Sand and Dust Storm - Warning Advisory and Assessment System

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Abstract

Given the important impacts of airborne dust on human health, the environment and diverse socio-economic sectors, in 2007, the World Meteorological Organization endorsed the launching of the Sand and Dust Storm - Warning Advisory and Assessment System (SDS-WAS) with the mission to enhance the ability of countries to deliver timely and high-quality sand and dust storm forecasts, observations, information and knowledge to users. This paper describes SDS-WAS' mission, organization and objectives, highlights its transition from R&D to operational forecast services and postulates the implementation of future dust early warning systems.

1. Introduction

Sand and dust storms are common hazards in arid and semi-arid regions of the planet. They occur when strong or very turbulent winds blow over dry, sparsely vegetated soils and lift loose particles from the Earth's surface to the atmosphere. The concentration of airborne particles increases rapidly and the visibility drops to few meters. The sand and dust storms occur mostly on the belt of tropical and subtropical deserts of the northern hemisphere, stretching from the Sahara through the Middle East to the Great Indian Desert, as well as on the mid-latitude deserts of Central Asia and China-Mongolia (Terradellas et al., 2017).

Between 1,000 and 3,000 megatons of particles are emitted annually to the atmosphere, where the finer fraction may be transported downwind over long distances, even across continents (Prospero and Nees, 1986). Airborne sand and dust is detrimental to human health, ecosystems and diverse socio-conomic sectors. Impacts on health include respiratory and cardio-vascular problems, eye infections and, in some regions, infectious diseases such as meningitis and valley fever (Goudie, 2014). Dust also can carry irritating spores, bacteria, viruses and persistent organic pollutants. Other impacts include negative effects on ground transport, aviation, agriculture and solar power plants.

It is necessary to mention that dust, especially once deposited back to the Earth's surface, has also positive environmental impacts, since it provides nutrients to terrestrial and oceanic ecosystems, boosting primary productivity. Many ocean biota, such as phytoplankton, are iron limited, such that the supply of bioavailable iron by the dust deposition enhances ocean productivity (Jickells et al. 2005). Similarly, the long-term productivity of many land ecosystems, for example the Amazon rainforest, is limited by the availability of phosphorus (Chadwick et al., 1999, Okin et al. 2004), such that the deposition of dust-borne phosphorus is often critical for ecosystem productivity.

Airborne dust affects weather and climate through a wide range of interactions. These include scattering and absorbing radiation, lowering snowpack albedo, altering atmospheric CO_2 concentrations by modulating ecosystem productivity, and serving as cloud nuclei and thereby likely increasing cloud lifetime and reflectivity (Andreae and Rosenfeld, 2008). Since mineral dust therefore affects Earth's radiation balance, changes in the atmospheric dust loading can produce a substantial radiative forcing (Tegen et al., 1996; Sokolik and Toon, 1996; Mahowald et al., 2006, 2010). Conversely, the global dust cycle is also highly sensitive to changes in climate, as evidenced by the several times larger global dust deposition rate during glacial maxima than during interglacials (Rea 1994, Kohfeld and Harrison, 2001).

The scientific community is aware that a significant part of the dust emission is the consequence of human-induced factors such as poor agricultural practices or land and water mismanagement. However, there is a great deal of uncertainty about the percentage it represents versus the total emission. There are also contradictory conclusions about the long-term trend of dust emissions, especially in relation to land use and climate change. Conversely, it is necessary to clarify on how changes in dust emissions may impact the atmosphere, climate and oceans in the future.

Over the last decades, the social interest and the eagerness of the research community to better understand the physical processes associated with the dust cycle, to predict future events and to prevent their undesired impacts has increased rapidly. This paper describes the response of the World Meteorological Organization (WMO) to the problems associated with suspended dust. The trans-boundary nature of the dust cycle makes international co-operation essential. In addition, this is a multidisciplinary phenomenon, and coordination with other United Nations agencies and programs is absolutely necessary.

2. Sand and Dust Storm – Warning Advisory and Assessment System

Recognizing the importance for multiple societal sectors around the world to better understand and monitor atmospheric sand and dust, in 2007, the WMO endorsed the launching of the Sand and Dust Storm - Warning Advisory and Assessment System (SDS-WAS) with the mission to enhance the ability of countries to deliver timely and high-quality sand and dust storm forecasts, observations, information and knowledge to users through an international partnership of research and operational communities (Terradellas et al., 2015).

The SDS-WAS works as an international network of research, operational centres and users, organized through regional nodes and coordinated by the SDS-WAS Steering Committee (Nickovic et al., 2015). Three regional nodes are currently in operation:

- Northern Africa, Middle East and Europe (NAMEE), coordinated by a Regional Center in Barcelona, Spain, hosted by the State Meteorological Agency (AEMET) and the Barcelona Supercomputing Center (BSC): https://sds-was.aemet.es.
- Asia, coordinated by a Regional Center in Beijing, China, hosted by the China Meteorological Administration (CMA): http://eng.nmc.cn/sds_was.asian_rc/.
- Pan-America, coordinated by a Regional Center in Bridgetown, Barbados, hosted by the Caribbean Institute for Meteorology and Hydrology (CIMH): http://sds-was.cimh.edu.bb/.
- The SDS-WAS Science and Implementation Plan (Nickovic et al., 2014) identifies the following objectives as the axis around which the activities of SDS-WAS shall be articulated during the period 2015-2020:
- Facilitating collaboration and coordination at regional and global scale between SDS-WAS partners and initiating joint research projects for improving dust observations and modelling.
- Encouraging experimental provision of near-real-time forecasts, models validation and models intercomparison.
- In collaboration with other WMO technical commissions, supporting

transfer of the SDS-WAS research observational and forecasting facilities to operational technology and to applications relevant for users.

- Providing training on use of the SDS-WAS research outcomes.
- Building bridges between SDS-WAS and other communities conducting aerosol-related studies (air quality, biomass burning, etc.).
- Participating in international multi-disciplinary research initiatives.
- Establishing links with the EU-funded Copernicus Atmosphere and Monitoring Services, satellite agencies and ground-based observing networks

3. Motivation for a Regional Center in West Asia

The Middle East is the second largest source of global dust after the Sahara desert, but, unlike North Africa, where large population centres are concentrated along the coasts of the Mediterranean and the Atlantic Ocean, relatively far away from dust sources, much of the population in West Asia lives inside, or in the vicinity of, dust sources. The dust impact on health, on ecosystems and on many economic and social activities is therefore of utmost importance. Furthermore, the usual coexistence of desert mineral dust with industrial aerosols from petrochemical activities constitutes an additional challenging problem (Cuevas, 2013).

The complex mixture of natural and anthropogenic sources is extensively described in Ginoux et al. (2012). Many of these sources are closely related to land degradation and overuse of water resources, so that many countries in the region have suffered a sharp increase in dust cases in recent years (Cuevas, 2013). The transport of airborne dust turns local changes in the soil conditions into a serious trans-boundary environmental problem that can only be addressed through international information exchange and cooperation to implement early warning systems, adopt preparedness and adaptation policies and take effective measures for mitigation.

The future is also worrisome, because global warming has the potential to cause major changes in dust emissions. The International Panel on Climate Change (Solomon, 2007; Stocker, 2014) suggests that, under most scenarios, many dry-land areas will suffer from lower rainfall regimes and drier terrains because of higher rates of evapotranspiration. Therefore, there is a likelihood of increased dust storm activity, though this conclusion depends on how winds may change - a matter of great uncertainty.

All these particular circumstances encourage the creation of a SDS-WAS regional node for West Asia. National Meteorological and Hydrological Services (NMHS), environment protection agencies, health institutions, aviation authorities, energy departments, marine resources and fishery agencies, wildlife, forestry and agriculture agencies, disaster risk and civil protection agencies, research institutions and universities should participate in this SDS-WAS regional node as contributors and/or as specialized users.

The Turkish State Meteorological Service (TSMS) and the Islamic Republic of Iran Meteorological Organization (IRIMO) have recently expressed their willingness to host the SDS-WAS Regional Center for West Asia and the SDS-WAS Regional Center for NAMEE is ready to support its implementation.

4. Dust monitoring

There are many complementary ways of observing airborne dust. In this Section, we focus on the most suitable observational methods for monitoring and now-casting dust events, leaving aside techniques commonly used for data assimilation into numerical models, verification of dust predictions, investigation of the physical processes involved in the dust cycle or impact assessment.

The main objective of the SDS-WAS Regional Centers is to facilitate user access, particularly for NMHSs, to observational and forecast products. Operational meteorologists typically use products generated from measurements performed by instruments on board geostationary satellites for dust monitoring and now-casting. These products have the advantages of large spatial coverage (regional to global) and regular observations, which can be made available to weather centres in near-real-time. However, the application of satellite products (Figure 1) to monitor dust events faces several problems and must be complemented with in-situ measurements. In this sense, the air quality monitoring stations and the ordinary meteorological stations play a fundamental role. Unfortunately, there is still no protocol for the international exchange of air quality data, unlike that for meteorological data, which has been in force for more than 50 years.

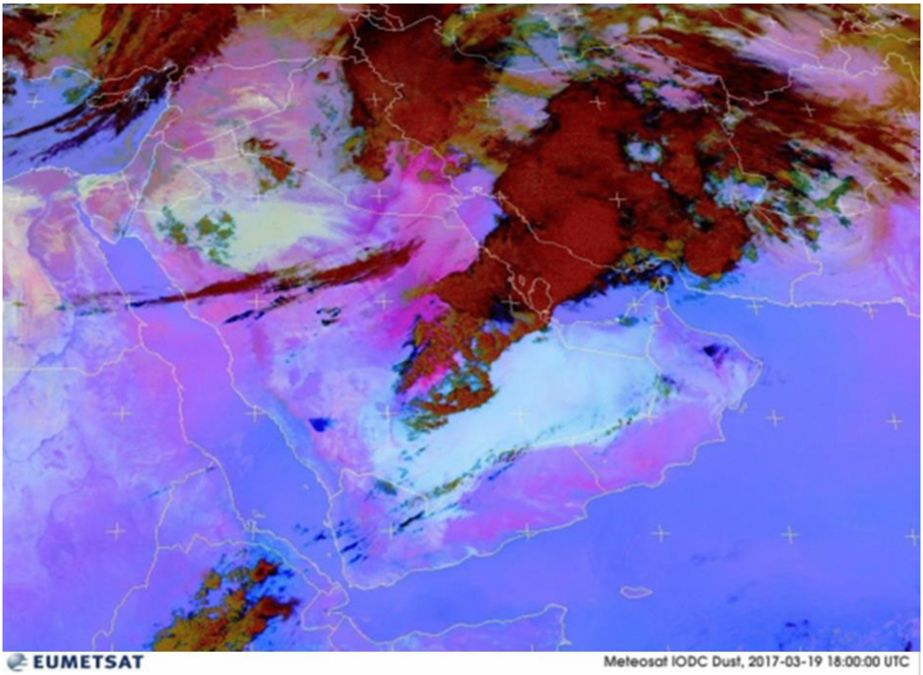

Figure 1. *EUMETSAT RGB-Dust product of 19 Mar 2017 at 18:00 UTC. Sandstorm 'Madar' originated in Northern Africa disrupted life in West Asia*

5. Dust forecasting

Numerical prediction of dust in Numerical Weather Prediction (NWP)-type models faces a number of challenges. First, the physical processes involved in the dust cycle, particularly in the dust emission, are not yet fully understood. Then, the range of scales required to fully account for all those processes is very wide. Dust production is a function of surface wind stress and soil conditions, but wind is an extremely variable parameter in both space and time and soil properties are highly heterogeneous and not always well characterized. Finally, the functional form of the emission parametrization is typically that of a power law in surface wind speed, making emissions highly sensitive to modelled wind fields. This section highlights the SDS-WAS initiatives related to dust prediction.

The SDS-WAS Regional Center for NAMEE daily collects and distributes through its website forecast products released by different numerical models. This initiative has grown significantly with the incorporation of more and more partners. At the time of writing this paper, twelve modelling groups provide three-hourly forecasts of dust surface concentration and dust optical depth at 550 nm for a reference area, which is intended to cover the main source areas in Northern Africa and Middle East, as well as the main transport routes and deposition zones from the equator to the Scandinavian Peninsula. The action involves forecasts up to 72 h with a 3-hour frequency.

Ensemble multi-model products are also daily generated after bi-linearly interpolating all forecasts to a common grid mesh of 0.5 x 0.5 degrees. Multi-model forecasting intends to alleviate the shortcomings of individual models while offering an insight on the uncertainties associated with a single-model forecast. Centrality products (median and mean) are aimed at improving the forecasting skill of the single-model approach. Spread products (standard deviation and range of variation) indicate whether forecast fields are consistent within multiple models, in which case there is greater confidence in the forecast.

The SDS-WAS Regional Center for Asia conducts a similar exercise. It daily collects and publishes on the web dust forecasts from five numerical models. Its geographical domain covers the main dust sources in Central and Eastern Asia, and transport routes and deposition zones up to the central Pacific.

6. From R&D to operational dust forecast

In 2012, in view of the demand of many NMHSs and the good results obtained by the SDS-WAS, which prove the feasibility and the need to begin developing operational services beyond the scope of R&D, WMO designated the consortium formed by AEMET and the BSC to host the first Regional specialized Meteorological Center with activity specialization on Atmospheric Sand and Dust Forecasts. Since February 2014, the Center, called Barcelona Dust Forecast Center (BDFC, https://dust.aemet.es) operationally generates and distributes dust predictions for Northern Africa (north of equator), Middle East and Europe.

The BDFC prepares regional forecast fields using the NMMB/BSC-Dust model continuously throughout the year on a daily basis (figure 2). Forecasts cover the period from the starting forecast time up to a forecast time of 72 hours, with an output frequency of 3 hours. They cover the geographical domain with a horizontal resolution of 0.1º longitude x 0.1º latitude. The forecasts are disseminated through the Center's website, the WMO Global Telecommunications System and the EUMETCast service. EUMETCast is a multi-service dissemination system based on standard digital video broadcast technology. It uses commercial telecommunication geostationary satellites to multi-cast files to a wide user community.

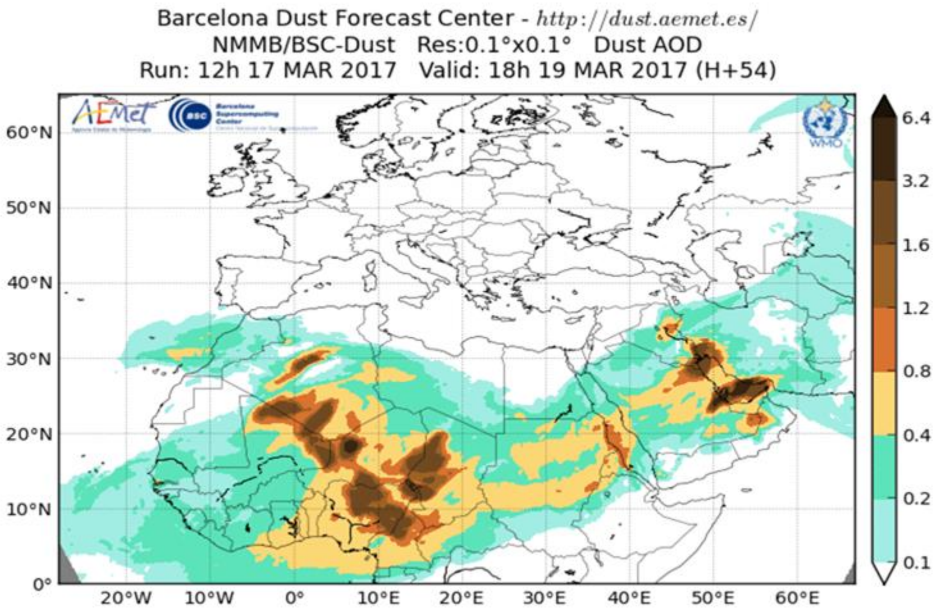

Figure 2. *54-hour forecast of dust optical depth for 19 Mar 2017 at 18 UTC. The dust prediction for West Asia was quite precise as observed after comparison with Figure 1*

7. Towards Dust Early Warning Systems

Traditionally, many countries have been reactive to natural disasters. The Hyogo Framework for Action 2005–2015 led to a paradigm shift in disaster risk management from emergency response to a comprehensive approach that includes preparedness and preventive strategies to reduce risk. Early Warning Systems (EWS) are well recognized as critical tools for reducing negative impacts of natural hazards.

Although the negative impacts of airborne dust are well known and the necessary tools for its observation and prediction are available, very few countries have implemented EWSs for airborne dust. A complete and effective EWS comprises four inter-related elements, spanning knowledge of hazards and vulnerabilities through to preparedness and capacity to respond:

Risk knowledge - The impact of airborne dust on air quality, human health, weather and climate, the environment and different economic sectors is generally known, although some aspects require further investigation. A clear case is the interaction between dust and climate, where there are still many uncertainties, as recognized by the International Panel on Climate Change. Also, though the impact of suspended particles on health is reasonably well known, the specific effect of mineral dust is highly uncertain. Thus, World Health Organization recently commissioned a report on this.

Monitoring and warning services - Warning services lie at the core of the system. Though the NMHS of a majority of countries has the ability to obtain and use the basic products of dust monitoring and prediction necessary to set up an EWS for dust operating 24 hours a day, such services have rarely been established. The cause probably lies in the lack of awareness that there is a sound scientific basis for predicting dust and that early warning can bring important benefits to the population and save economic costs to society. It is necessary to highlight that the inclusion of dust in a multi-hazard EWS could gain the benefit of shared institutional, procedural and communication networks.

Dissemination and Communication - Warnings must reach those at risk. Clear messages containing simple, useful information are critical to enable proper responses. Regional, national and community level communication systems must be pre-identified and appropriate authoritative voices established.

Response Capability - It is essential that communities understand their risks; respect the warning service and know how to react. Education and preparedness programmes play a key role. It is also essential that disaster management plans are in place, well practiced and tested.

8. WMO Airborne Dust Bulletin

Although the SDS-WAS Regional Centers provide information primarily through their respective websites, WMO has begun to publish an annual bulletin entitled 'WMO Airborne Dust Bulletin' (Terradellas et al., 2017) reporting on the atmospheric burden of mineral dust through the year, its geographical distribution and the inter-annual variation. The bulletin also includes descriptions of dust cases and dust-related news and events.

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