took place in the second fortnight of February (Figure 8), making February an exceptional month. The timing and geographical extent of the events were correctly predicted by the Barcelona Dust Regional Center, which is the WMO SDS Warning Advisory and Assessment System (WAS) regional centre for NAMEE. The SDS-WAS seeks to provide operational forecasting and warning advisory services for various regions of the world in a globally coordinated manner in order to reduce the impacts of SDSs on the environment, health and economies.

Sand and dust storm affecting Konya, Türkiye, 30 November 2021

A dust storm hit the Turkish cities of Konya, Aksaray, Nigde and Nevşehir on 30 November. This storm is an example of a mesoscale dust event and the significant impact it can have when it affects populated areas. The storm disrupted daily life in the south-eastern parts of the Central Anatolia Region. Strong southerly winds lifted dust particles from the arid and semi-arid areas in the Konya-Karapınar-Aksaray region and caused a sand and dust storm which moved towards the north (see Figure 9(a)). Hourly maximum wind speeds of 90 km per hour were measured in the southern part of the affected region (see Figure 9(b)).

Sandstorms caused several traffic accidents (Figure 10) on the highways connecting Konya to Ankara, Adana and Aksaray. During the dust storm, visibility decreased to 1 metre and 8 people were injured, 2 of them seriously, in a pile-up involving 30 vehicles. The highways in the sandstorm region were subsequently closed to traffic by the police.

One factor that contributed to this significant event was that the Central Anatolia Region did not receive sufficient rainfall during the summer period. The soil,

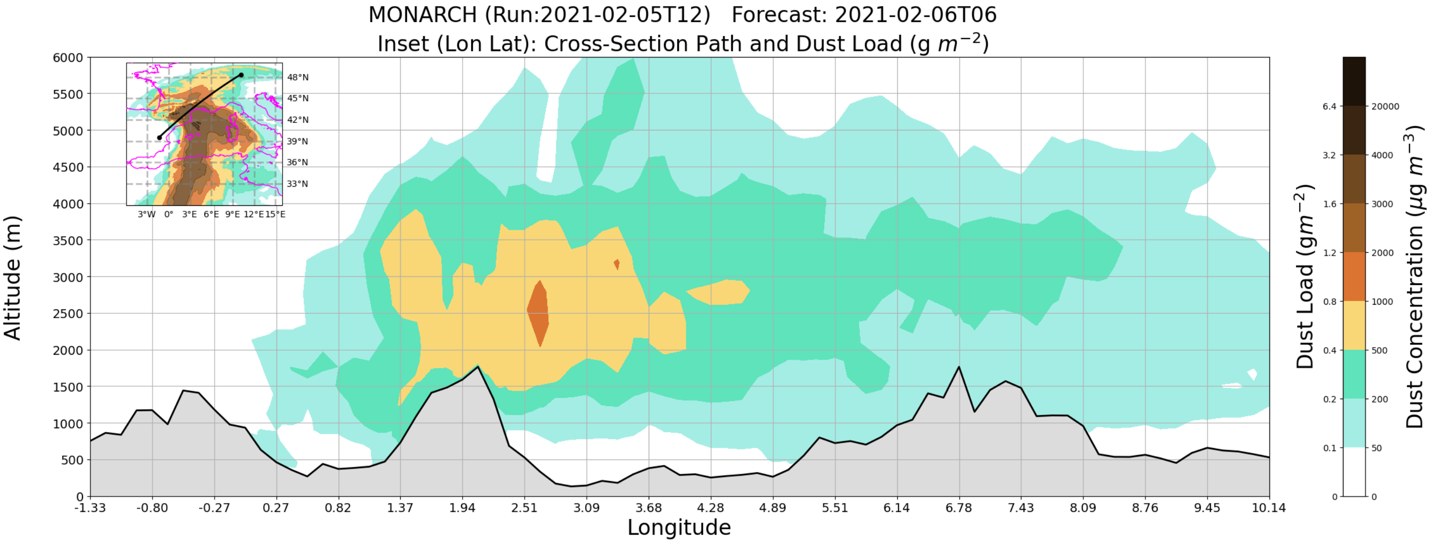


Figure 7. Cross-section MONARCH model over Pyrenees and Alps regions (*Source:* Barcelona Dust Regional Center)

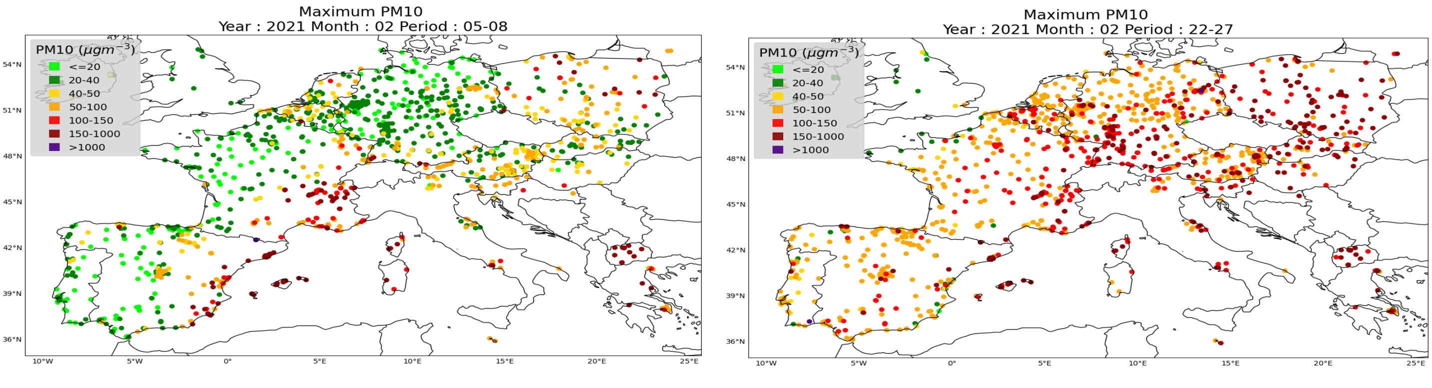


Figure 8. PM_{10} maximum values in Europe for two periods of Saharan dust intrusions: from 5 to 8 February (left panel) and from 22 to 27 February (right panel) (*Source:* European Environment Agency, EEA)

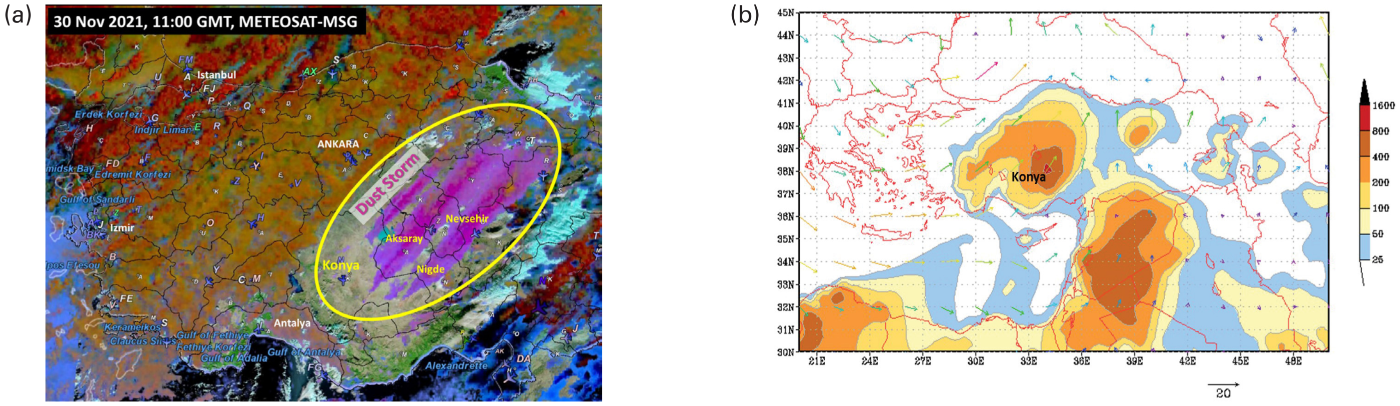


Figure 9. (a) RGB-Meteosat image: dust is represented by the colour pink within the encircled area (*Source:* EUTMETSAT); (b) Numerical output from the BSC-DREAMS8b model, showing forecast dust surface concentration for 30 November 2021 (*Source:* Turkish State Meteorological Service)

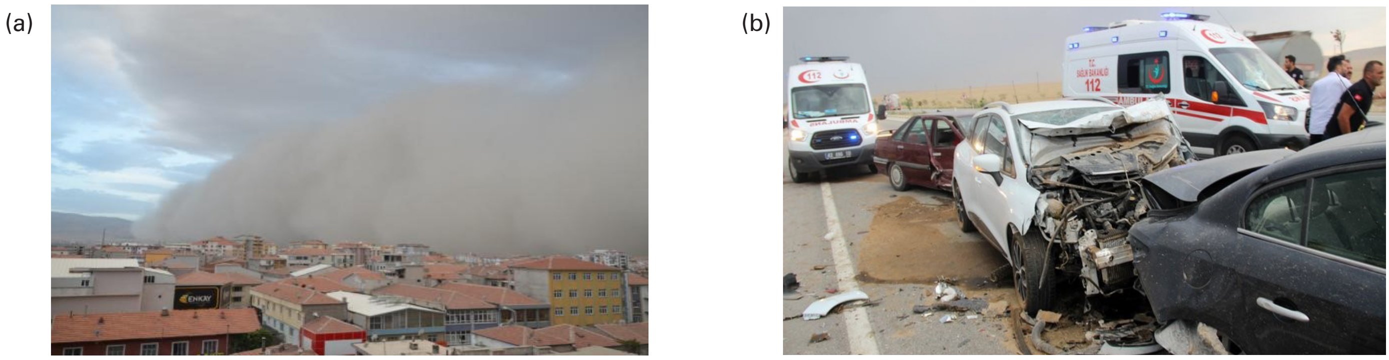


Figure 10. (a) Haboob over the Konya region; (b) Traffic pileup due to a haboob (*Source:* Turkish State Meteorological Service)

which had dried out due to extreme temperatures, was therefore easily carried by the strong southern winds, and caused the sand and dust storm, which later moved northward. This particular event demonstrates how important the previous soil conditions are, and that drought periods can lead to larger dust sources and more intense dust and sandstorm activity.

Synoptic-scale dust storm over West Africa, the Middle East and China, 11–20 March 2021

A huge synoptic-scale dust storm occurred over West Africa, Saudi Arabia, Iran and Afghanistan from 11 to 14 March 2021, and over China from 15 to 20 March 2021. The formation of a deep, cut-off low over Algeria on 11 March, accompanied by a considerably fast-moving upper-level trough over South-Western Asia , which led to dust genesis over Algeria and later over the Middle East, was considered a synoptic meteorological dust genesis mechanism. An RGB-Meteosat dust image (Figure 11, top panel) and MODIS True Color image (Figure 11, bottom panel) show simultaneous dust outbreaks over the region on 13 March 2021 at 0800 UTC.

A postfrontal dust storm broke out over the Middle East in the early morning (0300 UTC) of 12 March 2021. In this region, postfrontal dust storms occur during the winter months when shamal conditions exist behind a cold front. As the front moves across the dust-source regions of Iraq or Saudi Arabia, widespread dust is generated by the winds behind it (see *Establishing a WMO Sand and Dust Storm Warning Advisory and Assessment System Regional Node for West Asia: Current Capabilities and Needs – Technical Report*

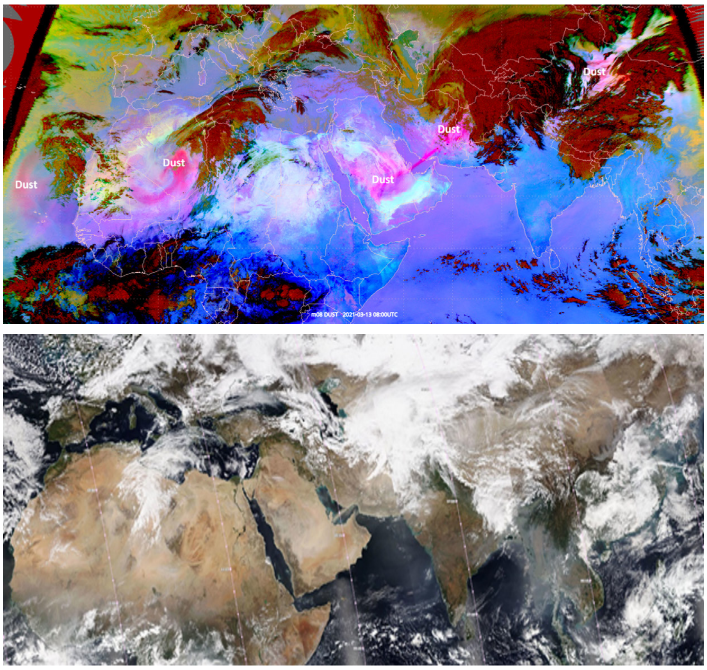
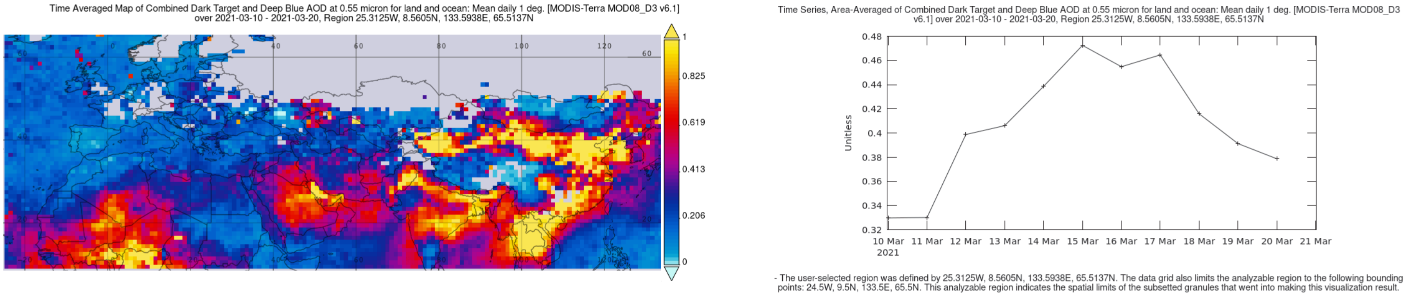


Figure 11. An RGB-Meteosat dust image, 13 March 2021 0800 UTC (top panel) (Source: EUMETSAT); MODIS True Color image, 13 March 2021 0800 UTC (bottom panel) (*Source:* NASA)


Time Averaged Map of Combined Dark Target and Deep Blue AOD at 0.55 micron for land and ocean: Mean daily 1 deg. [MODIS-Terra MOD08_D3 v6.1] over 2021-03-10 - 2021-03-20, Region 25.3125W, 8.5605N, 133.5938E, 65.5137N

Time Series, Area-Averaged of Combined Dark Target and Deep Blue AOD at 0.55 micron for land and ocean: Mean daily 1 deg. [MODIS-Terra MOD08_D3 v6.1] over 2021-03-10 - 2021-03-20, Region 25.3125W, 8.5605N, 133.5938E, 65.5137N

- The user-selected region was defined by 25.3125W, 8.5605N, 133.5938E, 65.5137N. The data grid also limits the analyzable region to the following bounding points: 24.5W, 9.5N, 133.5E, 65.5N. This analyzable region indicates the spatial limits of the subsetted granules that went into making this visualization result.

(a)

(b)

Figure 12. (a) Time averaged map and (b) time series (between 10 to 20 March 2021) of mean daily aerosol optical depth (AOD) retrieved from MODIS TERRA Satellite (*Source:* NASA)

(WMO-No. 1121)). On 12 March 2021, great amounts of dust were lifted behind a cold front, which crossed the entire Middle East. Typically, prefrontal dust storms occur across Jordan, the northern Arabian Peninsula, Iraq and western Iran, as low-pressure systems move across the region (Wilkerson, 1991).

Over the event period, dust was spread over a large region spanning from 20°W to 120°E, and from 10° N to 45°N (Figure 12(a)). The large geographic extent of this event makes it one of the most severe dust storms over this part of the world to date. The highest values were observed mainly from 15 to 17 March (Figure 12(b)).

Severe sand and dust storms in the Pan American Region

A series of severe sand and dust storms were recorded throughout 2021. Early in the year, on 16 March, a massive dust storm swept across the border between the United States of America and Mexico. At the University of Texas at El Paso, located right on the border, PM_{10} levels were up to 2,370 $\mu g\ m^{-3}$ while $PM_{2.5}$ levels were at 340 $\mu g\ m^{-3}$, making it dustier than Beijing that day. Outside conditions were reported to include a thick brown fog, while dirt and dust could be smelt from indoors (CIRA, 2021).

Another dust storm on 28 March in the state of Washington was responsible for 36 collisions spread between Kittitas and Grant Counties (Sarles, 2021). The largest accident was in Othello, Washington, where an eight-car pile-up occurred. There were a few minor injuries as a result of these crashes, but no fatalities.

Toward the end of the year, on 15 December, two people were killed in Grant County, Kansas, due to a series of crashes (involving several vehicles including a fire truck and ambulance that were responding to the accident), after blowing dust reduced visibility on a highway (KWCH, 2021). The winds responsible for this dust event were part of a greater storm that knocked out power for over 200 000 people across Kansas and Colorado (Watchers, 2021).

Eight people killed by a July 2021 dust storm in Utah, USA

On 26 July 2021, strong winds blew dust from nearby agricultural lands across the Interstate-15 highway in Utah, USA, reducing visibility. Over 20 vehicles were involved in a series of chain collisions (O'Donoghue, 2021) (Figure 13). A total of eight people died from these crashes and at least ten were injured. This is the second deadliest traffic accident caused by a dust storm in the United States in the past three decades. The winds were also erratic, creating conditions where visibility fluctuated unpredictably and rapidly (Firozi & Cappucci, 2021). This dust event occurred during a particularly hot and dry summer in the state of Utah, when the Great Salt Lake's water level was at record lows. Over 99% of Utah was categorized as experiencing "exceptional" or "extreme" drought at the time (Firozi & Cappucci, 2021). The dry conditions in Utah have persisted, leading to an increased risk of severe and frequent dust storms. The previous deadliest recorded dust storm occurred on 29 November 1991 in San Joaquin Valley, California, when high winds whipped up dust from nearby farmland. A total of 104 vehicles were involved in an accident killing 17 people, injuring a further 150 and causing the closure of a stretch of 150 miles of the highway for an entire day. At the time, the area was experiencing unusually dry conditions as a result of six years of drought.

Research highlights

High-latitude dust storms

There is widespread concern among the public regarding accelerated warming in the Arctic caused by processes at high latitudes, in which aerosols play a significant

Figure 13. Vehicles involved in the 22-car pile-up during the 26 July 2021 dust storm in Utah, USA, that killed eight people (Photo credit: Utah Highway Patrol)

role. An IPCC special report (IPCC, 2019) recognizes dark dust aerosol as a short-lived climate forcer and light-absorbing aerosol connected to cryospheric changes. High-latitude dust consists of particle types with various sizes and shapes, and with chemical, physical and optical properties that are different from crustal dust from deserts (Meinander et al., 2022). High-latitude dust (HLD) can induce significant direct and indirect effects on solar radiation fluxes and snow optical characteristics, strongly impacting Arctic amplification via radiative feedbacks. It has been shown that temperatures in fragile areas, such as the pristine polar regions, have been increasing at twice the global average rate, causing accelerated melting of the glaciers (IPCC, 2019). When dust is blown to a glacier surface, ice albedo decreases and influences glacier melt rates via the positive feedback mechanism (Meinander et al., 2022). Dust in particular changes snow/ice albedo and melting rates, affects marine productivity, alters microbial dynamics in glaciers and causes indirect (cloud formation) and direct (solar radiation) effects.

There are numerous observed examples of dust emissions in high-latitude regions, frequently generated from small-scale sources. Horizontal resolution of current global dust models, typically not exceeding several tens of kilometres, cannot sufficiently resolve such small-scale source structures. To overcome this limitation, a version of the DREAM dust model (Nickovic et al., 2001) covering a circumpolar region for latitudes > 60° with a grid resolution of ~10 km has been developed by the Republic Hydrometeorological Service of Serbia. By locating the geographic centre of the model at the North Pole, strong convergence of meridians is avoided, thus permitting time-efficient execution of the model with horizontal grid spacing that is much finer than resolutions of global models. Potential dust sources from bare land in the new Circumpolar DREAM model are specified using the Global Sand and Dust Storms Source Base Map (G-SDS-SBM) (Figure 14). The G-SDS-SBM is based on gridded (geo-referenced) values of the SDS source intensity, with resolution of 30 arcsec, recently developed by the United Nations Convention to Combat Desertification (UNCCD) in collaboration with WMO (Vukovic, 2019, 2021a and 2021b; Meinander et al., 2022; https://maps.unccd.int/sds/). G-SDS-SBM was developed from information on soil texture, topsoil moisture, temperature and land cover, obtained from the MODIS instrument.

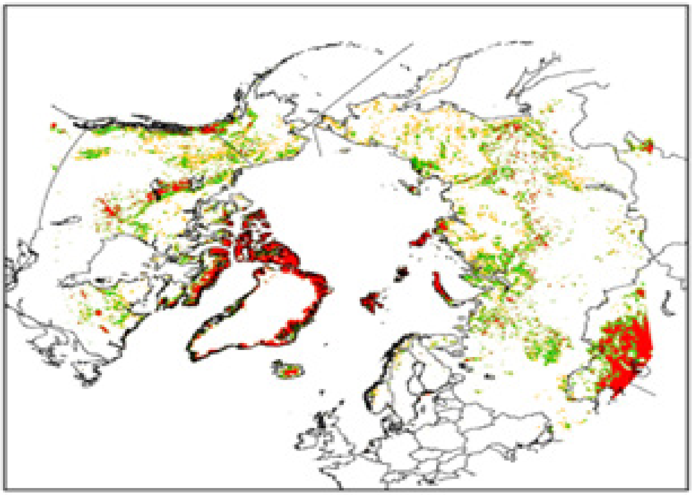


Figure 14. Dust sources from bare soils in the Circumpolar DREAM model, using the G-SDS-SBM

The Circumpolar DREAM has been used for two dust events (on 4 November 2013 and 1 October 2020), when multiple HLD emissions occurred. The model simulation for the 4 November 2013 event shows formation of sources and dust transport simultaneously from Greenland, the northern coastline of Canada and Iceland; the NASA MODIS observation indicates the coexistence of predicted dust patterns from Greenland and Canada (Figure 15, top panel). This dust storm event was also documented by Dagsson-Waldhauserova et al. (2019). The MODIS recordings of aerosol optical depth for the 1 October 2020 event shows dust emitted from Newfoundland and Labrador and which was transported toward the sea, as predicted by the Circumpolar DREAM model (Figure 15, bottom panel). The animated model concentration field for the two events is available at http://www.seevccc.rs/HLDpaper/.

The modelling experiments for the two dust events presented here demonstrate the potential of modelling and observational information to gain insight into why climate change is happening so fast in the high latitudes (UNGA, 2021). They were carried out as a part of the WMO SDS-WAS research agenda in order to gain a better understanding of the role of mineral dust in the cold regions as an environmental and climate factor.

NASA Earth Surface Mineral Dust Source Investigation, 2022

The imaging spectrometer instrument that is at the core of the NASA Earth Surface Mineral Dust Source Investigation (EMIT) is planned to begin measurement of the arid land mineral dust source regions of the Earth in 2022. To acquire these measurements, the instrument will be mounted on the exterior of the International Space Station (ISS), and is scheduled for launch in July 2022. The imaging spectrometer measures the spectral range from the visible to the short wavelength infrared portion of the electromagnetic spectrum where important dust source minerals have diagnostic spectral signatures. Measurements are made with an 80-kilometre swath. Full coverage will be built up over a year of observations. The EMIT imaging spectrometer is the first of its kind in terms of measurement precision and its extensive coverage of these important dust source regions of planet Earth. The instrument has been carefully calibrated in the laboratory and a complete data processing chain has been developed and tested. These new spectroscopic measurements, mineral maps and related data products will be validated and used for initialization of state-of-the-art Earth System Models to investigate the radiative forcing impacts of mineral dust aerosols in the Earth system (Figure 16). The EMIT mission will provide a suite of data products for all areas successfully measured. These data and derived products will be used to achieve the EMIT science

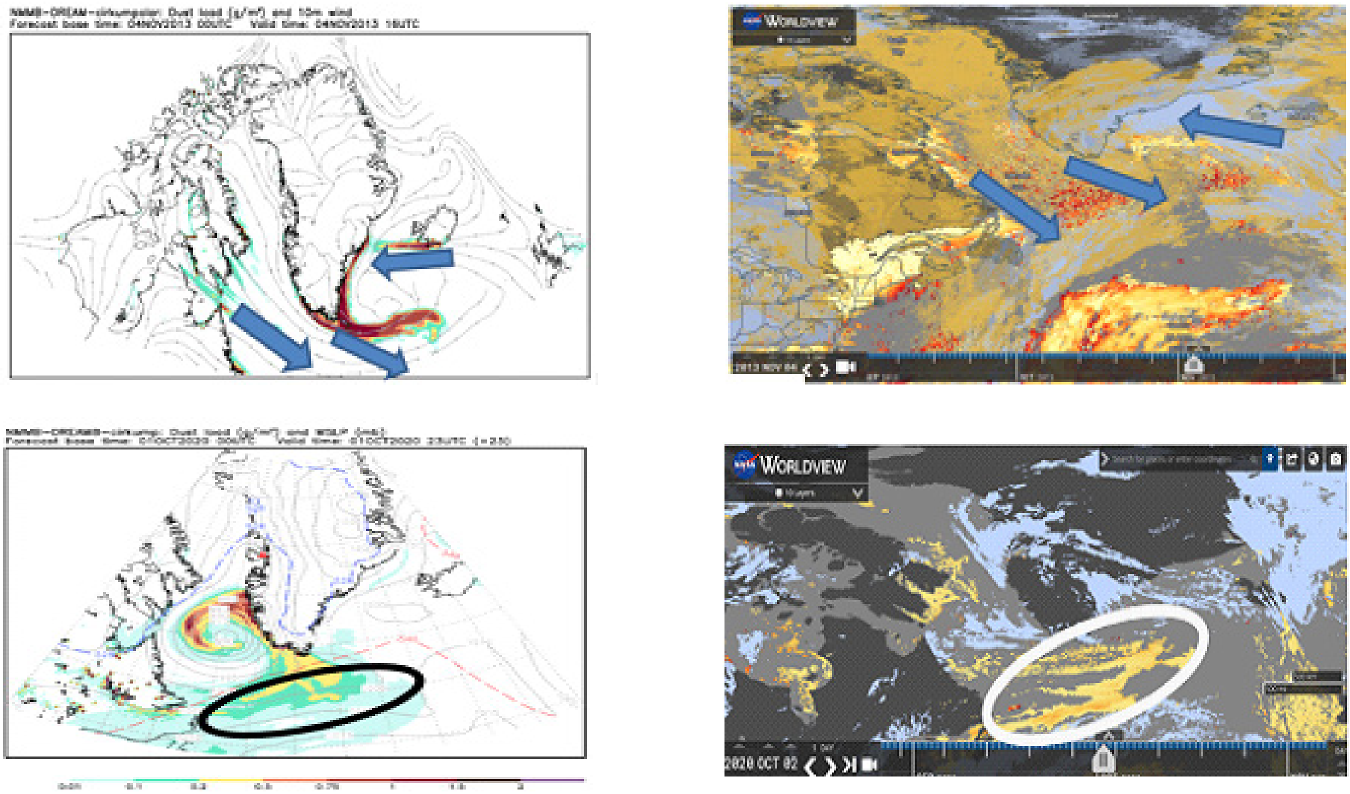


Figure 15. Circumpolar DREAM dust load in gm^2 (left panel) and MODIS observation (right panel) for 4 November 2013 (top panel) and 1 October 2020 (bottom panel). The arrows indicate the direction of dust transport.

objectives, reducing the uncertainty in mineral dust radiative forcing. All measurements will be delivered to the NASA Land Processes Distributed Active Archive Center, and made available to the broader community for the additional Earth science investigations it can enable. More information can be found on the EMIT web page: https://earth.jpl.nasa.gov/emit/.

Changes in dust emissions in the Gobi Desert

Emissions from SDSs in East Asia mainly occur in the northern hemisphere spring, in arid regions such as China and Mongolia. The impacts of SDSs are particularly pronounced near the sources, causing significant harm to humans, and economic damage. However, there is still uncertainty about how the emission from and transport pathways of SDSs will change with future climate change (Szopa et al., 2021). In order to accurately understand the future state of SDSs, it is necessary to consider the changes in the vegetation area due to feedbacks between land and weather (which include human activities), using a dynamic vegetation model. However, there is currently no model that can accurately handle these processes. Although this interaction in the vegetation area was not considered, as a first step Szopa et al. (2021) analysed how emissions from SDSs will change with future climate change. The analysis was based on the results of ensemble experiments on five major future warming scenarios as part of the Coupled Model Intercomparison Project Phase 6 (CMIP6) (O'Neill et al., 2016; Tebaldi et al., 2021) using the Meteorological Research Institute (MRI) Earth System Model version 2.0 (MRI-ESM2.0; Yukimoto et al., 2019). The MRI has been developing this model for many years. The long-term trend of emissions from SDSs, the monthly average horizontal distribution of emissions from SDSs and

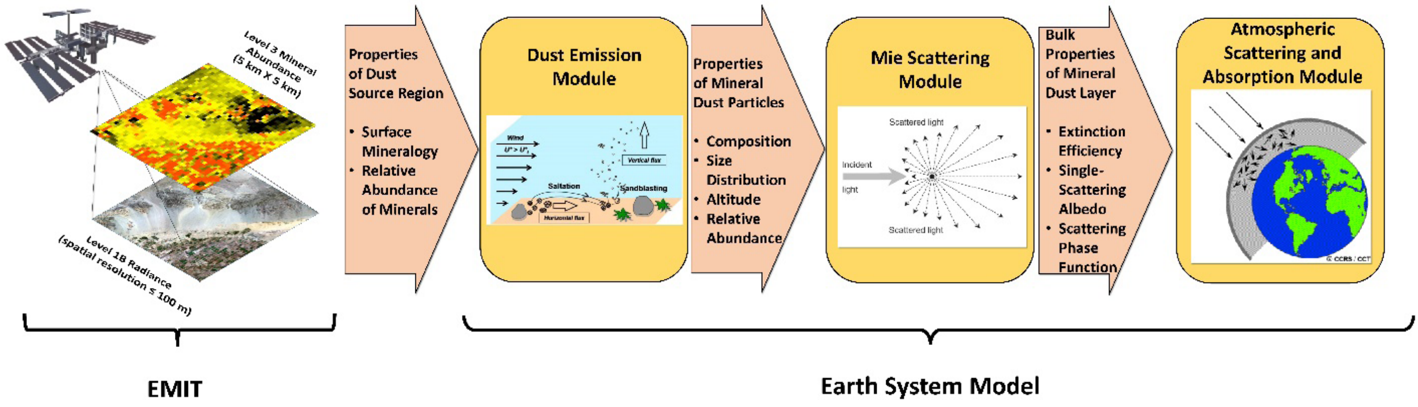


Figure 16. Process flow for EMIT and Earth System Models

related parameters averaged over a 10-year period were examined, as well as the correlation between the monthly average emissions from dust storms and related parameters. The ensemble mean and its variance for a 5-member ensemble experiment for each future warming scenario (SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) was also estimated, enabling quantitative evaluations of the impact of global warming.

The modelled trends in emissions from SDSs in the Gobi Desert (90°E–110°E, 35°N–45°N) for each month (2015–2100) are shown in Figure 17. Throughout the year, there is no significant change in the amount of emissions from SDSs associated with the future warming scenarios. However, the trend of increasing emissions from SDSs becomes larger as warming progresses, especially in the spring and autumn seasons when it is easier for SDSs to reach downstream regions.

This analysis revealed that the amount of emissions from SDSs around the Gobi Desert increases in spring and autumn due to the progress of global warming. The mechanism can be discussed as follows. In general, as global warming progresses throughout the twenty-first century, the temperature difference between the polar regions and the tropics will decrease, and wind speeds (including friction velocity) will tend to weaken overall. On the other hand, as global warming progresses, soil temperature will also increase. As a result, although the amount of precipitation (snow accumulation) in the vicinity of the SDS source does not change significantly, snowmelt is accelerated in the spring (snow accumulation is inhibited in the autumn), and the amount of snow accumulation decreases. As a result, the ground surface becomes more exposed, and the frictional velocity increases due to the increase in roughness. This decrease in snow cover and increase in frictional velocity results in an increase in emissions from SDSs in spring and autumn. This will have a major impact on the source of emissions from the SDS and the downstream areas. In general, the increase in emissions from East Asian SDSs during the spring season, coupled with the fact that aerosols are more easily transported from East Asia to more distant locations during this period, has a greater climatic or social impact. Future research should include an assessment of the impact in this respect.

Dust mask product of Suomi National Polar-orbiting Partnership Visible Infrared Imaging Radiometer Suite

The National Oceanic and Atmospheric Administration (NOAA) reprocessed nine years of Suomi National Polar-orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) aerosol detection products, which include dust mask, smoke mask and absorbing aerosol index, using consistent and well calibrated radiances. Products have daily global coverage with 750 m pixel resolution, and are made available to users in the form of individual granules in netCDF file format. The algorithm detects dust with 80% or higher probability of correct detection for thick dust plumes; product accuracy is lower for thin dust plumes that are downwind of the source regions (https://www.star.nesdis.noaa.gov/smcd/spb/aq/AerosolWatch/docs/JPSS_VIIRS_EPS_ADP_ATBD_V1.3_20180606.pdf).

The July dust fraction climatology generated with data from 2012 to 2020 shows thick dust near source regions in Africa, the Middle East and western China. Individual pixel level (750 m resolution) retrievals of smoke, dust, clear-sky/no aerosol and undetermined aerosol are mapped to a quarter degree grid. For each quarter degree grid, dust fraction is calculated as the ratio of the number of dust pixels to the total number of pixels. Dust over the continental United States is present in the south-west but is not as high as in Africa. The cross-Atlantic transport of dust is quite evident with the outflow from the Sahara. The product is available to users via

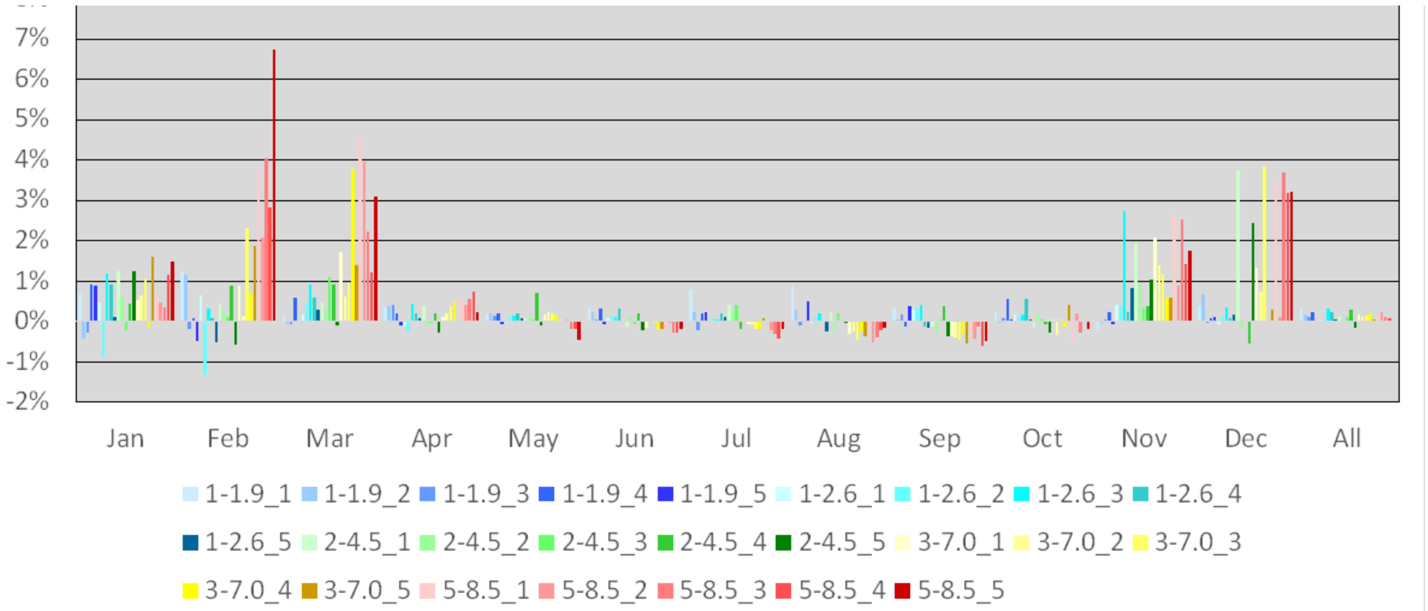


Figure 17. Rate of increase in emissions from SDSs in the Gobi Desert from 2015 to 2100 (% per year). The three numbers to the left of the underscore indicate the SSP scenario number, and the number to the right of the underscore indicates the ensemble member index. (*Source:* Based on Maki et al. (2022))

https://noaa-jpss.s3.amazonaws.com/index.html#SNPP/VIIRS/SNPP_Aerosol_Detection_Product_Reprocessed/. Python code to read, process, and display the data can be made available upon request by email to Shobha.Kondragunta@noaa.gov or Pubu.Ciren@noaa.gov.

Capacity building

The Dust Alliance for North America

The Dust Alliance for North America (DANA) and its operating arm, the DANA Steering Committee, is a new organization, a partnership of scientists and practitioners to accelerate the transition of dust-related research into service. It was formed from the October 2021 Southern New Mexico and Western U.S. Dust Symposium (Sprigg, et al., 2022). With a focus on North America, the DANA mission is to inspire, support and promote global science and service collaboration to uncover and adapt knowledge of airborne dust particulates in order to mitigate health, safety and quality of life risks (see, for example, Tong, et al., 2021). Member experts in research and public policy and service volunteer their time, experience and, often, resources, to network, coordinate and inform, such that products of research will be sped into application and public benefit.

Critical collaboration has begun, including via an annual symposium/workshop patterned after the October 2021 meeting, a monthly webinar series where cutting-edge research is publicly available to an internet-connected, global audience, and a DANA webpage (dustalliance.org). Recommendations for programmatic outreach and public education, awards and community recognition of accomplishment, early career support, training and capability building, and public dissemination of dust-related news and events are also being planned. Work to improve access to tools and information, and help transfer research results into public service more efficiently is ongoing.

North America shares airborne dust consequences (for example, as fertilizers to benefit ocean primary productivity, blinding dust threatening transportation safety, inhalable particles endangering public health, namely causing Valley fever and respiratory illness) and sources (for example, the deserts of Asia and Africa, the USA/Mexico Chihuahua desert, the exposed soil of receding glaciers in the Arctic). There is also shared environmental policy (for example, the Commission for Environmental Cooperation, a collaboration between Canada, Mexico and the United States). DANA's international community adds relevance and resources, such as information, policy and program resources and initiatives with the WMO SDS-WAS, and the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC).

Toward the development of dust services: inDust

Managing and mitigating SDS risks and effects requires fundamental and cross-disciplinary knowledge. Due to the significant impacts of sand and dust storms, the design of dust services is one of the major research issues identified by the United Nations Coalition to Combat Sand and Dust Storms, in which WMO is leading the forecasting and early warning strategy. This is the main objective of the European Union Cooperation in Science and Technology (COST) Action entitled *inDust*: the International Network to Encourage the Use of Monitoring and Forecasting Dust Products, that officially ended on 30 October 2021.

All activities developed as part of *inDust* sought to enhance awareness and visibility related to the impacts of sand and dust on various socioeconomic sectors (see, for example, Figure 18). It is a fundamental step for building capacity by promoting collaborations and by using the available products (through the organisation of training activities) in a regional context. All *inDust* outcomes are being considered as the basis for future development of the provision of dust services within the WMO SDS-WAS.

One of the final outcomes for *inDust* was the creation of a pop-up book The impacts of sand and dust storms (printed and interactive) and a related animated video presenting the impacts of sand and dust storms on transport and infrastructure, agriculture and energy, health and air quality, and the Earth system.

Apart from the establishment of a multidisciplinary network (that includes service providers, researchers and users), the *inDust* outcomes include (among others) outreach materials, a webinar series and a collaborative dust product catalogue accessible through the WMO Barcelona Dust Regional Center (which is the WMO SDS-WAS Regional Center for Northern Africa, the Middle East and Europe).

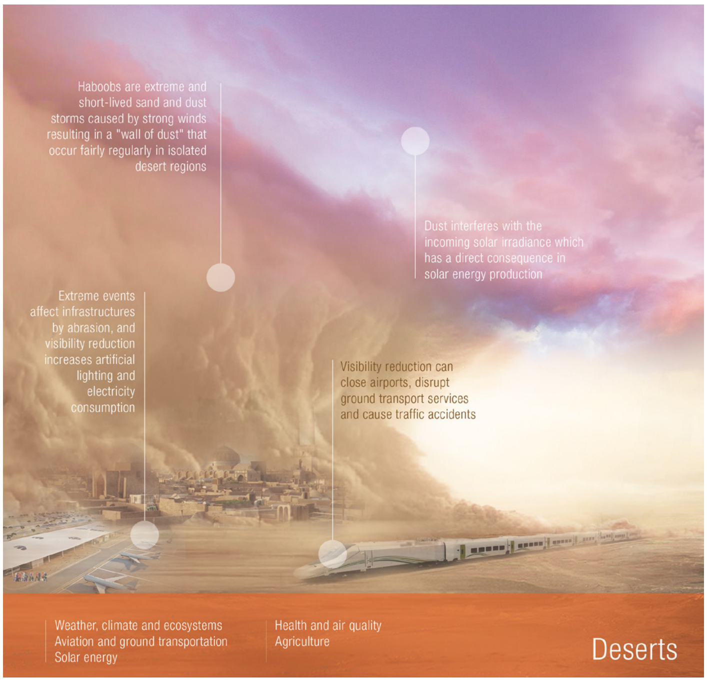


Figure 18. Extract from an *inDust* leaflet that outlines the dust impacts on different sectors. Available at https://cost-indust.eu/media-room/resources.

Other news

Sand and Dust Storms Day, 16 May 2022

To raise awareness about SDSs, Sand and Dust Storms Day was held at the Rio Conventions Pavilion at the Conference of the Parties (COP15) to the United Nations Convention to Combat Desertification (UNCCD). The day provided an opportunity for knowledge-sharing and capacity-development among stakeholders and partners involved in related issues. This included representatives from affected countries involved in policy and decision-making and implementation, as well as field practitioners, members of the United Nations Coalition to Combat Sand and Dust Storms (UN SDS Coalition) and representatives from the scientific and local communities. Discussion outcomes provided input to COP deliberations on SDS and other related fora. The Concept Note and Agenda for Sand and Dust Storms Day is available here. A comprehensive *Sand and Dust Storms Compendium: Information and Guidance on Assessing and Addressing the Risks* was also launched on the day. The WMO SDS-WAS and partners were actively involved in writing this United Nations multi-agency publication, coordinated by UNCCD and the UN SDS Coalition, with WMO specifically responsible for three chapters of the Compendium.

New regional initiatives for West Asia and Gulf Cooperation Council countries

Two important SDS-WAS regional initiatives took place; the first for Gulf Cooperation Council (GCC) countries, and the second for West Asia. All countries involved in these initiatives, outlined below, are also participants of the NAMEE Node of SDS-WAS.

Workshop on sand and dust storms on the Arabian Peninsula, 1–2 June 2022

The National Center for Meteorology in Saudi Arabia, in collaboration with the GCC and WMO, conducted a regional workshop in Jeddah on sand and dust storms on the Arabian Peninsula, to build awareness and gain a better understanding of the impacts. The workshop participants discussed the physical processes in the dust cycle and the effects of airborne dust on health, transportation and various other social and economic sectors. Participants also looked at the role of research studies in defining solutions and methods to reduce the negative effects of sand and dust storms. The participants reviewed the mandate and national, regional and international strategic goals of the GCC Node of the SDS-WAS, assessing the importance of its early warnings. The workshop participants agreed that better exchange of SDS-related data and information was needed between GCC members, and that more applied research on SDS is needed in the GCC region.

West Asia Regional SDS-WAS initiative (Islamic Republic of Iran and Türkiye)

The idea of establishing a West-Asia Regional SDS-WAS has been discussed within the WMO SDS-WAS and UNEP since 2013 (see *Establishing a WMO Sand and Dust Storm Warning Advisory and Assessment System Regional Node for West Asia: Current Capabilities and Needs – Executive Summary* (WMO-No. 1122) and *Technical Report* (WMO-No. 1121)), without any significant progress in bringing it to fruition. The Turkish State Meteorological Service (TSMS) and the Islamic Republic of Iran Meteorological Organization (IRIMO) both have long-standing experience with SDS observation, modelling and research, and actively participate in the NAMEE Node of SDS-WAS Regional Steering Group. Fortunately, in 2022, the TSMS and IRIMO worked together on the initiative and signed a Letter of Intent to establish a SDS-WAS in the West Asia region. The ceremony for the virtual signing of the Letter of Intent between IRIMO and TSMS was held on 8 March 2022, involving the Permanent Representative of both countries with WMO, as well as the presidents of WMO Regional Associations II (Asia) and VI (Europe).

Prestigious award for Dr Slobodan Nickovic

The 2022 Plinius Medal was awarded to Dr Slobodan Nickovic for his pioneering work on modelling sand and dust storms, and his significant contributions to the development of a global dust advisory and warning system (see Figure 19). The medal was established by the Natural Hazards Division of the European Geosciences Union (EGU) to recognise interdisciplinary natural-hazard research. The name of Gaius Plinius Secundus (~23–79 A.D.) acknowledges the role of those who have historically worked to improve both knowledge and mitigation of natural hazards. More details on Dr Nickovic's work can be found in this EGU blog. Dr Nickovic is currently a research consultant at the University of Physics in Belgrade, Serbia, and at the Republic Hydrometeorological Service of Serbia. He is also Chair of the WMO SDS-WAS NAMEE Node and a member of its Global Steering Committee (2014–2022), and was previously a Scientific Officer at the WMO Secretariat, where he was also focal point for the SDS-WAS project (2005–2013). Dr Nickovic was one of the pioneers of the WMO SDS-WAS: he initiated and developed this project and its scientific platform, together with Profs. Len Barrie, Xiaoye Zhang, J. M. Prospero, and many other scientists. Therefore, it is not surprising that he has been awarded this prestigious EGU Plinius Medal. Our congratulations go to Slobodan, a great SDS-WAS expert and WMO Secretariat former staff member!

Figure 19. Dr Slobodan Nickovic (right) is awarded the 2022 Plinius Medal by Dr Irina Didenkulova (left), President of the EGU Natural Hazards Division (*Source:* Alexander Baklanov, WMO)

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