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Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Dust modelling and forecasting in the BSC

Activities and developements

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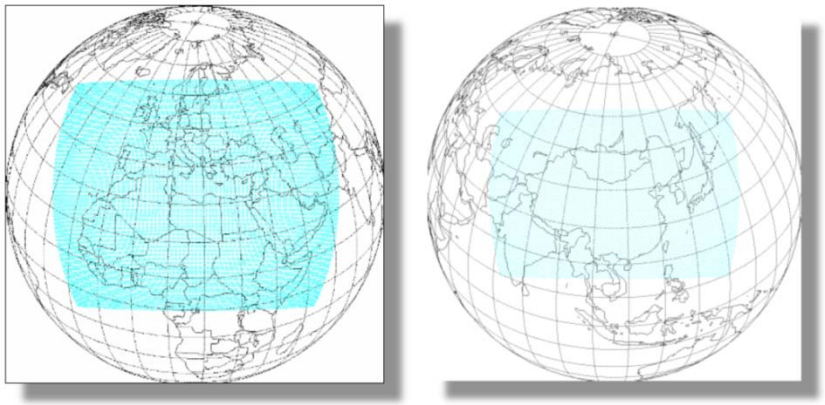
4th ICAP Workshop. Frascati, 14-17 May 2012

Mineral dust activities in the BSC-CNS

- Daily operational dust forecasts based on the BSC-DREAM8b model (Nickovic et al., 2001; Pérez et al., 2006; Basart et al., 2012) → *http://www.bsc.es/projects/earthscience/DREAM*
- Inclusion of Saharan dust contributions in the CALIOPE air quality forecasting system (Baldasano et al., 2011; Basart et al., 2012; Pay et al., 2010; Pay et al., 2011) → *www.bsc.es/caliope*
- Development of the NMMB/BSC-DUST (Pérez et al., 2011; Haustein et al., 2012)
- Management of the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) Regional Center for North Africa-Middle East-Europe → *http://sds-was.aemet.es/*
- Operations of Lidars (MPLNet and EARLINET) and sunphotometers (AERONET) at Barcelona site

The BSC-DREAM8b model

- Daily forecasts in 2 domains:
  - North Africa-Middle East-Europe (1/3º x 1/3º)
  - East Asia (0.5º x 0.5º)



- Main features
  - USGS 1km vegetation and FAO 4km soil texture data
  - 8 particle size bin distribution (0.1 -10 μm)
  - Dust radiative feedbacks (Pérez et al., 2006)

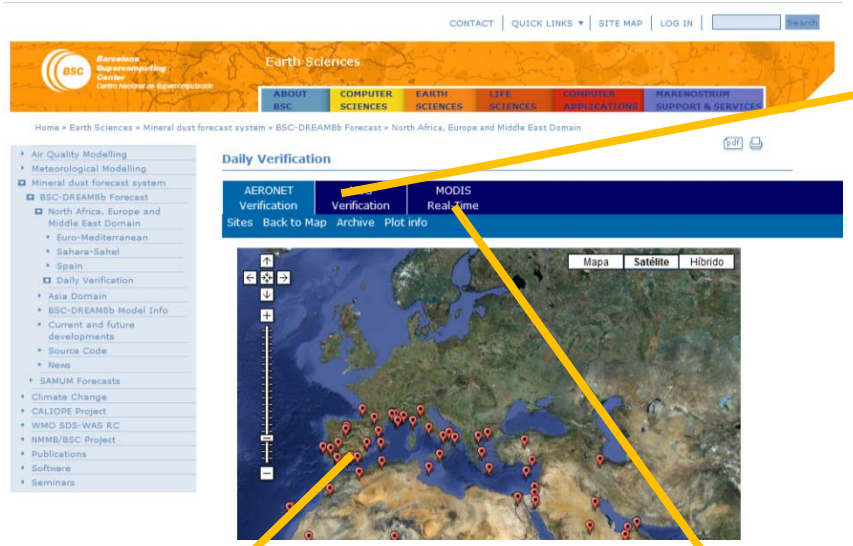
Latest developments (*pre-operational*):

  - Updated dry deposition
  - Inclusion of a preferential source mask

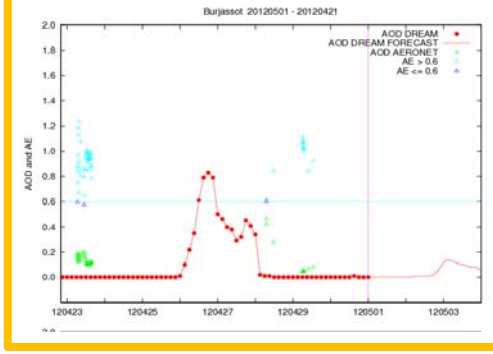
- Dust forecast evaluation studies:
  - Single events in the *Mediterranean* (e.g., Papayannis et al., 2005; Pérez et al., 2006)
  - Experimental campaigns in *source regions*
    - BoDEX 2005 (Todd et al., 2008)
    - SAMUM 2006 (Haustein et al., 2009)
  - Anual evaluation over North Africa, Mediterranean and Middle East (Pay et al., 2011; Basart et al., 2012)

    → *New model developments*
- Near-real time evaluation

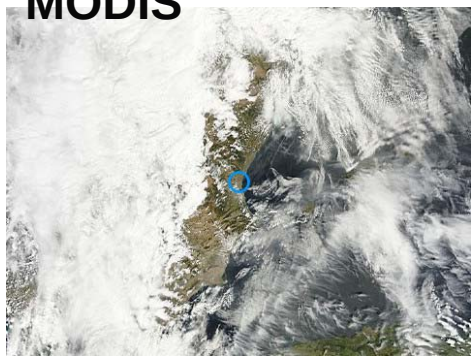
The BSC-DREAM8b model: Daily evaluation



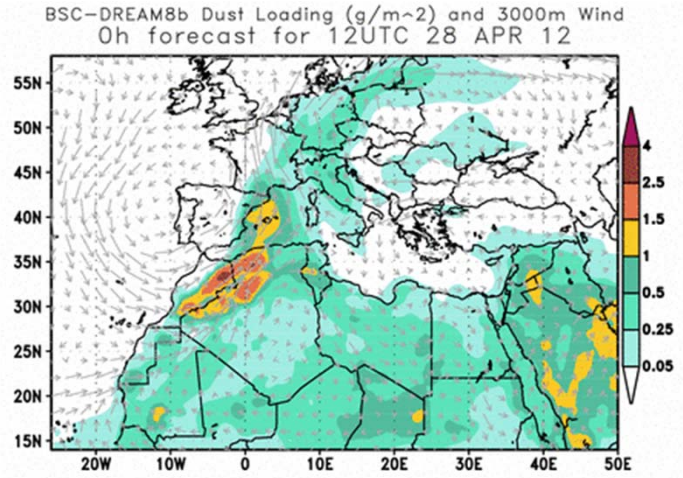
AERONET

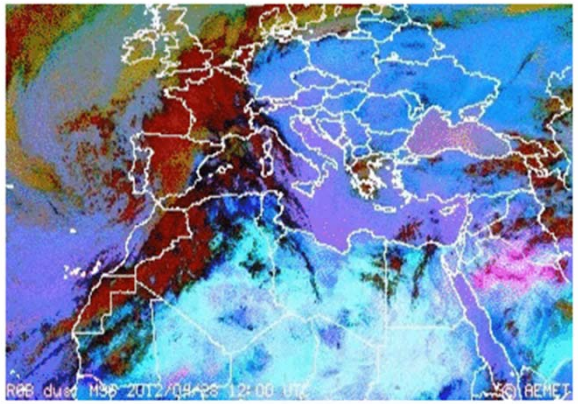


MODIS



MSG/RGB





Inclusion of new satellite aerosol products: OMI, CALIPSO and MISR

The CALIOPE air quality forecasting system

MODULES

- Meteorology: *WRF-ARW v3.0.1.1*,
IC & BC: EU = FNL/NCEP
IP = one-way nesting
38 sigma levels (50 hPa)

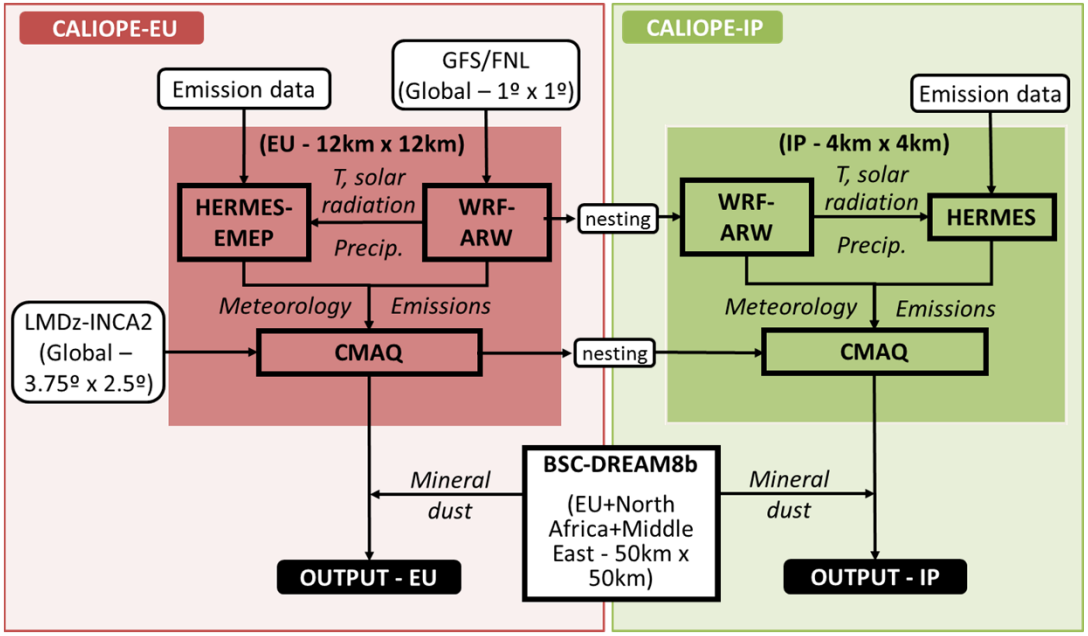
- Emissions: *HERMES-EMEP*

EU = Disaggregation from EMEP
IP = HERMES model bottom-up

- Chemical Transport Model: *CMAQv4.5*

BC: EU = LMDz-INCA2
IP = one-ways nesting
15 sigma levels (50 hPa)
CBIV, Cloud chem., AERO4

- Mineral dust: *BSC-DREAM8b*

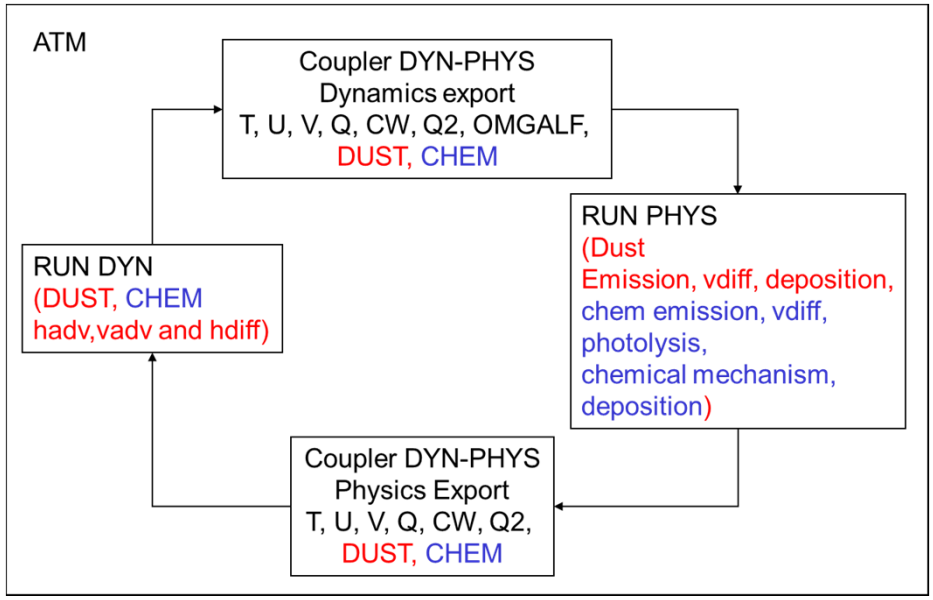


CALIOPE system: WRF-ARW/HERMES-EMEP/CMAQ/BSC-DREAM8b*

The NMMB/BSC-CTM Project

The Non-hydrostatic Multiscale Model (NMMB) :

- Under development at NCEP (Janjic, 2005; Janjic and Black, 2007) as evolution of the ETA model
- Developed within the Earth System Modeling Framework (ESMF)
- Arakawa B grid and regular (global) or rotated (regional) lat/lon coordinate
- NMMB is the regional operational meteorological model in NCEP since October 2011.
- Unified model for a broad range of spatial and temporal scales



On-line approach:

DUST (*Pérez et al., 2011; Haustein et al., 2012*) , SEA SALT (*Spada et al., 2012*) and gas-phase CHEM (*Jorba et al., 2011; Badia et al., 2012*) modules fully embeded within the atmospheric driver.

The NMMB/BSC-DUST model

- Evolution of the BSC-DREAM8b model (Nickovic et al., 2001; Pérez et al., 2006)
- NMMB/BSC-DUST is embedded into the NMMB model and solves the mass balance equation for dust taking into account the following processes:
  - Dust generation/emission by surface wind
  - Horizontal and vertical advection
  - Vertical transport/diffusion by turbulence and convection
  - Dry deposition and gravitational settling
  - Wet removal including in-cloud and below-cloud scavenging
  - RRTM SW/LW dust radiative feedback
- NMMB/BSC-DUST (Pérez et al., 2011; Haustein et al., 2012) main features:
  - Implementation of all common **on-line dust modules** for global and regional simulations
  - Nested regional domains at very high resolution are available
  - The current DREAM dust emission scheme is upgraded to a physically based scheme
    → *explicitly accounting for saltation and sandblasting*
  - New high resolution database for soil textures and vegetation fraction is included

The NMMB/BSC-DUST model: Emission scheme

Dust emission by surface wind

- Threshold friction velocity (Iversen and White, 1982; Marticorena and Bergametti, 1995, Fécan et al. 1999)

$$u_{*_t}(D, z_0, w) = \frac{u_{*dry}^{MB}(D)}{R(z_0, z_{0S})} \cdot H(w)$$

H=Moisture correction
R=Drag partition correction

- Horizontal flux (White, 1979)

$$H = \frac{\rho_{air}}{g} \cdot u_*^3 \cdot \sum_i \left(\left(1 + \frac{u_{*total}}{u_*} \right) \cdot \left(1 - \frac{u_{*total}^2}{u_*^2} \right) \cdot s_i \right)$$

H=Horizontal dust flux
s_i=relative surface area of each parent soil fraction

- Vertical flux (Shao et al., 1993; Marticorena and Bergametti, 1995, Tegen et al., 2002)

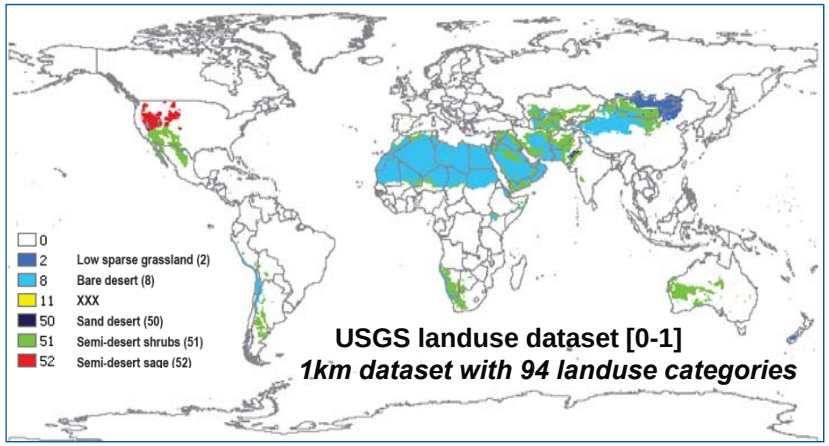
$$F_S = C \cdot \alpha \cdot \delta \cdot H$$

F_S=Vertical surface dust flux;
α=horizontal to vertical flux ratio;
δ=Source function

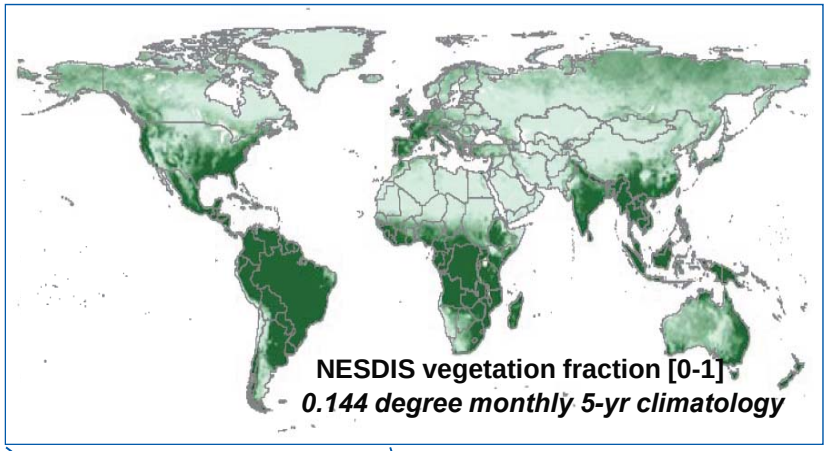
- Viscous sublayer effects near the surface (Janjic, 2001) which parameterizes the turbulent transfer of dust into the lowest model layer.

The NMMB/BSC-DUST model: Emission scheme

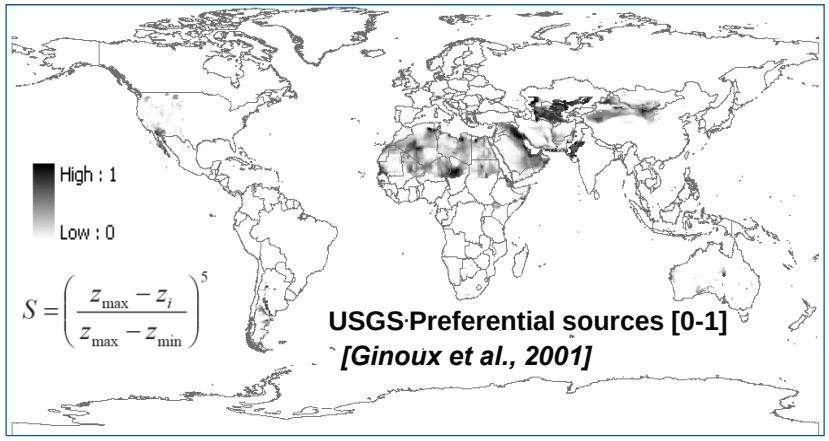
Source function, δ: update databases



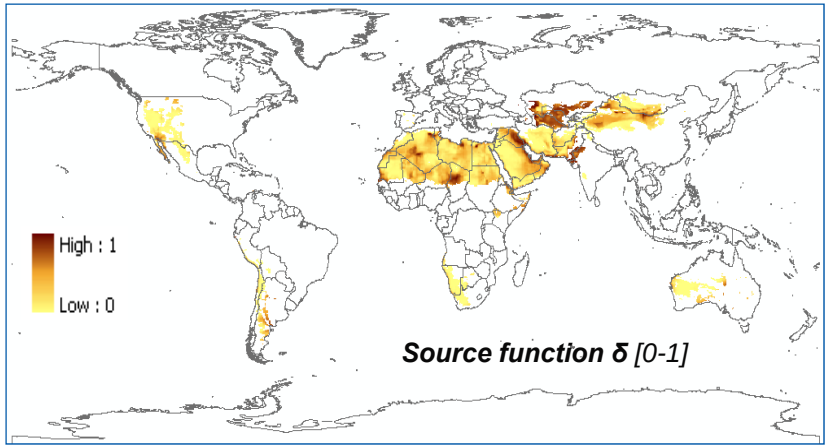
USGS landuse dataset [0-1]
1km dataset with 94 landuse categories



NESDIS vegetation fraction [0-1]
0.144 degree monthly 5-yr climatology



USGS Preferential sources [0-1]
[Ginoux et al., 2001]



***Source function δ** [0-1]*

$$\delta = USGS \cdot PREF \cdot (1 - VEGFRAC) \cdot (1 - SnowCover)$$

The NMMB/BSC-DUST model: Deposition scheme

- Dry deposition and gravitational settling

  - Gravitational settling or sedimentation (Slinn, 1982)

$$v_{gk} = \frac{d_k^2 g(\rho_k - \rho_a) C_c}{18\nu}$$

Cc=Cunningham correction

  - Dry deposition (Zhang et al., 2001): Brownian diffusion, interception and impaction are considered.

$$v_{dk} = v_{gk} + \frac{1}{(R_a + R_s)}$$

- Wet removal including in-cloud and below-cloud scavenging

  - Dust scavenging is computed separately for convective and grid-scale precipitation
  - Ferrier grid-scale microphysics and Betts-Miller-Janjic convective adjustment scheme
  - Below cloud scavenging in each layer (Slinn, 1984; Loosmoore and Cederwall, 2004)

The NMMB/BSC-DUST: Model configuration

Global configuration:

- Global domain at 1.4º x 1º horizontal resolution
- 24 vertical levels
- fundamental time step of 180s
- Cold start without data assimilation
- Initial conditions from NCEP meteorological analysis 1x1º and Meteorological fields updated with NCEP every 24 h

  - *Annual simulation: 2000 (Pérez et al., 2011)*

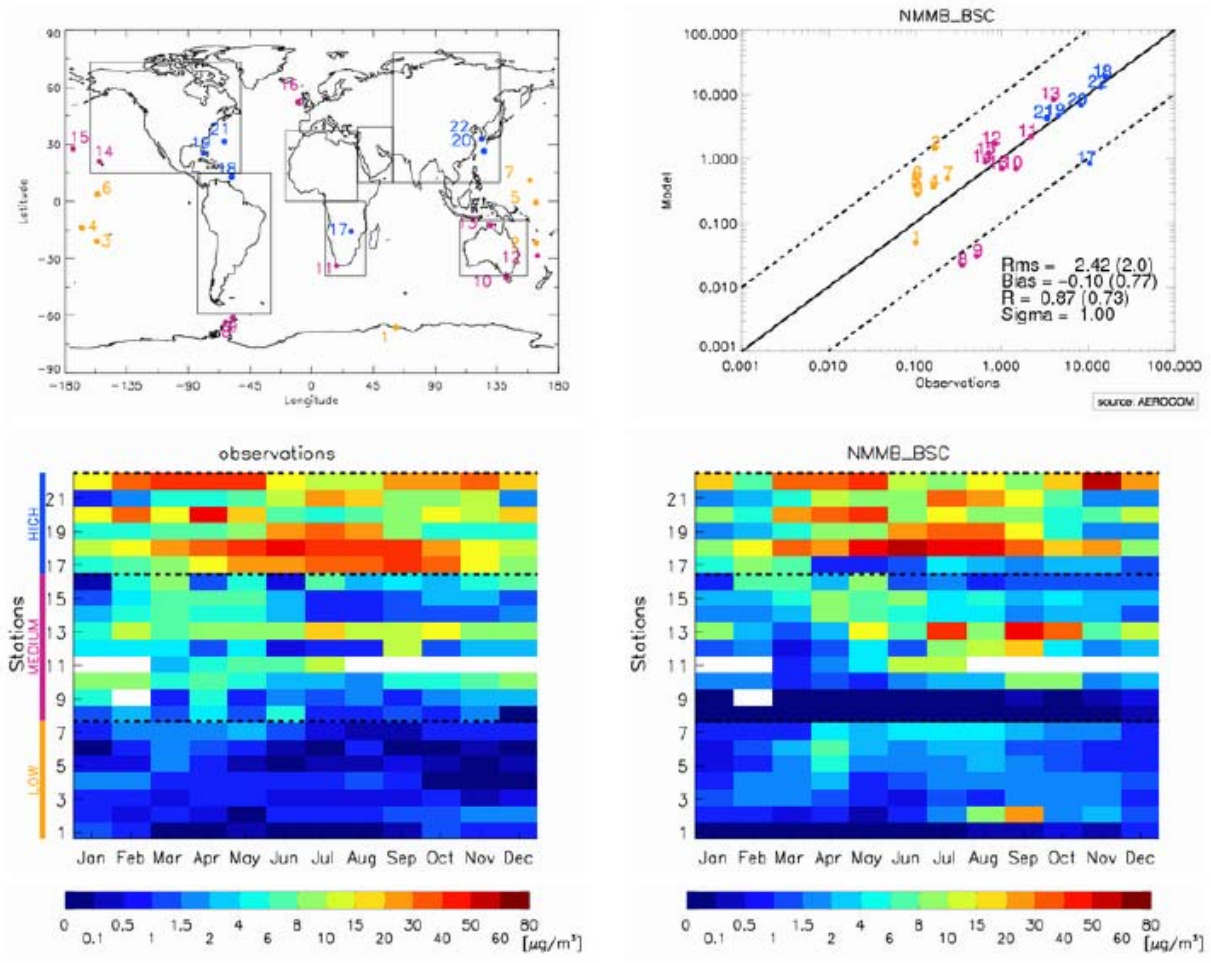
Regional configuration:

- North African domain at 0.25º x 0.25º horizontal spatial resolution
- 40 vertical layers
- fundamental time step of 40s
- Cold start without data assimilation
- Initial conditions from NCEP meteorological analysis 1x1º and meteorology fields updated boundary conditions every 6 h

  - *Annual simulation: 2006 (Pérez et al., 2011)*
  - *SAMUM-I period May 2006 (Haustein et al., 2012)*

The NMMB/BSC-DUST: Global domain

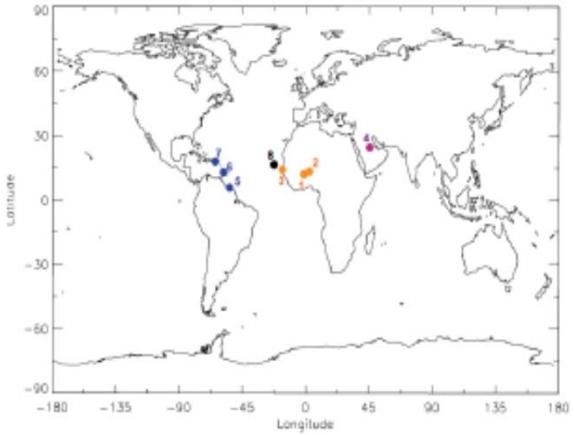
Surface concentration for 2000 (Pérez et al., 2011)



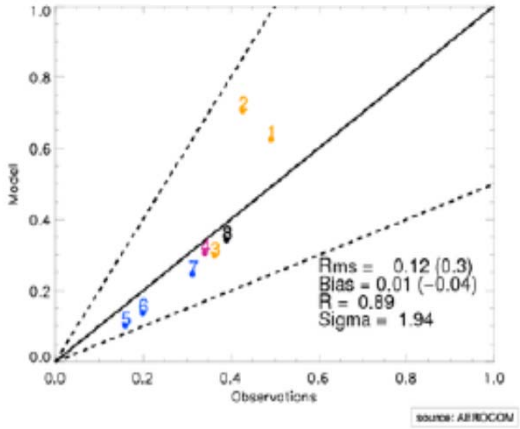
The NMMB/BSC-DUST: Global domain

AOD for 2000 (Pérez et al., 2011)

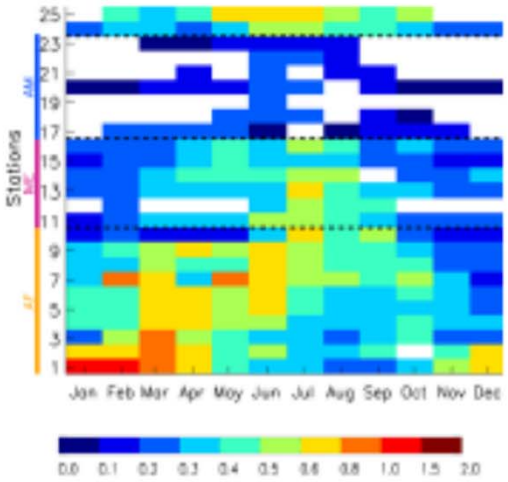
AERONET sites



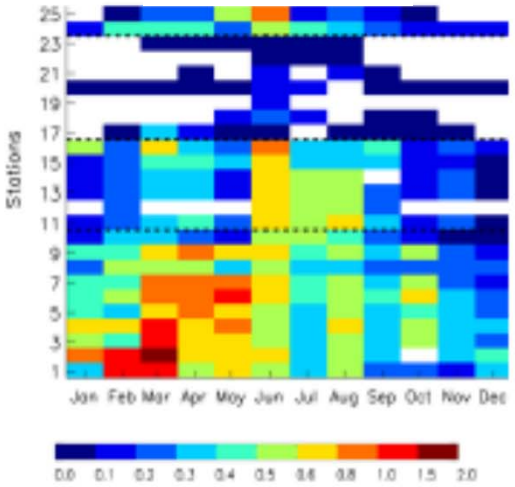
NMMB/BSC-DUST



Total AOD observations



NMMB/BSC-DUST



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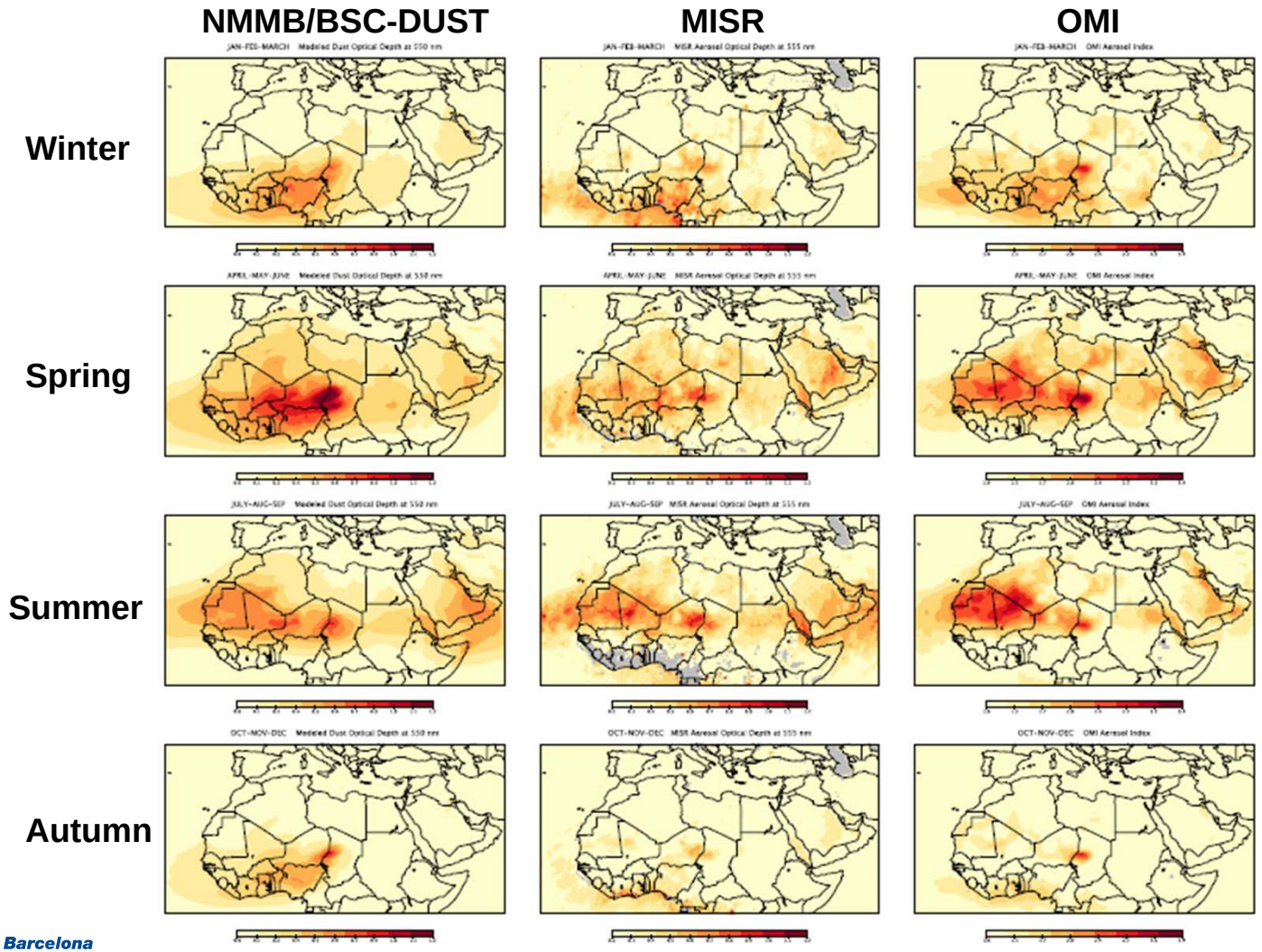
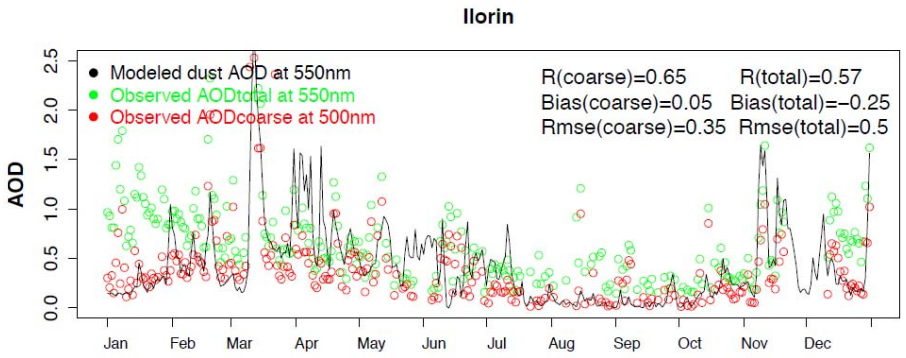
The NMMB/BSC-DUST: Regional domain

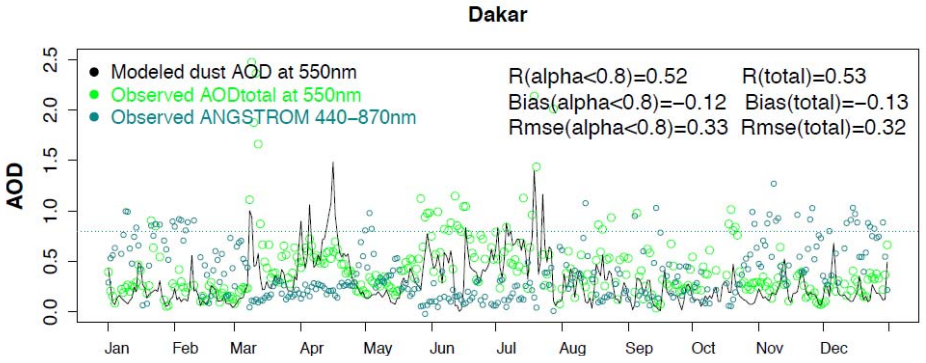
Satellite comparison for 2006 (Pérez et al., 2011)

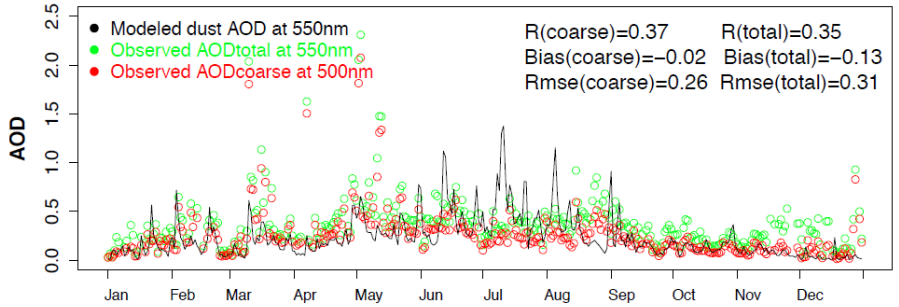


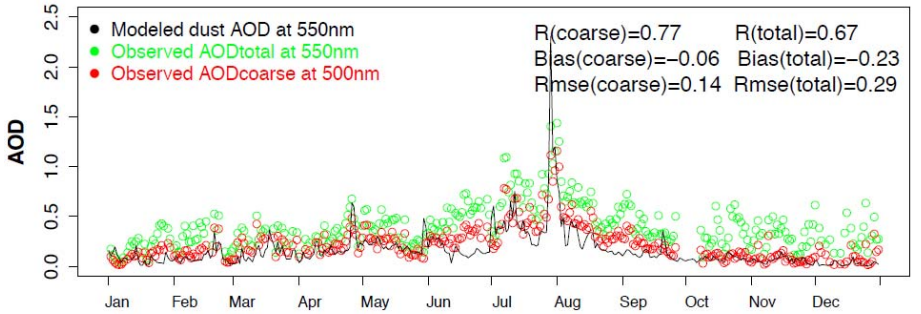
The NMMB/BSC-DUST: Regional domain Results

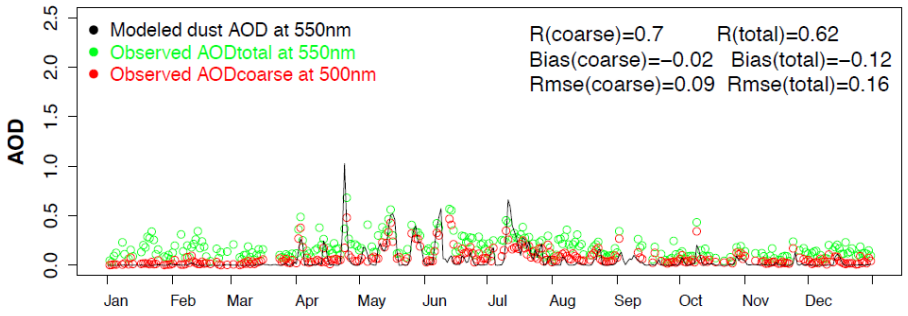
AERONET comparison for 2006 (Pérez et al., 2011)

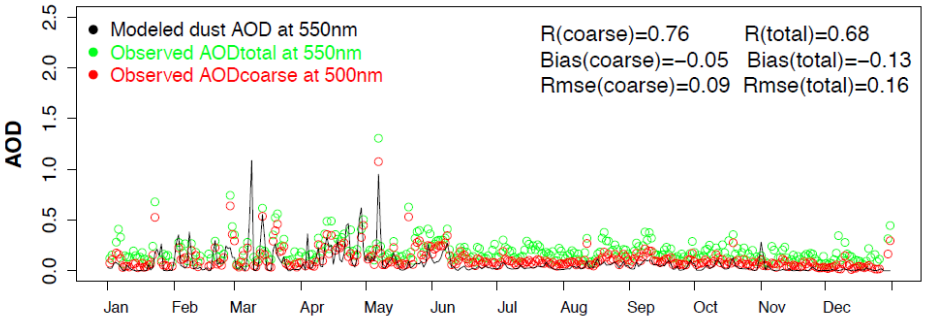






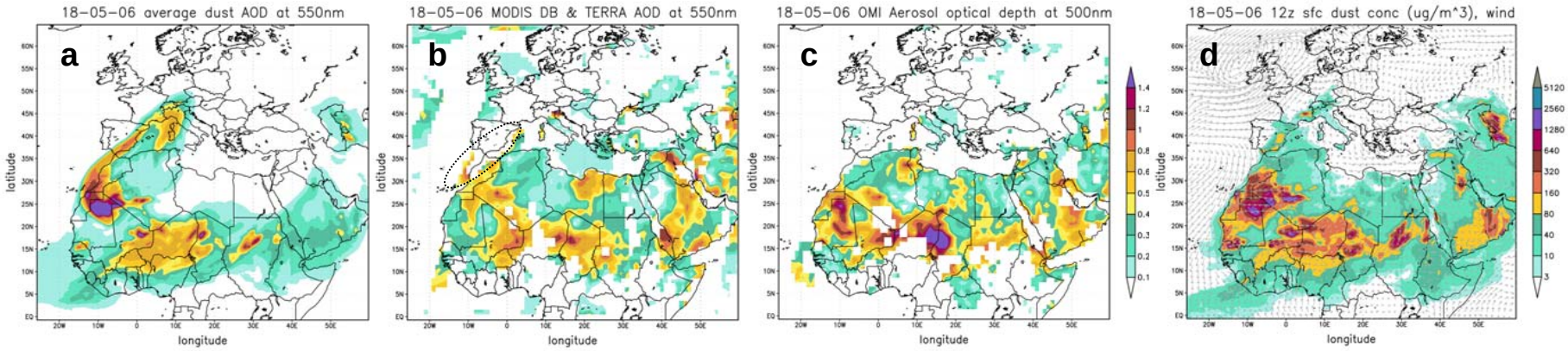






The NMMB/BSC-DUST: Regional domain

SAMUM-I on 18 May 2006 – Satellites (Haustein et al., 2012)



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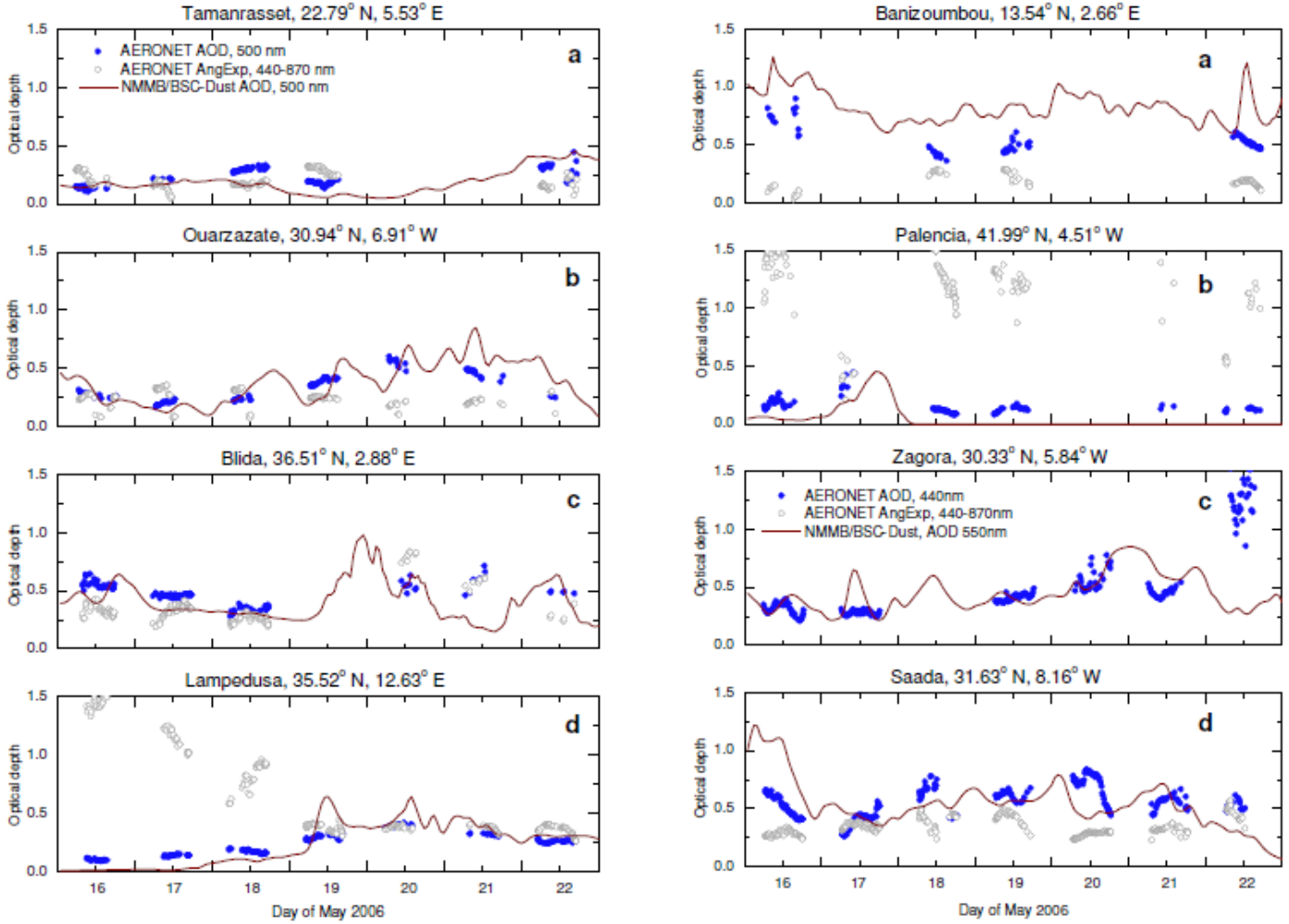
The NMMB/BSC-DUST: Regional domain

SAMUM-I May 2006 – AERONET (Haustein et al., 2012)



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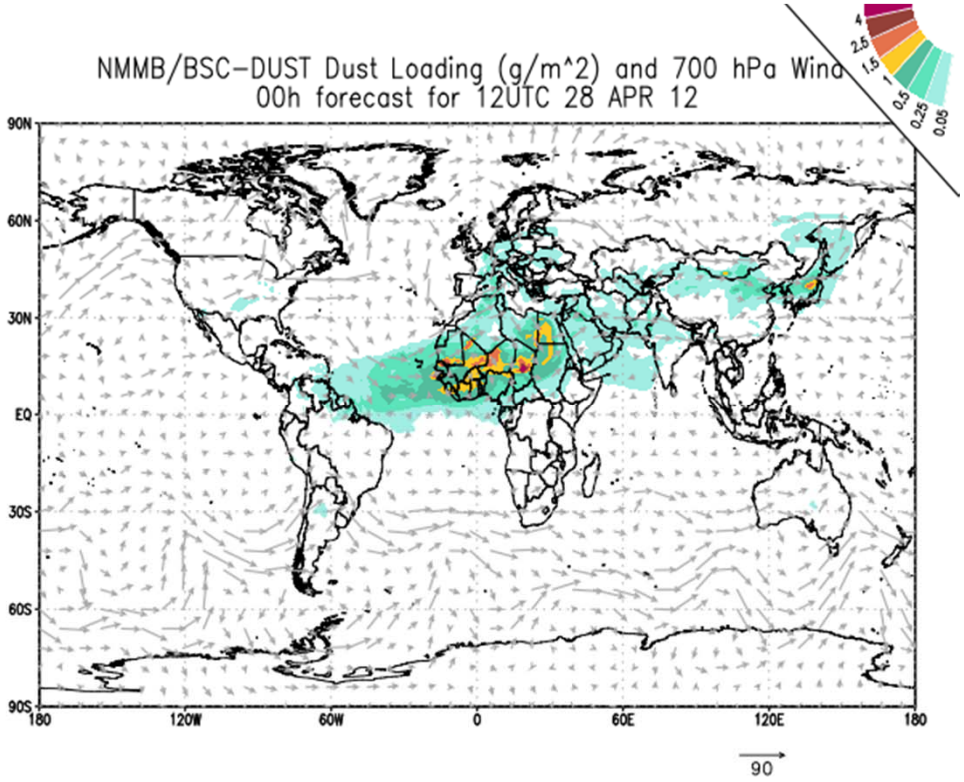
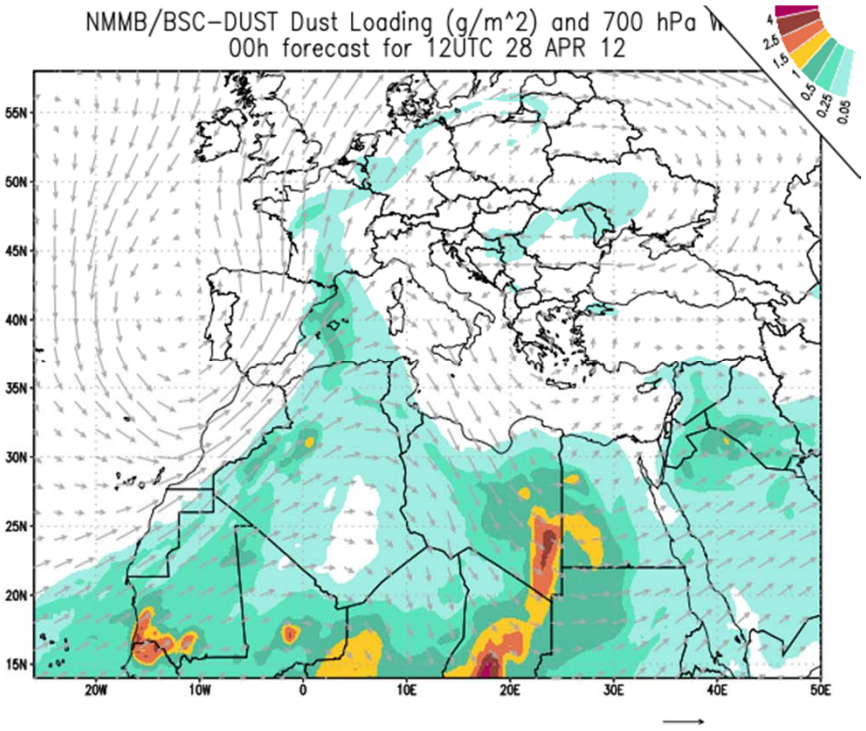
The NMMB/BSC-DUST

*Dust forecasts on **global** and **regional** domains are running in pre-operational in the **BSC***

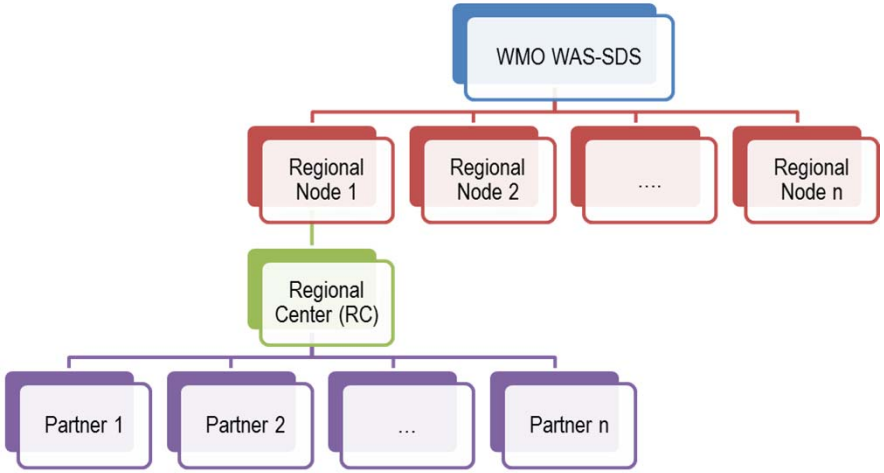




WMO SDS-WAS

The WMO SDS-WAS mission is to enhance the ability of countries to deliver timely and quality dust forecasts, observations, information and knowledge to users through an international partnership of research and operational communities.

Photo: Steve & Jemma Copley, 15-2-2008
Severe sand storm in Salmiya, Hawalli, Kuwait

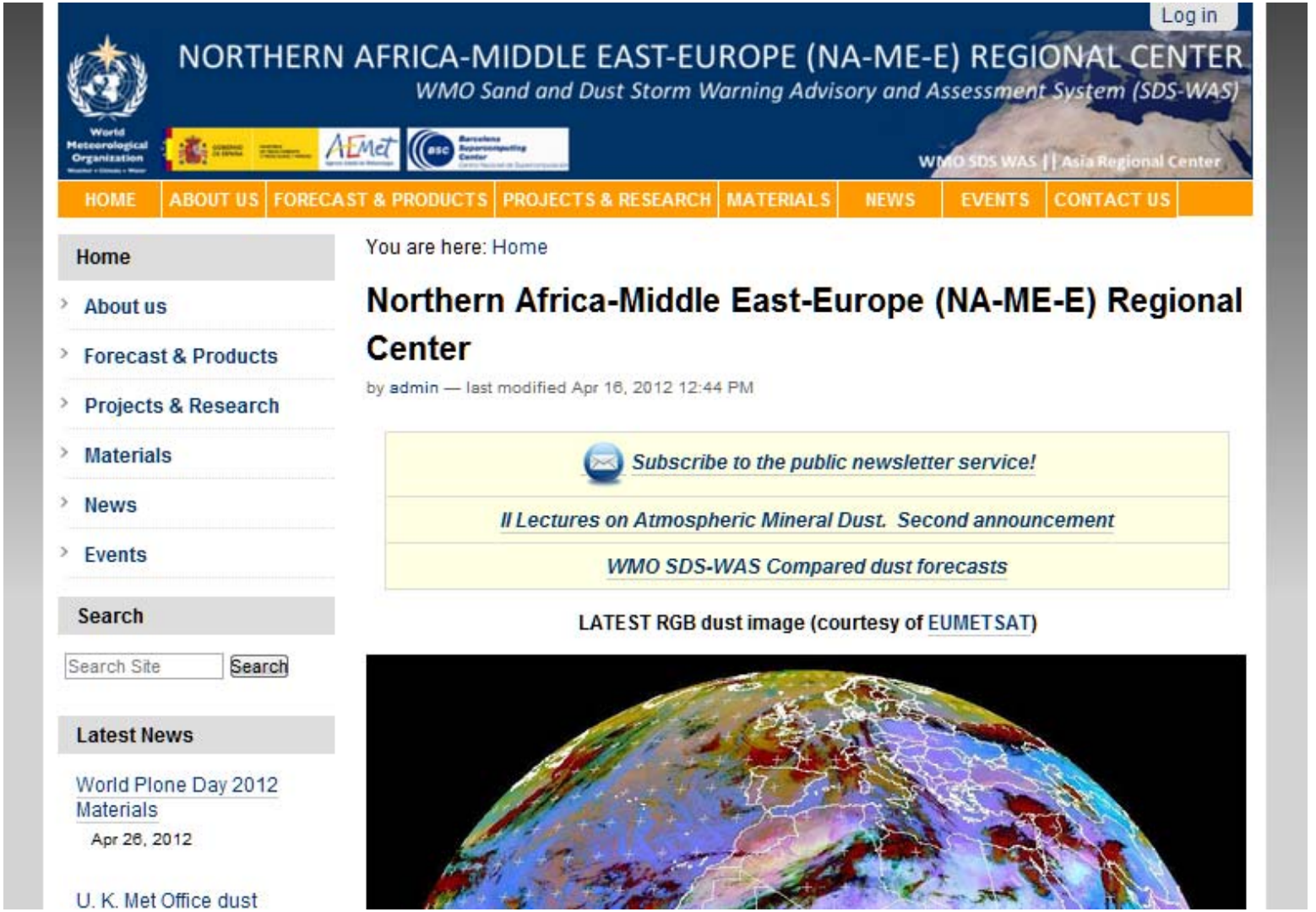


The WMO SDS-WAS North Africa-Middle East-Europe (NA-ME-E) Regional Center is jointly managed by AEMET and the BSC-CNS. It is located in Barcelona, at BSC-CNS.

AEMet Agencia Estatal de Meteorología

BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación

The WMO SDS-WAS NA-ME-E RC (sds-was.aemet.es)



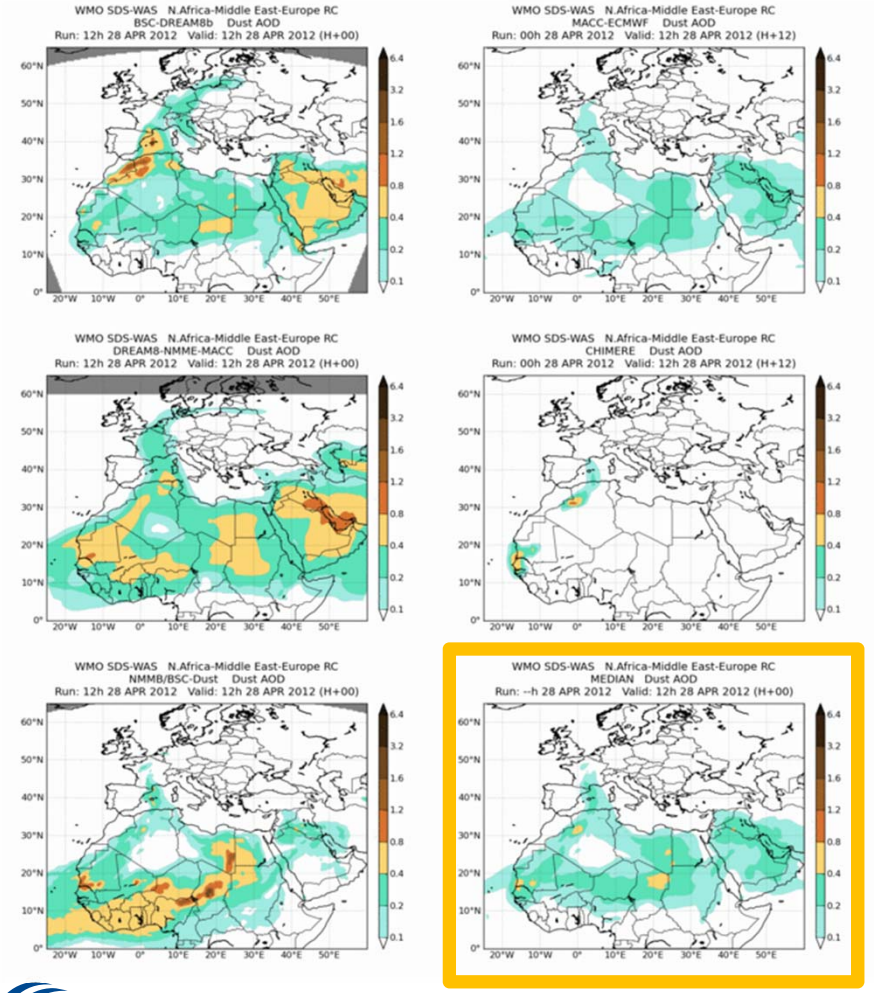
Forecast and Products: Dust models

- Data exchange
- Joint visualization
- Common forecast evaluation
- Generation of multimodel products
- Calculation of monthly evaluation metrics
- New sources of data for model evaluation
- Sharing model output data files
- Time-averaged products

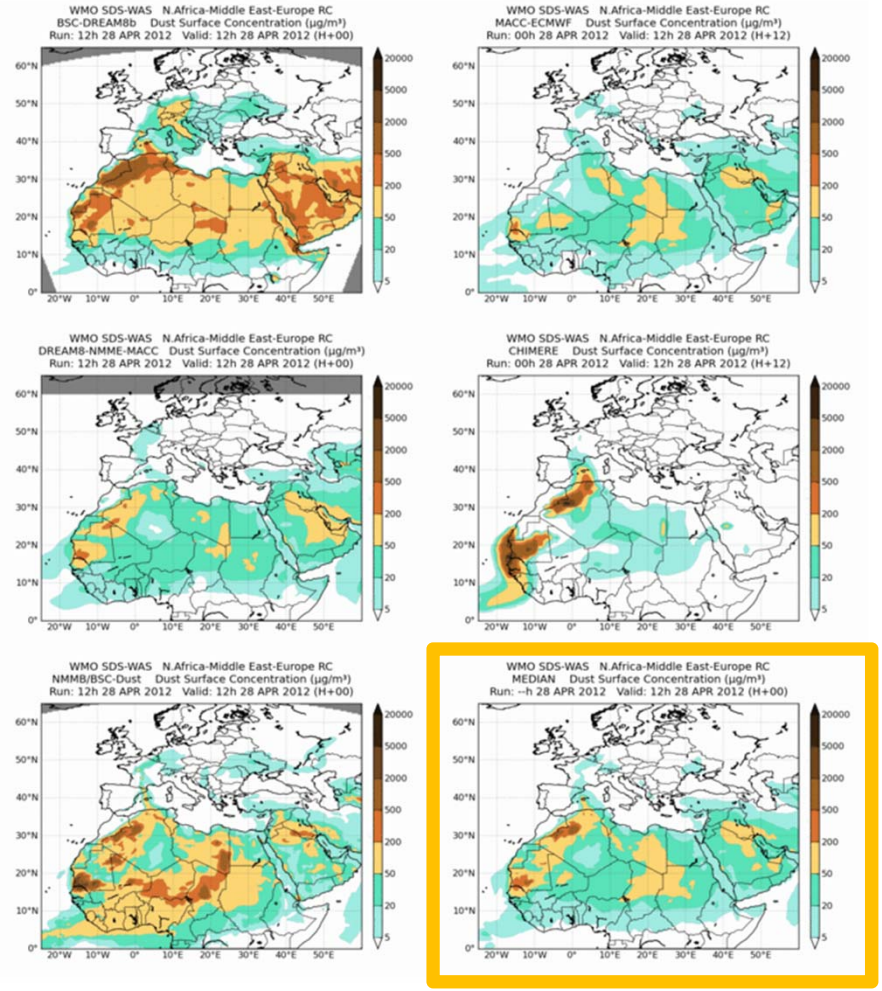
MODEL	INSTITUTION	CONTACT
BSC-DREAM8b	BSC-CNS	J. M. Baldasano
CHIMERE	LMD	L. Menut
LMDzT-INCA	LSCE	M. Schulz
MACC-ECMWF	ECMWF	J. J. Morcrette A. Benedetti
DREAM-NMME-MACC	SEEVCC	G. Pejanovic
NMMB/BSC-DUST	BSC-CNS	J. M. Baldasano
UM	U. K. MetOffice	D. Walters

Forecast and Products

Dust Optical Depth (at 550nm)

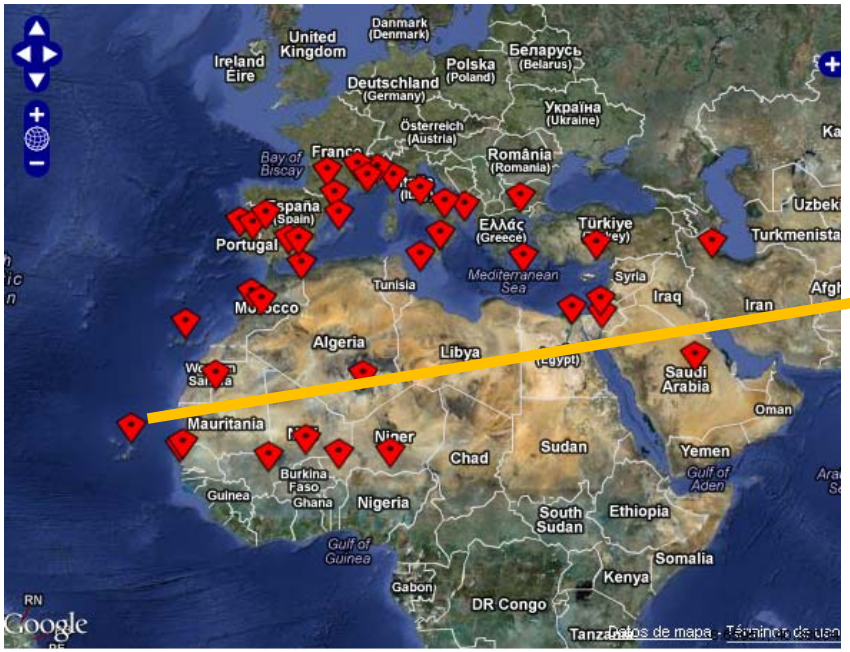


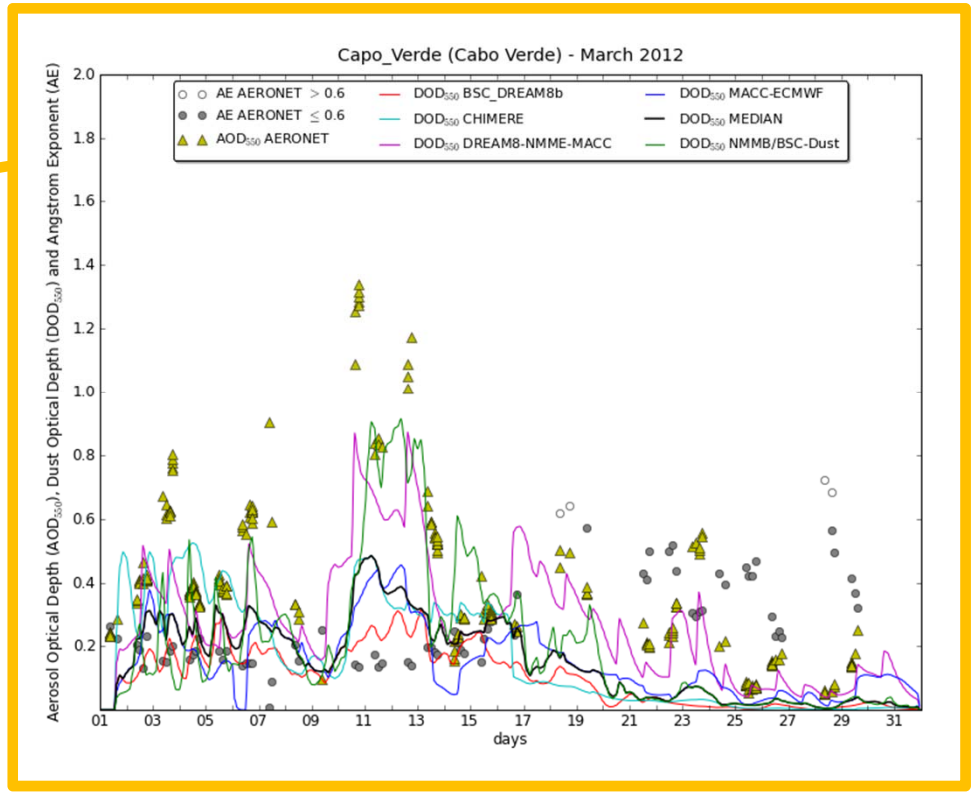
Surface Concentration (in $\mu g/m^3$)



Forecast and Products

Forecast evaluation using AERONET data





Calculation of monthly evaluation metrics

Mar 2012. Dust Optical Depth.

Threshold Angstrom Exponent = 0.600

BIAS show stations

	BSC_ DREAM8b	MACC-ECMWF	DREAM8-NMME-MACC	CHIMERE	NMMB/BSC-Dust	MEDIAN
TOTAL	-0.36	-0.39	-0.20	-0.41	-0.15	-0.35

ROOT MEAN SQUARE ERROR show stations

	BSC_ DREAM8b	MACC-ECMWF	DREAM8-NMME-MACC	CHIMERE	NMMB/BSC-Dust	MEDIAN
TOTAL	0.62	0.57	0.45	0.59	0.50	0.53

NUMBER OF CASES show stations

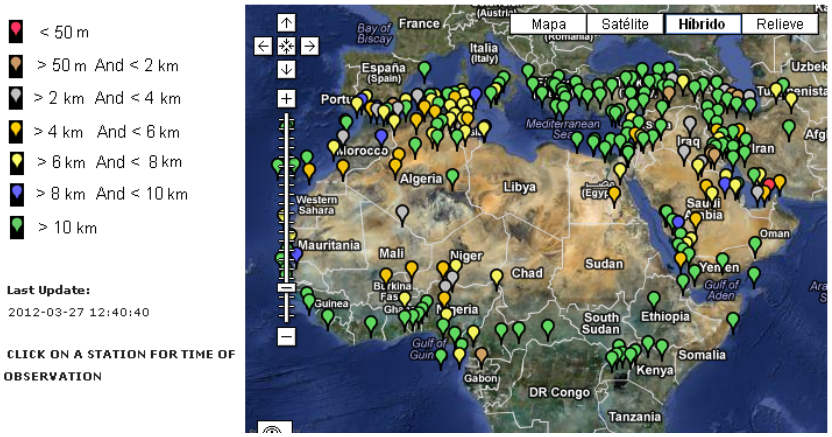
	BSC_ DREAM8b	MACC-ECMWF	DREAM8-NMME-MACC	CHIMERE	NMMB/BSC-Dust	MEDIAN
TOTAL	1033	846	977	1007	1007	1007

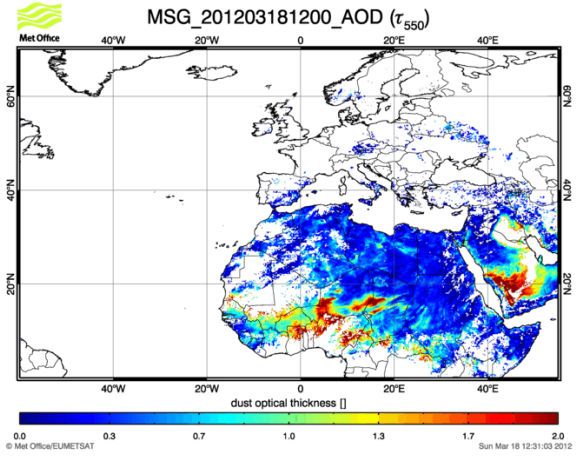
- Besides dust, there might be other aerosol types (anthropogenic, biomass burning, etc.). Then, a small BE could be expected.
- Scores for individual sites can be little significant for being calculated from a small number of data.
- The RMSE is strongly dominated by the largest values. Especially in cases where prominent outliers occur, the usefulness of the RMSE is questionable and the interpretation becomes more difficult.

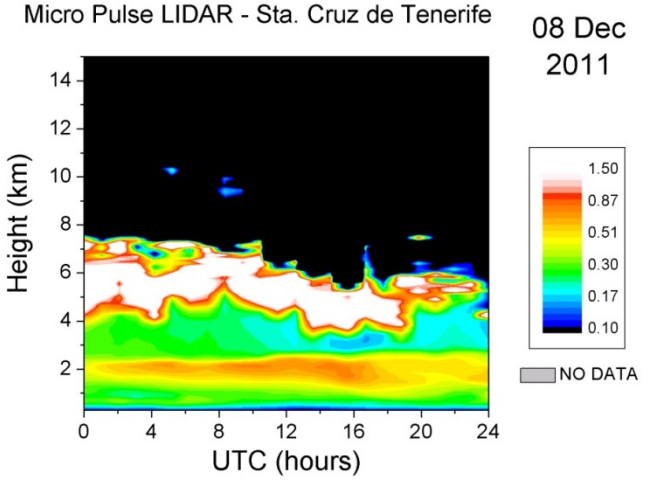
Forecast and Products

New sources of data for model evaluation

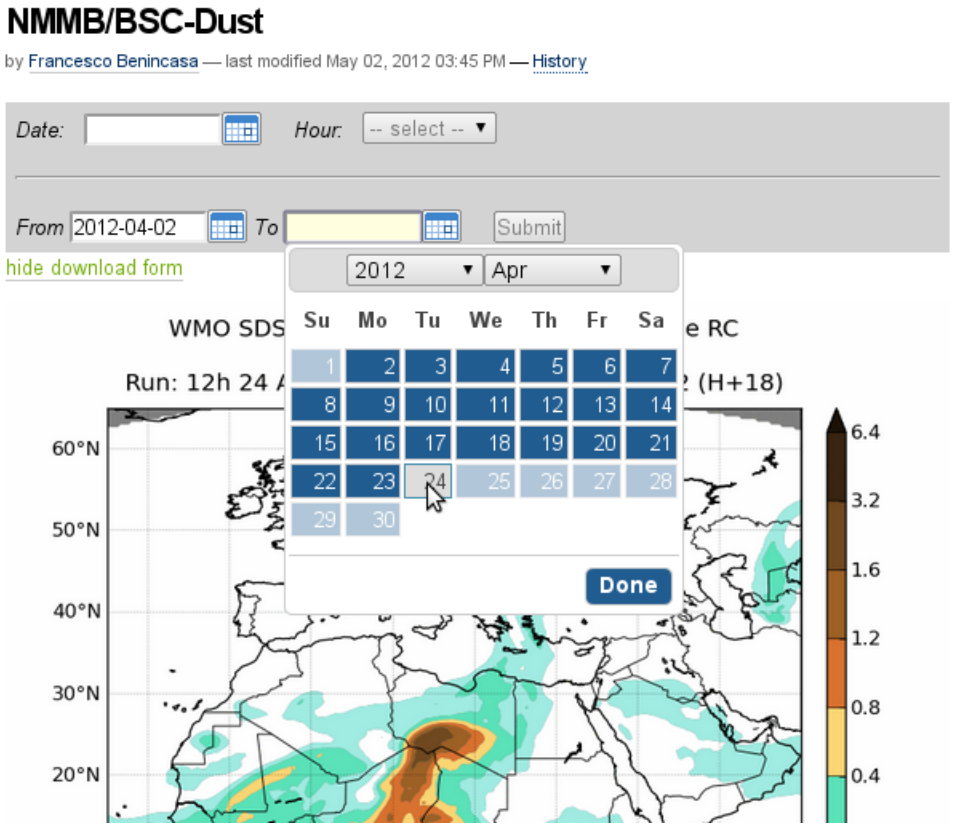
- Visibility
- MSG
- MODIS
- OMI
- CALIPSO
- PARASOL
- MPLNET
- PM_{10}







Sharing model output data



- 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.

Dust model intercomparison: April 2011

MODIS True color 7 April 18:00

- The selected dust event corresponds to the one which occurred between the 5th and 7th of April of 2011.
- Comparison of each forecast output to in-situ measurements of AOD (from AERONET), surface concentration (PM) and satellite retrieved AOD (MODIS, MISR, PARASOL) and vertical profiles of aerosol extinction (CALIPSO).

Next events

The event is targeted to operational meteorologists as well as to early career scientists (advanced students, PhD candidates and postdoctoral researchers) with a background in the Earth system sciences.

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Simulations have been performed in the Marenostrum supercomputer.