Modeling the dust cycle at BSC
From R&D to operational forecast

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Training Workshop on Sand and Dust Storms in the Arab Region, Cairo, Egypt, 10-12 February 2018
BSC Earth Sciences Department

**What**

Environmental modelling and forecasting

**Why**

Our strength ...  
... research ...  
... operations ...  
... services ...  
... high resolution ...

**How**

Develop a capability to model air quality processes from urban to global and the impacts on weather, health and ecosystems

Implement climate prediction system for subseasonal-to-decadal climate prediction

Develop user-oriented services that favour both technology transfer and adaptation

Use cutting-edge HPC and Big Data technologies for the efficiency and user-friendliness of Earth system models

**Earth system services**

**Climate prediction**

**Atmospheric composition**

**Computational Earth sciences**
Air Quality Modelling

CALIOPE
(www.bsc.es/caliope)

- Quantify relation between emissions, meteorology and air concentration
- Forecast air pollution episodes
- Provide and develop short and long term mitigation plans

Domains:
Europe (12 km, 480 x 400 cells)
Spain (4 km, 399 x 399 cells)
NMNM-MONARCH: Atmospheric Composition and Air Quality

- The main system is build on the meteorological driver NMNM
- Multiscale: global to regional scales allowed (nesting capabilities)
- Nonhydrostatic dynamical core: single digit kilometre resolution allowed
- Fully on-line coupling: weather-chemistry feedback processes allowed
- Enhancement with a data assimilation system

Known as NMNM/BSC-Dust
NMNMB-MONARCH: Data Assimilation

NMNMB-MONARCH coupled with a Local Ensemble Transform Kalman Filter (LETKF) for the assimilation of aerosol optical depth observations

Mineral dust application
The ensemble forecast is based on uncertainties in the dust emission scheme
- vertical flux,
- size distribution at emission
- threshold on friction velocity

(DiTomaso et al., GMD, 2016)
Mineral Dust modelling: Dust sources

Understanding of the mineral dust sources
Natural and anthropogenic based on MODIS Deep

In collaboration P. Ginoux (NOAA-GFDL)
Mineral Dust modelling: Topography
Mineral Dust modelling: Topography

Impact of the topography on dust transport

MODIS/Terra March 18, 2012

MODIS/Aqua March 19, 2012

MSG/RGB March 19, 2012

(Basart et al., Aeolian Research, 2016)
Two simulations using the NMMB/BSC-Dust model demonstrates how the dust prediction in the vicinity of complex terrains improves using high-horizontal resolution simulations.

(Basart et al., Aeolian Research, 2016)
MODEL CONFIGURATION

Study domain: 6ºW-10ºE to 15ºN-31ºN
Study period: from 14 to 15 July 2011
Horizontal resolution: 0.03ºx0.03º (about 3 km) → allowing explicit convection
Vertical resolution: 60σ-layers (12-15σ-layers in the first 1000 m)
Cold start (No data assimilation)

(Vendrell et al., in preparation)
Mineral dust Services

BSC dust operational forecast (global and regional domains)

http://www.bsc.es/ESS

✓ Contribution to the ICAP multi-model ensemble (global) http://icap.atmos.und.edu

WMO Dust Centers

SDS-WAS. North Africa, Middle East and Europe Regional Center. http://sds-was.aemet.es started in 2010 – Research

Barcelona Dust Forecast Center.
First specialized WMO Center for mineral dust prediction. http://dust.aemet.es started in 2014 - Operational
BSC dust operational forecast

http://www.bsc.es/ESS
The WMO SDS-WAS project

OBJECTIVES:

- Identify and improve products to monitor and predict atmospheric dust by working with research and operational organizations, as well as with users
- Facilitate user access to information
- Strengthen the capacity of countries to use the observations, analysis and predictions provided by the WMO SDS-WAS project
The SDS-WAS Regional Centers

Annual mean frequency distribution of M-DB2 (2003–2009) DOD > 0.2 (red), TOMS (1980–1991) aerosol index ≥ 0.5 (blue), and OMI (2004–2006) aerosol index ≥ 0.5 (green). The isocontours of TOMS and OMI have been removed over oceans for clarity.

Extracted from Ginoux et al. (2012, Rev. Geophys.)
SDS-WAS NAMEE RC
Dust prediction models provide 72 hours (at 3-hourly basis) of dust forecast (AOD at 550nm and surface concentration) covering the NAMEE region.

<table>
<thead>
<tr>
<th>MODEL</th>
<th>RUN TIME</th>
<th>DOMAIN</th>
<th>DATA ASSIMILATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSC-DREAM8b</td>
<td>12</td>
<td>Regional</td>
<td>No</td>
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<tr>
<td>CAMS ECMWF</td>
<td>00</td>
<td>Global</td>
<td>MODIS AOD</td>
</tr>
<tr>
<td>DREAM8-NMME</td>
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<td>CAMS analysis</td>
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<tr>
<td>NMMB/BSC-Dust</td>
<td>00</td>
<td>Regional</td>
<td>No</td>
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<tr>
<td>MetUM</td>
<td>12</td>
<td>Global</td>
<td>MODIS AOD</td>
</tr>
<tr>
<td>GEOS-5</td>
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<td>Global</td>
<td>MODIS reflectances</td>
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<td>NGAC</td>
<td>00</td>
<td>Global</td>
<td>No</td>
</tr>
<tr>
<td>RegCM4 EMA</td>
<td>00</td>
<td>Global</td>
<td>No</td>
</tr>
<tr>
<td>DREAMABOL</td>
<td>12</td>
<td>Regional</td>
<td>No</td>
</tr>
<tr>
<td>WRF-CHEM NOA</td>
<td>12</td>
<td>Regional</td>
<td>No</td>
</tr>
<tr>
<td>SILAM</td>
<td>12</td>
<td>Regional</td>
<td>No</td>
</tr>
<tr>
<td>LOTOS-EUROS</td>
<td>12</td>
<td>Regional</td>
<td>No</td>
</tr>
</tbody>
</table>

http://sds-was.aemet.es/
Daily forecasts of dust surface concentration and dust optical depth will be displayed on a page together with a menu to allow visualization of the archived products and/or download of the numerical files for a selected range of dates.

Access to the download pages shall be restricted to those groups that authorize the exchange of their own data.

Needed registered user!

http://sds-was.aemet.es/
SDS-WAS Multi-model

SDS-WAS product

12 Global – Regional models (from ~ 100 to 10 km)

Dust Surface Conc. from 15-Oct-2017 12:00 to 18-Oct-2017 00:00

http://sds-was.aemet.es/
SDS-WAS Multi-model

SDS-WAS product

12 Global – Regional models
(from ~ 100 to 10 km)

http://sds-was.aemet.es/
SDS-WAS NAMEE: Multi-model

Surface concentration

Dust AOD at 550nm

from 15-Oct-2017 12:00 to 18-Oct-2017 00:00

Model outputs are bi-linearly interpolated to a common 0.5ºx0.5º grid mesh. Then, different multi-model products are generated:

CENTRALITY: median - mean
SPREAD: standard deviation – range of variation

http://sds-was.aemet.es/
SDS-WAS NAMEE: Multi-model - ICAP

Dust AOD at 550nm
from 15-Oct-2017 12:00 to 18-Oct-2017 00:00

Only global models!

http://sds-was.aemet.es/
SDS-WAS NAMEE: DOD Model Evaluation

- Evaluation with AERONET data
  - Graphical NRT Evaluation by site
  - Evaluation scores monthly/seasonal/annual and sites

- Evaluation with MODIS data onto the Atlantic
  - Evaluation scores monthly/seasonal/annual

- Evaluation of dust models with MODIS Deep Blue retrievals
  - Evaluation scores monthly/seasonal/annual

http://sds-was.aemet.es/forecast-products/forecast-evaluation
SDS-WAS NAMEE: DOD AERONET Evaluation

http://sds-was.aemet.es/
A set of evaluation metrics are selected: **Bias, RMSE, correlation coefficient and FGE**

Calculations evaluation metrics are done for:
- **monthly/seasonal/annual sites and regions**
**SDS-WAS NAMEE: DOD MODIS Evaluation**

![Map Image](http://sds-was.aemet.es/)

<table>
<thead>
<tr>
<th>Model</th>
<th>Bias</th>
<th>RMSE</th>
<th>Correlation Coefficient</th>
<th>Fractional Gross Error</th>
<th>Number of Cases</th>
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<tbody>
<tr>
<td>BSC_ DREAMb</td>
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<td>0.48</td>
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![Map Image](http://sds-was.aemet.es/)

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<th>Correlation Coefficient</th>
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<th>Number of Cases</th>
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</table>

[http://sds-was.aemet.es/](http://sds-was.aemet.es/)
SDS-WAS NAMEE: Model Evaluation

New observational datasets for model evaluation in Northern Africa and Middle East

NOTE: There is available an historical archive of the MSG RBG dust products.
SDS-WAS NAMEE: Model Evaluation

New observational datasets for model evaluation in Northern Africa and Middle East

- Visibility
- MSG/SEVIRI
- MODIS
- OMI
- CALIPSO
- PARASOL
- MPLNET
- PM$_{10}$

MODIS composite 8$^{th}$ March 2015 from EOSDIS World Viewer

http://sas-was.aemet.es/
SDS-WAS NAMEE: Studies

Model Intercomparison: European dust outbreak on April 2011

- The selected dust event corresponds to the one which occurred between the 5th and 11th of April of 2011.
- Participating models: BSC-DREAM8b, NMMB/BSC-Dust, ECMWF-MACC, UKMetOffice-UM and NMME-DREAM-MACC
- Comparison of each forecast (at 24, 48 and 72h) output to in-situ measurements of AOD (from AERONET), surface concentration (PM) and satellite retrieved AOD (MODIS, CALIPSO) and meteorology.

(MSG/SEVIRI RGB product 7 April Courtesy of EUMETSAT)

(Huneeus et al., ACP, 2016)
SDS-WAS NAMEE: Studies

Model Intercomparison: European dust outbreak on April 2011 – DOD

(Huneeus et al., ACP, 2016)
SDS-WAS NAMEE: Studies

Model Intercomparison: European dust outbreak on April 2011 - Emissions

(Huneeus et al., ACP, 2016)
SDS-WAS NAMEE: Studies

Model Intercomparison: EU-EARLINET vertical dust profiles: 2011-2013

(Binietoglou et al., ATM, 2015)
The extreme dust storm occurred in Tehran (Iran) on 2nd June 2014 lasting less than 2 hours according to public evidence.

Based on public news, the dust storm caused several deaths, reduction of visibility to several tenths meters in the city, and adverse disturbance of the public traffic. The blowing wind reached 110 km/h.

This project aims to better understand generation and development of small-scale dust storms contributing so to exploring a potential of dust models to more accurately simulate such events, considering them as the most difficult ones to be operationally predicted.
Iranian Haboob: Teheran 2\textsuperscript{nd} June 2014

Information from reports
- reached city at 5.30 p.m. local time;
- passing of the sand storm over the fixed site lasted about 15 min;
- storm duration less than 2 h;
- reduction of visibility to \(~10\) m; wind velocity reached 110 km/h;
- temperature dropped from 33 to 18\(^\circ\)C in several min;
- at least 5 deaths, 82 injured; multiple vehicle collision;
Iranian Haboob: Teheran 2\textsuperscript{nd} June 2014

Intensive cold downbursts from convective cells produced high velocity surface wind, creating cold front which was lifting, mixing and pushing dust towards the city;

Expected: high wind speed, drop in temperature, rise in humidity, rise in pressure, reduction of visibility.

(Vukovic et al., in preparation)
Explicit convection simulations are highly dependent on the initial conditions and the microphysical scheme → *Probabilistic dust forecast based on model ensembles*

(Vukovic et al., in preparation)
SDS-WAS NAMEE: PM10 Evaluation

AMMA network: PM10 in Sahel for the year 2013

Not all PM10 is dust: Local and biomass burning from Savannah fires.
Dust filter: Considering the localizations of the desert dust sources the filter is based on wind direction.

AMMA (Marticorena et al., 2010)

http://sds-was.aemet.es/
SDS-WAS NAMEE: PM10 Evaluation

AMMA network: PM10 in Sahel for the year 2013

http://sds-was.aemet.es/
SDS-WAS NAMEE: PM10 Evaluation

AQ network: Canary Islands 2013-2014

Not all PM10 is dust: Local sources

Dust filter: Moving 40th percentile of 30 days, 15 days before and 15 days after (Escudero et al. 2007).

http://sds-was.aemet.es/
SDS-WAS NAMEE: PM10 Evaluation

AQ network: Canary Islands 2013-2014

http://sds-was.aemet.es/
SDS-WAS NAMEE: PM10 Evaluation

AQ network: Canary Islands 2013-2014

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

NRT visibility evaluation: 6th April 2016 0-12UTC

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

NRT visibility evaluation: 6\textsuperscript{th} April 2016 0-12UTC

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

NRT visibility evaluation: 6\textsuperscript{th} April 2016  0-12UTC

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

NRT visibility evaluation: 19th June 2016

http://sds-was.aemet.es/
SDS-WAS NAMEE: Dust Profiles Evaluation

Ceilometers
Tenerife, Granada and Montsec (Spain)

+ High density of stations
- Qualitative products

Lidar
M’Bour (Senegal)

- Low number of stations
+ Quantitative products

http://sds-was.aemet.es/projects-research/evaluation-of-model-derived-dust-vertical-profiles
SDS-WAS NAMEE: Dust Profiles Evaluation

W. Mediterranean dust event: 2 - 5 November 2016

[Map and graphs related to dust event]
SDS-WAS NAMEE: Dust Profiles Evaluation

Atlantic dust event: 2 - 5 November 2016
SDS-WAS NAMEE: Dust Profiles Evaluation

Atlantic dust event: 9 - 12 December 2016
SDS-WAS NAMEE: Dust Profiles Evaluation

Atlantic dust event: 9 - 12 December 2016
In 2014, the First Specialized Center for Mineral Dust Prediction of WMO is created. NMMB/BSC-Dust selected to provide operational forecasts for NAMEE region.

@Dust_Barcelona
http://dust.aemet.es/
Barcelona Dust Forecasting Center

Website visits: 1 January 2015 – 20 October 2017

10 Feb: Middle East event
26 Aug: Algeria event
22 Feb: Sahel and IP event
18 Jun: Arabian event
20 Feb: Spain event
15 Oct: UK event

http://dust.aemet.es/

@Dust_Barcelona

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Website visits: 1 January 2015 – 20 October 2017

10 Feb: Middle East event
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20 Feb: Spain event
15 Oct: UK event

http://dust.aemet.es/

@Dust_Barcelona
BDFC: Operational Products

Dust Optical Depth at 550nm
Dust Dry Deposition
Dust Load
Dust Surface Concentration
Dust Surface Extinction at 550nm
Dust Wet Deposition

@Dust_Barcelona
http://dust.aemet.es/
BDFC: Dust event Canary Islands Feb 2015

http://dust.aemet.es/
BDFC: Dust event Canary Islands Mar 2015

MODIS composite 8th March 2015 from EOSDIS World Viewer

http://dust.aemet.es/
BDFC: Dust event Europe May 2015

http://dust.aemet.es/
BDFC: Dust event Europe June 2015

http://dust.aemet.es/
BDFC: Dust event Middle East Feb 2015

http://dust.aemet.es/
BDFC: Dust event Middle East Apr 2015

http://dust.aemet.es/
COST Action InDust (CA16202)

INTERNATIONAL NETWORK TO ENCOURAGE THE USE OF MONITORING AND FORECASTING DUST PRODUCTS

Chair: Dr Sara Basart (Barcelona Supercomputing Center, Spain)
Vice-chair: Dr Slobodan Nickovic (Republic Hydrometeorological Service of Serbia)

http://www.cost.eu/COST_Actions/ca/CA16202
The overall objective of the proposed Action is to establish a network involving research institutions, service providers and potential end users of information on airborne dust.

The Action will search to coordinate and harmonise the process of transferring dust observation and prediction data to users as well as to assist the diverse socio-economic sectors affected by the presence of high concentrations of airborne mineral dust.
COST Action InDust – Participants

• 28 COST EU members countries signed the MoU:
  • Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Cyprus, Denmark, Finland, France, fYR Macedonia, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Spain, Switzerland, Turkey and United Kingdom.

• 3 COST Near-Neighbour Countries:
  • Jordan (University of Jordan), Morocco (Ministry of Health) and Egypt (The Egyptian Meteorological Authority and Cairo University).

• one international organisation:
  • World Meteorological Organization (WMO)

Moreover, InDust also accounts with the participation of a number of researchers from Africa, America and Asia.
COST InDust - Structure

**WP1 Dust observations**
- **GOAL:** Identification and catalogue of dust (ground-based and satellite) observations best suited to be transferred to modelling groups and end-users

**WP2 Dust modelling and forecast**
- **GOAL:** Identification of the most suitable model products (forecasts, hindcasts, reanalysis) for the user's communities

**WP3 Assessment of user and societal benefits**
- **GOAL:** Creation of a network that enables fruitful collaborations between researchers and end-user communities

**WP4 Transfer of dust products to user-oriented application and service value**
- **GOAL:** To propose the most suitable products for the application areas identified by users involved in the Action and also identified by WG3
COST InDust – Events
1st Joint Working Group meeting in Barcelona on 14-15 March

Nexus II Building. Barcelona

MareNostrum supercomputer
Ongoing projects to design dust services

**Dust Storms Assessment** for the development of user-oriented Climate Services in Northern Africa, Middle East and Europe

- SDS is a serious hazard
- Lack of dust observations, particularly in Africa

**GOAL:** Develop dust-related services to specific socio-economic sectors based on an advanced dust reanalysis
Next dust events

Updated in the SDS-WAS website: http://sds-was.aemet.es/
Thank you

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