Airborne Dust: A Hazard to Human Health, Environment and Society


Sydney Oats/Flickr

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Over the last decade, the scientific community has come to realize the important impacts of airborne dust on climate, human health, the environment and various socio-economic sectors. WMO and its Members, having started implementation of monitoring, forecasting and early warning systems for airborne dust in 2004, are at the vanguard on evaluating these impacts and developing products to guide preparedness, adaptation and mitigation policies.

This article will first provide an overview of the dust cycle and discuss its interaction with weather, the climate system, and terrestrial and marine ecosystems, before looking at its impacts on health and diverse economic sectors. It will then highlight the international network coordinated by WMO and its ambitious plan for providing policy-oriented products. The intent is to raise awareness in National Meteorological and Hydrological Services (NMHSs) on the extent of the adverse impacts of airborne dust and to inform readers of WMO efforts to understand these better. The article highlights the WMO initiative to provide operational services that can facilitate dust forecasting and early warning in order to invite other interested organisations to actively participate in this important work.

The dust cycle

Dust storms are common meteorological hazard in arid and semi-arid regions. They are usually caused by thunderstorms, or strong pressure gradients associated with cyclones, that increase wind speed over a wide area. These strong winds lift large amounts of sand and dust from bare, dry soils into the atmosphere, transporting them hundreds to thousands of kilometres away.

Gravity keeps dust pinned down on the Earth surface. The heavier a dust particle – due to size, density or the presence of water in the soil – the stronger the gravitational force holding it down. A dust storm can only occur when the wind force exceeds the threshold value for the loose particles to be lifted off the ground. Vegetation serves as a cover, protecting the Earth surface from this wind (Aeolian) erosion. Thus, drought contributes to the emergence of dust storms, as do poor farming and grazing practices or inadequate water management, by exposing the dust and sand to the wind.


Darcy Burbank

Dust storm at Abéché airport, Chad, on 23 November 2007

Some 40% of aerosols in the troposphere (the lowest layer of Earth's atmosphere) are dust particles from wind erosion. The main sources of these mineral dusts are the arid regions of Northern Africa, the Arabian Peninsula, Central Asia and China. Comparatively, Australia, America and South Africa make minor, but still important, contributions. Global estimates of dust

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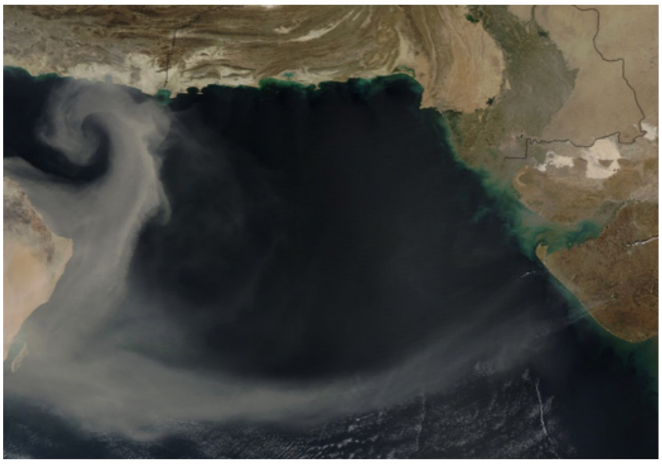
emissions, mainly derived from simulation models, vary between one and three Gigatons per year.



Dust plume coming off the Arabian Peninsula on 8 March 2015 at 08:45 UTC captured by the MODIS spectrometer on board the NASA's Aqua satellite

Once released from the surface, dust particles are raised to higher levels of the troposphere by turbulent mixing and convective updrafts. They are then transported by winds for lengths of time, depending on their size and meteorological conditions. Gravitation remains the major force pulling dust particles back down to the surface. Together with impaction and turbulent diffusion, it contributes to what is called dry deposition. As larger particles sediment more quickly than smaller ones, there is a shift toward smaller particle sizes during transport. Dust is also washed out of the atmosphere by precipitation – wet deposition. The average lifetime of dust particles in the atmosphere ranges from a few hours for particles with a diameter larger than 10 μm, to more than 10 days for the sub-micrometric ones.

Interaction with weather and climate

Aerosols, particularly mineral dusts, impact weather as well as global and regional climate.[4] Dust particles, especially if coated by pollution, act as condensation nuclei for warm cloud formation and as efficient ice nuclei agents for cold cloud generation. The ability of dust particles to serve as such depends on their size, shape and composition, which in turn depend on the nature of parent soils, emissions and transport processes. Modification of the microphysical composition of clouds changes their ability to absorb solar radiation, which indirectly affects the energy reaching the Earth's surface.[5] Dust particles also influence the growth of cloud droplets and ice crystals, thus affecting the amount and location of precipitation.

Airborne dust functions in a manner similar to the greenhouse effect: it absorbs and scatters solar radiation entering Earth's atmosphere, reducing the amount reaching the surface, and absorbs long-wave radiation bouncing back up from the surface, re-emitting it in all directions. Again, the ability of dust particles to absorb solar radiation depends on their size, shape and mineralogical and chemical composition. The vertical distribution of dust in the air (vertical profile) and the characteristics of the underlying surface are also required to quantify this impact.

Impacts on human health

Airborne dust presents serious risks for human health. Dust particle size is a key determinant of potential hazard to human health. Particles larger than 10 μm are not breathable, thus can only damage external organs – mostly causing skin and eye irritations, conjunctivitis and enhanced susceptibility to ocular infection. Inhalable particles, those smaller than 10 μm, often get trapped in the nose, mouth and upper respiratory tract, thus can be associated with respiratory disorders such as asthma, tracheitis, pneumonia, allergic rhinitis and silicosis. However, finer particles may penetrate the lower respiratory tract and enter the bloodstream, where they can affect all internal organs and be responsible for cardiovascular disorders. A global model assessment in 2014 estimated that exposure to dust particles caused about 400 000 premature deaths by cardiopulmonary disease in the over 30 population.[6]

Some infectious diseases can be transmitted by dust. Meningococcal meningitis, a bacterial infection of the thin tissue layer that surrounds the brain and spinal cord, can result in brain damage and, if untreated, death in 50% of cases.[7] Outbreaks occur worldwide, yet the highest incidence is found in the "meningitis belt", a part of sub-Saharan Africa with an estimated population of 300 million. These outbreaks have a strong seasonal pattern – many studies have linked environmental conditions, such as low humidity and dusty conditions, to the time and place of infections.[8] Researchers believe that the inhalation of dust particles in hot dry weather may damage nose and throat mucosa creating favourable conditions for bacterial infection.[9] Moreover, iron oxides embedded in dust particles may enhance the risk of infection.[10]

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[4] Nickovic et al., 2004; Perez et al., 2006; Wang et al., 2010

[5] Boucher et al., 2013

[6] Giannadaki, et al., (2014)

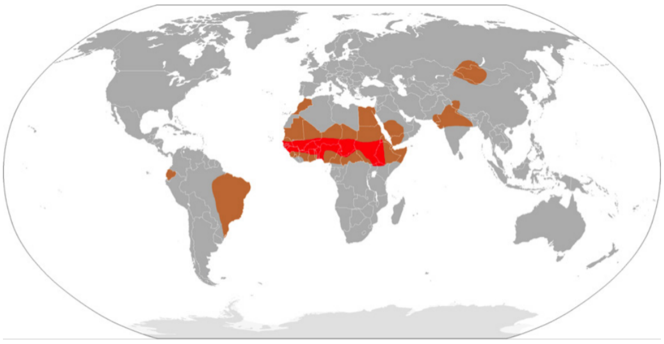
[7] www.who.int/mediacentre/factsheets/fs141/en/

[8] Molesworth et al., 2003

[9] Dukic et al., 2012

[10] Thompson et al, 2013

Dust also plays a role in the transmission of valley fever – a potentially deadly disease – in the Southwest of the United States and in the Northern Mexico by acting as a transporter of Coccidioides fungi spores.



Map of meningitis belt (in red) and regions of high risk of epidemics (brown) all other regions may have lower incidence of outbreaks and sporadic cases (source: World Health Organization)

Impacts on the environment and society

Surface dust deposits are a source of micro-nutrients for both continental and maritime ecosystems. Saharan dust is thought to fertilize the Amazon rainforest, and dust transports of iron and phosphorus are know to benefit marine biomass production in parts of the oceans suffering from the shortage of such elements.[11] But dust also has many negative impacts on agriculture, including reducing crop yields by burying seedlings, causing loss of plant tissue, reducing photosynthetic activity and increasing soil erosion.

Indirect dust deposit impacts include filling irrigation canals, covering transportation routes and affecting river and stream water quality. Reductions in visibility due to airborne dust also have an impact on air and land transport. Poor visibility conditions are a danger during aircraft landing and taking off – landings may be diverted and departures delayed. Dust can also scour aircraft surfaces and damage engines.

Dust can impact on the output of solar power plants, especially those that rely on direct solar radiation. Dust deposits on solar panels are a main concern of plants operators. Keeping the solar collectors dust-free to prevent particles from blocking incoming radiation requires time and labour.

The response of WMO

The WMO Sand and Dust Storm Project was implemented in 2004 and its Sand and Dust Storm Warning Advisory and Assessment System[12] (SDS-WAS) in 2007. SDS-WAS enhances the ability of countries to deliver timely, quality sand and dust storm forecasts, observations, information and knowledge to users through an international partnership of research and operational communities. It operates through two SDS-WAS Regional Nodes:

- Northern Africa, Middle East and Europe, coordinated by a Regional Centre in Barcelona, Spain, hosted by the State Meteorological Agency (AEMET) and the Barcelona Supercomputing Centre (BSC) and
- Asia, coordinated by a Regional Centre in Beijing, China, that is hosted by the China Meteorological Administration (CMA).

The third Regional Node for Pan-America, recently established in the USA, with a possible regional centre hosted by the Caribbean Institute for Meteorology and Hydrology (CIMH) in Barbados, will focus on the health implications of airborne dust. And yet another may soon be established for Western Asia in collaboration with the United Nations Environment Programme (UNEP).

Regional Centre for Northern Africa, Middle East and Europe

The main objective of the Regional Centre (RC) for Northern Africa, Middle East and Europe is to facilitate user access, particularly for NMHSs, to observational and forecast products as well as to other sources of basic information related to airborne dust. Its web portal[13] provides NMHSs with the information needed to issue operational predictions and warning advisories related to the dust content in the atmosphere.

The RC for Northern Africa, Middle East and Europe recently established an exchange for experimental forecast model products among partners for a joint visualization and evaluation initiative. The reference area for the initiative covers the main dust sources in Northern Africa and Middle East as well as main transport routes and deposition zones from the equator to the Scandinavian Peninsula. The initiative considers forecasts of up to 72 hours with a 3-hour frequency. The nine models listed in the table (below) provide numerical outputs to the initiative on a daily basis. Predicted surface dust concentration levels and dust optical depth values at 550 nm (DOD550), for each model, are plotted side-by-side daily using a common colour palette. The product is a powerful tool for issuing short-term predictions and early warning notices.

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11 Bristow et al., 2010

12 www.wmo.int/pages/prog/arep/wwrp/new/Sand_and_Dust_Storm.html

13 http://sds-was.aemet.es

Models contributing to the SDS-WAS Model Joint Visualization and Evaluation for Northern Africa, Middle East and Europe

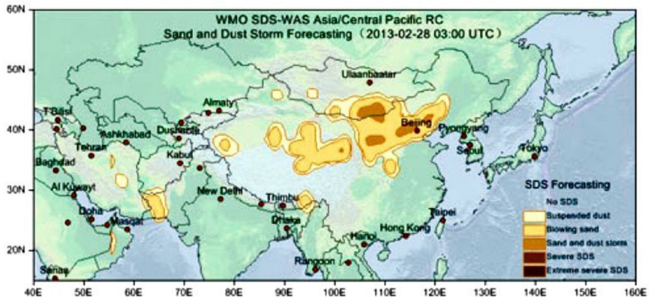
Model	Institution	Domain
BSC-DREAM8b	Barcelona Supercomputing Center, Spain	Regional
MACC	European Center for Medium-Range Weather Forecast, U. K.	Global
DREAM-NMME-MACC	South-Eastern European Virtual Climate Change Center, Serbia	Regional
NMMB/BSC-Dust	Barcelona Supercomputing Center, Spain	Regional
MetUM	Met Office, U. K.	Global
GEOS-5	National Aeronautics and Space Administration, U. S. A.	Global
NGAC	National Centers for Environment Prediction, U. S. A.	Global
RegCM4-EMA	Egyptian Meteorological Authority	Regional
DREAMABOL	National Research Council, Italy	Regional

Every day, the RC for Northern Africa, Middle East and Europe generates ensemble multi-model prediction products: median and means aimed at improving the forecasting skill of the single model-based approach and graphs of spreads between the model outputs at specific times in the future (standard deviation and range of variation). When the ensemble spread is small and forecast outputs are consistent within multiple models, there is greater confidence in the forecast.

The RC for Northern Africa, Middle East and Europe compares model and multi-model medians with observational data in order to assess whether these are successfully simulating dust-related parameters. For this purpose, sun-photometric observations from 40 dust-prone stations of the AERONET network are retrieved and plotted together with predictions for the same times and places on graphs. In addition to monthly plots, the evaluation system computes monthly, seasonal and annual scores. An evaluation product based on aerosol optical depth retrievals from the MODIS spectrometer travelling on board NASA's geosynchronous Terra and Aqua satellites has also been developed.

Regional Centre for Asia and Central Pacific

The Regional Centre for Asia and Central Pacific (Asian RC) supports a global network of SDS-WAS research and operational partners, including the NMHSs of Japan, Kazakhstan, Mongolia, People's Republic of China and Republic of Korea. It routinely runs one global and two regional models to provide dust forecast; the CUACE/Dust forecasting system has been operational since 2007. The results of the different national forecasting systems – at present China, Korea and Japan – are shared on a web portal[14] maintained by the Asian RC. A protocol for near real-time exchange of daily numerical forecasts for a joint visualisation and evaluation has also been recently established at the Asian RC. The reference area covers the main dust sources in Central and Eastern Asia and transport routes and deposition zones up to the Central Pacific. Similarly to the RC for Northern Africa, Middle East and Europe, the initiative considers forecasts of surface concentration and dust optical depth with a 3-hour frequency up to a lead-time of 72 hours.



Sand and dust storm forecast for 28 February 2013 at 03:00 UTC issued by the WMO SDS-WAS Asian RC

Models contributing to the SDS-WAS model joint visualization and evaluation for Asia

Model	Institution	Domain
CUACE/Dust	China Meteorological Administration	Regional
MASINGAR	Japan Meteorological Agency	Global
ADAMI	Korea Meteorological Administration	Regional

The Asian RC has also developed a common threat scoring system in order to facilitate the advancement of forecasting techniques and to improve the forecast accuracy.[15]

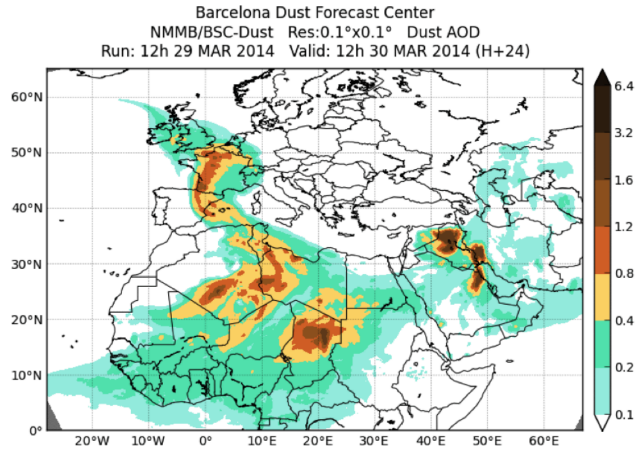
The Barcelona Dust Forecast Centre

In order to develop the operational component of SDS-WAS and to transfer the experience gained in the research phase to the operational services, the Barcelona Dust Forecast Centre was opened in February 2014, following the WMO decision that dust prediction was mature enough to implement operational services. AEMET and BSC host this Regional Specialized Meteorological Centre for Atmospheric Sand and Dust Forecasts (RSMC-ASDF) with the mission to generate and disseminate operational predictions for Northern Africa (north of equator), Middle East and Europe.

The forecast fields are generated using the NMMB/BSC-Dust model run at a horizontal resolution of 0.1 degrees

[14] http://eng.weather.gov.cn/dust/
[15] Wang et al., 2008

and distributed through the Centre's web portal[16], through the WMO Global Telecommunications System and through EUMETCast, a dissemination system managed by EUMETSAT based on standard digital video broadcast technology that uses commercial telecommunication geostationary satellites to multi-cast files (data and products) to a wide user community.



H+24 forecast of dust optical depth at 550 nm released by the Barcelona dust Forecast Centre on 29 March 2014 at 12 UTC

Invitation to further research

The WMO SDS-WAS mission is to achieve comprehensive, coordinated and sustained observations and modelling capabilities for sand and dust storms in order to improve dust monitoring, understanding of dust processes and to enhance prediction capabilities. Since WMO started the SDS-WAS project ten years ago, great progress has been achieved. Two Regional Centres have coordinated research and managed to develop tools for dust observation and forecast.

All interested NMHSs and potential end-users are invited to use the SDS-WAS products for the region of Northern Africa (north of equator), Middle East and Europe and for the Asia region (see the regions covered by the forecast on the above figures).

The 17th World Meteorological Congress appreciated that the SDS-WAS, a joint activity between Global Atmosphere Watch and World Weather Research Programme, has raised awareness and has contributed to a better understanding of dust-related phenomena. Congress agreed that the SDS-WAS Science and Implementation Plan: 2015-2020 forms the basis for continuing the research component of the project. An SDS-WAS Steering Committee as well as a Trust Fund for contributing Members was established by the Executive Council meeting in June. SDS-WAS welcomes the participation of other organizations in this work.

References are available in the online version of the Bulletin: www.wmo.int/bulletin/content/airborne-dust-hazard

[16] http://dust.aemet.es