Airborne dust monitoring and forecasting at the WMO SDS-WAS Regional Center for Northern Africa, Middle East and Europe

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Abstract

Over recent years, the scientific community has realized the importance of studying the release of mineral dust into the atmosphere, its transport over long distances and its interaction with the Earth's climate system, terrestrial and marine ecosystems, as well as its impact on air quality, human health and various socio-economic sectors. Responding to societal demands, the World Meteorological Organization (WMO) launched 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 quality sand and dust storm forecasts, observations, information and knowledge to end-users. This communication reports the activity of the SDS-WAS Regional Center for Northern Africa, Middle East and Europe in the field of dust monitoring and forecasting, with special emphasis on the dust model inter-comparison and forecast evaluation. As part of this initiative, the Regional Center daily provides dust predictions from ten state-of-the-art numerical models run by different research and operational agencies around the world, ensemble multi-model products and comparison with remote-sensing products. Finally, 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 Center was opened in February 2014 to generate and disseminate operational dust 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 and distributed through the center web portal, the WMO Global Telecommunications System and EUMETCast.

Keywords**:** *dust monitoring, dust numerical model, ensemble multi-model products, forecast evaluation*

1. Introduction

In the recent decades the scientific community has realized the importance of studying the release of mineral dust into the atmosphere, its transport over long distances and its interaction with the Earth's climate system, terrestrial and marine ecosystems, as well as its impact on air quality, human health and different socio-economic sectors. Evaluation of the economic and social impacts, preparedness, adaptation and mitigation policies require a deep understanding of the physical phenomena involved in the dust cycle (emission, transport and dry and wet deposition) and the establishment of monitoring, forecasting and early warning systems. Responding to societal demands, the World Meteorological Organization (WMO) has developed an ambitious plan to establish a comprehensive system that brings together all these components. In May 2007, the 14th Congress of the WMO endorsed the launching of the Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) (Terradellas et al., 2015) with the mission to enhance the ability of countries to deliver timely and quality sand and dust storm forecasts, observations, information and knowledge to users through an international partnership of research and operational communities.

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. Three regional nodes are currently in operation:

- Northern Africa, Middle East and Europe, coordinated by a Regional Center in Barcelona, Spain, hosted by the State Meteorological Agency (AEMET) and the Barcelona Supercomputing Center (BSC).
- Asia-Pacific, coordinated by a Regional Center in Beijing, China, that is hosted by the China Meteorological Administration (CMA)
- Pan-America, coordinated by a Regional Center in Barbados, that is hosted by the Caribbean Institute for Meteorology and Hydrology (CIMH)

2. Dust monitoring

The first option to address dust monitoring is the use of satellite products. They have the advantage of a large spatial coverage (regional to global), they are made regularly, and their observations are made available to weather centers and other institutions in Near-Real-Time (NRT). Shortcomings include satellite measurements' highly integrated nature, not only over the atmospheric column but also over all aerosol components. Another limitation is the low aerosol detectability over bright surfaces, which affects instruments operating in the visible part of the spectrum. The new generation of high-resolution infrared spectrometers and interferometers on polar-orbiting satellite platforms (e.g. IARS, IASI) has the potential to provide good quality dust information (Peyridieu et al., 2010; Klüser et al., 2011; Hilton et al., 2012). However, they present an insufficient time resolution. The latest generation of geostationary satellites represent a useful tool for real-time dust monitoring, because they combine the specific advantages of the geostationary orbit (high time resolution over a wide geographic domain) and geometric, radiometric and spectroscopic capabilities of the high resolution radiometers.

In-situ measurements of air quality monitoring networks are the main surface data source. As with the satellites, air quality measurements integrate the contribution of the different types of atmospheric aerosol. Furthermore, observational values are usually limited to the concentration of particulate matter with an aerodynamic diameter less than 10 µm (PM10), which does not always encompass the full size range of dust particles suspended in the atmosphere. It is important to consider the selection of stations used for dust monitoring, since many of them are located in cities, industrial parks or roads, where local human activity is the main source of particles, obscuring the contribution of dust to measured quantities.

Air quality networks perform systematic measurements with high spatial density in developed countries, but very sparse, discontinuous and rarely near-real-time available close of the main dust sources. Furthermore, there is not any protocol for routine international exchange of air quality data, so their use is often limited to a national level.

Visibility data included in meteorological observations are sometimes used as an alternative source of information (Shao et al, 2003). Visibility is mainly affected by the presence of aerosol and water in the atmosphere. Therefore, the use of visibility data has to be complemented with information on present weather to discard those cases where visibility is reduced by the presence of hydrometeors (fog, rain, etc.). Several empirical relationships between visibility and dust surface concentration can be found in the literature (d'Almeida, 1986; Shao et al., 2003; Camino et al., 2015). However, the validity of these relationships is very limited, because visibility reduction depends not only on the dust mass concentration, but also on the size spectrum of particles, as well as their density, chemical and mineralogical composition and atmospheric humidity. The SDS-WAS Regional Center for Northern Africa, Middle East and Europe (RC NAMEE) routinely produces 6-hourly plots indicating the stations, where the visibility has been reduced by sand or dust to less than 5 km. METAR aeronautical meteorological reports and SYNOP synoptic meteorological bulletins from more than 1,500 stations are used to it. Brownish circles indicate stations where 'sand' or 'dust' has been explicitly reported. Triangles indicate stations where the present weather has been reported as 'haze', meaning that the visibility is reduced by particles of unspecified origin (Figure 1).

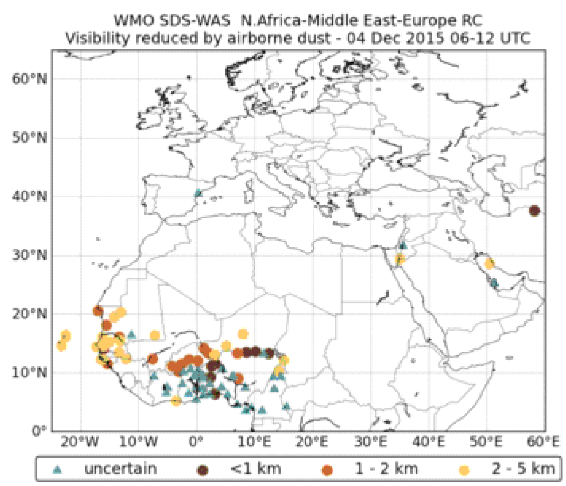

Figure 1: Visibility reduction by sand / dust on 4 December 2015 between 6 and 12 UTC

Direct-sun photometric measurements are a powerful remote sensing tool that provides retrieval of column-integrated aerosol microphysical and optical properties. In particular, AERONET is a comprehensive set of continental and coastal sites complemented with several sparsely distributed oceanic stations that provides large and refined data sets in near-real-time (Holben et al., 1998; Dubovik and King, 2000). Integral parameters such as aerosol optical depth are complemented with spectral information. A major shortcoming of these measurements is their unavailability under cloudy skies and during night time. The RC NAMEE conducts, in collaboration with WMO, the SDS-Africa project aimed at reinforcing the observational capacity for mineral dust in Northern Africa. The main goal of the project is to establish a ground-based network of sun-photometers in selected locations of Northern Africa for detecting and monitoring dust storms. They are also useful for NRT satellite sensor validation and calibration, and for the evaluation of dust models. Four stations are currently in operation and integrated in the AERONET network: Ouarzazate (Morocco), Tamanrasset (Algeria), Tunis-Carthague (Tunisia) and Cairo (Egypt)

Lidar and the most recent generation of ceilometers permit routine measurement of aerosol vertical profiles. However, continuous measurements in ground-based stations are only performed in a few stations that are, in general, far from the main dust sources. On the other hand, space-borne lidars (e.g. CALIOP) provide global spatial coverage, but their temporal resolution is limited.

3. Dust model inter-comparison and forecast evaluation

The exchange of forecast products is the basis for a model inter-comparison and joint evaluation conducted by the RC NAMEE (Terradellas et al., 2014). At the beginning of 2016, ten modelling groups (Table 1) provide daily files with numerical predictions of dust surface concentration (DSC) and dust optical depth (DOD) at 550 nm for a reference area extending from 25°W to 60°E in longitude and from 0° to 65°N in latitude. This area 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.

Table. 1. Models contributing to the dust model inter-comparison and joint evaluation

Model	**Agency**	**Domain**	**Data assimilation**
BSC-DREAM8b v2	BSC	Regional	No
CAMS	ECMWF	Global	MODIS AOD
DREAM-NMME-MACC	SEEVCCC	Regional	CAMS analysis
NMMB/BSC-Dust	BSC	Regional	No
MetUM	U K Met office	Global	MODIS AOD
GEOS-5	NASA	Global	MODIS reflectances
NGAC	NCEP	Global	No
EMA REG CM4	EMA	Regional	No
DREAMABOL	CNR-ISAC	Regional	No
WRF-CHEM	NOA	Regional	No

The DSC and DOD provided by each model are daily plotted side-by-side for the reference area using a common color palette (Figure 2). This product is a powerful tool to issue short-term predictions and early warning notices. Archived products are also available online.

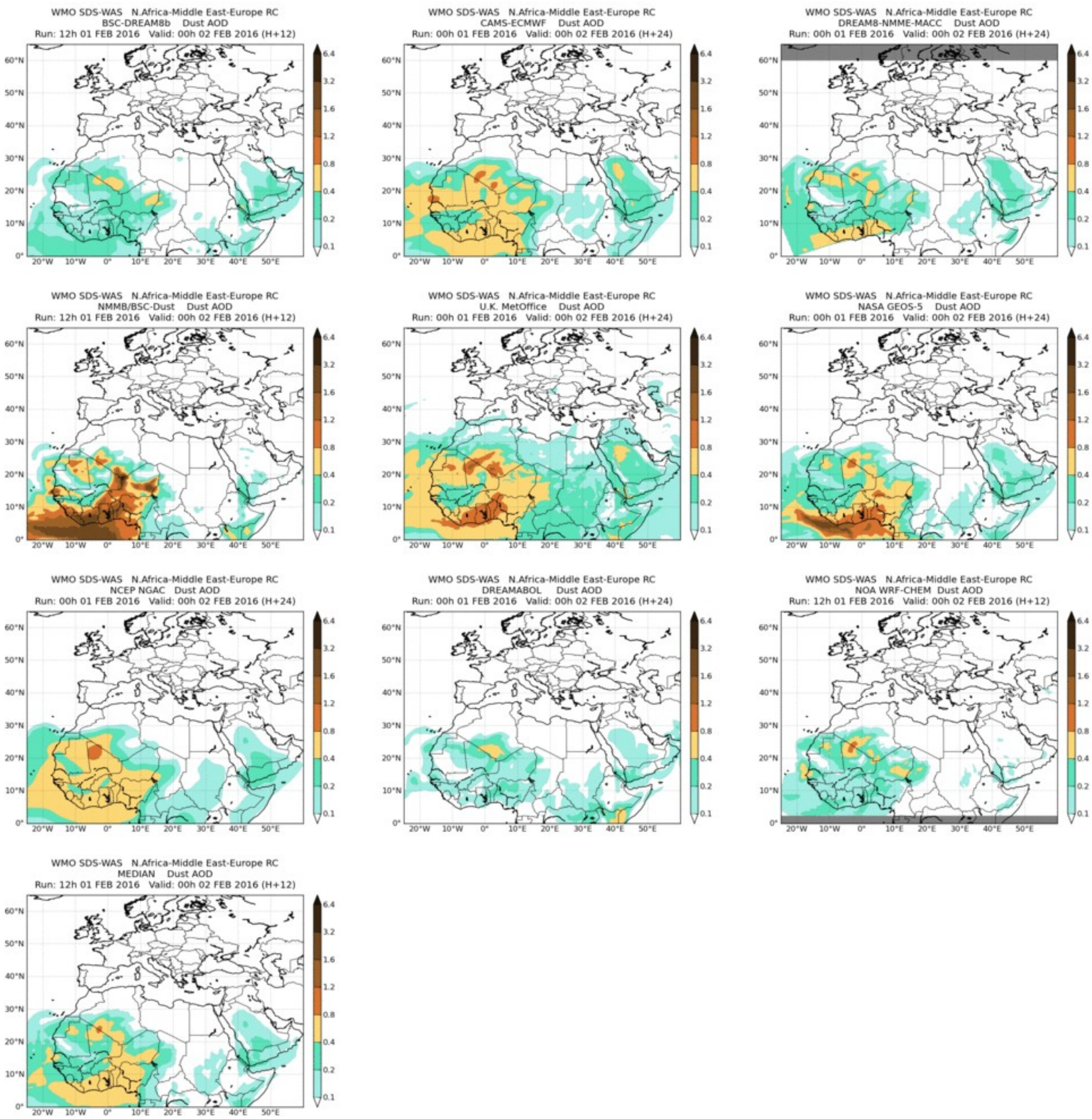

Figure 2: Inter-comparison of 24-hour forecasts of dust optical depth at 550 nm released by different numerical models on 1 February 2016

The RC NAMEE also generates multi-model products based on the exchanged forecasts. Products describing both centrality (multi-model median and mean) and spread (standard deviation and range of variation) are computed and posted on the web. In particular, the multi-model median is considered for the model inter-comparison and forecast evaluation.

A common evaluation has been established in order to assess whether the modeling systems successfully simulate the temporal and spatial evolution of the 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 monthly graphs. In addition to these plots, the evaluation system computes monthly, seasonal and annual scores. An evaluation product based on aerosol optical depth retrievals from the MODIS spectrometer traveling on board NASA's geosynchronous Terra and Aqua satellites has also been developed.

4. Operational forecast service

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 Center was opened in February 2014, following the WMO decision that dust prediction was mature enough to implement operational services. AEMET and BSC host this WMO Regional Specialized Meteorological Center 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 and distributed through the center web portal (http://dust.aemet.es), 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.

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