Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

Modeling the dust cycle at BSC

From R&D to operational forecast

Carlos Pérez García-Pando (carlos.pérez@bsc.es)

S. Basart, O. Jorba, E. Di Tomaso, L. Vendrell, E. Terradellas, G. García-Castrillo, F. Benincasa and K. Serradell

CURSO: EL CICLO DEL POLVO MINERAL EN LA ATMÓSFERA: OBSERVACIÓN Y PREDICCIÓN

AEMET

BSC Earth Sciences Department

What

Environmental modelling and forecasting

Why

Our strength …
- … research …
- … operations …
- … services …
- … high resolution …

MareNostrum supercomputer

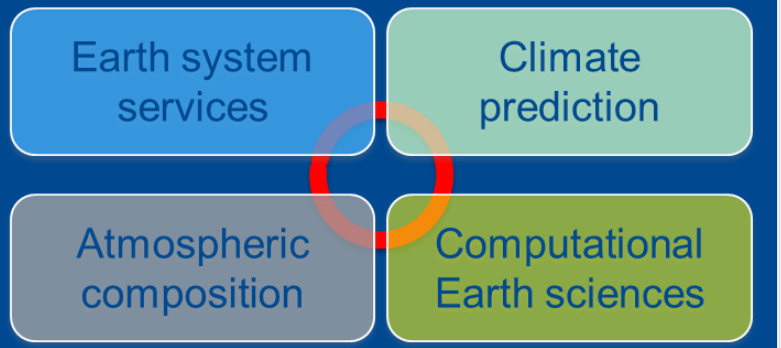
How

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

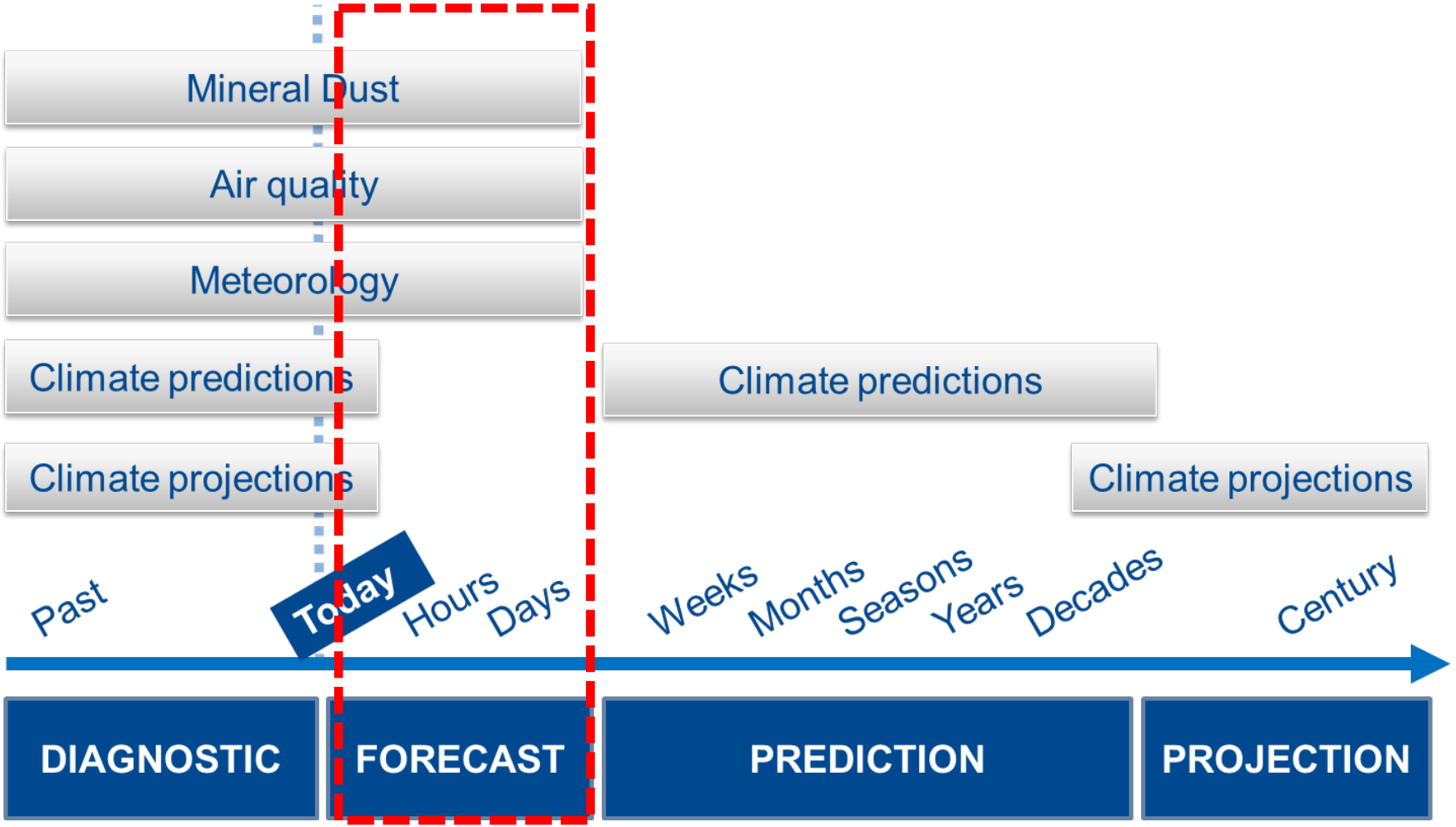
Implement climate prediction system for subseasonal-to-decadal climate prediction

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



BSC Earth Sciences Department



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

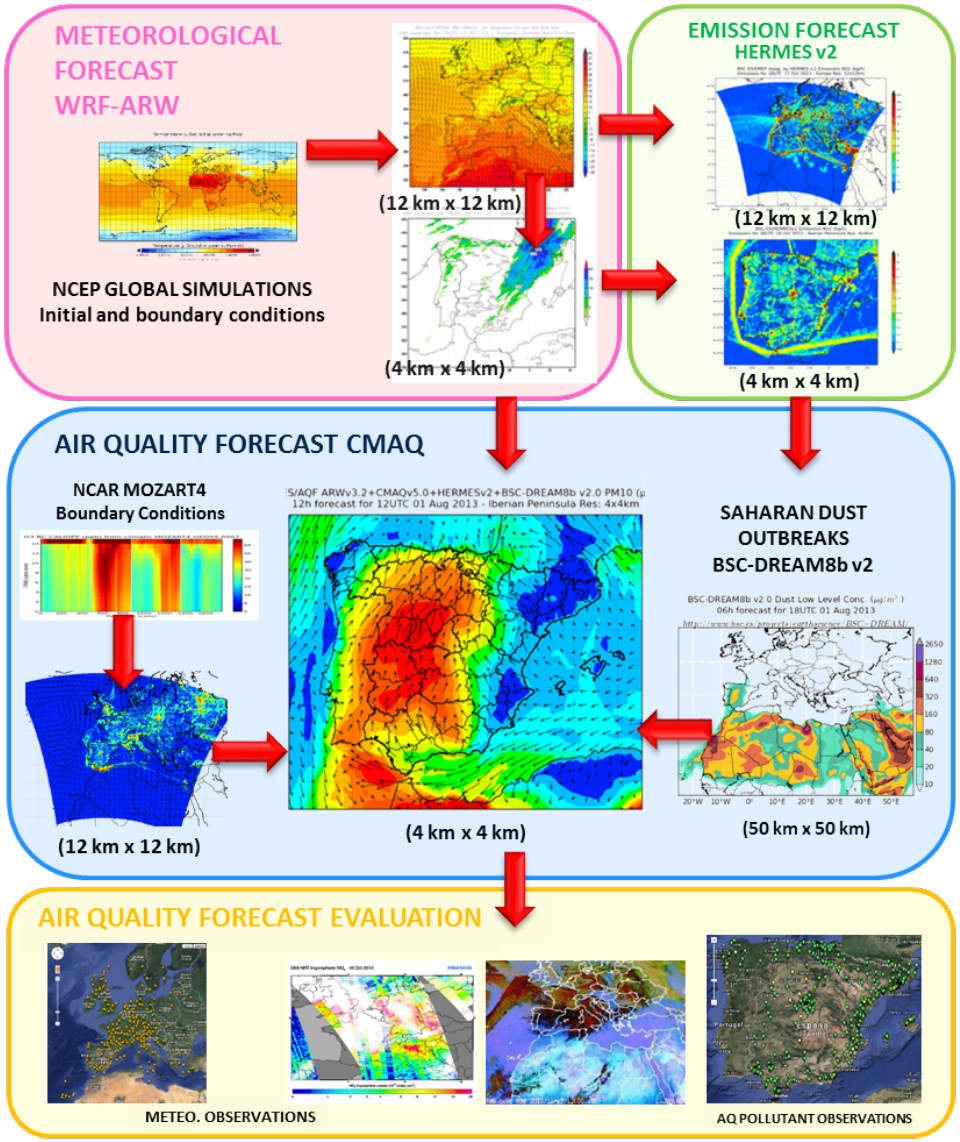
Short-term forecast

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

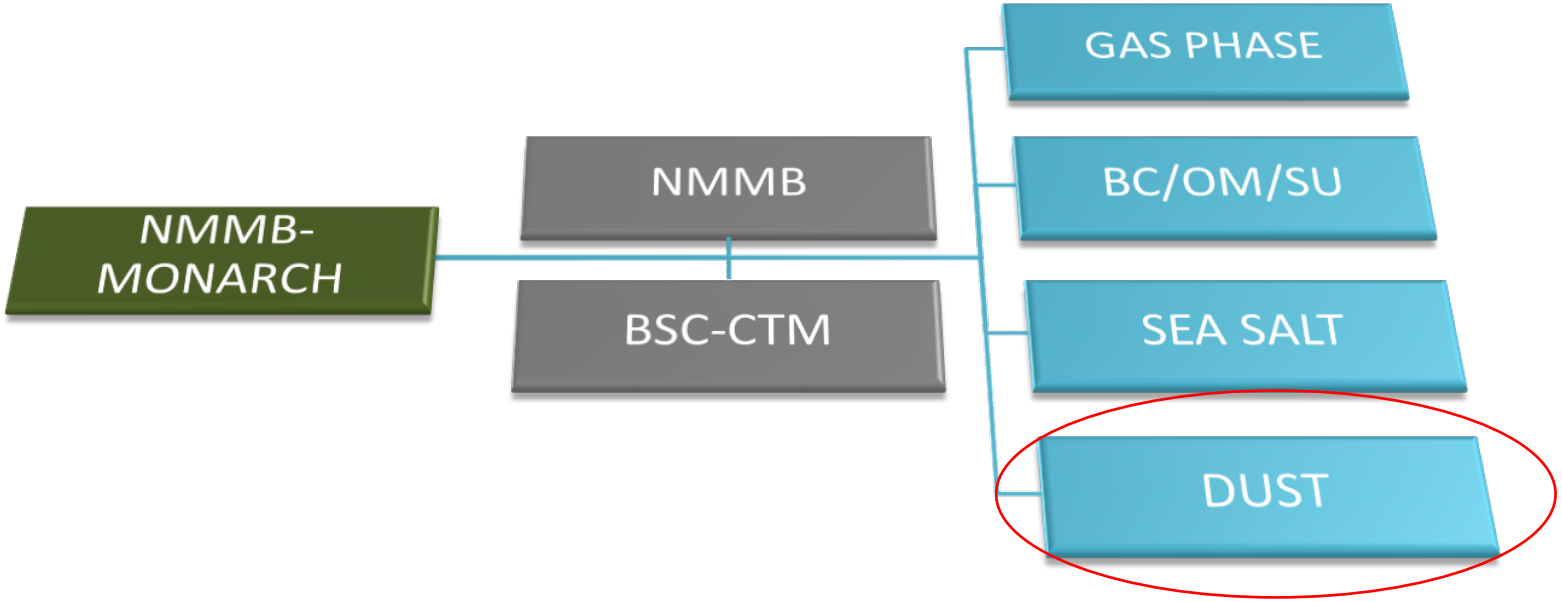
Domains:
Europe (12 km, 480 x 400 cells)
Spain (4 km, 399 x 399 cells)



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Atmospheric Composition modelling: NMMB-MONARCH

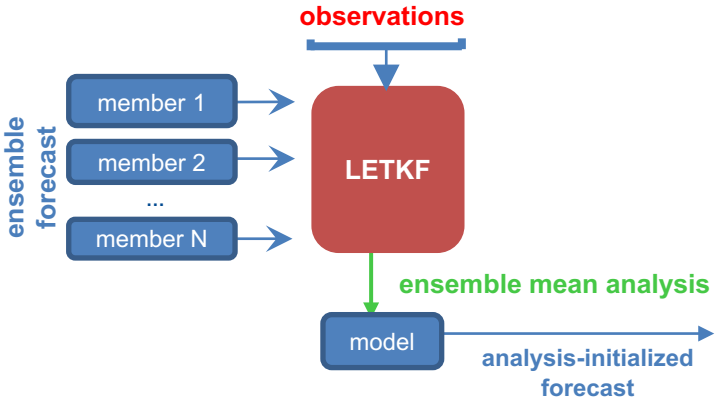
- The main system is build on the **meteorological driver NMMB**
- ***Multiscale***: global to regional scales allowed (nesting capabilities)
- ***Nonhydrostatic*** dynamical core: single digit kilometre resolution allowed
- Fully ***on-line*** coupling: weather-chemistry feedback processes allowed
-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



Known as **NMMB/BSC-Dust**

NMMB-MONARCH: Data Assimilation

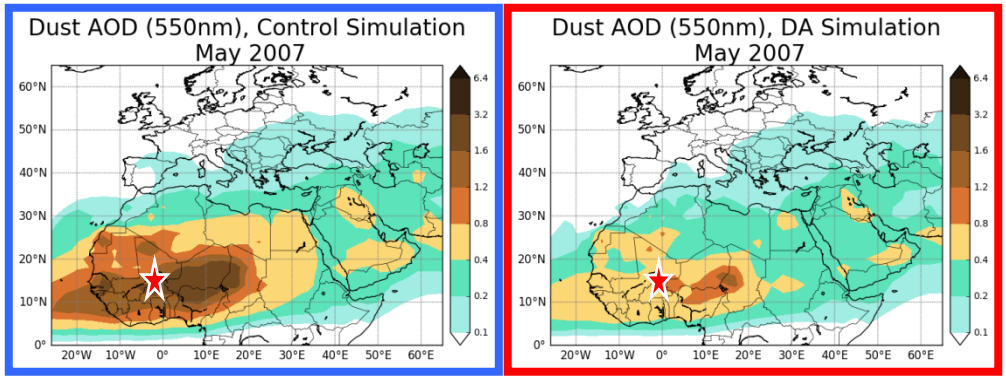
NMMB-MONARCH coupled with a Local Ensemble Transform Kalman Filter (**LETKF**) for the assimilation of aerosol optical depth observations

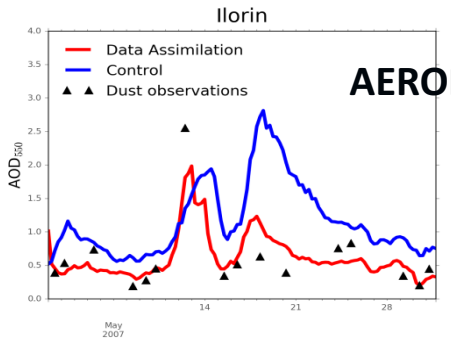


Mineral dust application
The ensemble forecast is based on uncertainties in the dust emission scheme

- vertical flux,
- size distribution at emission
- threshold on friction velocity

(DiTomaso et al., GMD, 2016)

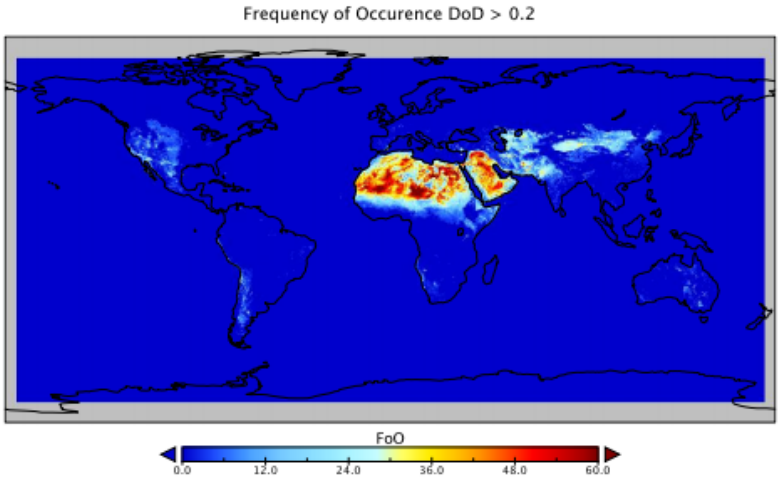


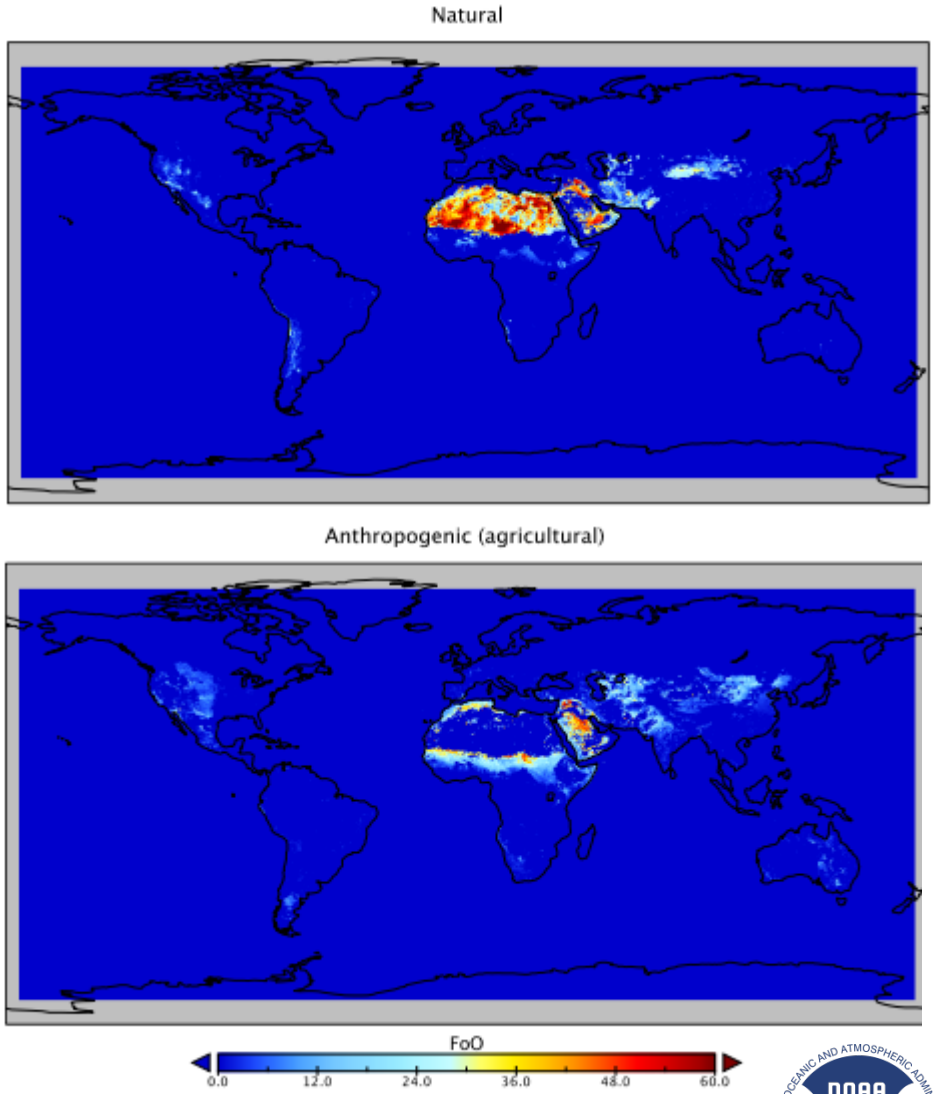


AERONET Validation

Mineral Dust modelling: Dust sources

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

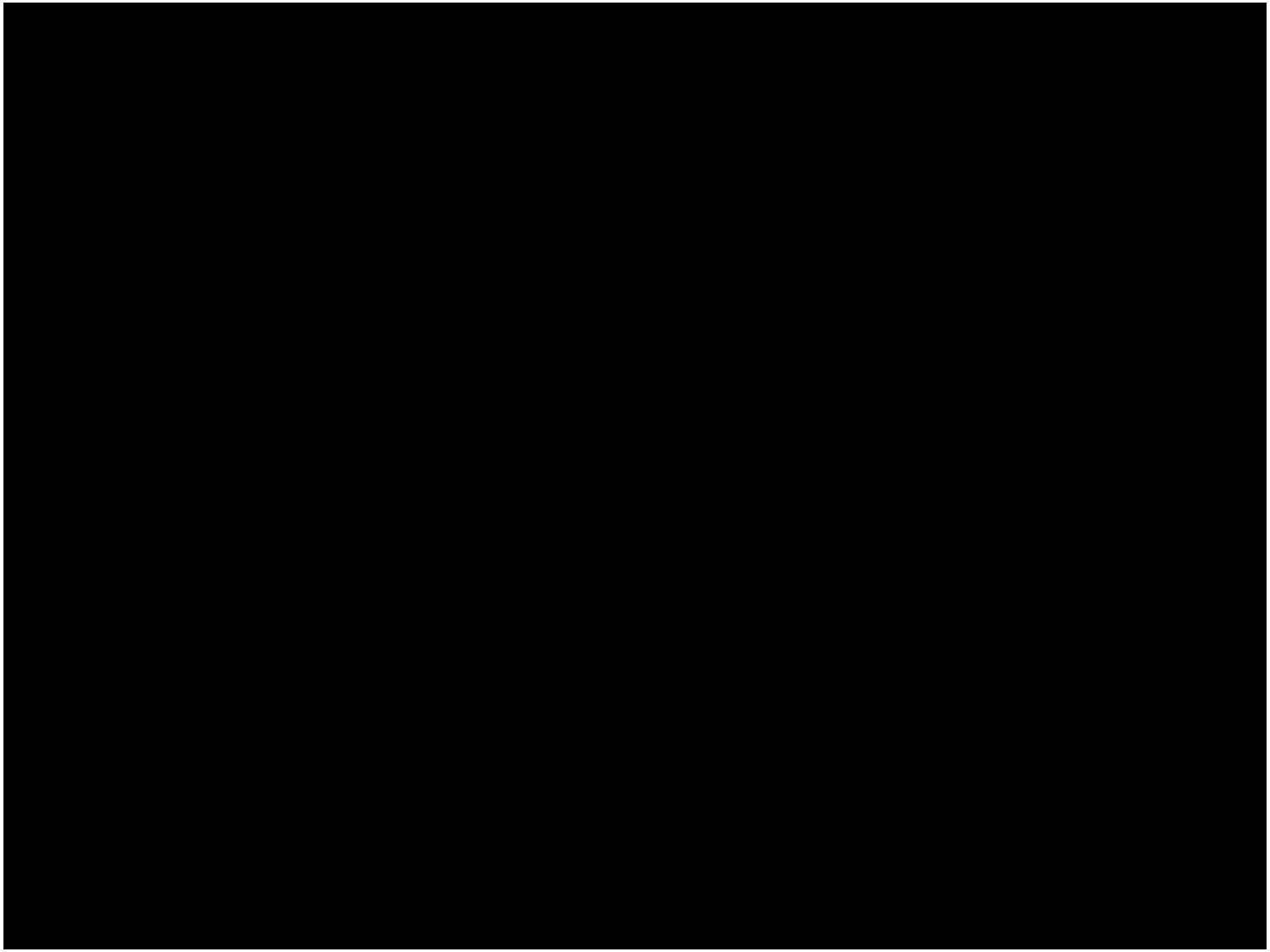




In collaboration P. Ginoux (NOAA-GFDL)

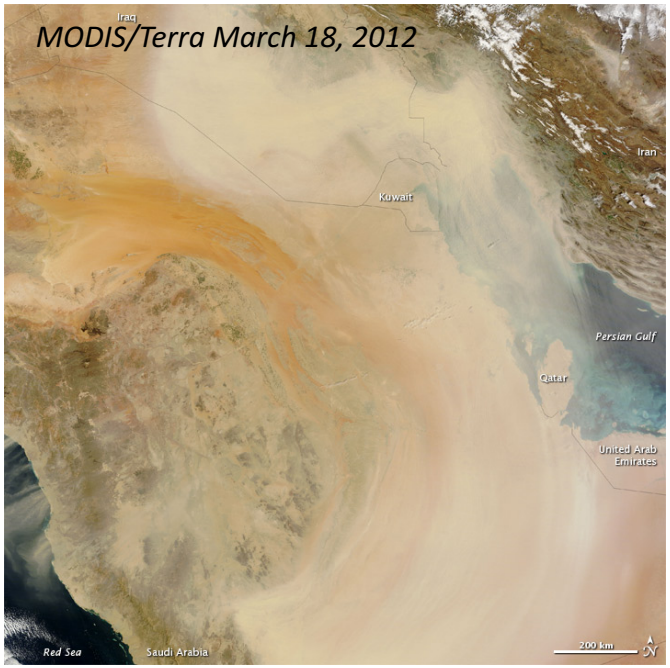
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

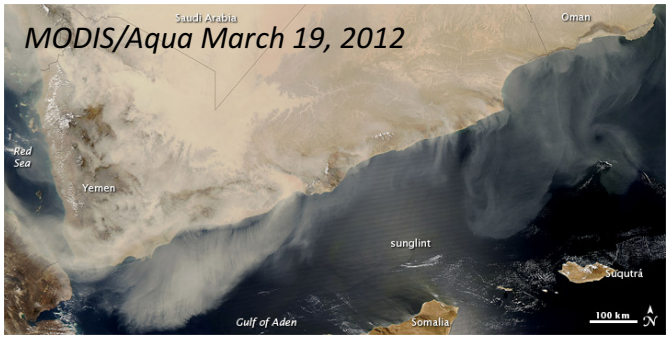
Mineral Dust modelling: Topography



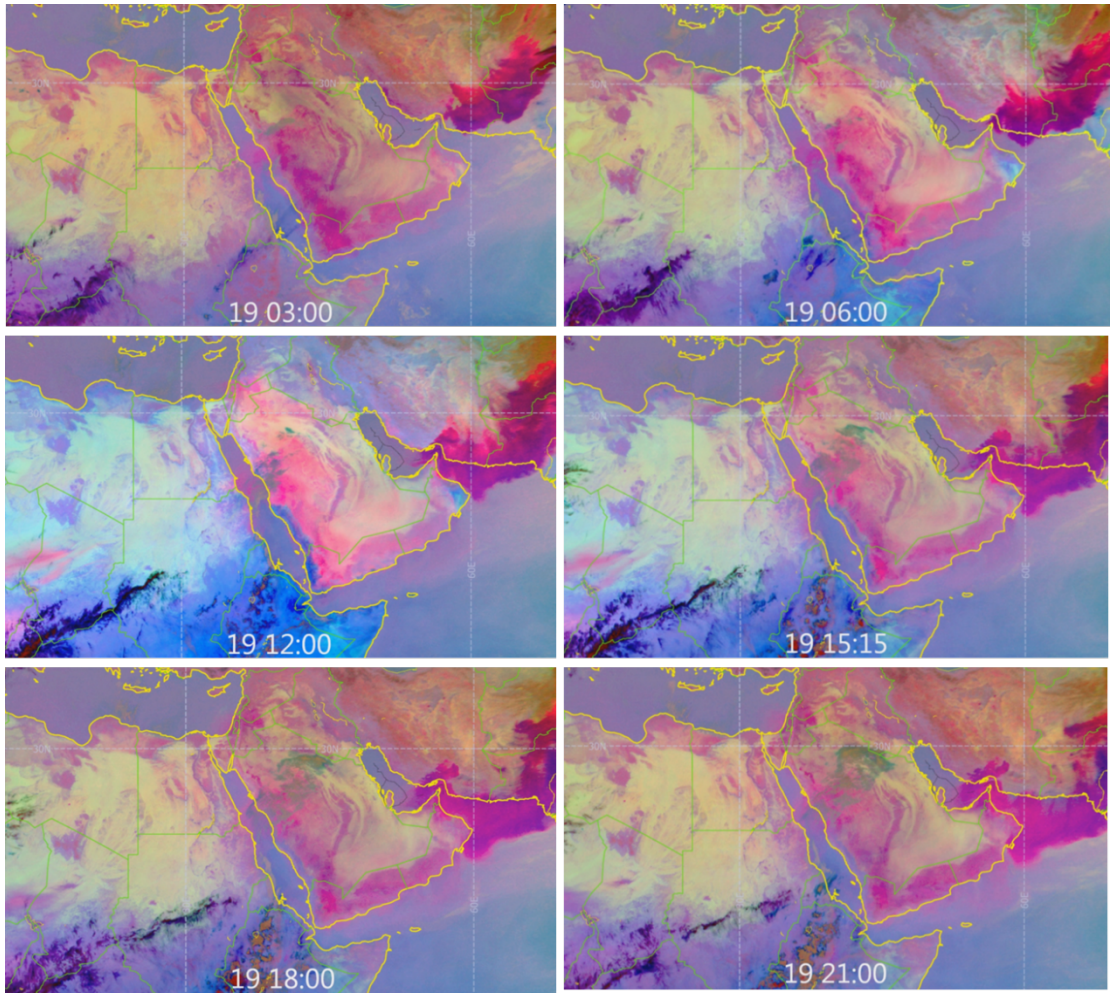
Mineral Dust modelling: Topography

Impact of the topography on dust transport



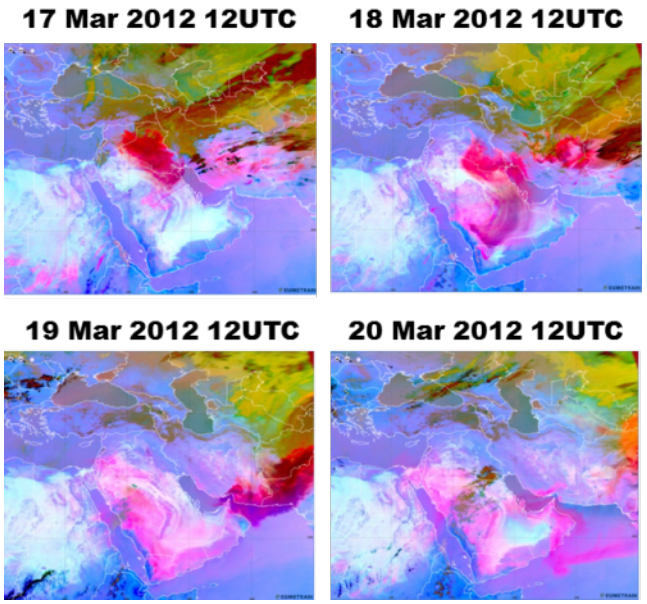


MSG/RGB March 19, 2012

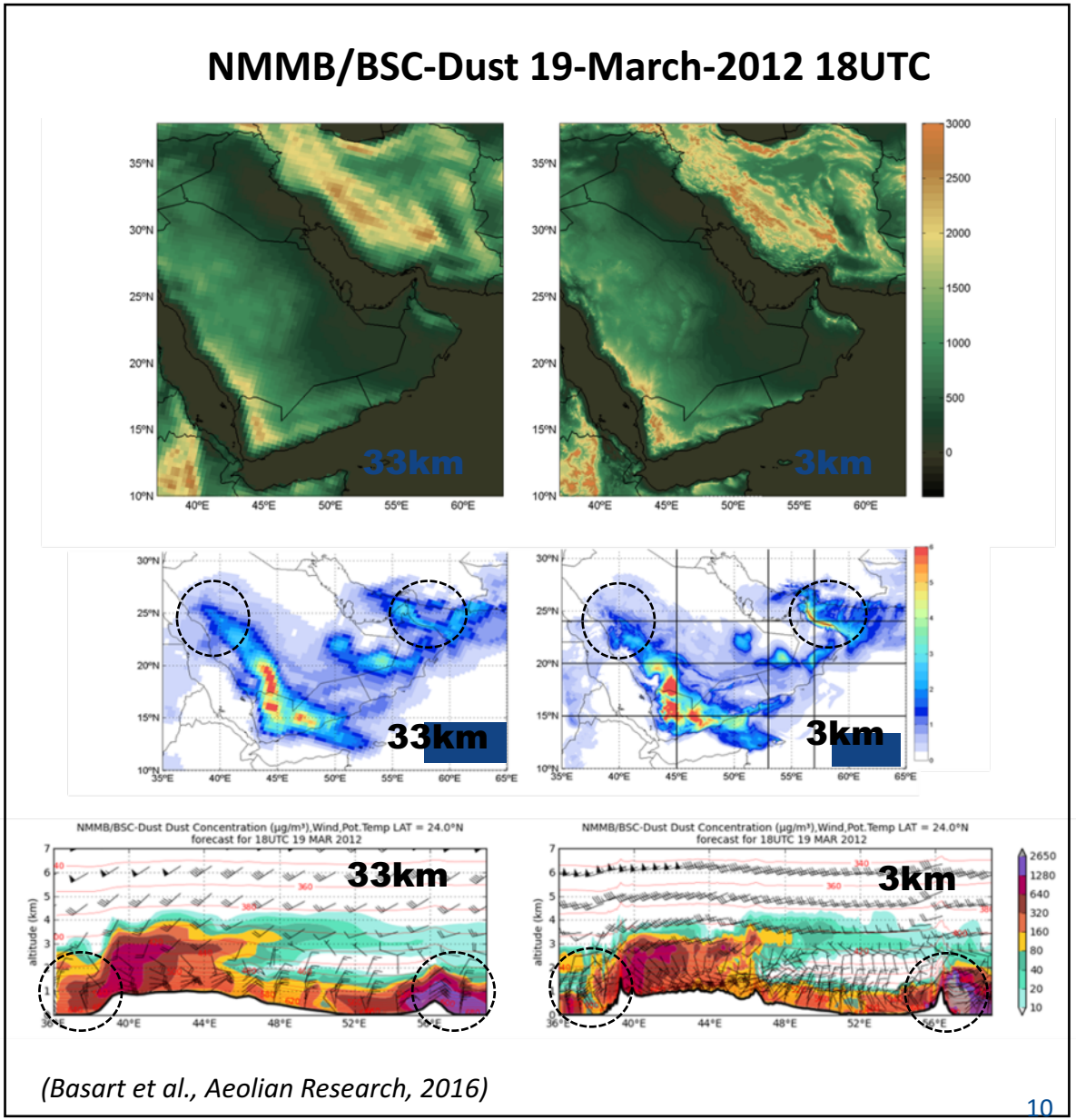


(Basart et al., Aeolian Research, 2016)

Mineral Dust modelling: Topography

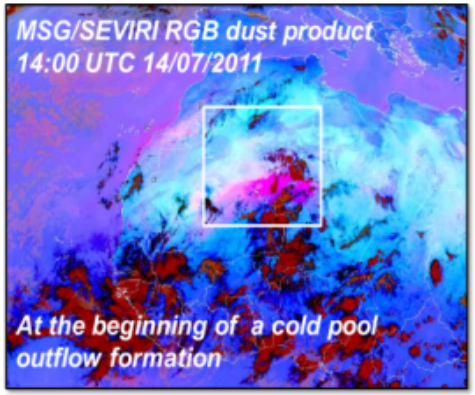


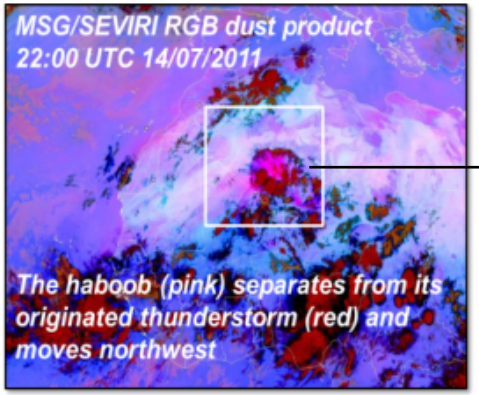
Two simulations using the **NMMB/BSC-Dust** model demonstrates results demonstrate how the dust prediction in the vicinity of complex terrains improves using high-horizontal resolution simulations.

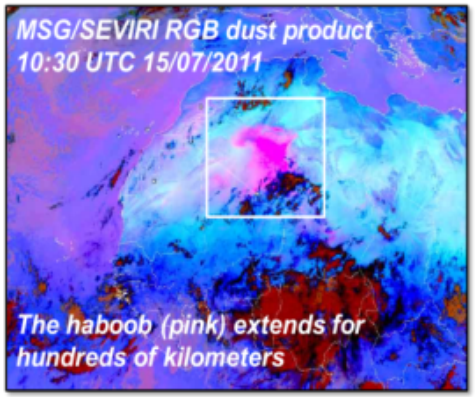


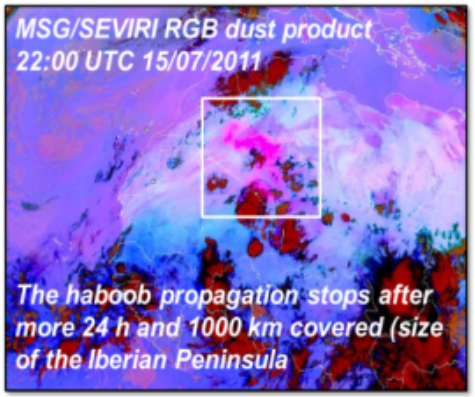
(Basart et al., Aeolian Research, 2016)

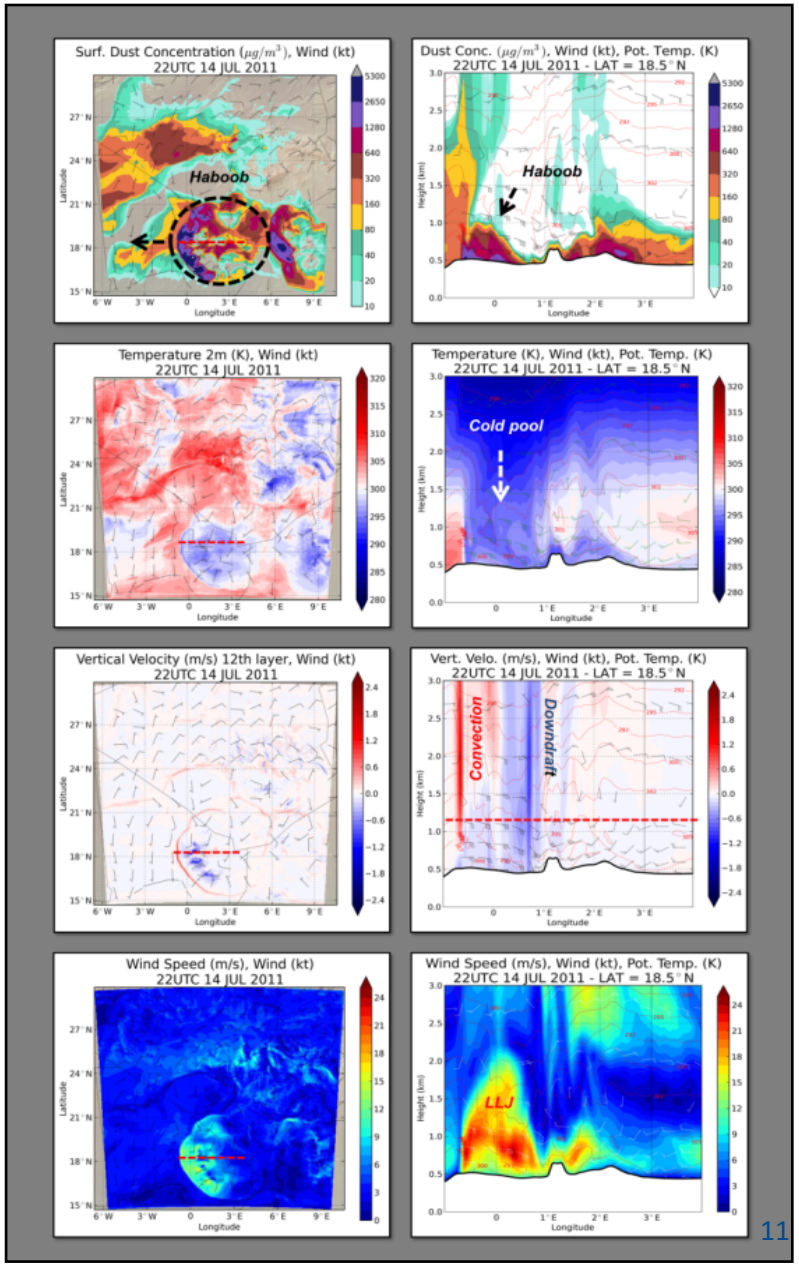
Mineral Dust modelling: Haboobs











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)*

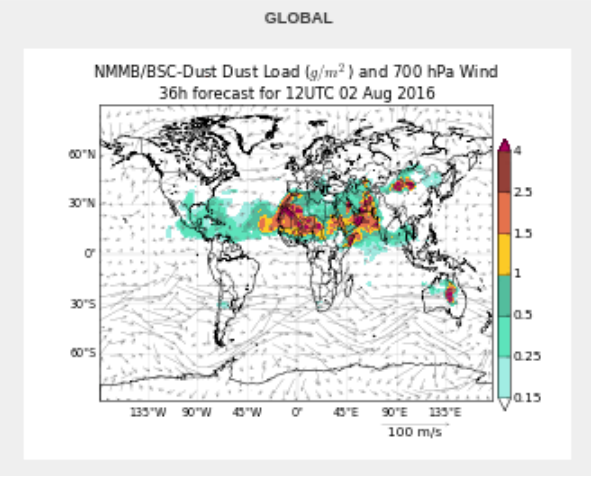
(Vendrell et al., in preparation)

Mineral dust Services

BSC dust operational forecast (global and regional domains)

http://www.bsc.es/ESS

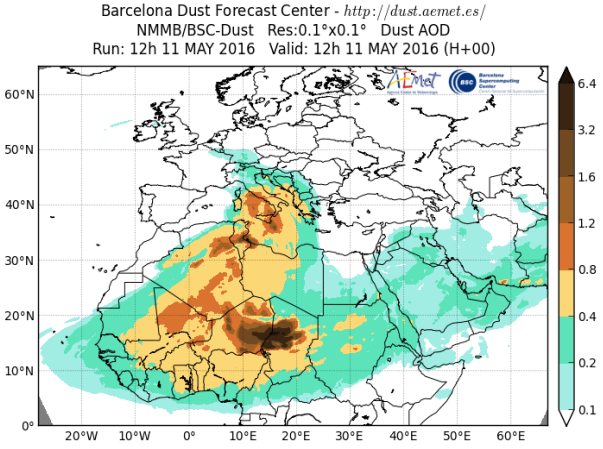
✓ *Contribution to the **ICAP** multi-model ensemble (global) http://icap.atmos.und.edu*



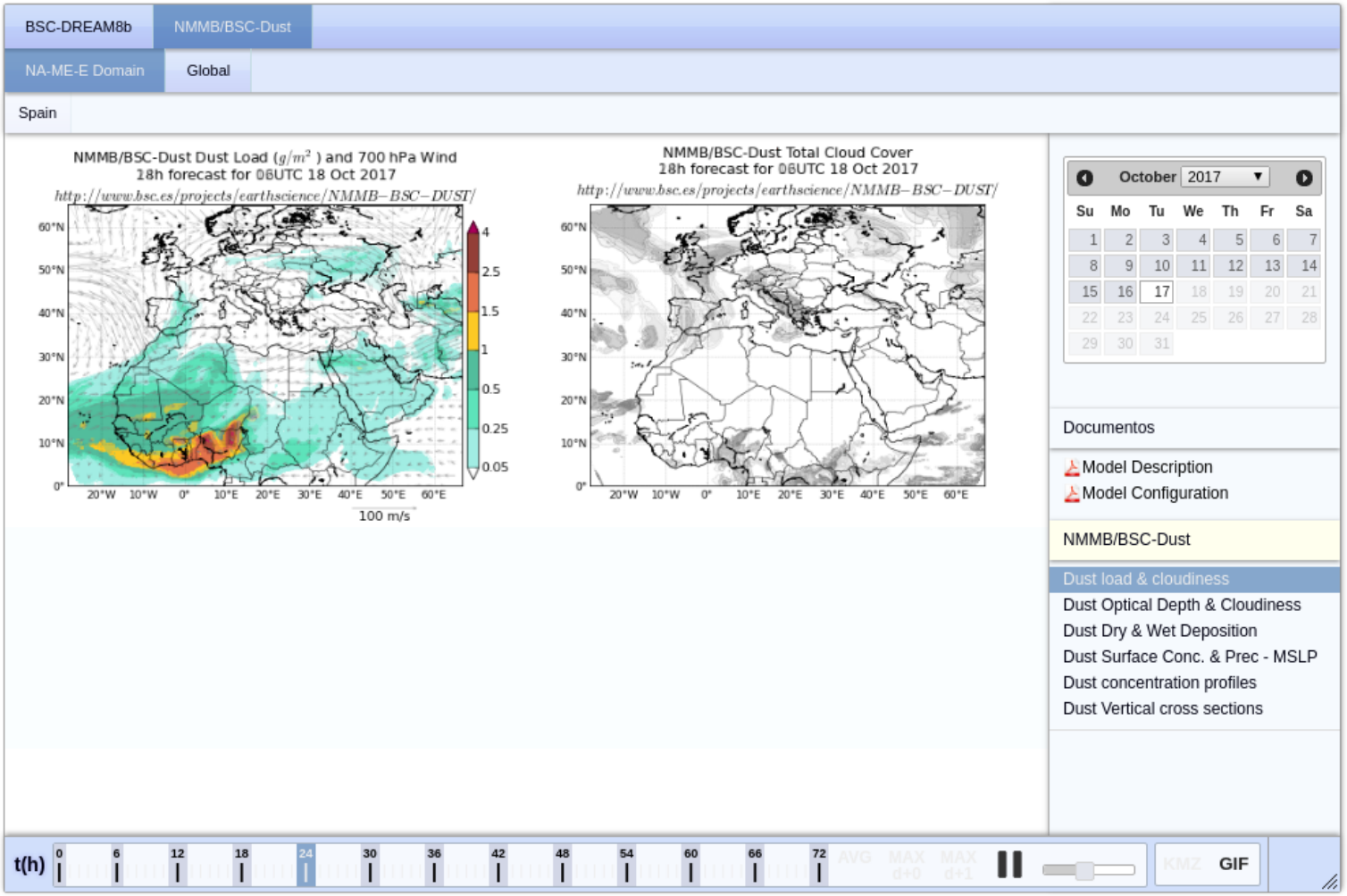
WMO Dust Centers

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

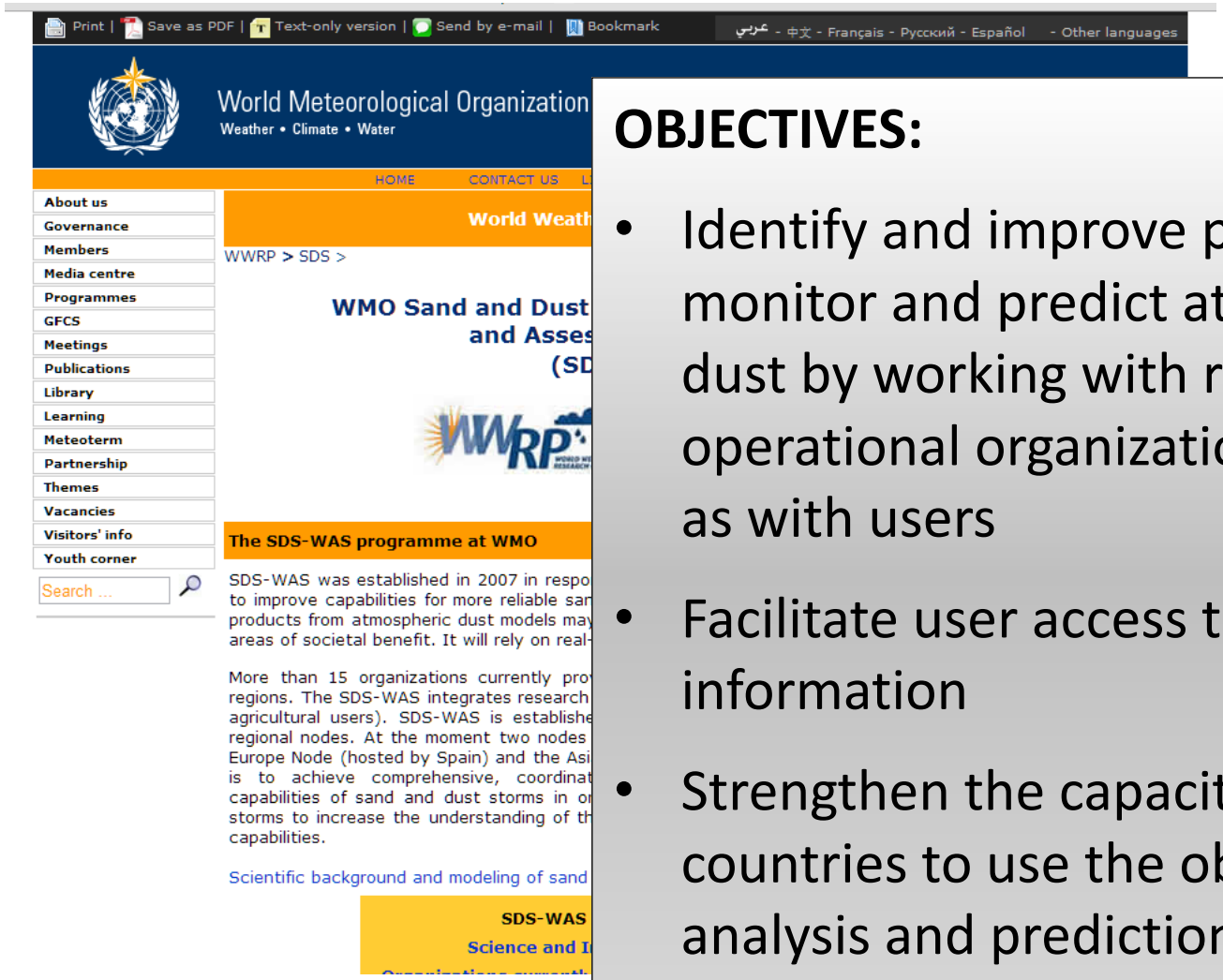


BSC dust operational forecast



http://www.bsc.es/ESS

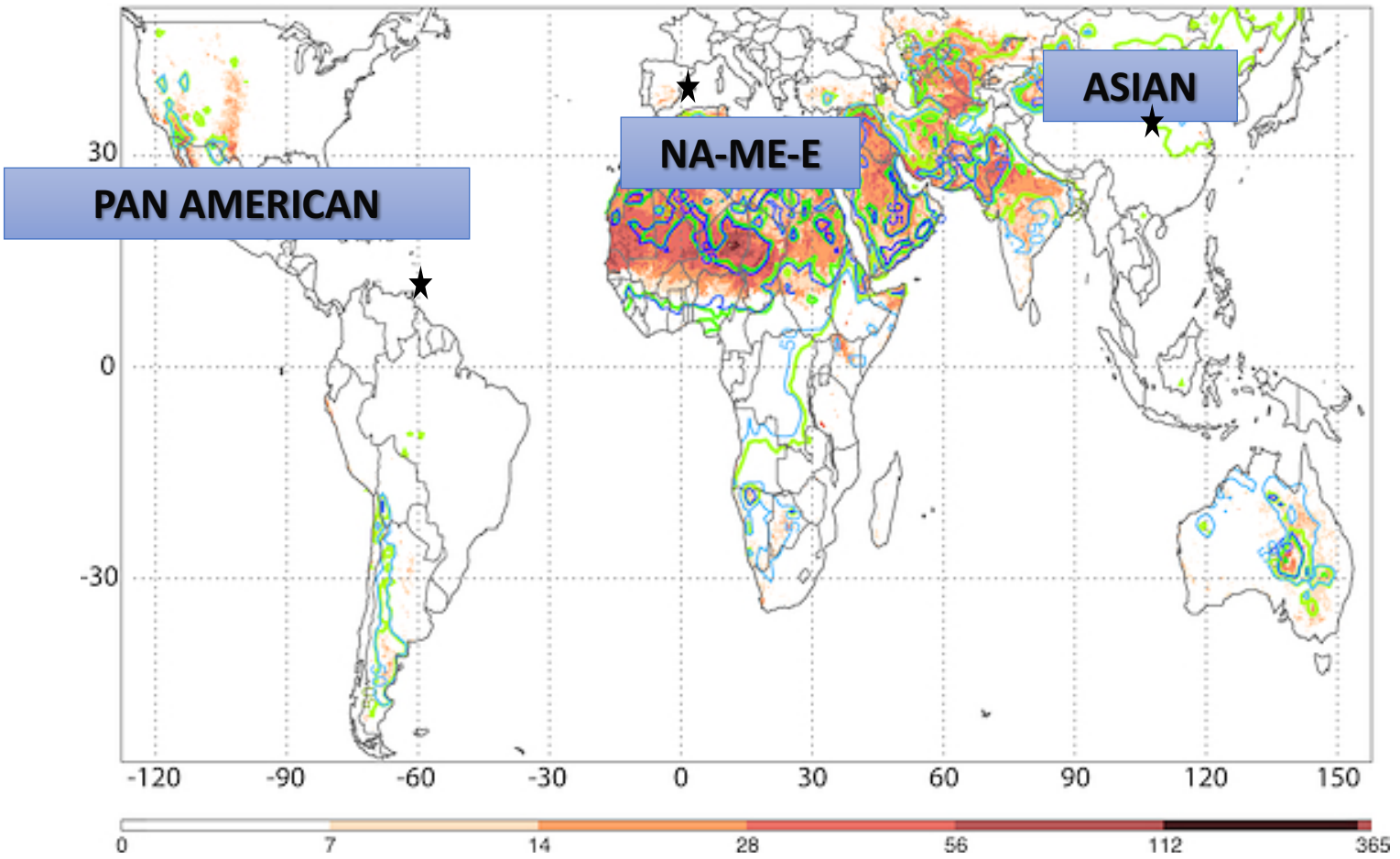
The WMO SDS-WAS project



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

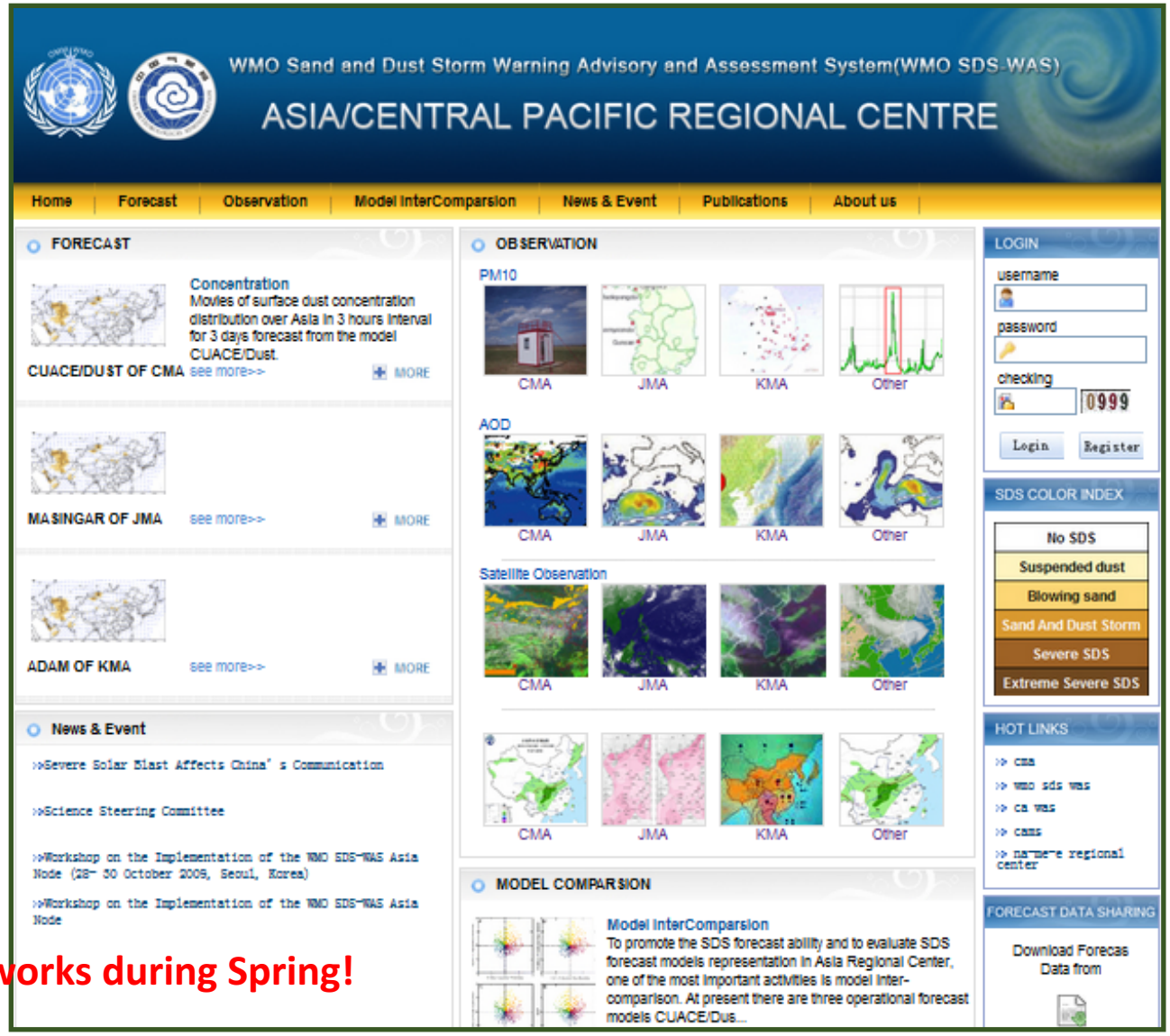
The SDS-WAS Regional Centers



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 Asian RC



Only works during Spring!

http://www.sds.cma.gov.cn

SDS-WAS Pan-American RC

http://sds-was.cimh.edu.bb/

SDS-WAS NAMEE RC

The Center is managed by a consortium of AEMET and the Barcelona Supercomputing Center (BSC-CNS)

GOBIERNO DE ESPAÑA
MINISTERIO DE MEDIO AMBIENTE Y MEDIO RURAL Y MARINO
AEMet Agencia Estatal de Meteorología

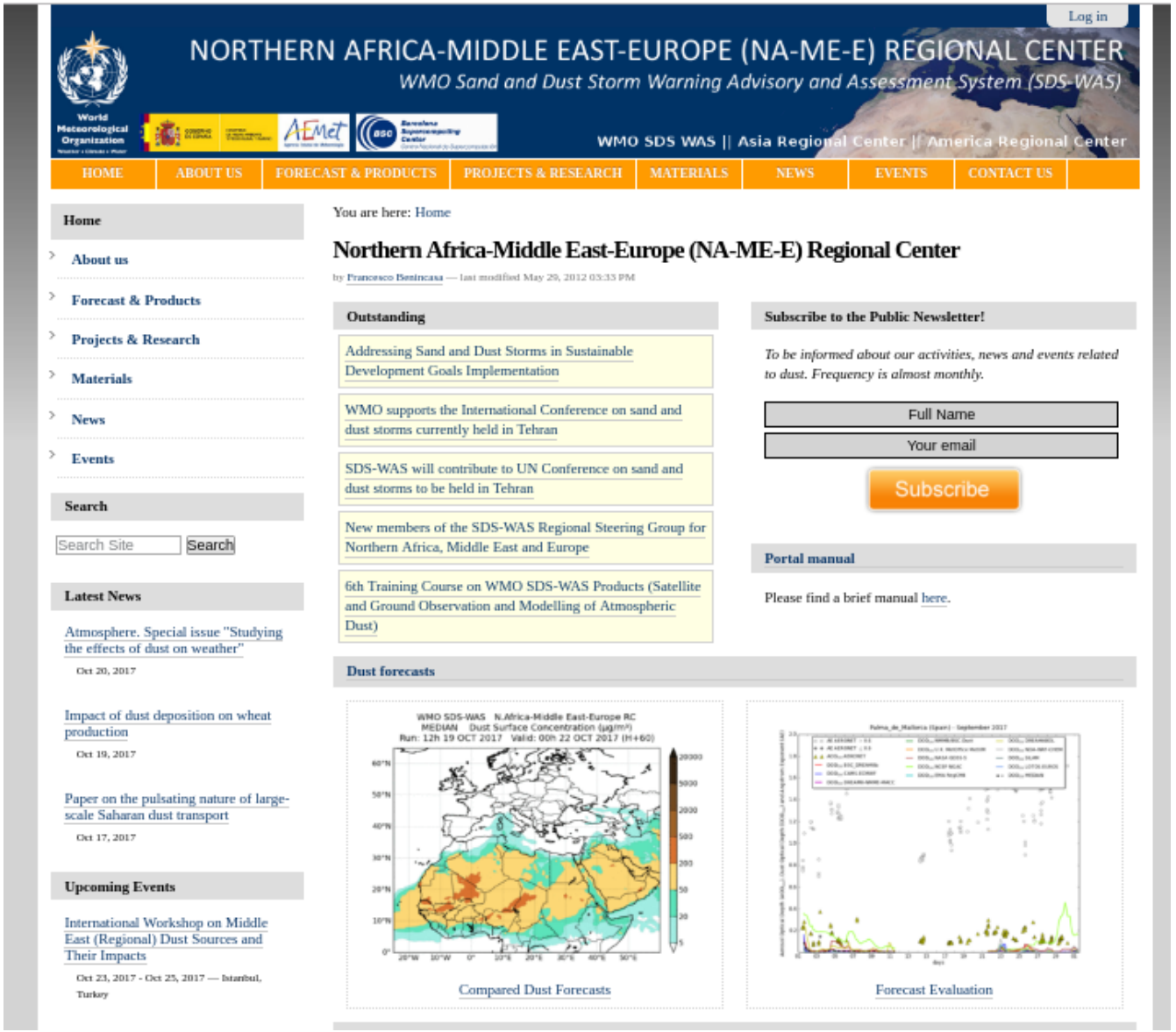
BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Nexus II Building. Barcelona

MareNostrum supercomputer

http://sds-was.aemet.es

SDS-WAS NAMEE RC



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

SDS-WAS NAMEE: Dust Forecasts

Dust prediction models provide 72 hours (at 3-hourly basis) of dust forecast (AOD at 550nm and surface concentration) covering the NAMEE region.

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

SDS-WAS NAMEE: Files Download

BSC-DREAM8b v2.0	PUBLIC Files RESTRICTED Files	Model website	
CAMS-ECMWF	PUBLIC Files RESTRICTED Files	Model website	
DREAM-NMME-MACC	PUBLIC Files RESTRICTED Files	Model website	
NMMB/BSC-I			
NASA-GEOS-			
NCEP-NGAC			
DREAMABOI			
EMA-RegCM4			

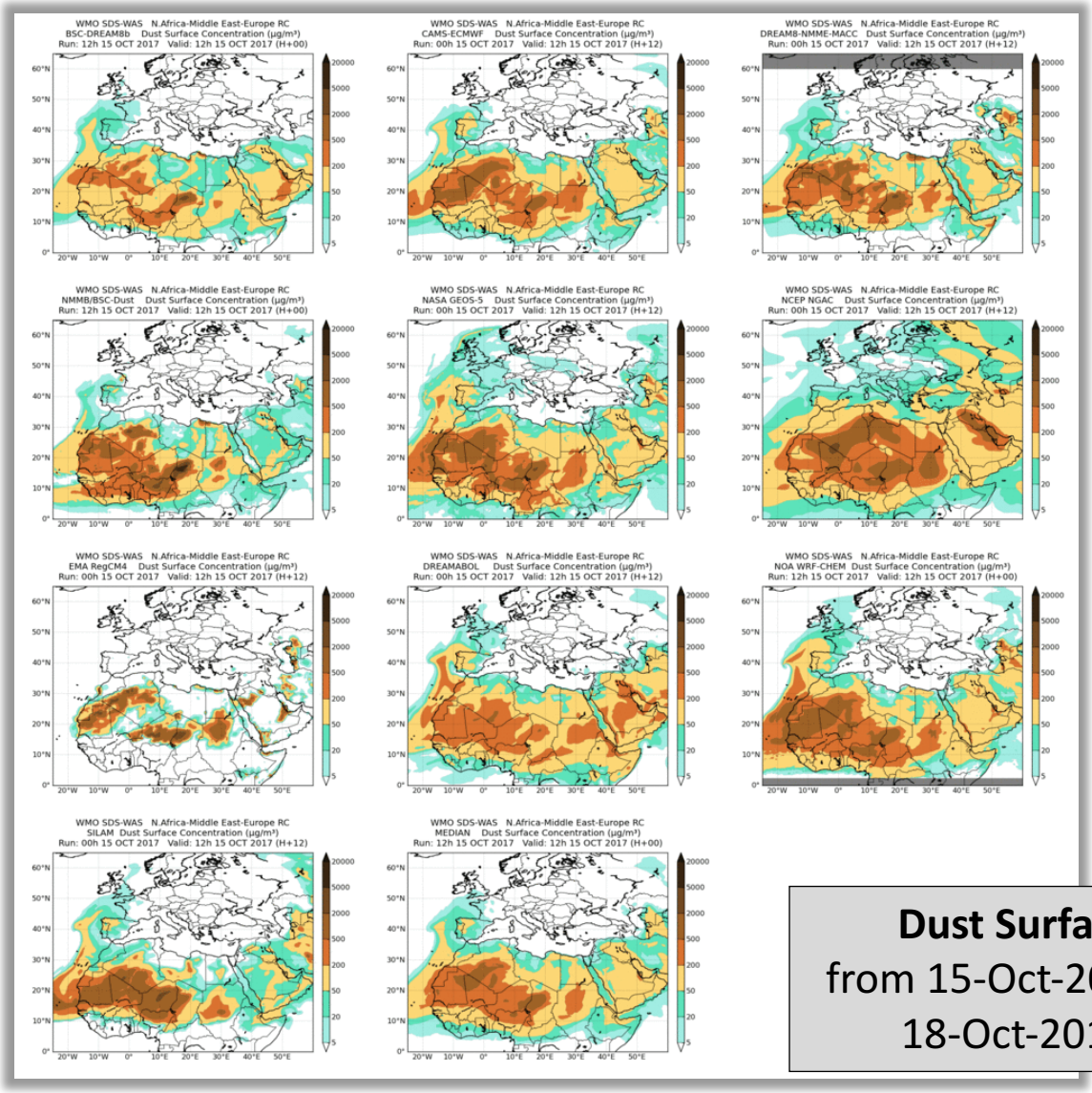
Title	Size	Modified
latest - *(download all)*	4.0 kB	Oct 19, 2017 10:40 PM
2017 - *(download all)*	4.0 kB	Oct 03, 2017 10:40 PM
2016 - *(download all)*	4.0 kB	Dec 03, 2016 10:40 PM
2015 - *(download all)*	4.0 kB	Mar 07, 2016 12:49 PM
2014 - *(download all)*	4.0 kB	Mar 07, 2016 12:49 PM
2013 - *(download all)*	4.0 kB	Mar 07, 2016 12:49 PM
2012 - *(download all)*	4.0 kB	Mar 07, 2016 12:49 PM

- 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 NAMEE: Joint Visualization



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

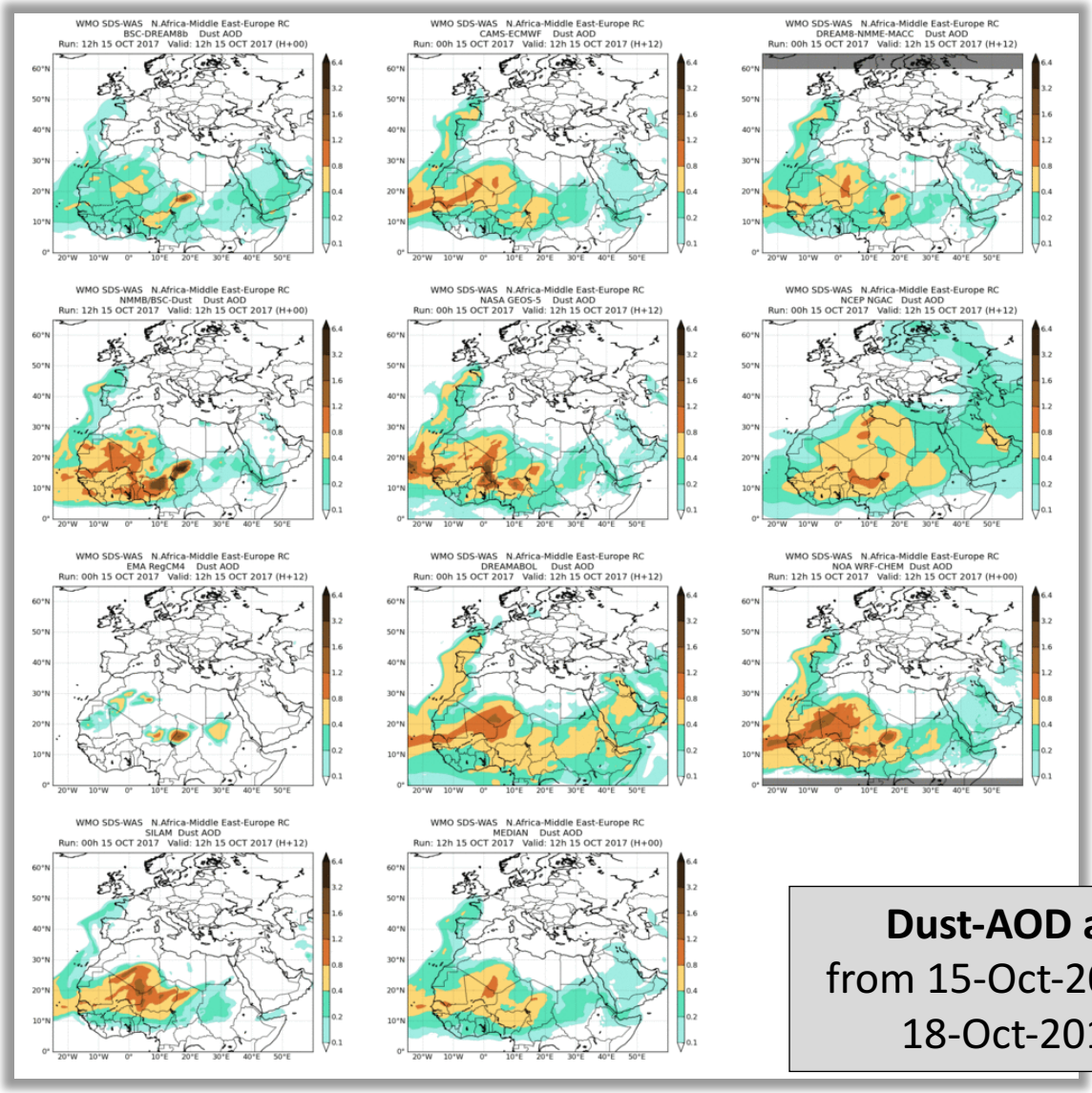
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

AEMet Agencia Estatal de Meteorología

World Meteorological Organization

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

SDS-WAS NAMEE: Joint Visualization



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

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

AEMet Agencia Estatal de Meteorología

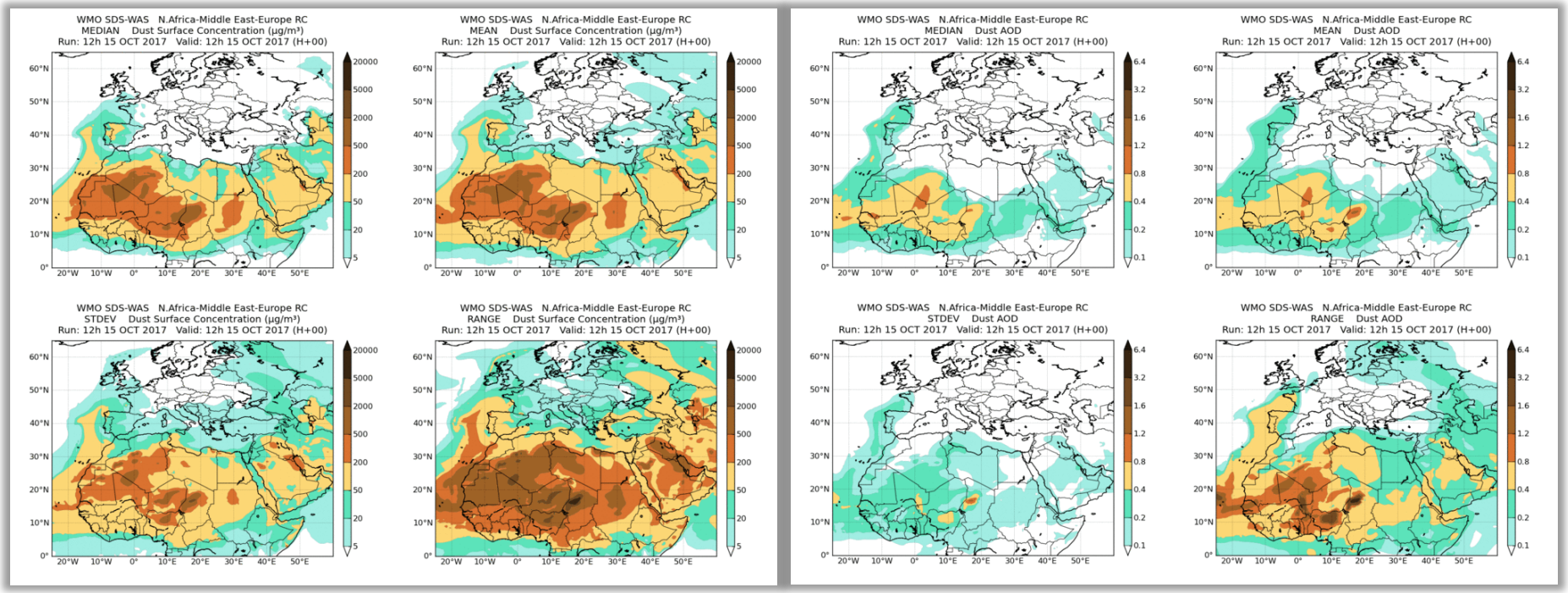
World Meteorological Organization

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

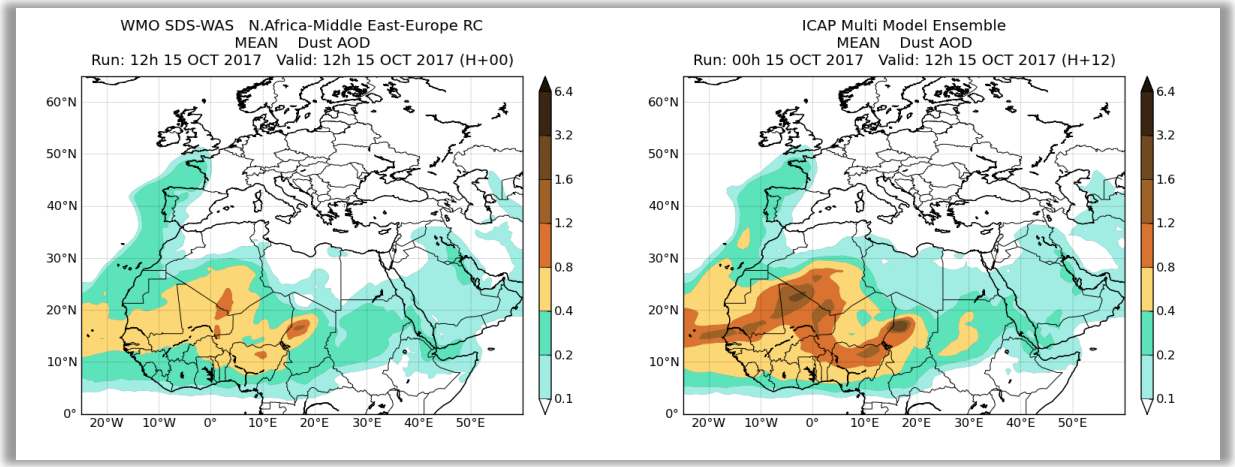
SPREAD: standard deviation – range of variation

SDS-WAS NAMEE: Multi-model - ICAP

Dust AOD at 550nm

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

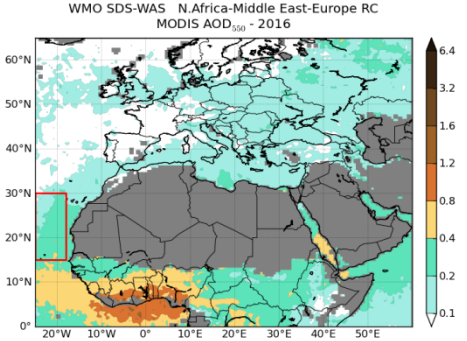
Only global models!



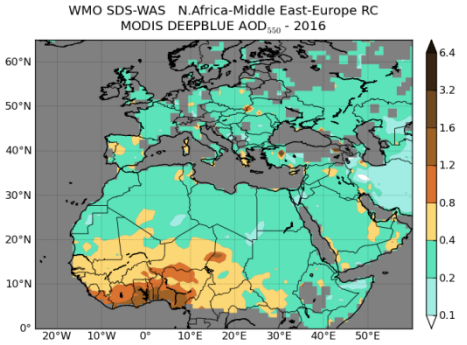
SDS-WAS NAMEE: DOD Model Evaluation

- **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

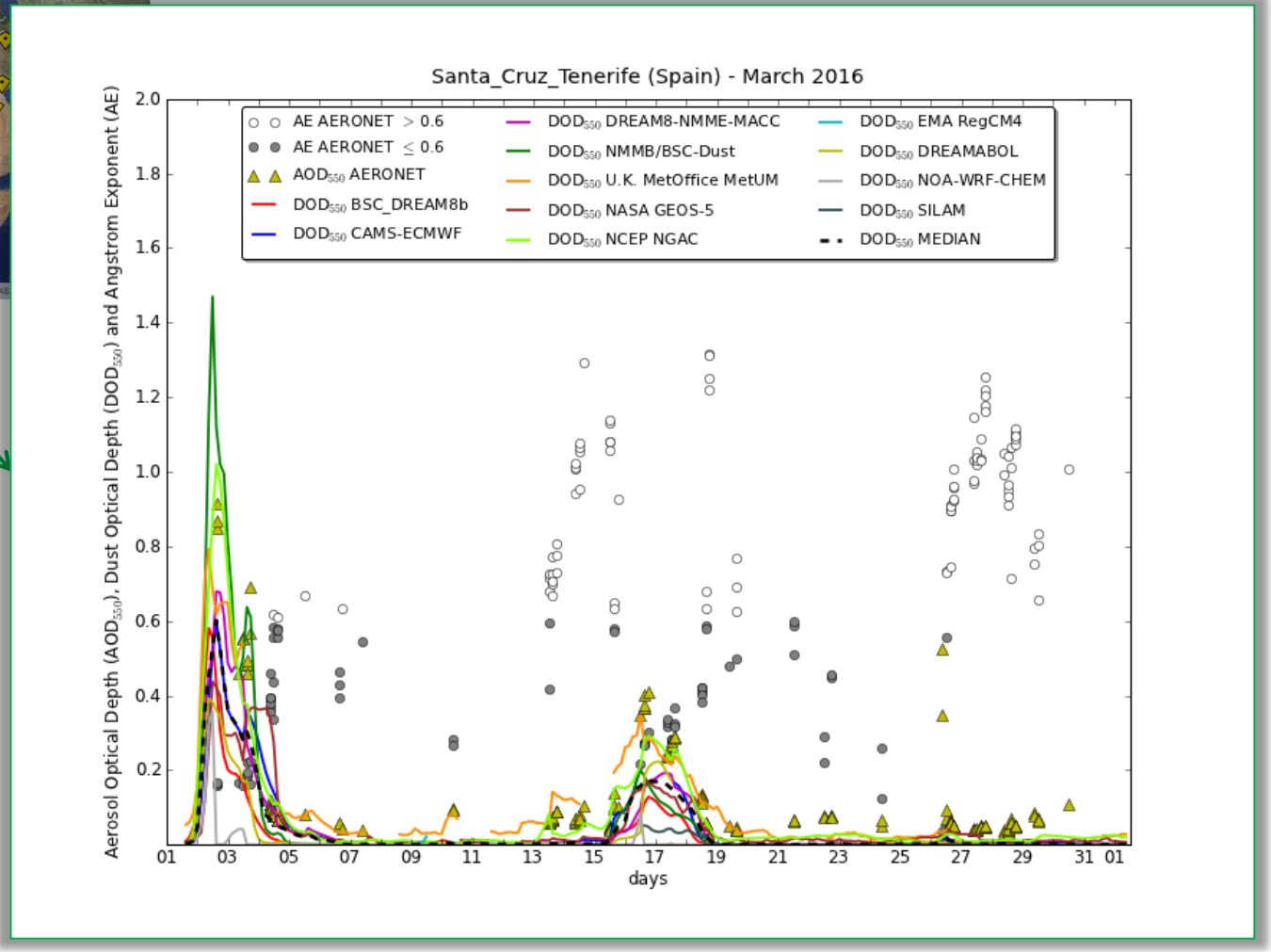


- **Evaluation of dust models with MODIS Deep Blue retrievals**
  - Evaluation scores monthly/seasonal/annual

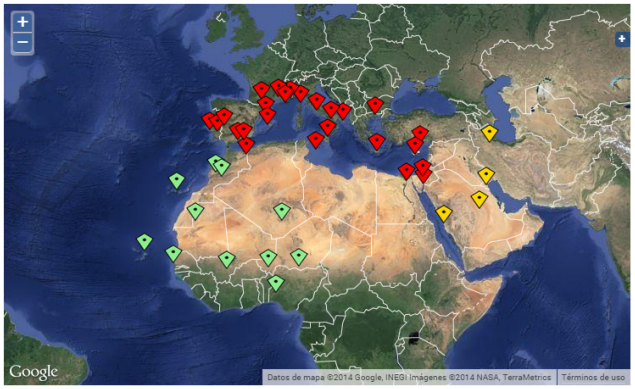


http://sds-was.aemet.es/forecast-products/forecast-evaluation

SDS-WAS NAMEE: DOD AERONET Evaluation



SDS-WAS NAMEE: DOD AERONET Evaluation



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***

Date: - Select Year - ▼

Jan 2016 - Dec 2016. Dust Optical Depth.
Threshold Angstrom Exponent = 0.600

BIAS

	BSC_ DREAM8b	CAMS-ECMWF	DREAM8-NMME-MACC	NMMB/BSC-Dust	U.K. Met Office	NASA GEOS-5	NCEP NGAC	EMA RegCM4	DREAM ABOL	NOA-WRF-CHEM	SILAM	MEDIAN
Sahel/Sahara show stations	-0.30	-0.17	-0.20	-0.11	-0.16	-0.20	-0.06	0.03	-0.13	-0.13	-0.06	-0.18
Middle East show stations	-0.12	-0.10	-0.05	-0.17	-0.12	-0.16	-0.11	1.13	0.06	-0.14	0.01	-0.13
Mediterranean show stations	-0.16	-0.12	-0.12	-0.15	-0.10	-0.14	-0.05	-0.02	-0.09	-0.12	-0.10	-0.13
TOTAL	-0.24	-0.14	-0.16	-0.13	-0.14	-0.18	-0.06	0.08	-0.10	-0.13	-0.07	-0.16

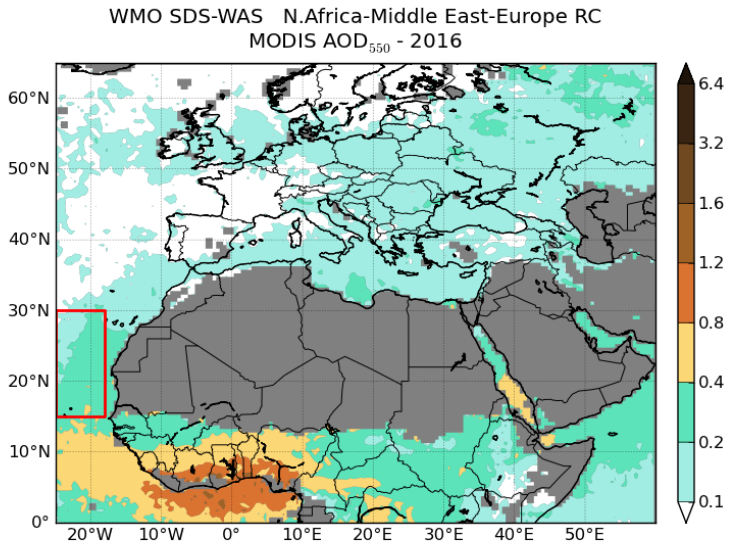
ROOT MEAN SQUARE ERROR

	BSC_ DREAM8b	CAMS-ECMWF	DREAM8-NMME-MACC	NMMB/BSC-Dust	U.K. Met Office	NASA GEOS-5	NCEP NGAC	EMA RegCM4	DREAM ABOL	NOA-WRF-CHEM	SILAM	MEDIAN
Sahel/Sahara show stations	0.51	0.42	0.45	0.43	0.44	0.42	0.39	0.64	0.48	0.44	0.82	0.42
Middle East show stations	0.35	0.25	0.28	0.44	0.27	0.31	0.29	11.39	0.34	0.32	0.62	0.28
Mediterranean show stations	0.30	0.29	0.30	0.29	0.27	0.29	0.27	0.40	0.30	0.31	0.44	0.28
TOTAL	0.44	0.37	0.39	0.39	0.38	0.38	0.35	2.86	0.42	0.39	0.71	0.37

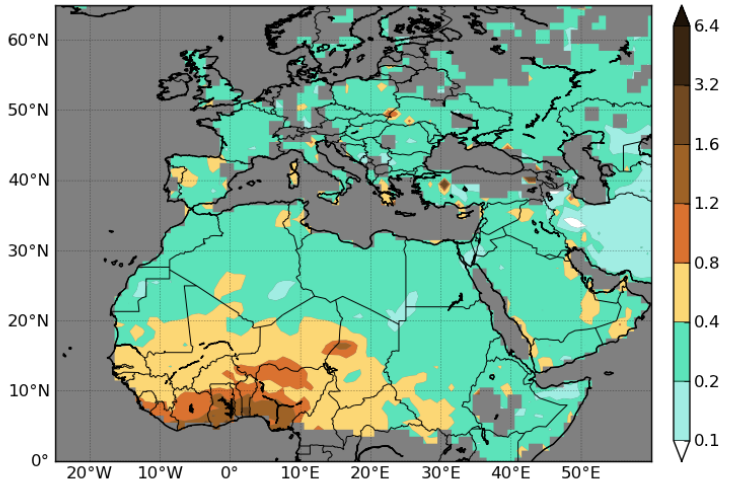
CORRELATION COEFFICIENT

	BSC_ DREAM8b	CAMS-ECMWF	DREAM8-NMME-MACC	NMMB/BSC-Dust	U.K. Met Office	NASA GEOS-5	NCEP NGAC	EMA RegCM4	DREAM ABOL	NOA-WRF-CHEM	SILAM	MEDIAN

SDS-WAS NAMEE: DOD MODIS Evaluation



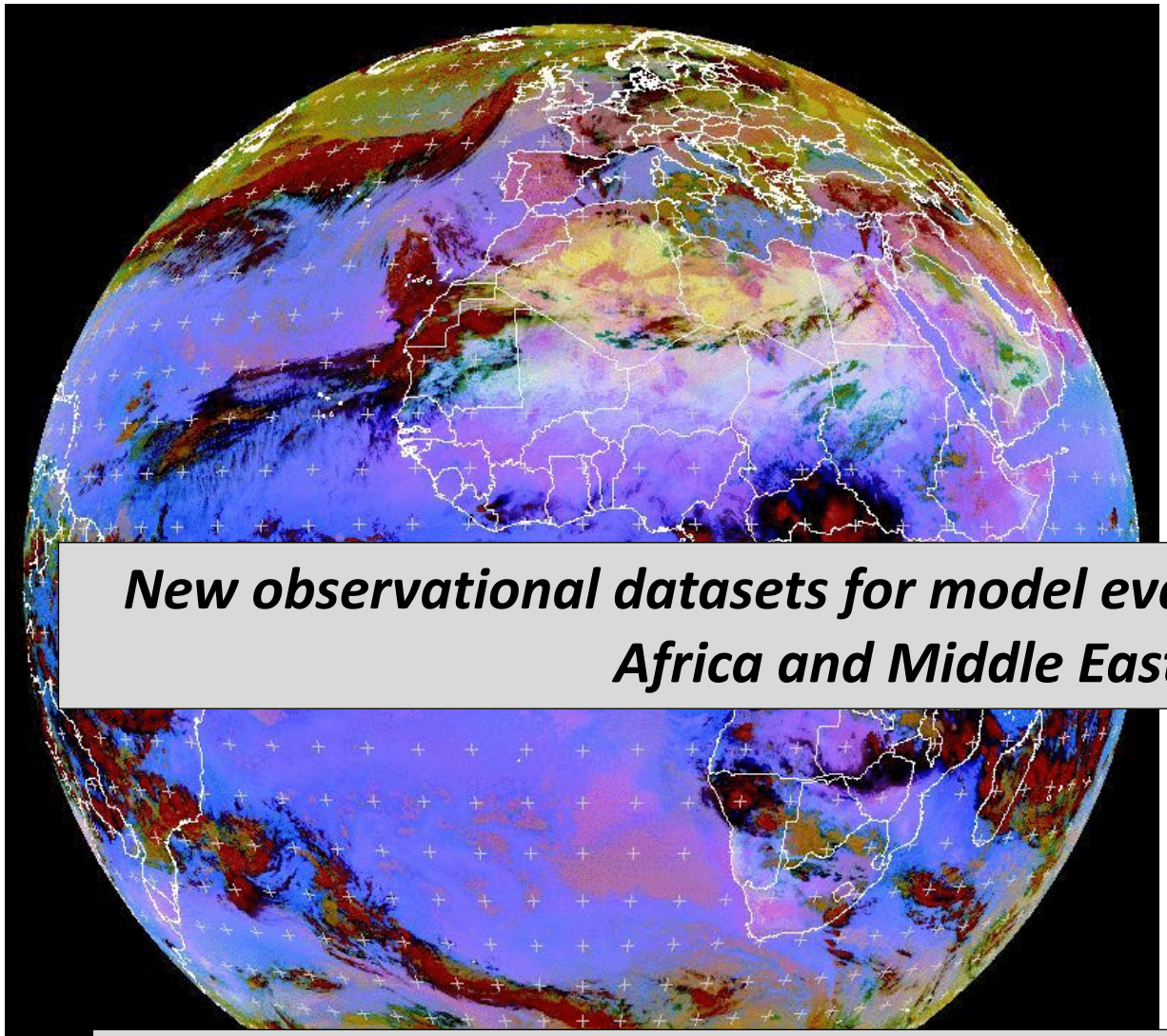
	BIAS	ROOT MEAN SQUARE ERROR	CORRELATION COEFFICIENT	FRACTIONAL GROSS ERROR	NUMBER OF CASES
BSC_ DREAM8b	-0.16	0.26	0.70	0.97	18493
NMMB/BSC-Dust	-0.11	0.22	0.72	0.83	18293
NCEP NGAC	0.08	0.21	0.79	0.51	18465
EMA RegCM4	0.03	0.35	0.34	1.11	8039
DREAMABOL	-0.06	0.27	0.51	0.84	17834
NOA-WRF-CHEM	-0.00	0.18	0.79	0.71	18141
SILAM	0.03	0.48	0.45	0.93	12302



	BIAS	ROOT MEAN SQUARE ERROR	CORRELATION COEFFICIENT	FRACTIONAL GROSS ERROR	NUMBER OF CASES
BSC_ DREAM8b	-0.16	0.32	0.40	0.76	189314
NMMB/BSC-Dust	-0.10	0.29	0.66	0.82	188183
NCEP NGAC	-0.03	0.27	0.52	0.55	189348
EMA RegCM4	0.25	1.51	0.07	0.82	94099
DREAMABOL	-0.01	0.36	0.24	0.70	181446
NOA-WRF-CHEM	-0.04	0.25	0.61	0.59	186946
SILAM	0.10	0.79	0.27	0.93	142429

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

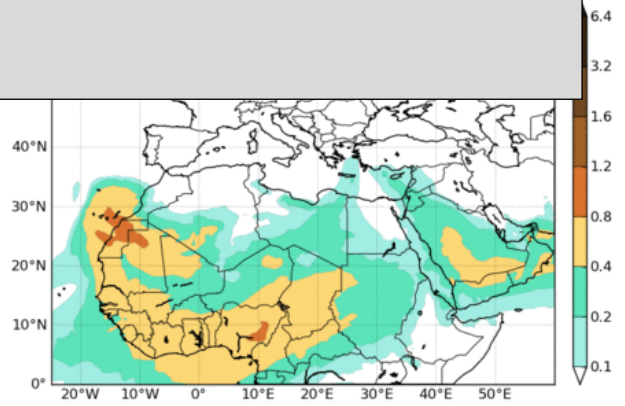
SDS-WAS NAMEE: Model Evaluation



EUMETSAT

7 March 2015

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

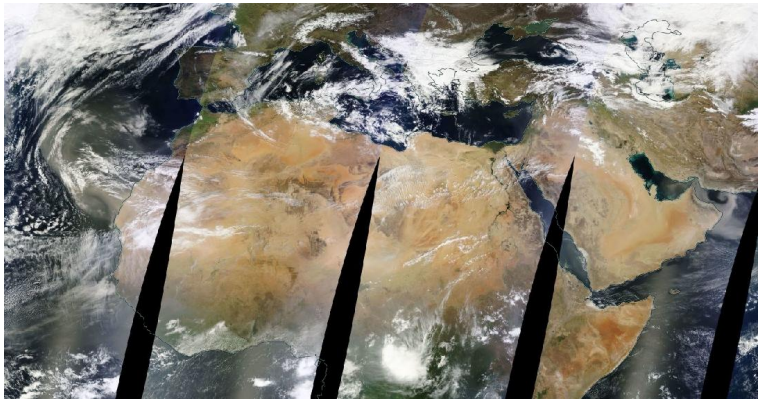


NOTE: There is available an historical archive of the MSG RBG dust products.

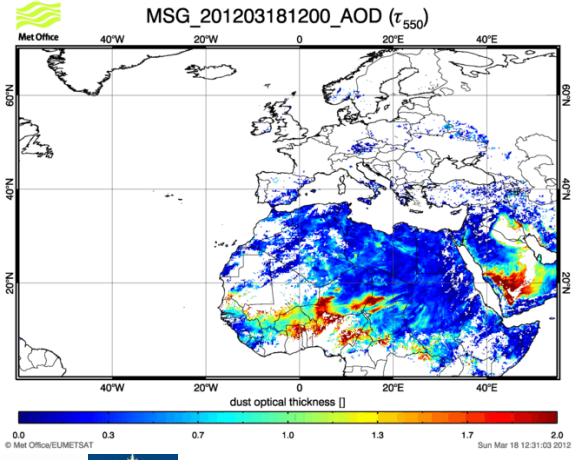
SDS-WAS NAMEE: Model Evaluation

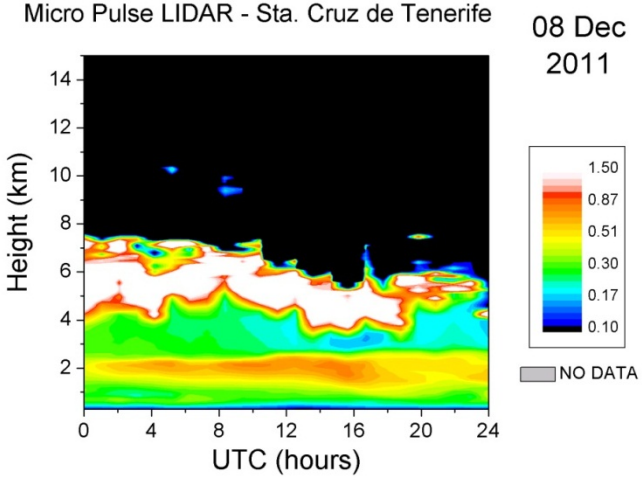
New observational datasets for model evaluation in Northern Africa and Middle East

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



MODIS composite 8th March 2015 from EOSDIS World Viewer

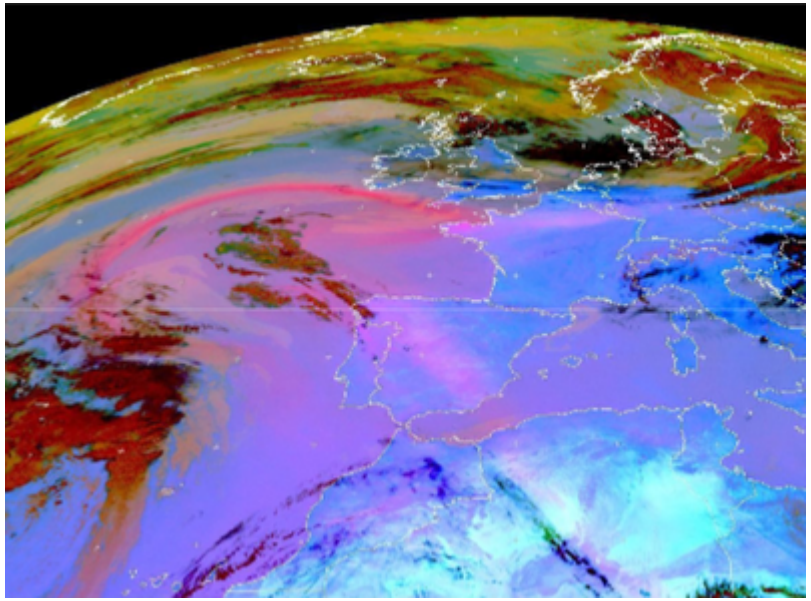




http://sds-was.aemet.es/

SDS-WAS NAMEE: Studies

Model Intercomparison: European dust outbreak on April 2011



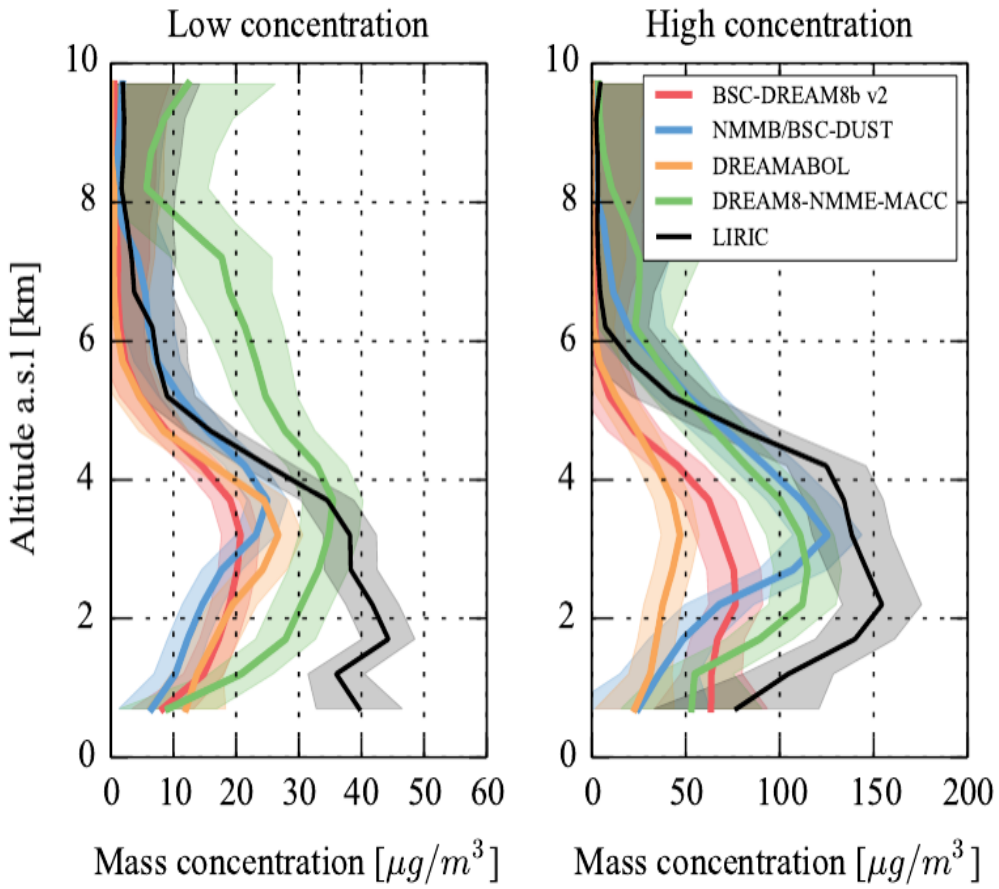
MSG/SEVIRI RGB product 7 April
Courtesy of EUMETSAT

- 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.

(Huneeus et al., ACP, 2016)

SDS-WAS NAMEE: Studies

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



(Binietoglou et al., ATM, 2015)

SDS-WAS NAMEE: Studies

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.

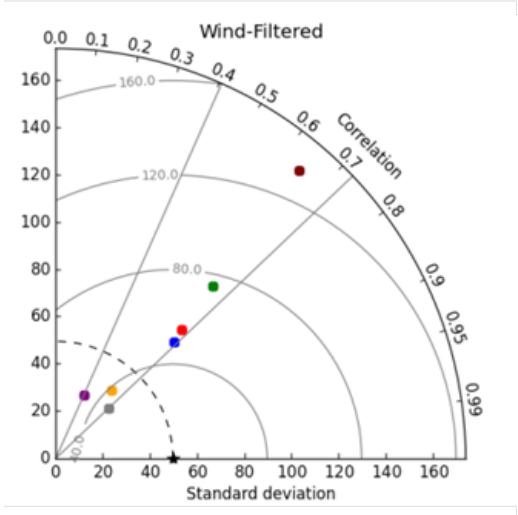
SDS-WAS NAMEE: PM10 Evaluation

AMMA network: PM10 in Sahel for the year 2013

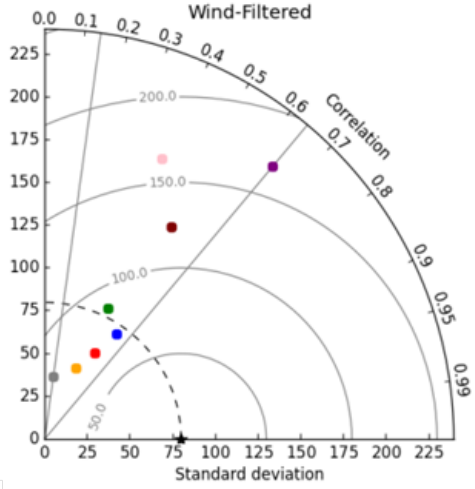
Not all PM10 is dust: *Local and biomass burning from Savannah fires.*

Dust filter: *Considering the localizations of the desert dust sources the filter is based on wind direction.*

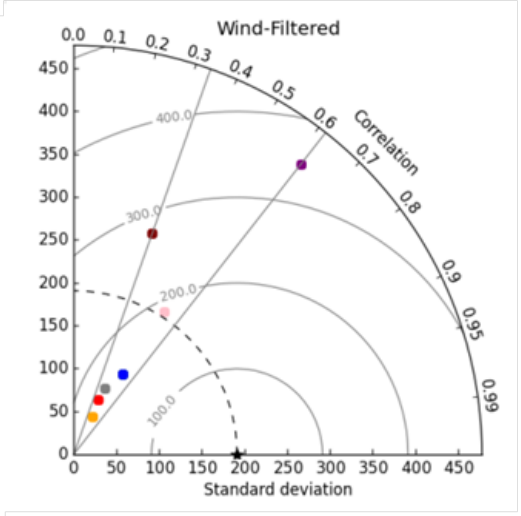
M'Bour-Senegal

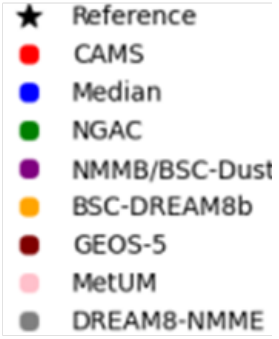


Cinzana-Mali



Banizoumbou-Niger



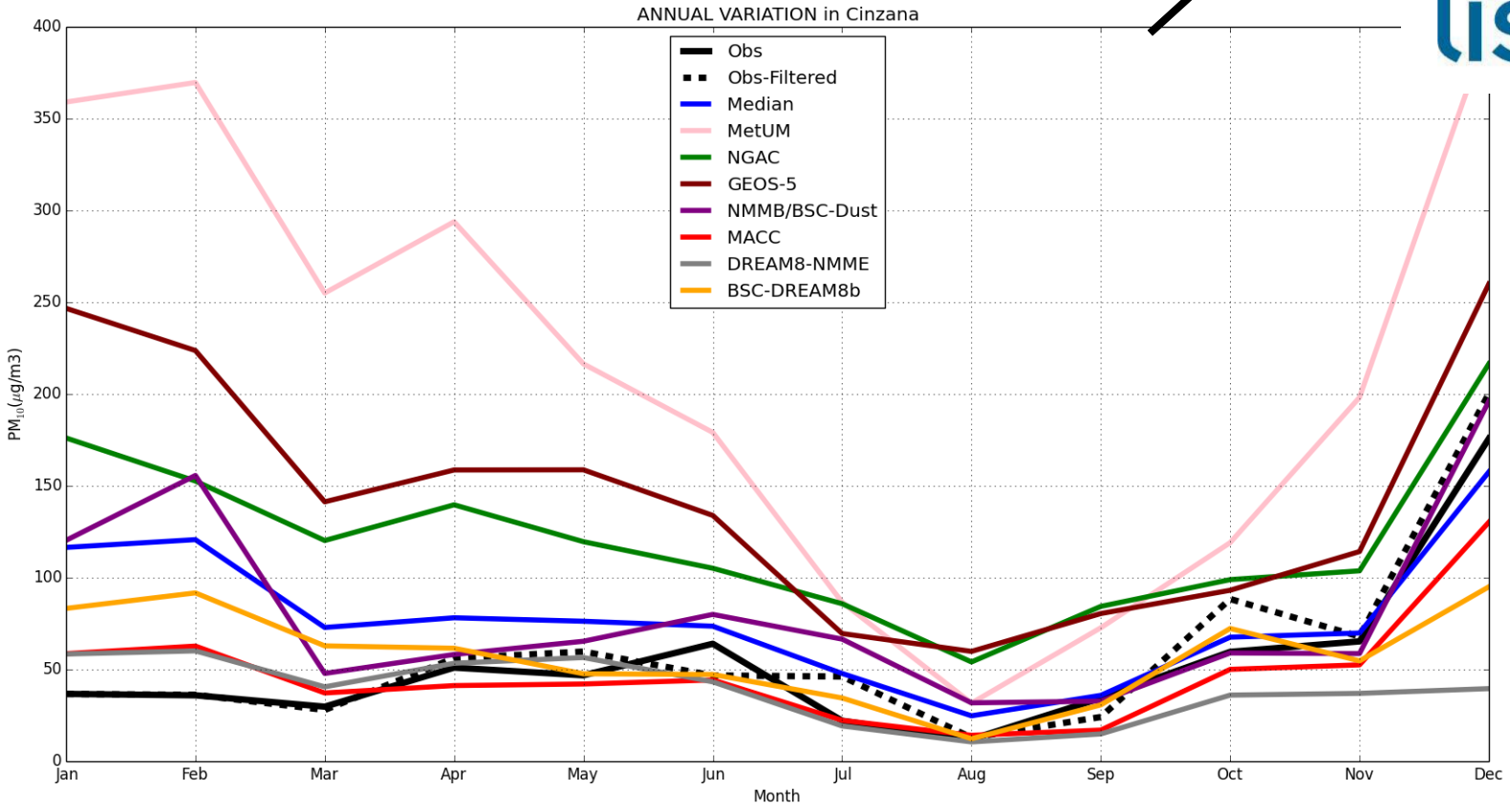


AMMA (Marticorena et al., 2010)

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

SDS-WAS NAMEE: PM10 Evaluation

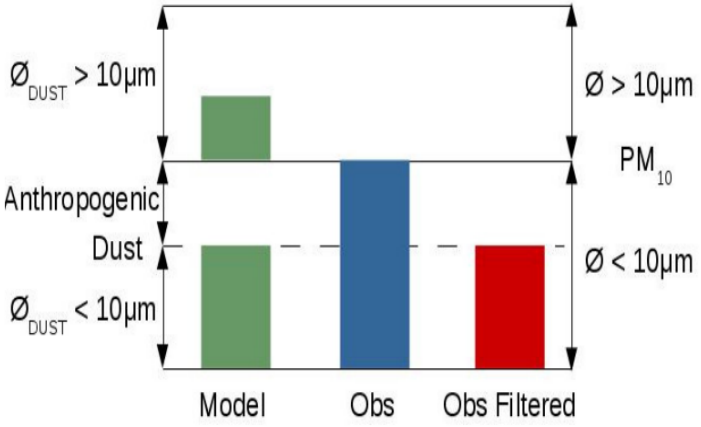
AMMA network: PM10 in Sahel for the year 2013



SDS-WAS NAMEE: PM10 Evaluation

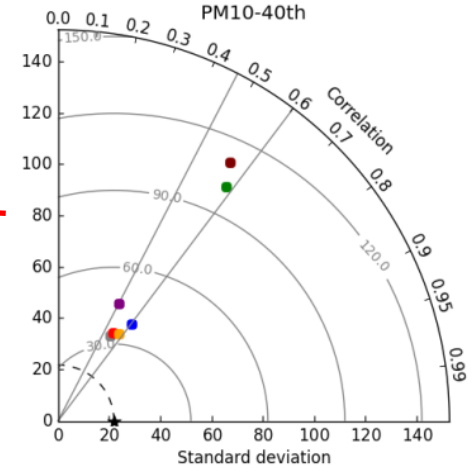
AQ network: Canary Islands 2013-2014

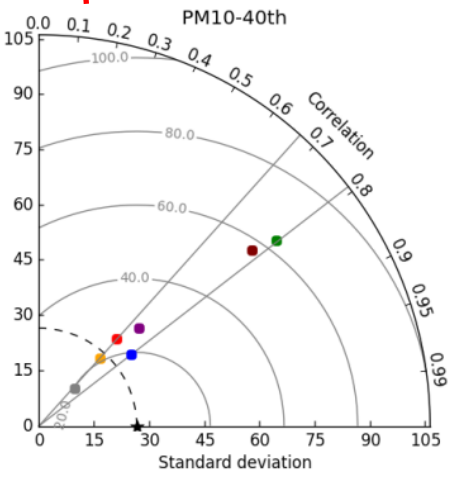
Not all PM10 is dust: *Local sources*
Dust filter: *Moving 40th percentile of 30 days, 15 days before and 15 days after (Escudero at al. 2007).*

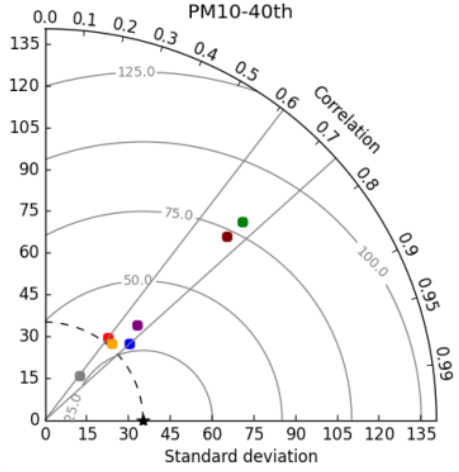


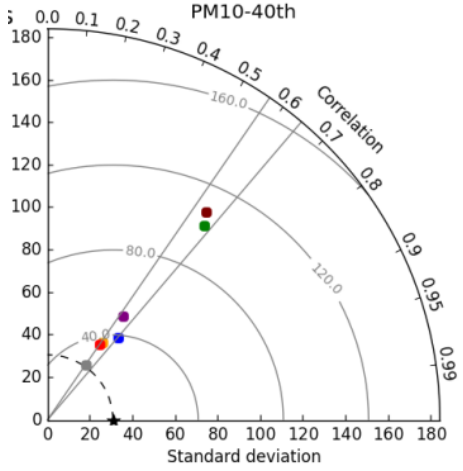
SDS-WAS NAMEE: PM10 Evaluation

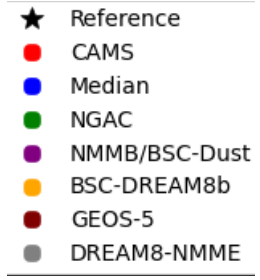
AQ network: Canary Islands 2013-2014











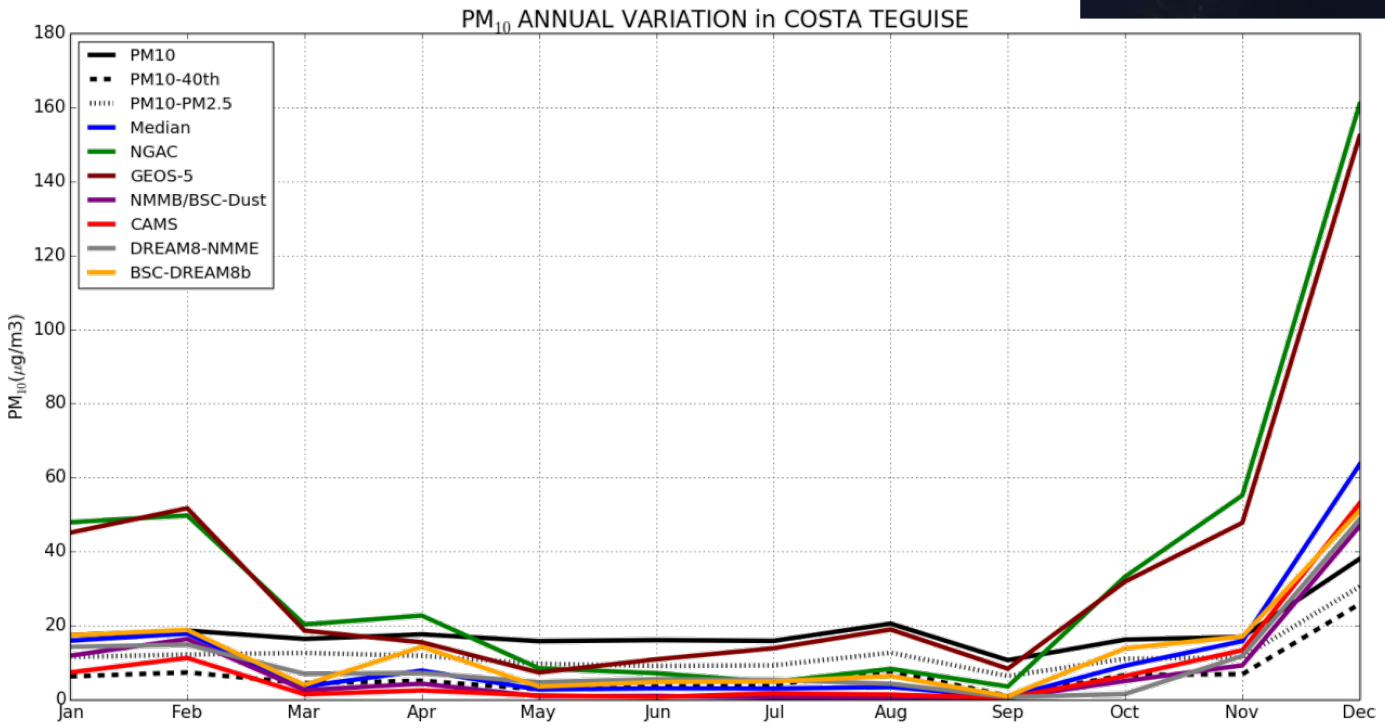
Supercomputing Center
Centro Nacional de Supercomputación

Agencia Estatal de Meteorología

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

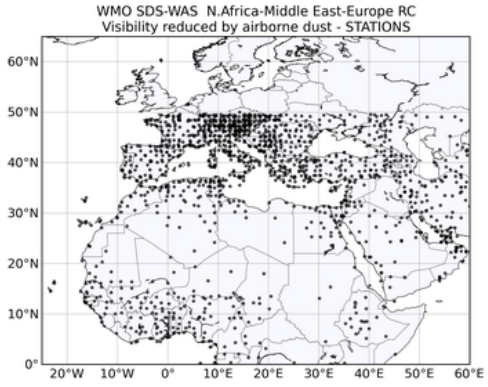
SDS-WAS NAMEE: PM10 Evaluation

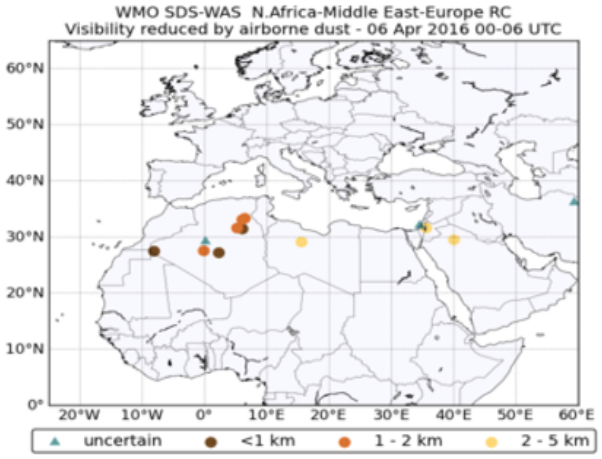
AQ network: Canary Islands 2013-2014

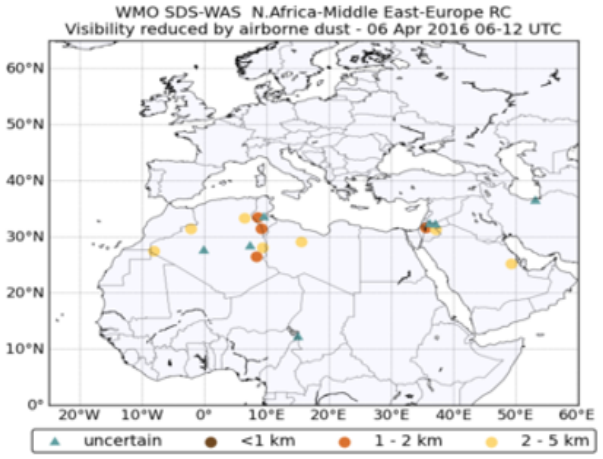


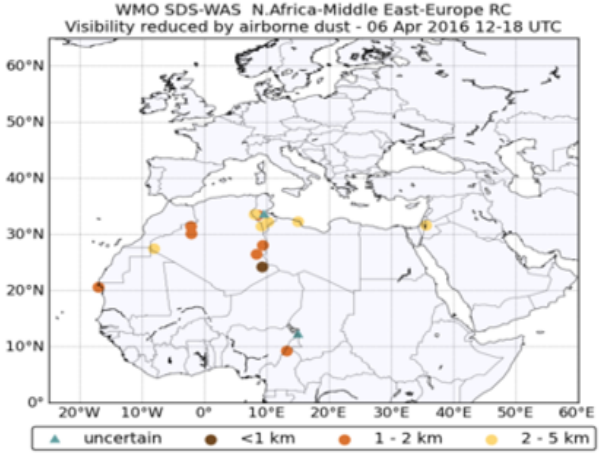
SDS-WAS NAMEE: Visibility vs Surf. Conc.

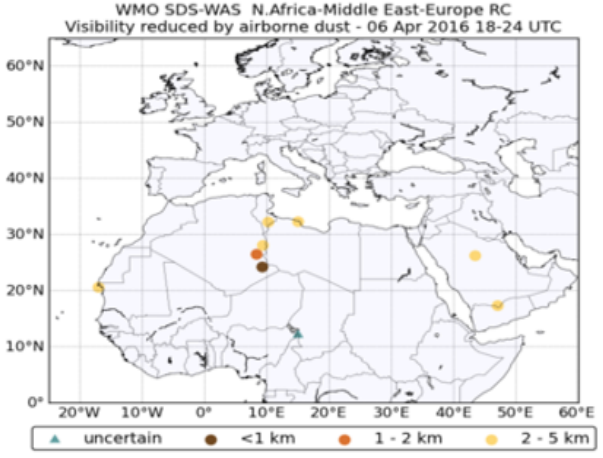
NRT visibility evaluation: 6th April 2016 0-12UTC











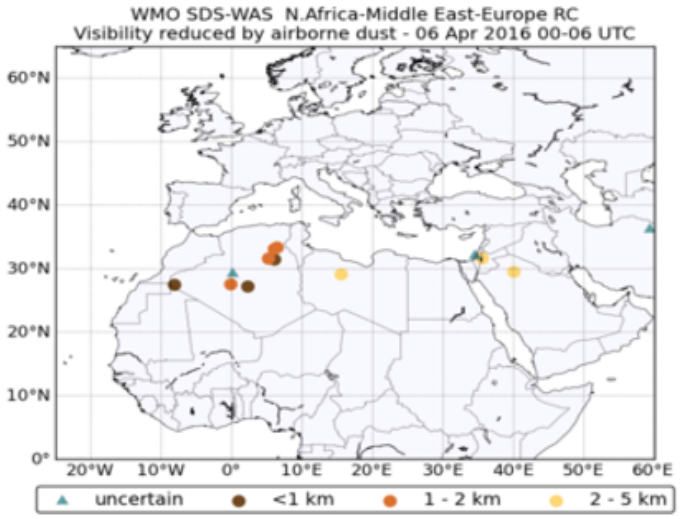
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

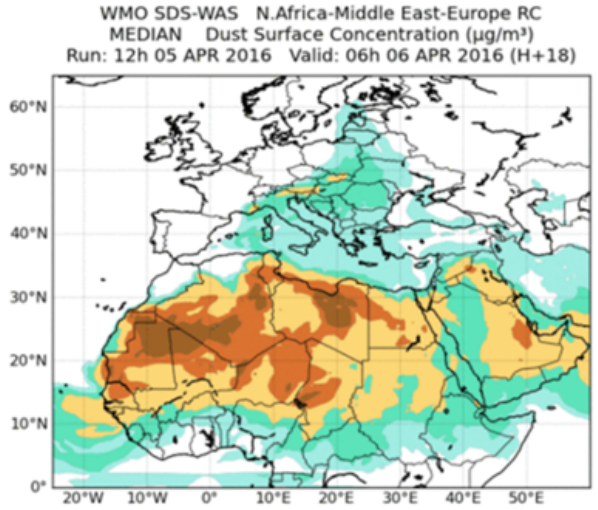
AEMet Agencia Estatal de Meteorología

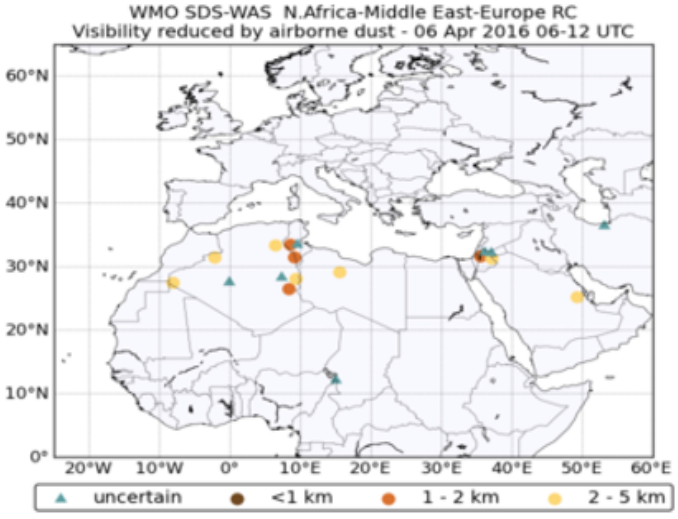
http://sds-was.aemet.es/

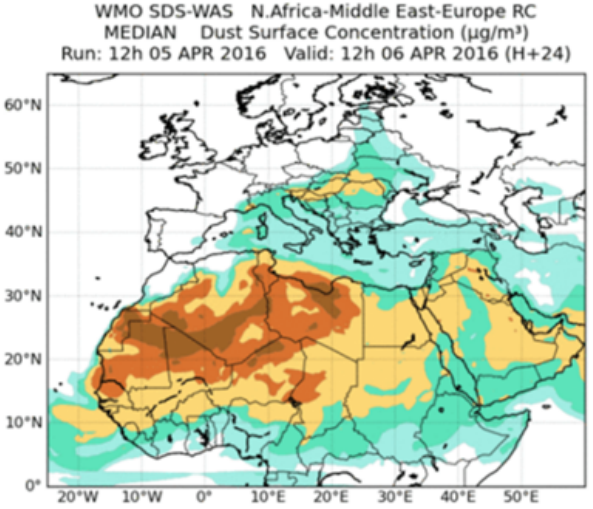
SDS-WAS NAMEE: Visibility vs Surf. Conc.

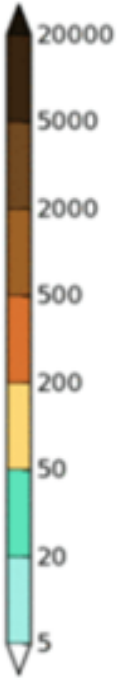
NRT visibility evaluation: 6th April 2016 0-12UTC







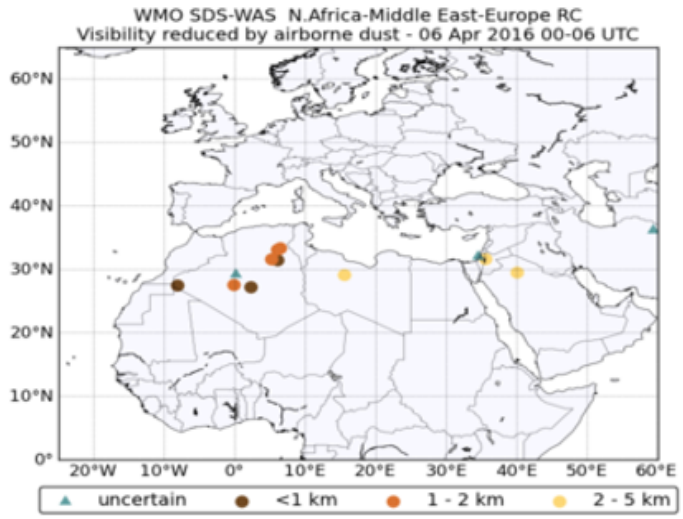


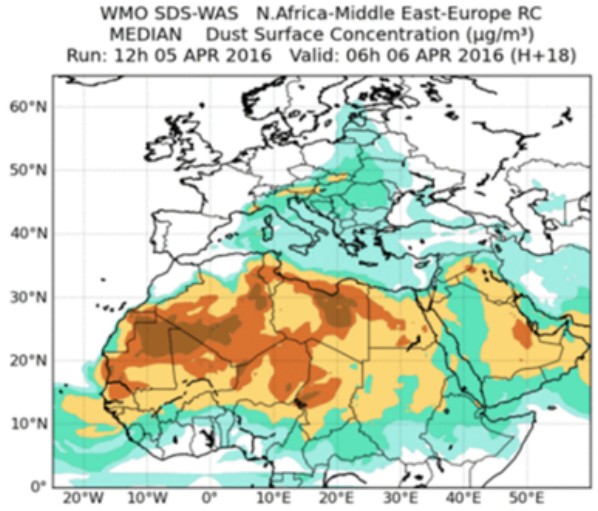


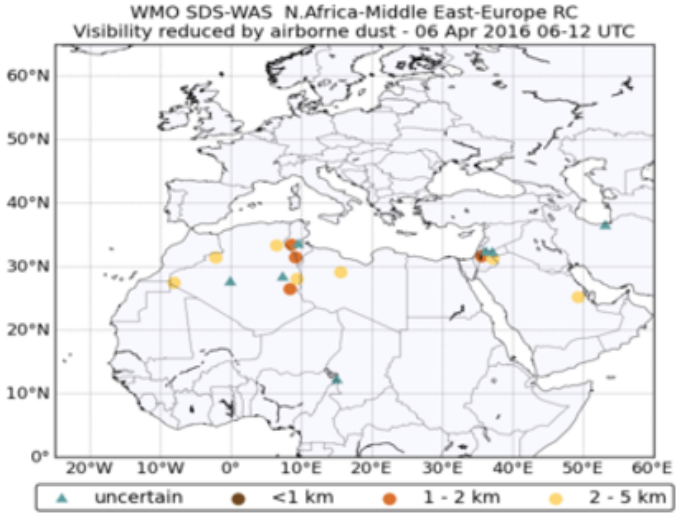
http://sds-was.aemet.es/

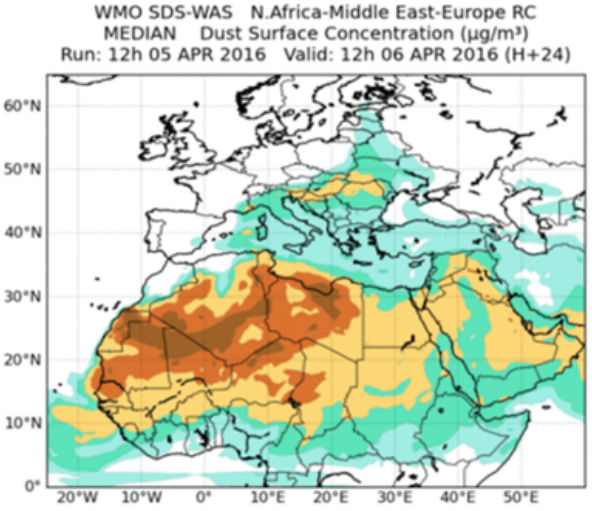
SDS-WAS NAMEE: Visibility vs Surf. Conc.

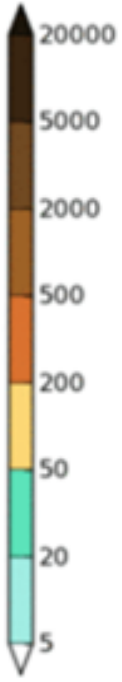
NRT visibility evaluation: 6th April 2016 0-12UTC











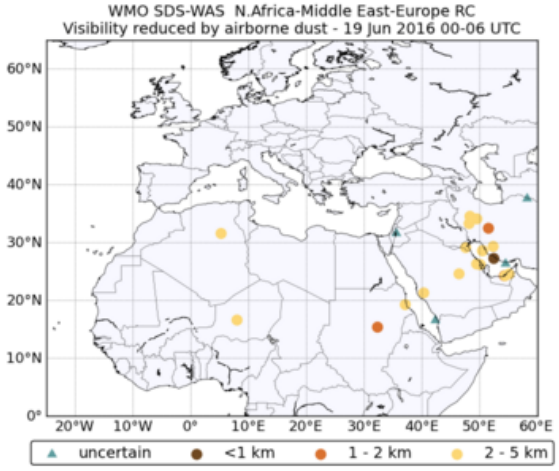
Barcelona Supercomputing Center
Centro Nacional de Supercomputación

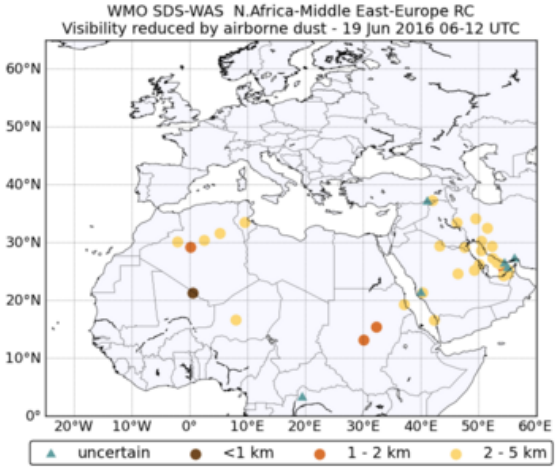
Agencia Estatal de Meteorología

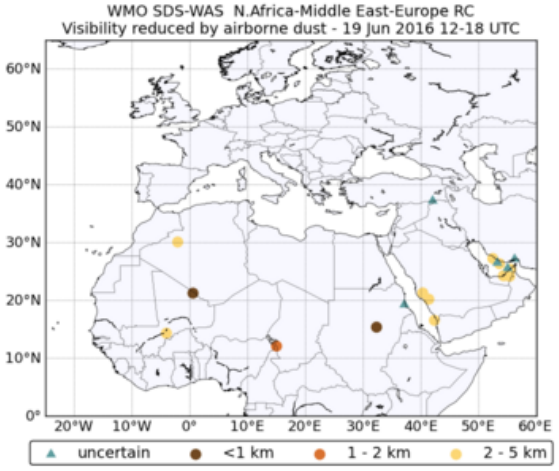
http://sds-was.aemet.es/

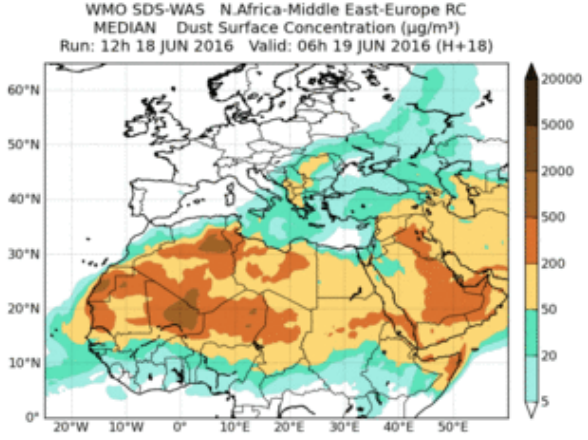
SDS-WAS NAMEE: Visibility vs Surf. Conc.

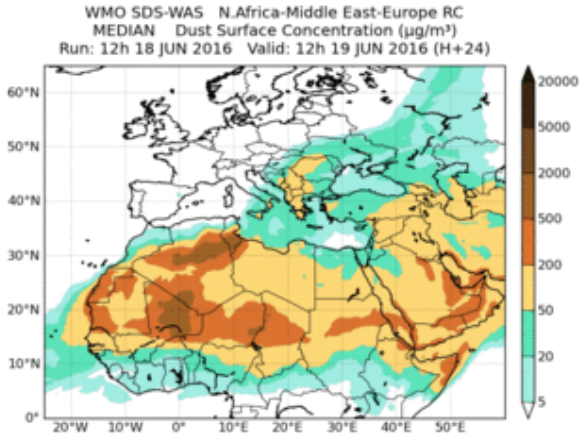
NRT visibility evaluation: 19th june 2016

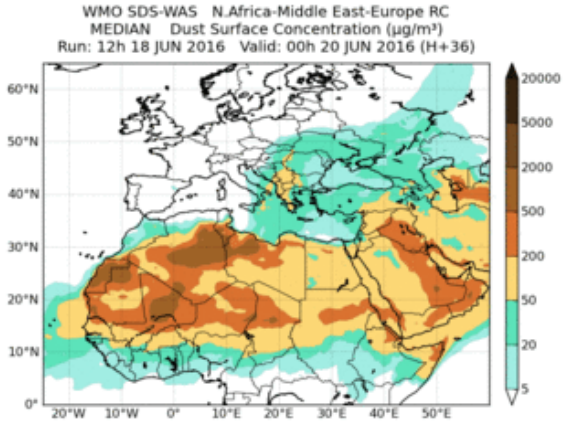








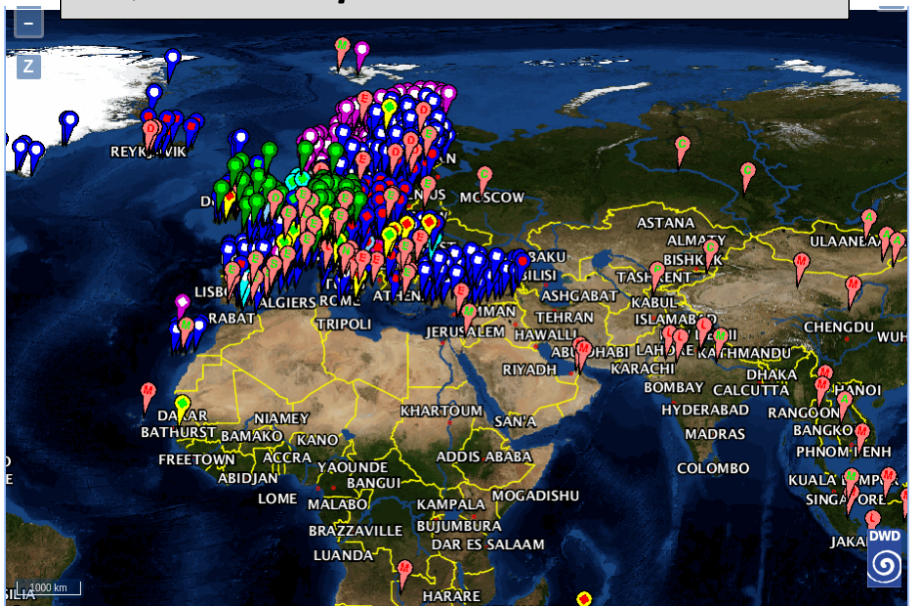




SDS-WAS NAMEE: Dust Profiles Evaluation

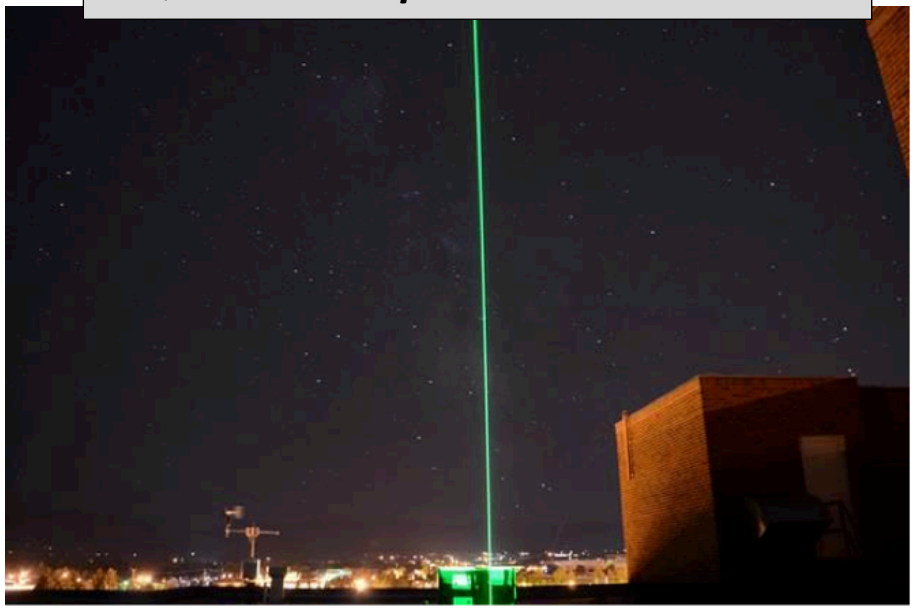
Ceilometers
Tenerife, Granada and Montsec (Spain)

+ High density of stations
- Qualitative products



Lidar
M'Bour (Senegal)

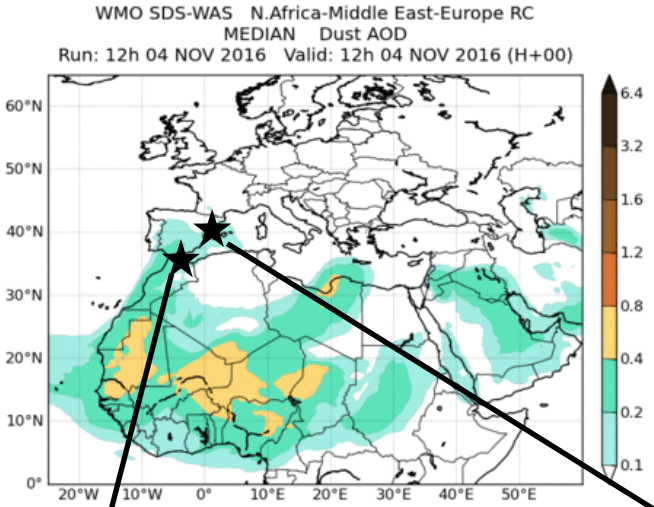
- Low number of stations
+ Quantitative products



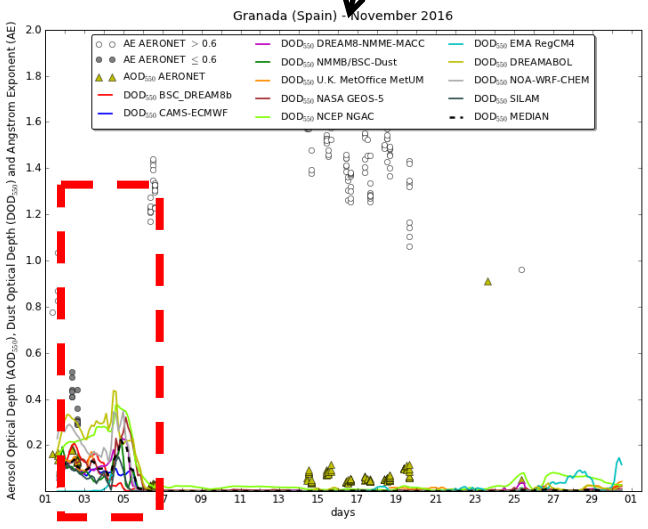
http://sds-was.aemet.es/projects-research/evaluation-of-model-derived-dust-vertical-profiles

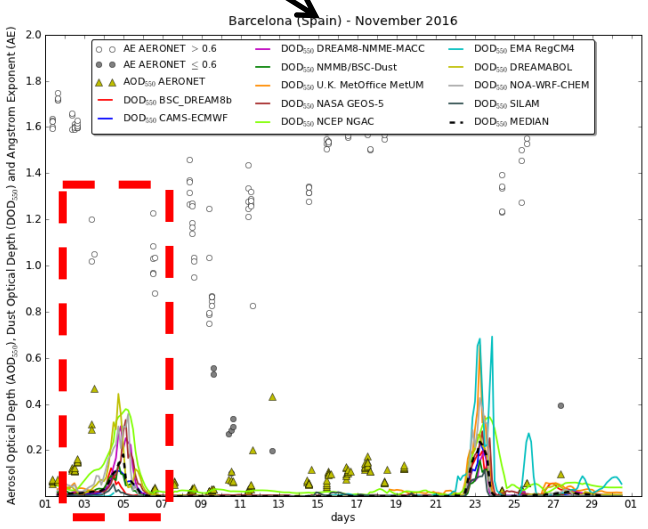
SDS-WAS NAMEE: Dust Profiles Evaluation

W. Mediterranean dust event: 2 - 5 November 2016



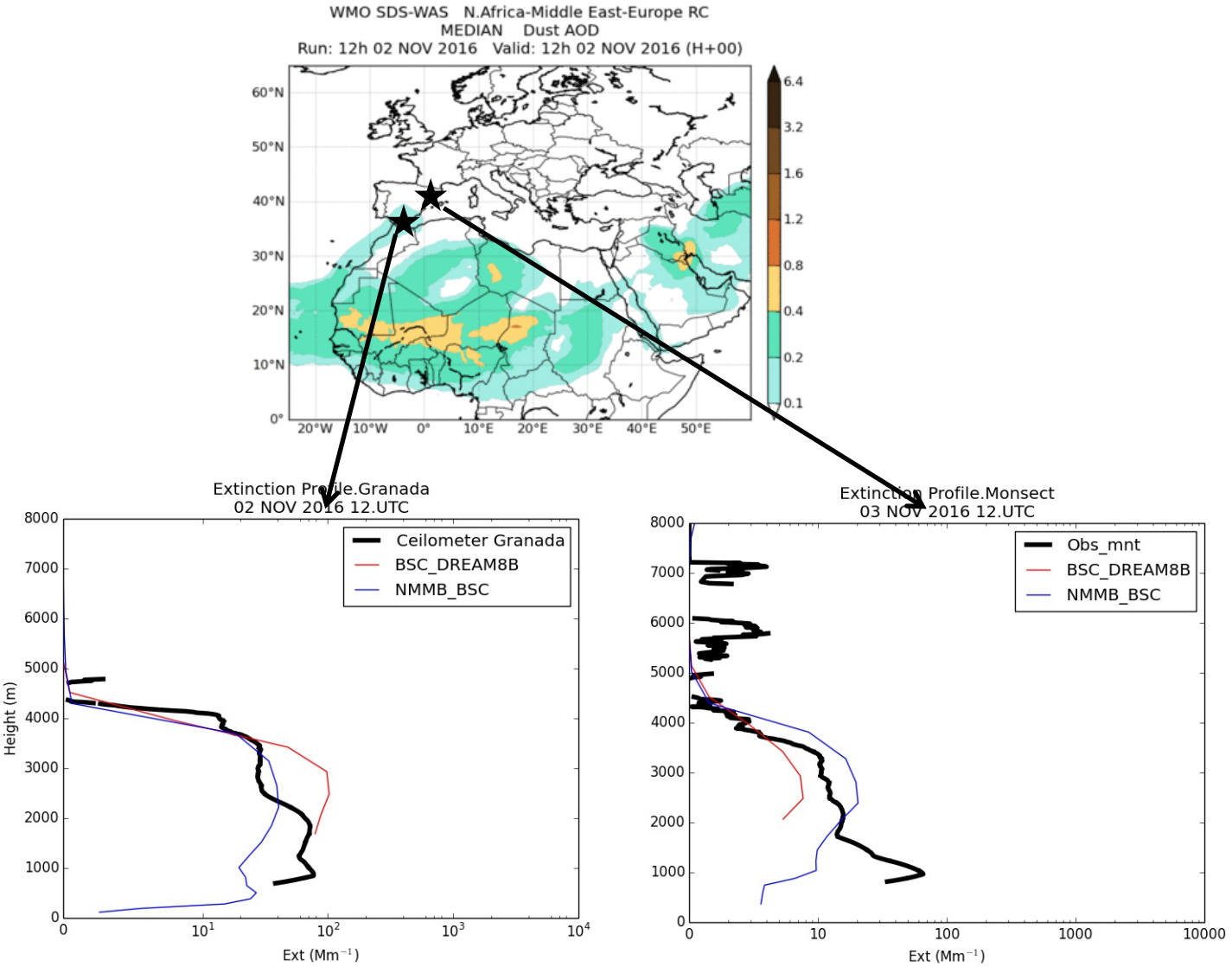
AERONET





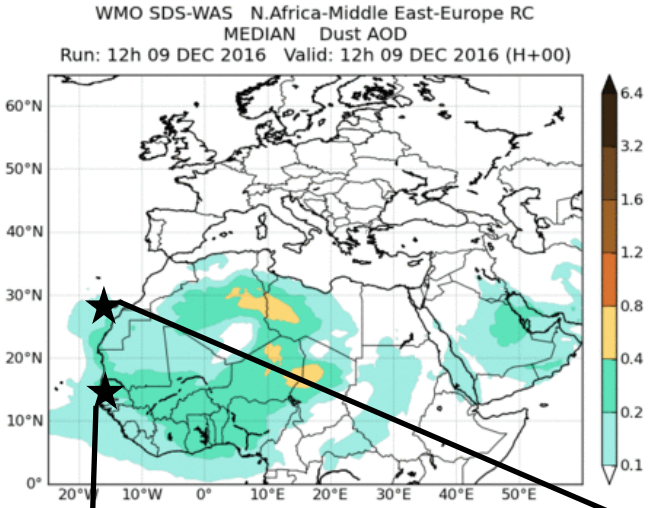
SDS-WAS NAMEE: Dust Profiles Evaluation

Atlantic dust event: 2 - 5 November 2016

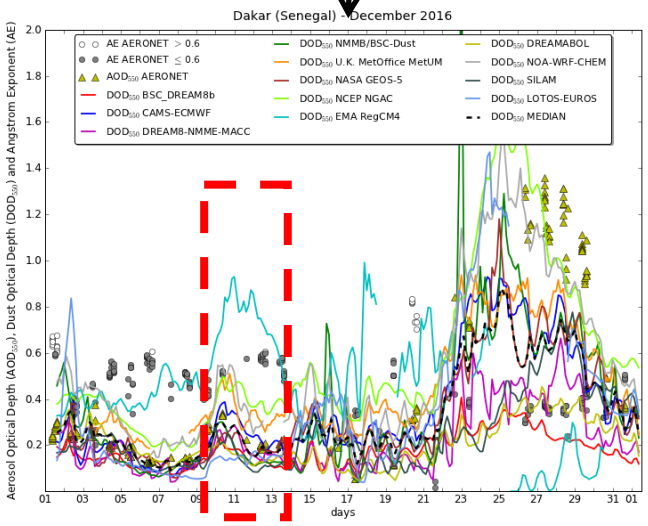


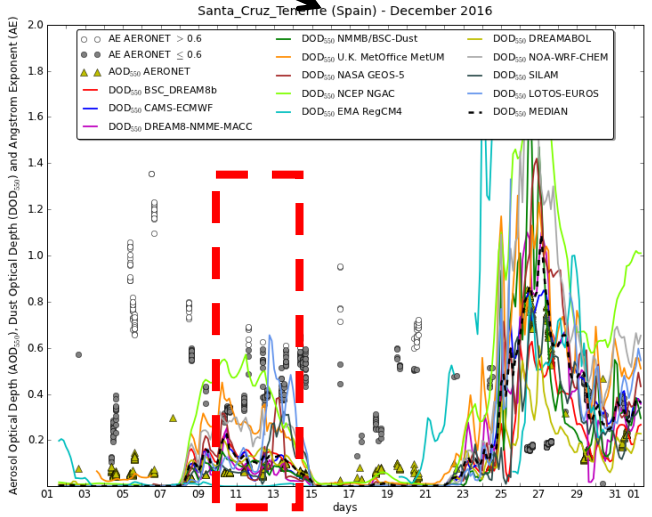
SDS-WAS NAMEE: Dust Profiles Evaluation

Atlantic dust event: 9 - 12 December 2016



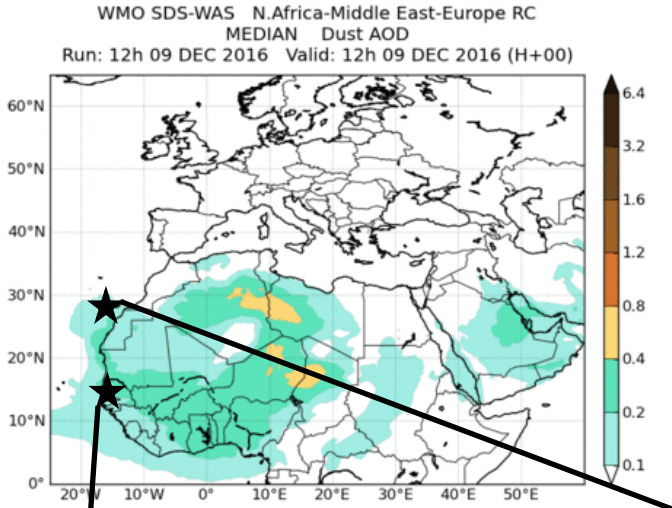
AERONET

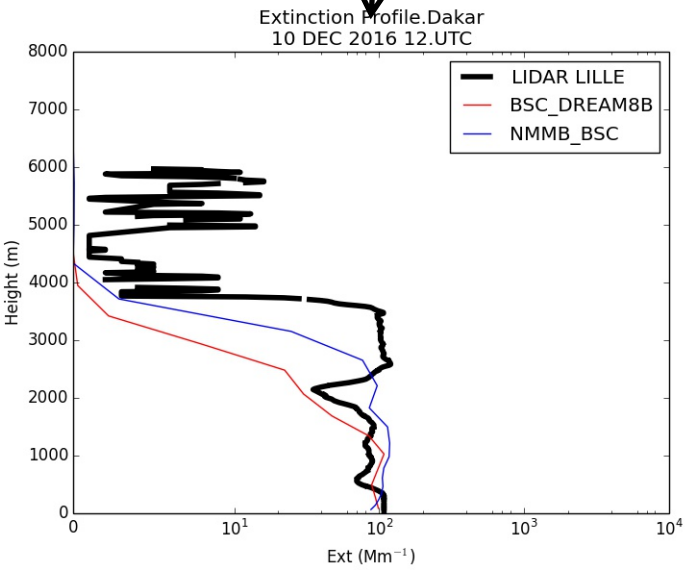


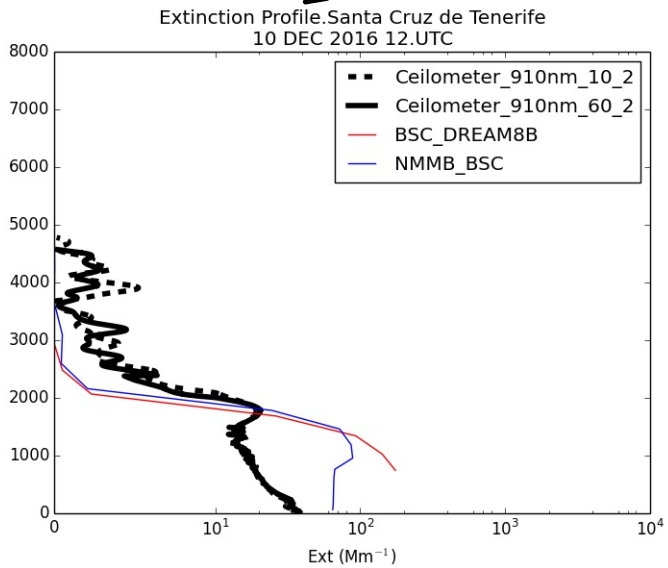


SDS-WAS NAMEE: Dust Profiles Evaluation

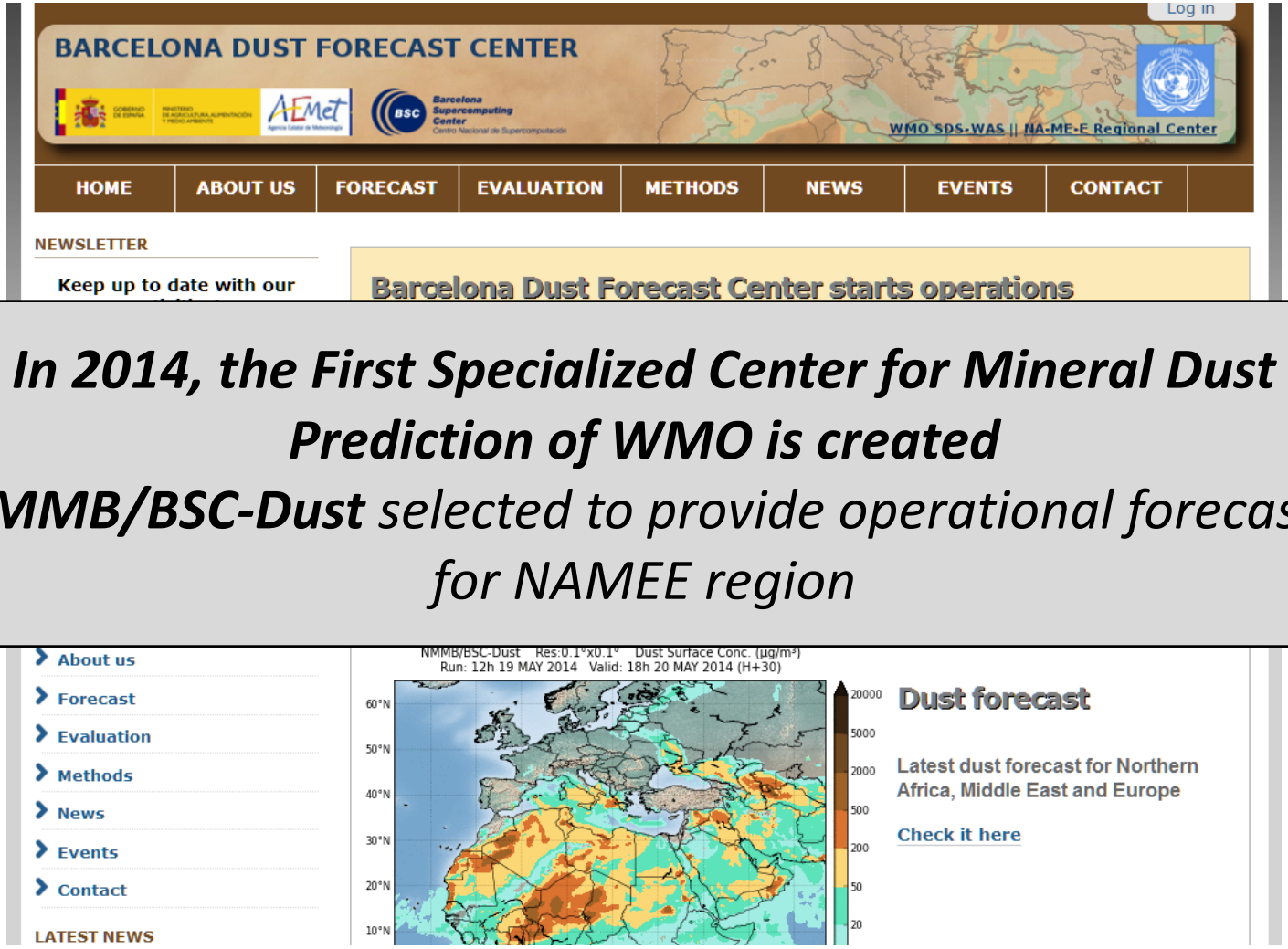
Atlantic dust event: 9 - 12 December 2016







Barcelona Dust Forecasting Center



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*

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

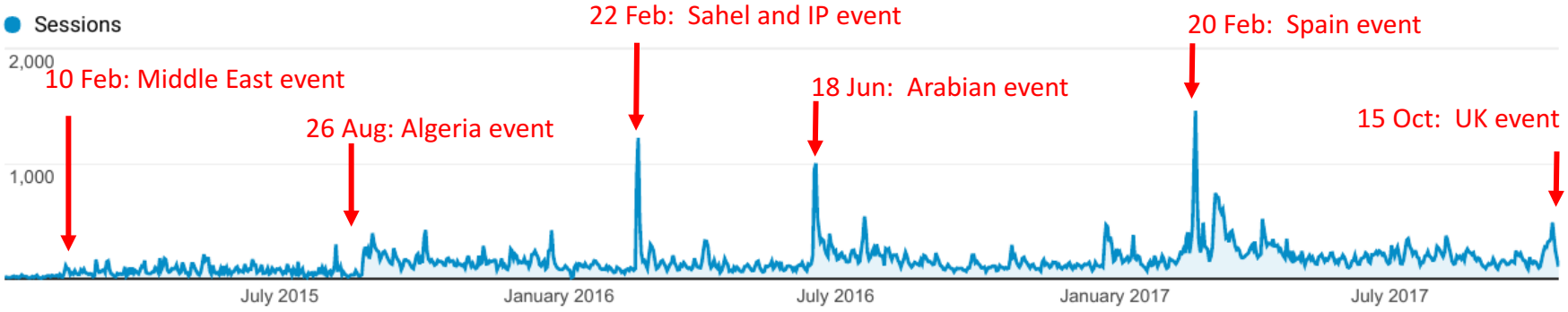
AEMet
Agencia Estatal de Meteorología

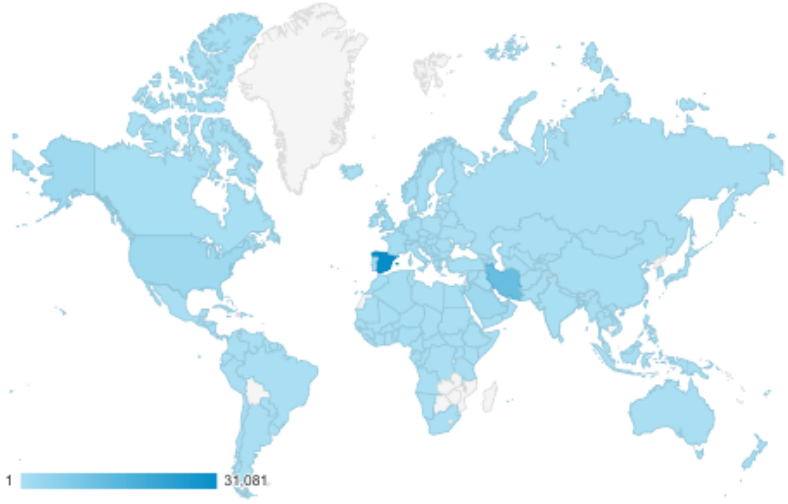
@Dust_Barcelona

http://dust.aemet.es/

Barcelona Dust Forecasting Center

Website visits: 1 January 2015 – 20 October 2017 ***http://dust.aemet.es/***

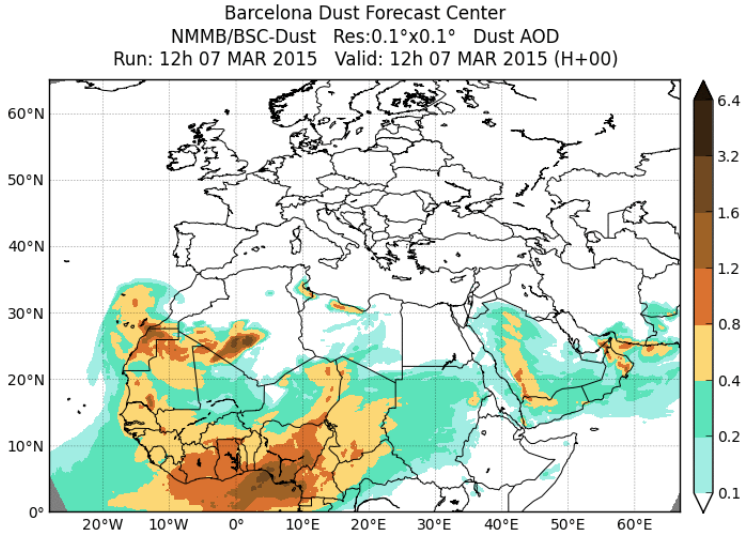


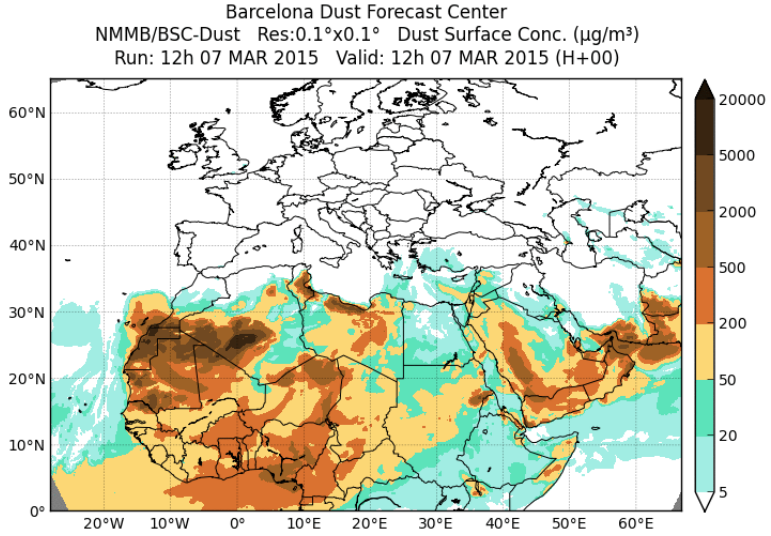


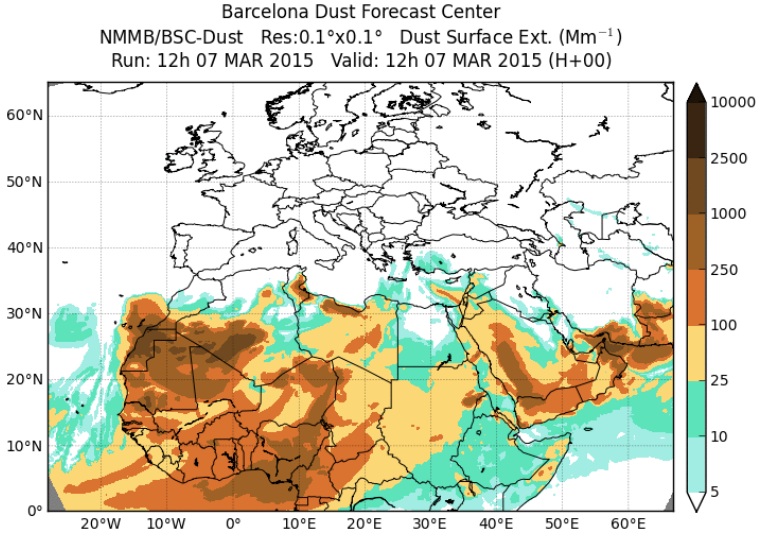
@Dust_Barcelona

BDFC: Operational Products

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



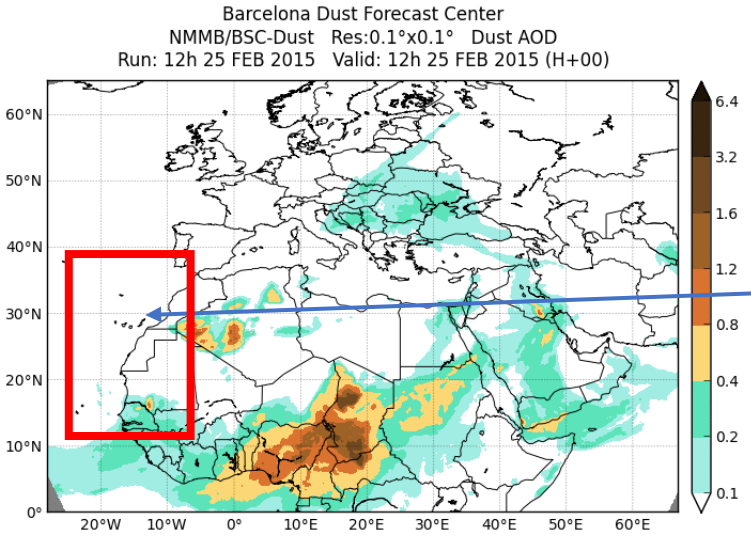


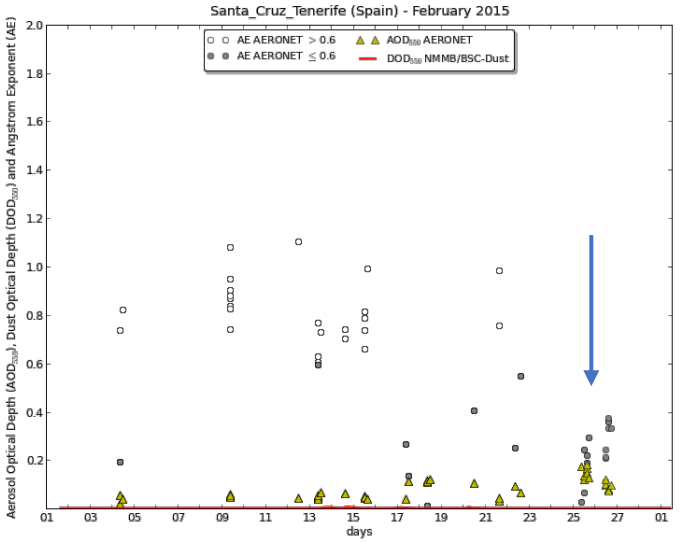


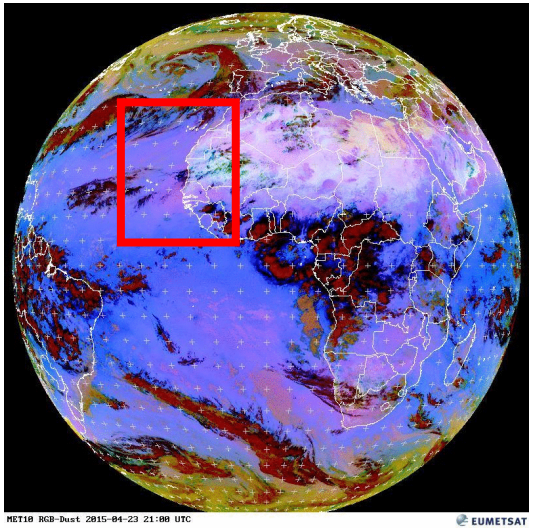
@Dust_Barcelona

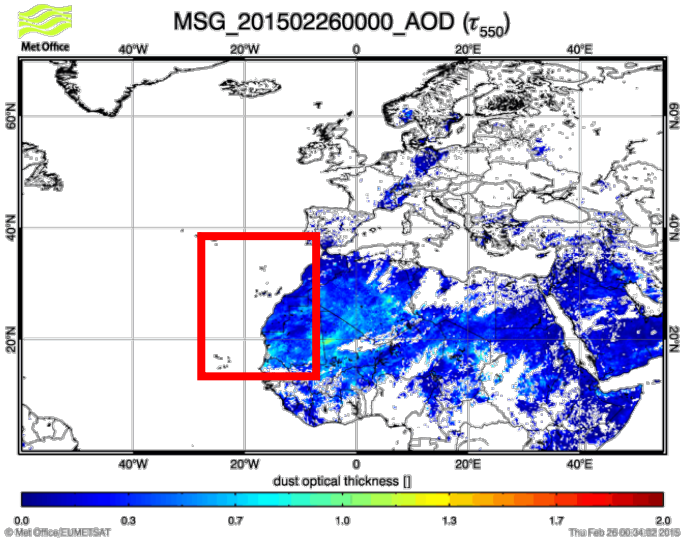
http://dust.aemet.es/

BDFC: Dust event Canary Islands Feb 2015



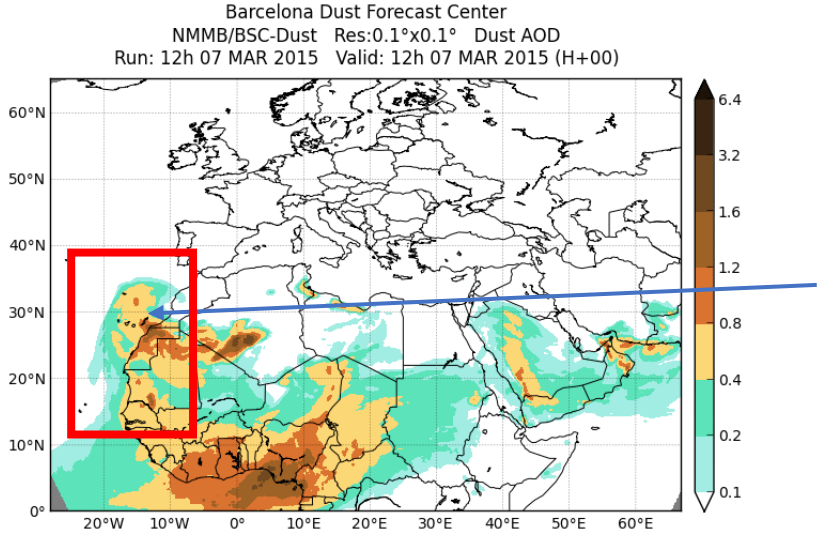


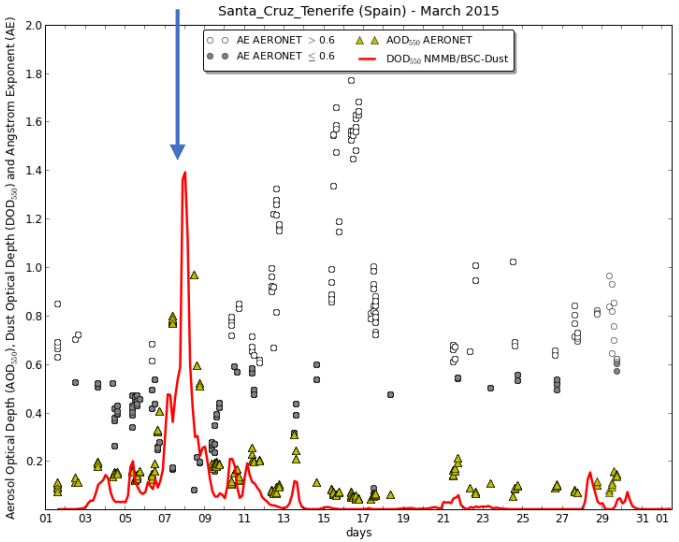


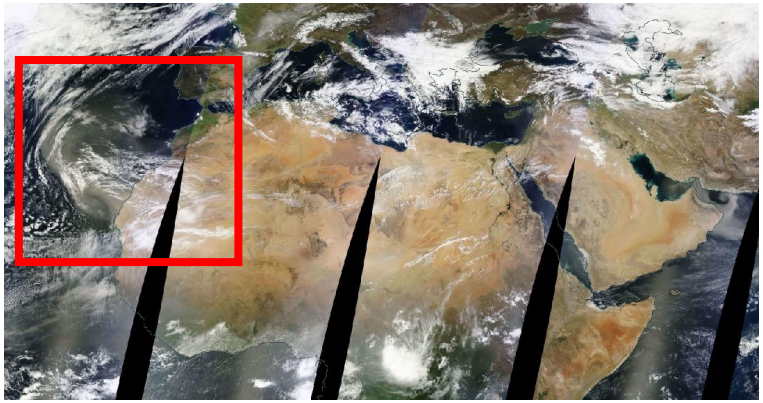


http://dust.aemet.es/

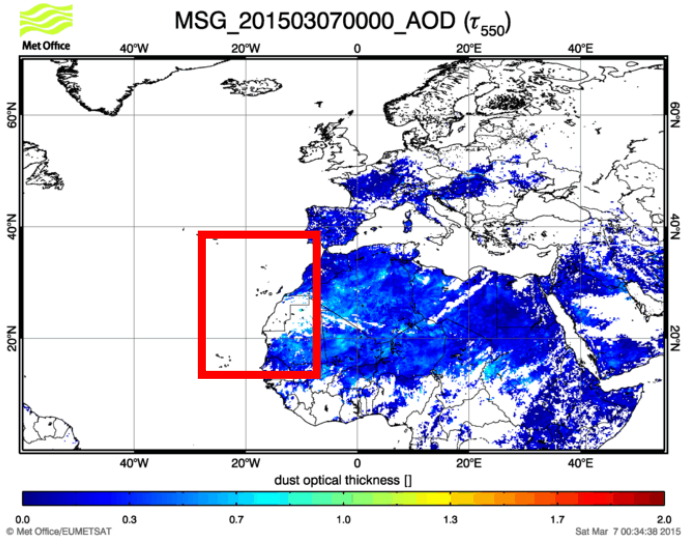
BDFC: Dust event Canary Islands Mar 2015





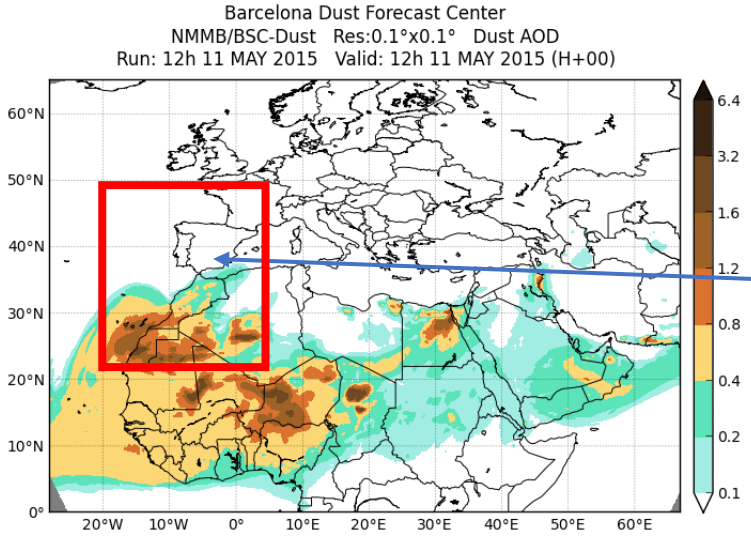


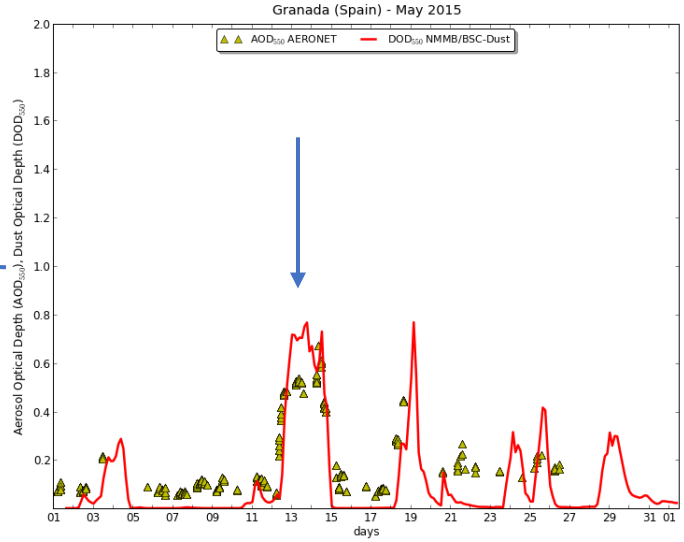
MODIS composite 8th March 2015 from EOSDIS World Viewer

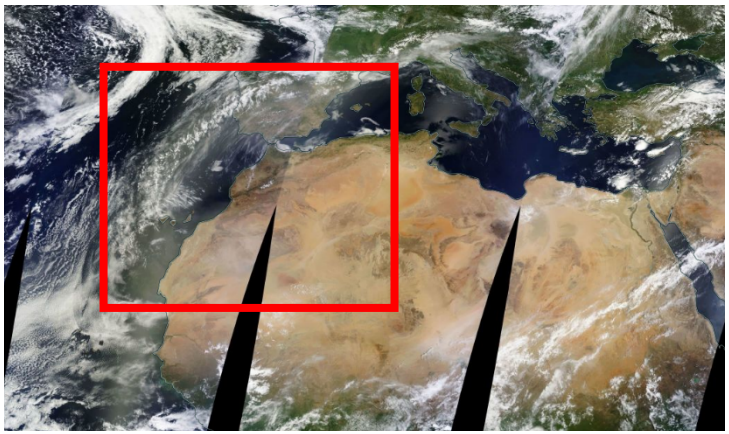


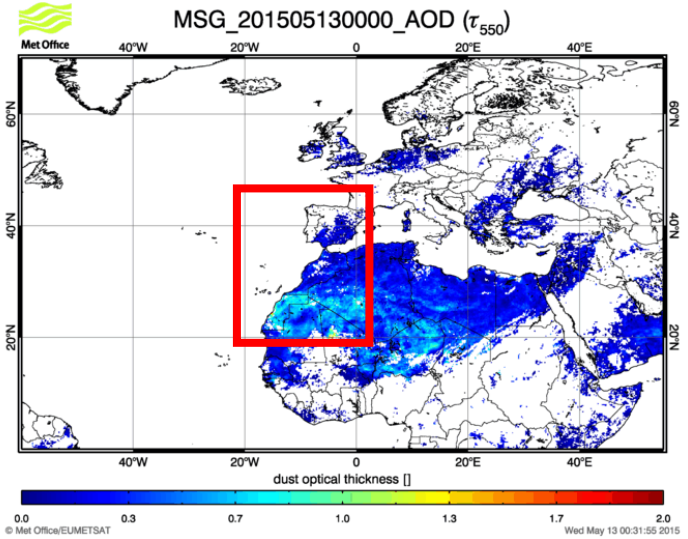
http://dust.aemet.es/

BDFC: Dust event Europe May 2015



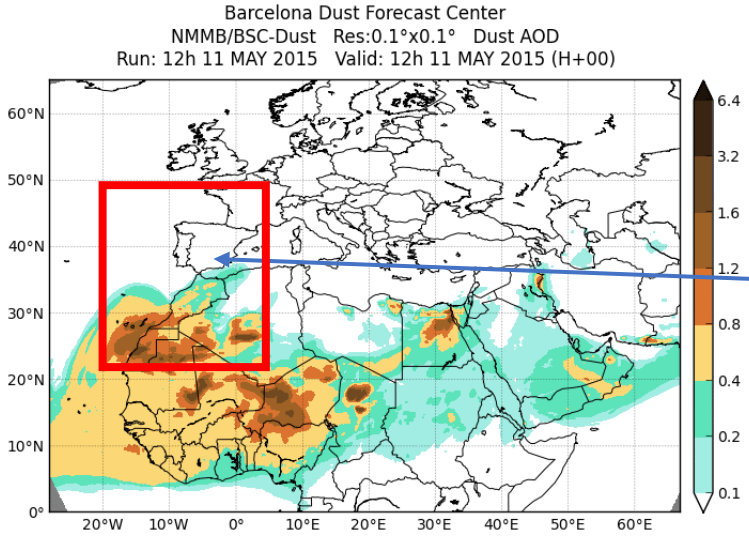


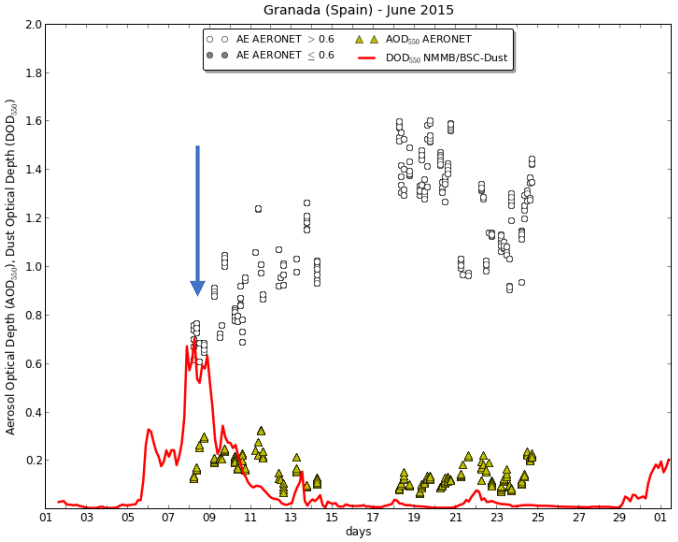


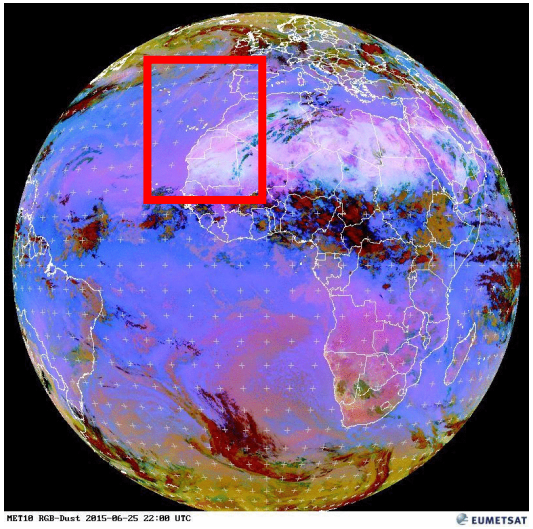


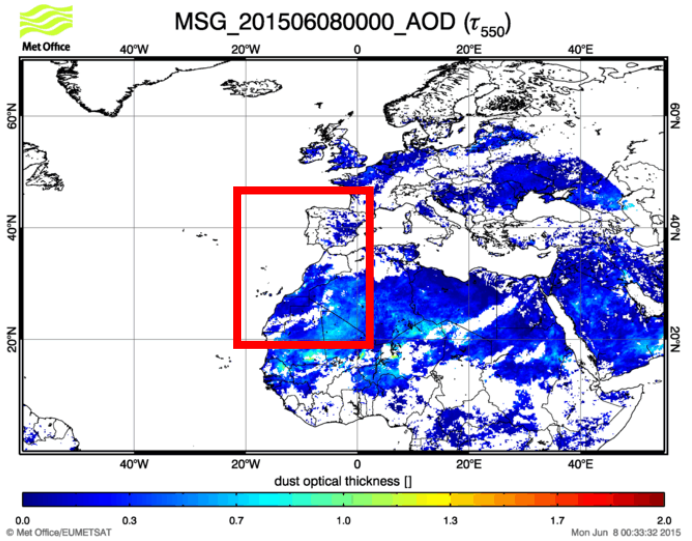
http://dust.aemet.es/

BDFC: Dust event Europe June 2015



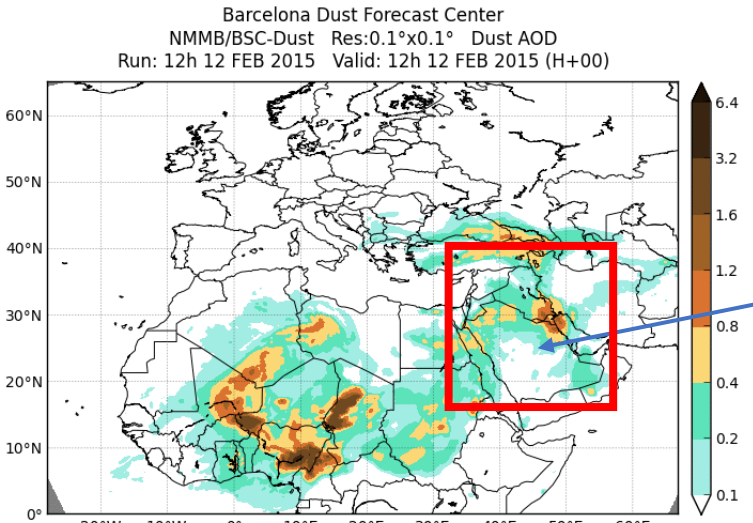


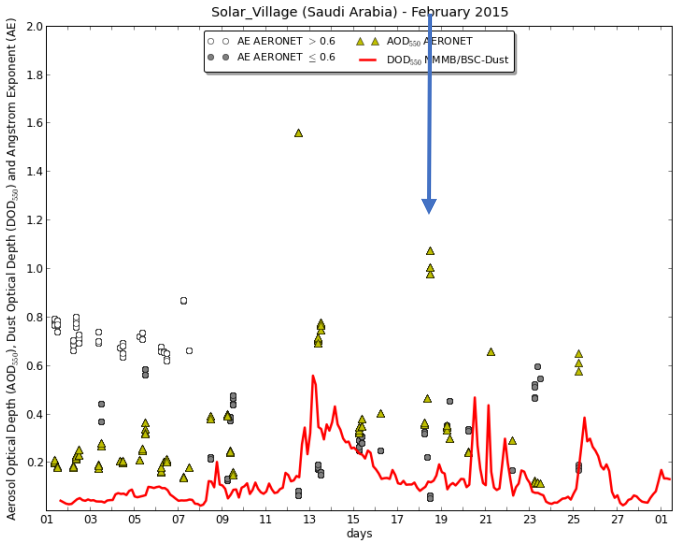


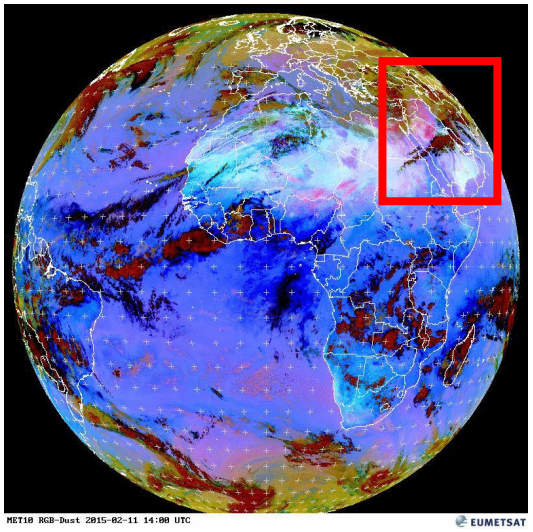


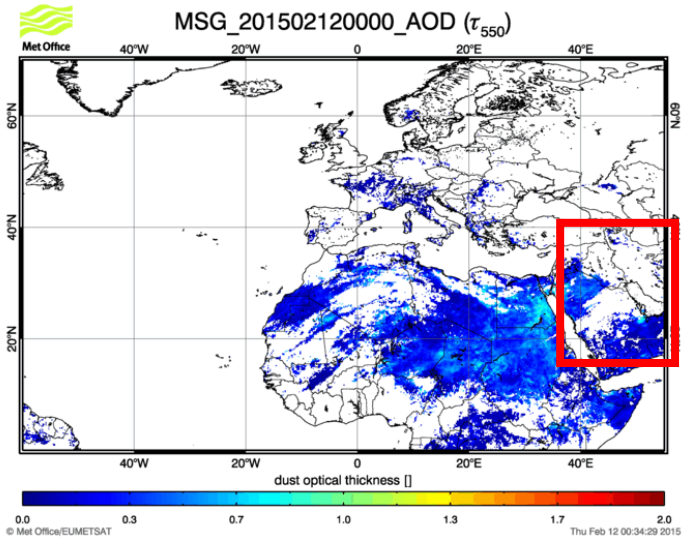
http://dust.aemet.es/

BDFC: Dust event Middle East Feb 2015



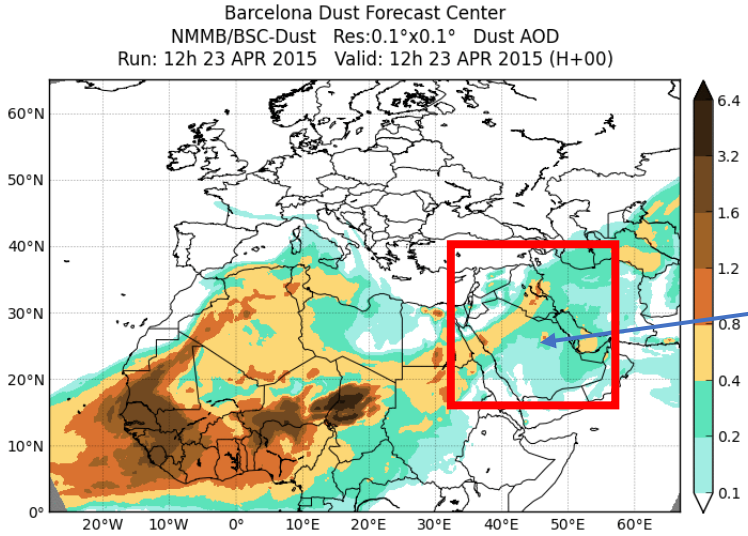


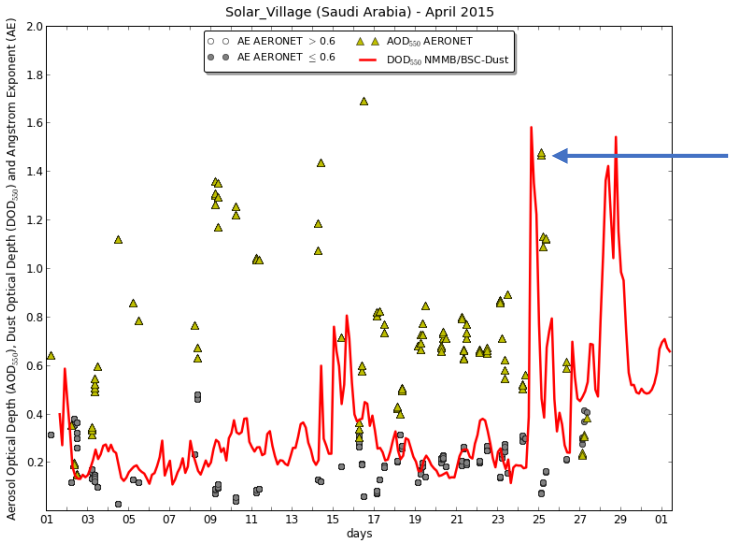


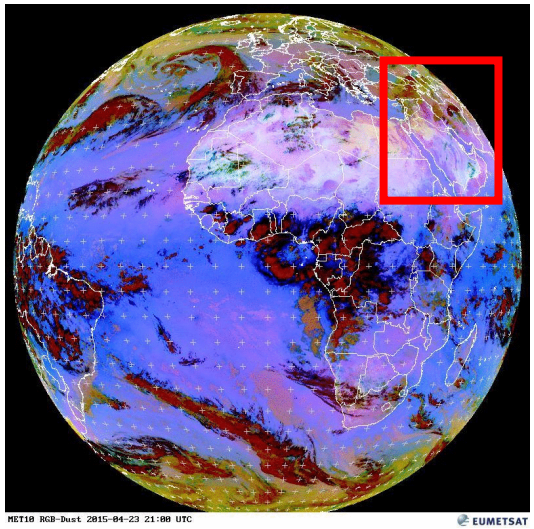


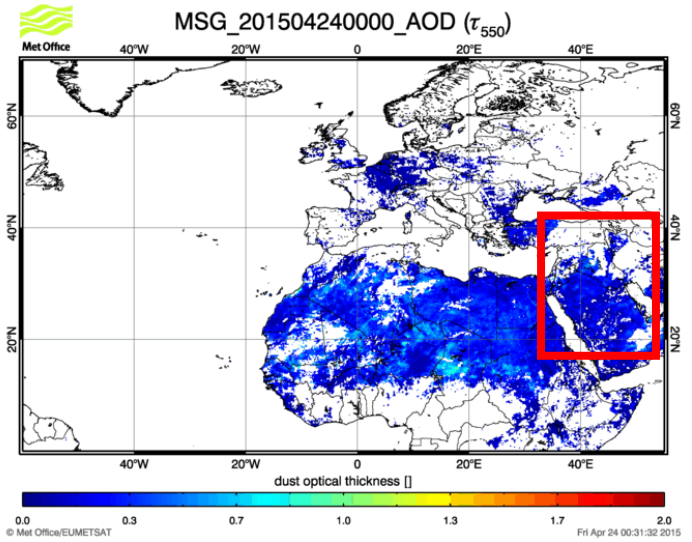
http://dust.aemet.es/

BDFC: Dust event Middle East Apr 2015









http://dust.aemet.es/

Summary

Ongoing **NMMB/BSC-Dust** model developments to improve the quality of daily dust forecast includes:

- Data assimilation of satellite aerosol products for mineral dust analysis
- Exploration of the advantages of the high-resolution simulations (> 4km spatial horizontal resolution) $\rightarrow$ Dust sources, haboobs and complex terrains

Ongoing activities of the **WMO Dust Centers** includes:

- **Dust model evaluation** including data from satellites, and lidar, Sun-photometer and in-situ networks covering multiple time-scales
- Increased education and awareness to promote the information and forecasts that are publically and freely available
- Establishment of appropriate communication channels for the dissemination of interpreted dust forecasts at a frequency that enables preparedness (i.e. through weather news networks, text message alerts)

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

GOBIERNO DE ESPAÑA
MINISTERIO DE MEDIO AMBIENTE Y MEDIO RURAL Y MARINO
AEMet Agencia Estatal de Meteorología
World Meteorological Organization

Thank you

Acknowlegde to Carlos Pérez García-Pando, Emilio Cuevas, Slodoban Nickovic, Francesco Benincasa, Gerardo García-Castrillo, Enza DiTomaso, Oriol Jorba, Kim Serradell, Enric Terradellas as well as AERONET, MODIS, U.K. Met Office MSG, MSG Eumetsat and EOSDIS World Viewer principal investigators and scientists for establishing and maintaining data used in the present contribution. Also special thank to all researchers, data providers and collaborators of the WMO SDS-WAS NA-ME-E Regional Node.

sara.basart@bsc.es

Mineral Dust Modelling

Historical evolution