BARCELONA DUST FORECAST CENTER
(WMO Regional Specialized Meteorological Center with activity specialization on Atmospheric Sand and Dust Forecast)

Activity Report 2014

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Barcelona, 11 February 2015

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Introduction

In May 2007, the 14th WMO Congress endorsed the launching of the **Sand and Dust Storm Warning Advisory and Assessment System** (WMO SDS-WAS, http://www.wmo.int/pages/prog/arep/wwrp/new/Sand_and_Dust_Storm.html). The SDS-WAS mission is 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. It works as an international network of research, operational centres and users, organized through regional nodes and coordinated by the SDS-WAS Steering Committee. Two nodes are currently in operation:

- Regional Node for 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-CNS): http://sds-was.aemet.es/
- Regional Node for Asia, coordinated by a Regional Center in Beijing, China, that is hosted by the China Meteorological Administration (CMA): http://www.sds.cma.gov.cn/

In May 2013, in view of the demand of many national meteorological services 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, the 65th Session of the WMO Executive Council designates the consortium formed by AEMET and the BSC-CNS to create in Barcelona the first Regional Specialized Meteorological Center with activity specialization on Atmospheric Sand and Dust Forecast (RSMC-ASDF). The Center shall operationally generate and distribute predictions for Northern Africa (north of equator), Middle East and Europe. The **Barcelona Dust Forecast Center** (BDFC, http://dust.aemet.es) was created in February 2014 to be this RSMC-ASDF and was publicly presented on 10 June 2014.

Dust forecasts

The **Barcelona Dust Forecast Center** (BDFC) prepares regional forecast fields using the **NMMB/BSC-Dust** model continuously throughout the year on a daily basis. The model consists of a numerical weather prediction model incorporating on-line parameterizations of all the major phases of the atmospheric dust cycle. It is run at a horizontal resolution of 0.1 degrees longitude per 0.1 degrees latitude for a domain covering Northern Africa, Middle East and Europe (25ºW-65ºE, 0º-65ºN). This domain covers the main dust 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 BDFC generates forecasts of the following set of variables:

- Dust load (kg.m-2)
- Dust surface concentration (µg.m-3)
- Dust optical depth at 550 nm (-)
- 3-hour accumulated dry and wet deposition (kg.m-2)
- Dust surface extinction (Mm-1)

Forecasts cover the period from the starting time (12 UTC) up to a lead time of 72 hours. They are distributed in pictorial form through the Center's web portal, where are posted 12 hours after the starting forecast time and through the **WMO Global Telecommunications System** (GTS).

The headers of the GTS bulletins are as follows:

PZBcnn **LEMM** dd**1200,** where:

- c=**A** denotes a 0-hour forecast, c=**B** a 3-hour forecast, ..., c=**Y** a 72-hour forecast
- nn=**01** denotes dust surface concentration, nn=**02** dust optical depth, nn=**03** dust dry deposition, nn=**04** dust wet deposition and nn=**05** dust load.
- dd indicates the day

The model outputs are stored, both in netcdf and in WMO **FM 92 GRIB Edition 2** formats. For GRIB files, version 13.0.0 of the code tables is used:

- Code and flag tables v. 13.0.0
- Local tables v. 1.0.0 (see Table 1). These tables have been built by the Barcelona Dust Forecast Center to complement the WMO Master Tables in order to enable encoding/decoding dust-related products.

Number	Parameter	Units
248	Dust surface extinction at 550 nm	Mm^{-1}
249	Dust load	$g.m^{-2}$
250	3-hour accumulated dust dry deposition	$mg.m^{-2}$
251	3-hour accumulated dust wet deposition	$mg.m^{-2}$
252	Dust surface concentration	$\mu g.m^{-3}$
253	Dust optical depth at 550 nm	-

Table 1. Code Table 4.2 - Parameter number by product discipline and parameter category. **Product discipline 0** - Meteorological products, parameter category 13: aerosols

The NMMB/BSC-Dust model

The NMMB/BSC-Dust (Pérez et al., 2011; Haustein et al., 2012) is an online multi-scale atmospheric dust model designed and developed at the BSC-CNS) in collaboration with the **National Centers for Environmental Prediction** (NCEP), the **Goddard Institute for Space Studies** and the **International Research Institute for Climate and Society** (IRI). The dust model is fully embedded into the **Non-hydrostatic Multiscale Model** on B-grid (NMMB) model developed at NCEP (Janjic, 2005; Janjic and Black, 2007; Janjic et al., 2011) and is intended to provide short to medium-range dust forecasts for both regional and global domains.

The NMMB/BSC-Dust model solves the mass balance equation for dust taking into account the following processes:

- Dust generation and uplift by surface wind and turbulence. The emission scheme considers saltation and sandblasting processes (White, 1979; Marticorena and Bergametti, 1995) and the presence of a viscous sublayer between the surface

and the lowest model layer (Janjic, 1994). The size distribution of soil particles is based on the soil textures of the STATSGO-FAO soil map. Then, the dust vertical flux is distributed over eight size bins. For the source function, the model uses the topographic preferential source approach described by Ginoux et al. (2001) and climatological vegetation data from the National Environmental Satellite, Data, and Information Service (NESDIS).

- Soil wetness effects on dust production (Fécan, 1999).
- Horizontal and vertical advection (Janjic et al., 2009).
- Horizontal diffusion and vertical transport by turbulence and convection (Janjic et al., 2009).
- Dry deposition and gravitational settling (Zhang et al., 2001).
- Wet removal, which includes in-cloud and below-cloud scavenging from convective and stratiform clouds (Betts, 1986; Janjic, 1994; Ferrier et al., 2002).
- Furthermore, in order to take into account the radiative effects of mineral dust, the rapid radiative transfer model (RRTM) (Mlawer et al, 1997) has been implemented.

Near-Real-Time Evaluation

The Near-Real-Time (NRT) model evaluation is an assessment of how the forecast behaves relative to observations that are NRT available, allowing the modelling group and the end users to have a quick overview of the quality of the forecast. Forecasts of dust optical depth (DOD) are compared with total aerosol optical depth (AOD) provided by the AErosol RObotic NETwork (AERONET, http://aeronet.gsfc.nasa.gov/) for selected dust-prone stations located in Northern Africa, Middle East and Southern Europe. At present, 40 AERONET stations are used. They are listed in Table 2.

Site name	Longitude	Latitude	Country	Region
Avignon	4.88ºE	43.93ºN	France	Mediterranean
Banizoumbou	2.66ºE	13.54ºN	Niger	Sahel/Sahara
Barcelona	2.12ºE	41.39ºN	Spain	Mediterranean
Cabo_da_Roca	9.50ºW	38.78ºN	Portugal	Mediterranean
Caceres	6.34ºW	39.48ºN	Spain	Mediterranean
Cairo_EMA_2	31.29ºE	30.08ºN	Egypt	Mediterranean
Capo_Verde	22.93ºW	16.73ºN	Cabo Verde	Sahel/Sahara
CUT-TEPAK	33.04ºE	34.67ºN	Cyprus	Mediterranean
Dakar	16.96ºW	14.39ºN	Sénégal	Sahel/Sahara
Eilat	34.92ºE	29.50ºN	Israel	Mediterranean
Ersa	9.36ºE	43.00ºN	France	Mediterranean
ETNA	15.02ºE	37.61ºN	Italy	Mediterranean
Evora	7.91ºW	38.57ºN	Portugal	Mediterranean
FORTH_CRETE	25.28ºE	35.33ºN	Greece	Mediterranean
Granada	3.60ºW	37.16ºN	Spain	Mediterranean
IASBS	48.51ºE	36.70ºN	Iran	Middle East
IER_Cinzana	5.93ºW	13.28ºN	Mali	Sahel/Sahara
Ilorin	4.34 ºE	8.32ºN	Nigeria	Sahel/Sahara
IMAA_Potenza	15.72ºE	40.60ºN	Italy	Mediterranean
IMS-METU-ERDEMLI	34.26ºE	36.56ºN	Turkey	Mediterranean
KAUST_Campus	39.10 ºE	22.30 ºN	Saudi Arabia	Middle East
Kuwait University	47.97 ºE	29.33 ºN	Kuwait	Middle East
Lampedusa	12.63ºE	35.52ºN	Italy	Mediterranean
Lecce_University	18.11ºE	40.33ºN	Italy	Mediterranean
Oujda	1.90ºW	34.65ºN	Morocco	Mediterranean
Ouarzazate	6.91ºW	30.93ºN	Morocco	Sahel/Sahara
Palma_de_Mallorca	2.62ºE	39.55ºN	Spain	Mediterranean
Porquerolles	6.16ºE	43.00ºN	France	Mediterranean
Rome_Tor_Vergata	12.65ºE	41.84ºN	Italy	Mediterranean
Saada	8.16ºW	31.62ºN	Morocco	Sahel/Sahara
Santa_Cruz_Tenerife	16.25ºW	28.47ºN	Spain	Sahel/Sahara
SEDE_BOKER	34.78ºE	30.85ºN	Israel	Mediterranean
Seysses	1.26ºE	43.50ºN	France	Mediterranean
Solar_Village	46.40ºE	24.91ºN	S. Arabia	Middle East
Tabernas_PSA-DLR	2.36ºW	37.09ºN	Spain	Mediterranean
Tamanrasset_INM	5.53ºE	22.79ºN	Algeria	Sahel/Sahara
Villefranche	7.33ºE	43.68ºN	France	Mediterranean
Xanthi	24.92ºE	41.15ºN	Greece	Mediterranean
Zinder_Airport	8.99ºE	13.78ºN	Niger	Sahel/Sahara
Zouerate-Fennec	12.48ºW	22.75ºN	Mauritania	Sahel/Sahara

Table 2. AERONET stations, where the evaluation has been implemented.

The AERONET program is a federation of ground-based remote sensing aerosol networks established by the U. S. National Aeronautics and Space Administration

(NASA) and the French network PHOTONS managed by the Lille 1 University, the National Centre for Space Studies (CNES) and the National Centre for Scientific Research (CNRS). The AERONET network is greatly expanded by collaborators from national agencies, institutes, universities and other partners. The program provides a long-term, continuous and readily accessible public domain database of aerosol optical, microphysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases. The network imposes standardization of instruments, calibration, processing and distribution.

Version 2 Level 1.5 of AERONET products are used for the NRT evaluation. Level 1.5 data are automatically cloud screened but not have final calibration applied. However, differences between Level 1.5 and Level 2 are normally quite small if the instrument has not suffered dramatic changes between the pre and the post calibration. Anyway, these differences are normally within the error of the model predictions. Since AERONET sun photometers do not yield AOD at 550 nm, this variable is calculated from AOD at 440, 675 and 870 nm and the Ångström exponent 440-870 using the Ångström law.

AERONET-based evaluation scores

Besides the NRT evaluation, a system to evaluate the performance of the model has been set. The system yields, on a monthly, seasonal and annual basis, evaluation scores computed from the comparison of the simulated DOD and the AERONET retrievals of AOD used in the NRT evaluation. Rather than time-interpolated, retrievals are assigned to the nearest multiple-of-3 hour. In case more than one value is assigned to the same hour, only the closest-in-time is considered.

The evaluation system is applied to instantaneous forecast values of DOD ranging from the initial day (D) at 15:00 UTC to the following day (D+1) at 12:00 UTC, that is for lead times ranging from 3 to 24 hours.

To minimize the sources of error, it is intended to restrict the comparison to situations in which mineral dust is the dominant aerosol type. Threshold discrimination is made by discarding observations with an Ångström exponent 440-870 higher than 0.6. However, other particles are always present (anthropogenic aerosol, products from biomass burning, etc.) and therefore a negative bias can be expected.

The scores are computed for each AERONET site, for 3 sub-regions (Sahel/Sahara, Middle East and Mediterranean) as well as globally considering all sites (Table 2). It should be noted that scores for individual stations can be little significant for being calculated from a small number of data.

The metrics that are used to quantify the mean departure between modelled (c_i) and observed (o_i) quantities are the mean bias error (BE), the root mean square error (RMSE), the correlation coefficient (r) and the fractional gross error (FGE). They are presented in the Table 3, where n denotes the number of data.

Statistic Parameter	Formula	Range	Perfect score
Mean Bias Error (BE)	$$BE = \frac{1}{n}\sum_{i=1}^{n}\left(c_i - o_i\right)$$	$-\infty$ to $+\infty$	0
Root Mean Square Error (RMSE)	$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(c_i - o_i\right)^2}$$	0 to $+\infty$	0
Correlation coefficient (r)	$$r = \frac{\sum_{i=1}^{n}\left(c_i - \bar{c}\right)\cdot\left(o_i - \bar{o}\right)}{\sqrt{\sum_{i=1}^{n}\left(c_i - \bar{c}\right)^2}\cdot\sqrt{\sum_{i=1}^{N}\left(o_i - \bar{o}\right)^2}}$$	-1 to 1	1
Fractional Gross Error (FGE)	$$FGE = \frac{2}{n}\sum_{i=1}^{n}\left|\frac{c_i - o_i}{c_i + o_i}\right|$$	0 to 2	0

Table 3. Metrics used in the forecast evaluation.

Some considerations about these metrics are the following:

− The **mean bias error** (BE) captures the average deviations between two datasets. It has the same units as the variable. Values near 0 are the best, negative values indicate underestimation and positive values indicate overestimation.

− The **root mean square error** (RMSE) combines the spread of individual errors. It is strongly dominated by the largest values, due to the squaring operation. Especially in cases where prominent outliers occur, the usefulness of RMSE is questionable and the interpretation becomes more difficult.

− The **correlation coefficient** (r) indicates the extent to which patterns in the model match those in the observations.

− The **fractional gross error** (FGE) is a measure of model error, ranging between 0 and 2 and behaves symmetrically with respect to under- and overestimation, without over-emphasizing outliers.

The results for the whole period (starting 9 February) are summarized in Table 4.

Region / sub-region	BE	RMSE	r	FGE	n
Sahel /Sahara	-0.12	0.38	0.51	0.75	7427
Middle East	-0.10	0.27	0.39	0.64	112
Mediterranean	-0.19	0.30	0.46	1.34	4623
Total	**-0.15**	**0.35**	**0.52**	**0.98**	**12162**

Table 4. Annual evaluation scores (2014)

Time-averaged products

Decadal (10 days) and monthly averages of dust surface concentration are computed for long-term monitoring. Seasonal and annual averages are expected to be implemented in the near future.

The **Daily average** is computed as the mean value of the forecasts with lead times ranging from 0 to 21 hours. It means that the daily average for a specific day is an estimation of the mean value predicted over the period from 12 UTC of that day to 9 UTC of the following day. The **monthly average** is computed as the mean value of the daily averages from the first to the last day of the concerned month.

Decadal averages are not published on the web portal, but are available on demand. In particular, they are delivered to the African Center of Meteorological applications for Development (ACMAD; http://www.acmad.net/new/) that uses them in health-oriented programs.

Training

The 4th Training Course on WMO SDS-WAS products (satellite and ground observation and modelling of atmospheric dust) was held 17-20 November 2014 in Casablanca, Morocco. The event has been organized by the **Barcelona Dust Forecast Center**, the **Regional Center for Northern Africa, Middle East and Europe of the WMO SDS-WAS** and the **National Meteorology Direction** (DMN) of Morocco and financed by AEMET and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

The event was targeted to operational meteorologists and early career scientists (advanced students, PhD candidates and postdoctoral researchers) with interest on the Earth system sciences. Participants from Algeria, Egypt, The Gambia, Iran, Morocco, Niger, Togo and ACMAD attended a series of lectures and practical exercises. In particular, they became familiar with the products distributed by the BDFC and learnt the most efficient way to introduce them in their daily work.

Health applications

The activities carried out by the Barcelona Dust Forecast Center were presented at the World Health Organization's Regional Consultation Meeting on Air Quality and Health for the Eastern Mediterranean Region held at Amman, Jordan, 10-11 December 2014 and attended by public health and environment managers from the region.

Staff

Enric Terradellas, technical director
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Users

The BDFC makes a quarterly monitoring of the accesses to its web portal. The results (Table 5) show a steady increase in the number of users, sessions and page views.

Season	Users	Sessions	Page views
Spring (Mar-May)	422	878	2521
Winter (Jun-Aug)	1132	2449	6134
Autumn (Sep-Nov)	1909	3175	6901

Table 5. Access to the web portal. Quarterly review (2014)

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