Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

Modeling the dust cycle at BSC

From R&D to operational forecast

Sara Basart (sara.basart@bsc.es)

C. Pérez García-Pando, O. Jorba, E. Di Tomaso, E. Terradellas, G. García-Castrillo, F. Benincasa and K. Serradell

7th Training Course on WMO SDS-WAS Products, Ahvaz, Iran, 10-14 November 2018

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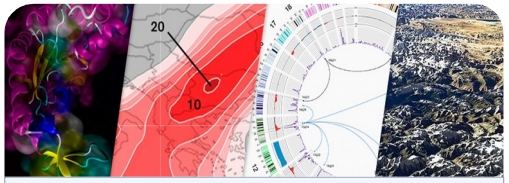
BSC-CNS objectives

Supercomputing services to Spanish and EU researchers



R&D in Computer, Life, Earth and Engineering Sciences

PhD programme, technology transfer, public engagement

BSC-CNS is a consortium that includes

Spanish Government	60%	Gobierno de España · Ministerio de Economía, Industria y Competitividad
Catalonian Government	30%	Generalitat de Catalunya, Departament d'Empresa i Coneixement
Univ. Politècnica de Catalunya (UPC)	10%	Universitat Politècnica de Catalunya, BarcelonaTech

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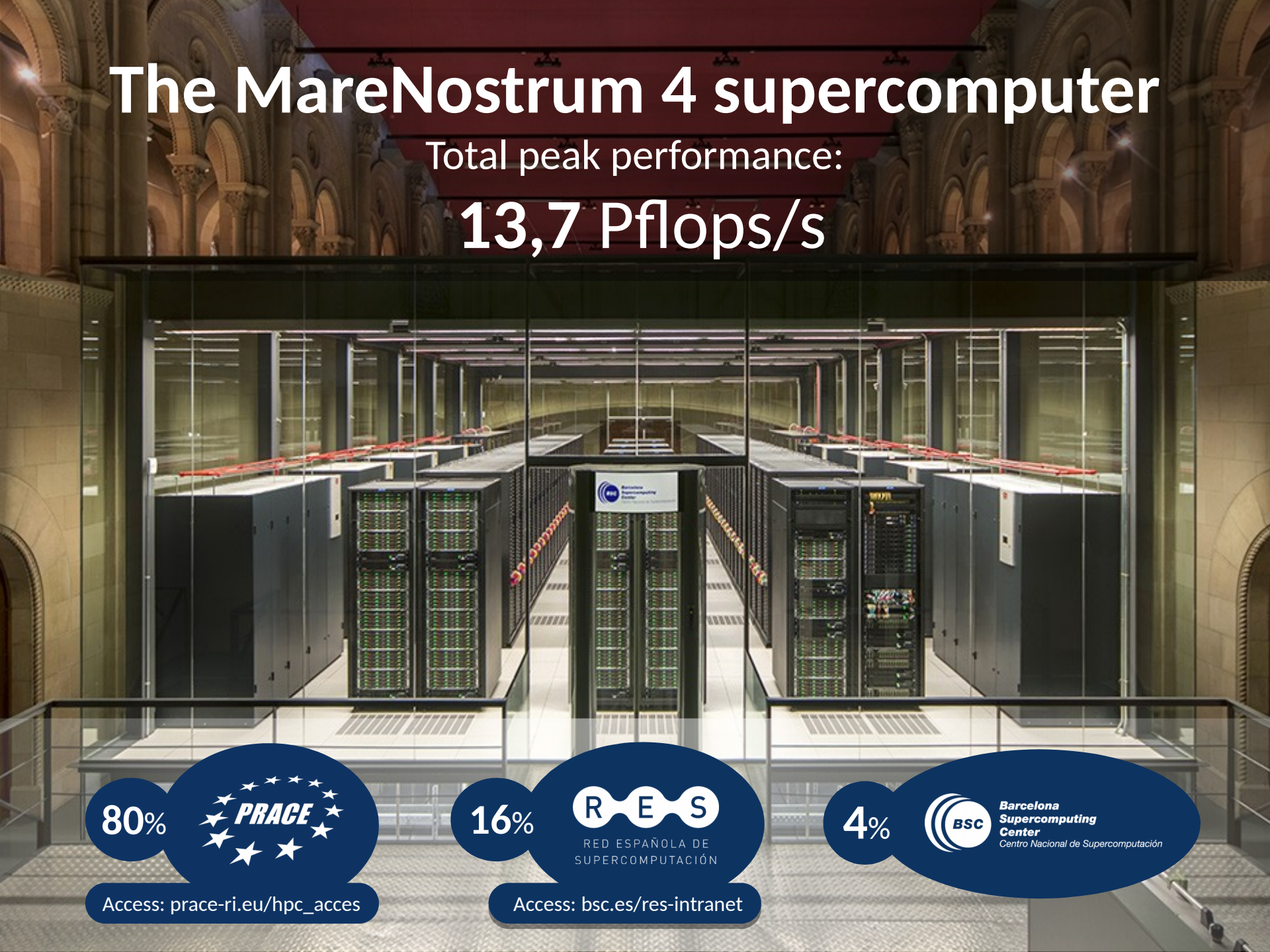
The MareNostrum 4 supercomputer

Total peak performance:

13,7 Pflops/s



80% PRACE

Access: prace-ri.eu/hpc_acces

16% RES RED ESPAÑOLA DE SUPERCOMPUTACIÓN

Access: bsc.es/res-intranet

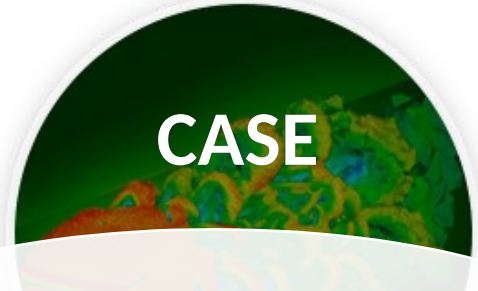
4% BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación

Mission of BSC Scientific Departments

To influence the way machines are built, programmed and used: programming models, performance tools, Big Data, computer architecture, energy efficiency

To develop and implement global and regional state-of-the-art models for short-term air quality forecast and long-term climate applications

To understand living organisms by means of theoretical and computational methods (molecular modeling, genomics, proteomics)



To develop scientific and engineering software to efficiently exploit super-computing capabilities (biomedical, geophysics, atmospheric, energy, social and economic simulations)

Earth Sciences Department

Environmental modelling and forecasting, with a particular focus on weather, climate and air quality

Modeling **air quality** and **Sand and Dust Storms** Processes from urban to Global and the impacts on weather, health and ecosystems

Research and Forecasts

Climate predictions system from subseasonal-to-decadal forecasts

AXA Research Fund

Service Users Sectors

Infrastructures

Solar Energy

Urban development

Transport

Wind Energy

Agriculture

Insurance

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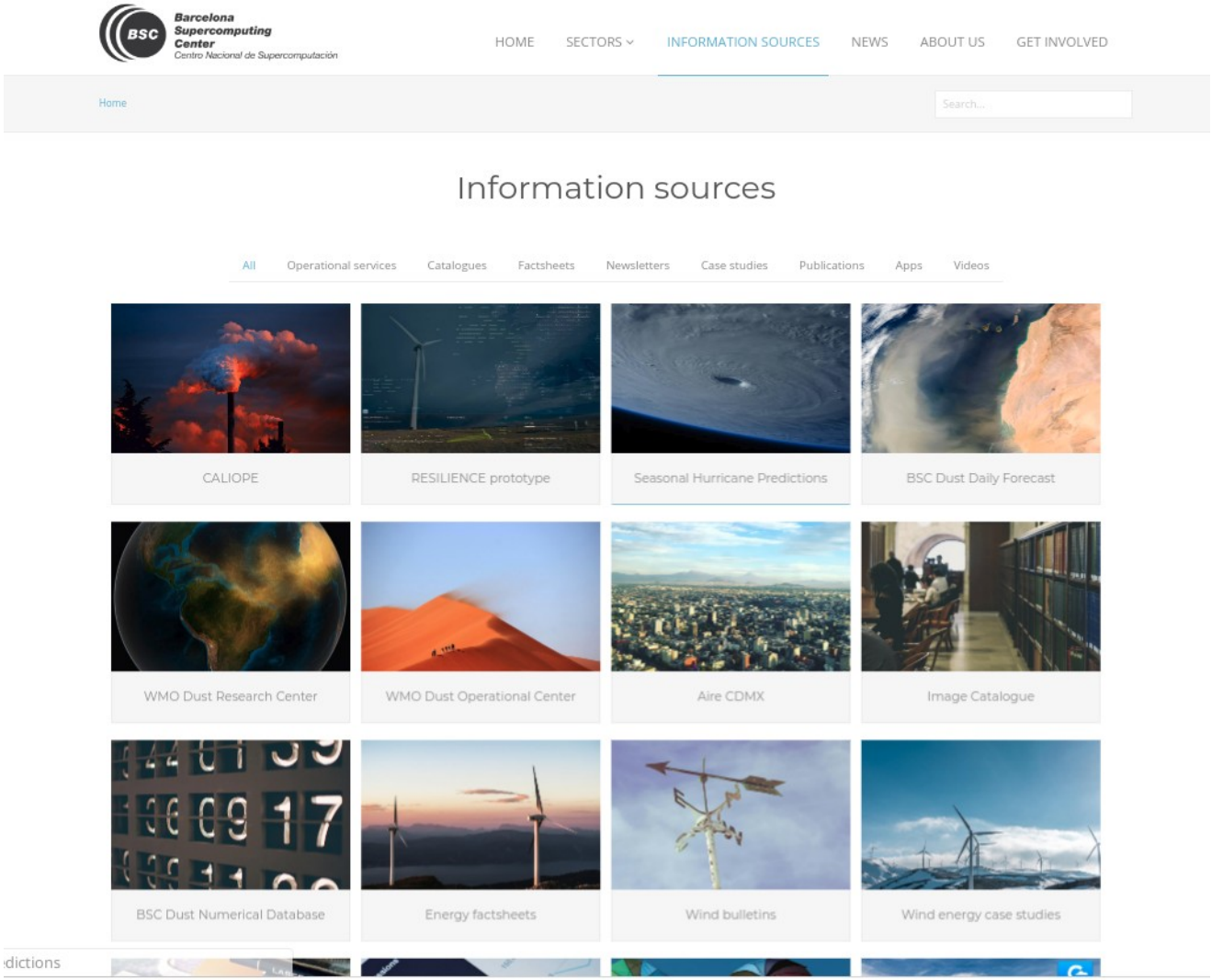
Earth Services



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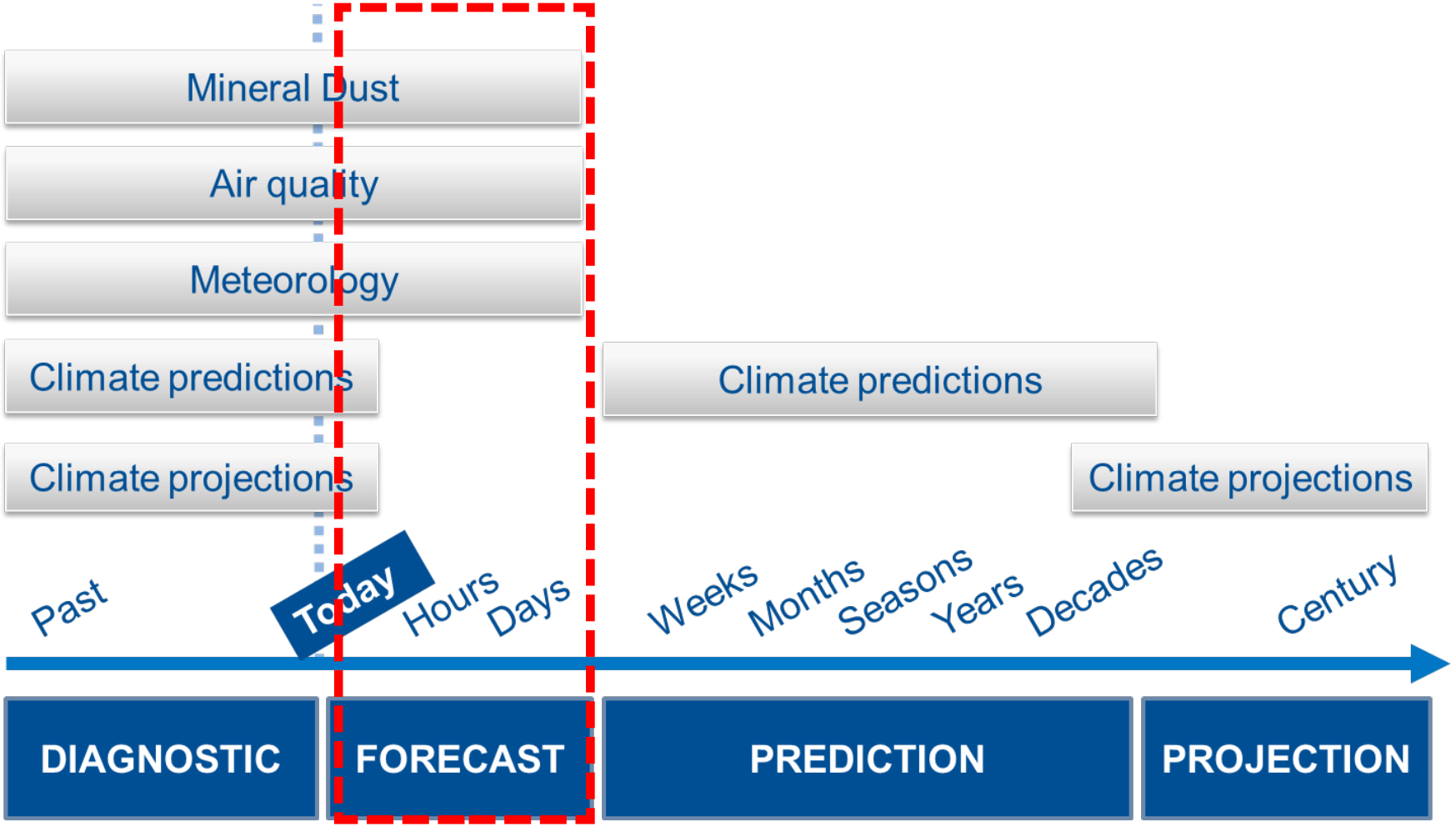
(www.bsc.es/ess/)

BSC Earth Sciences Department



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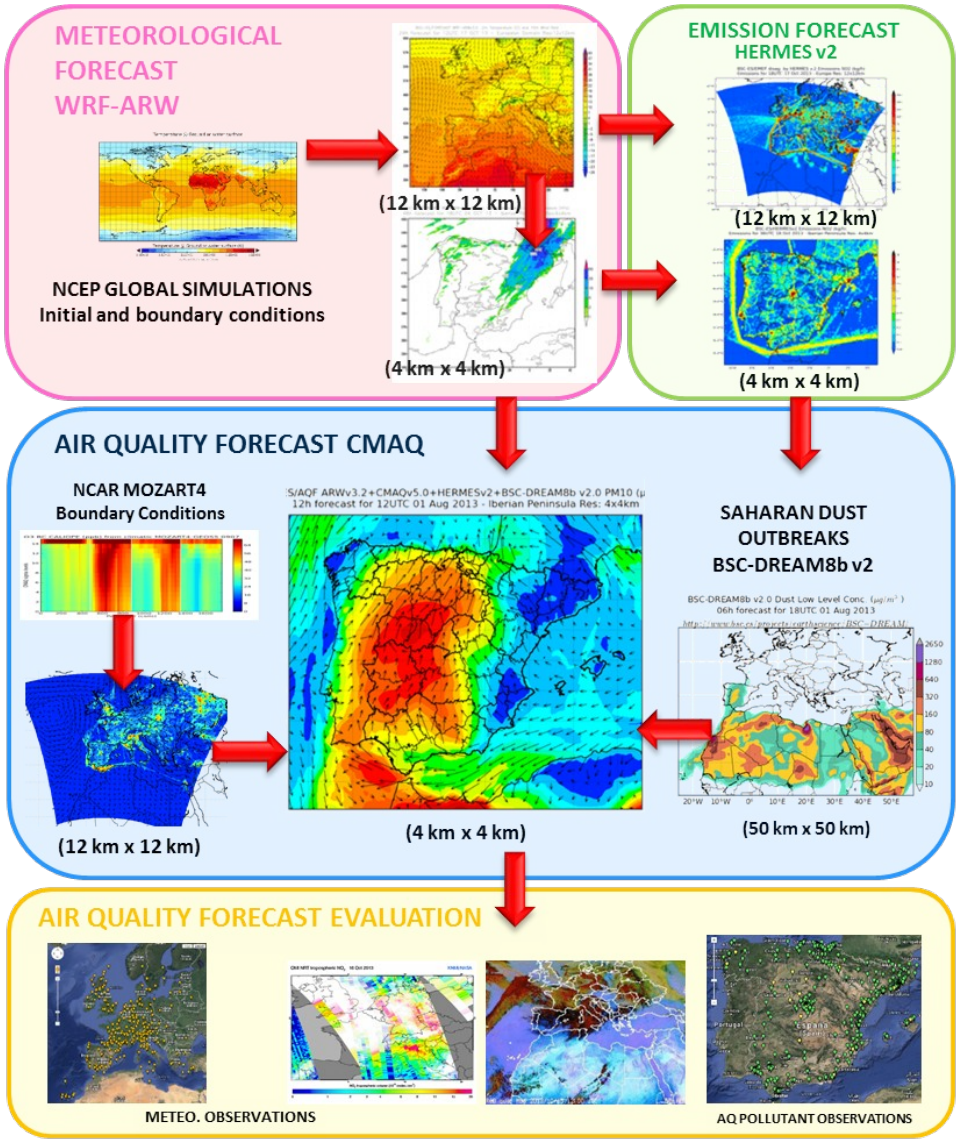
Short-term forecast

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)



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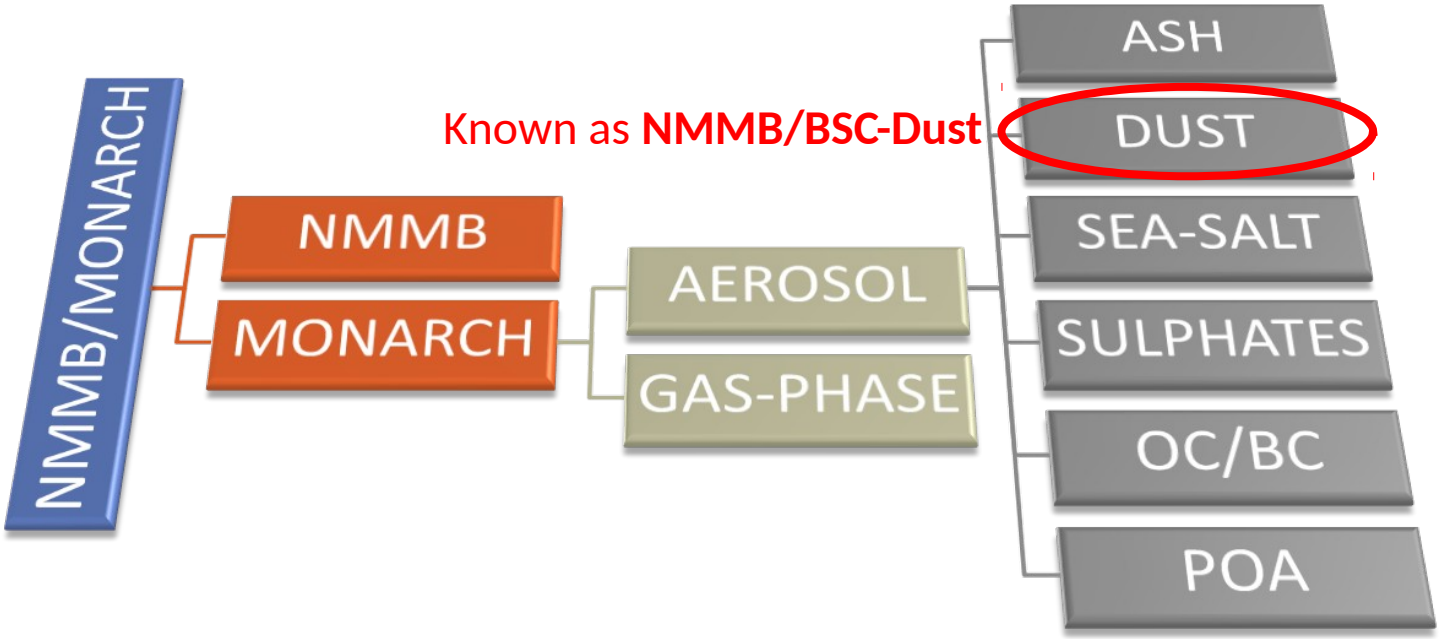
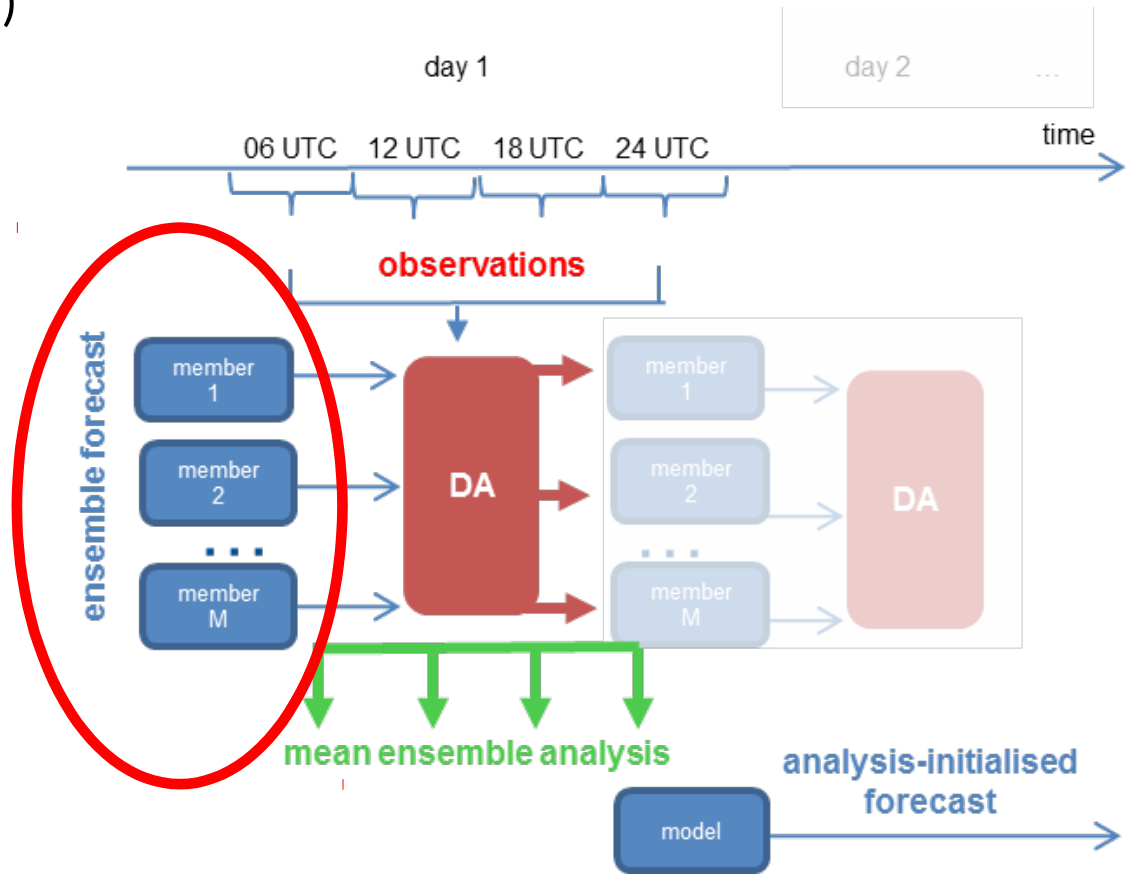
NMMB-MONARCH:
Atmospheric Composition and Air Quality

- 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



NMMB-MONARCH: Data Assimilation Ensemble perturbations

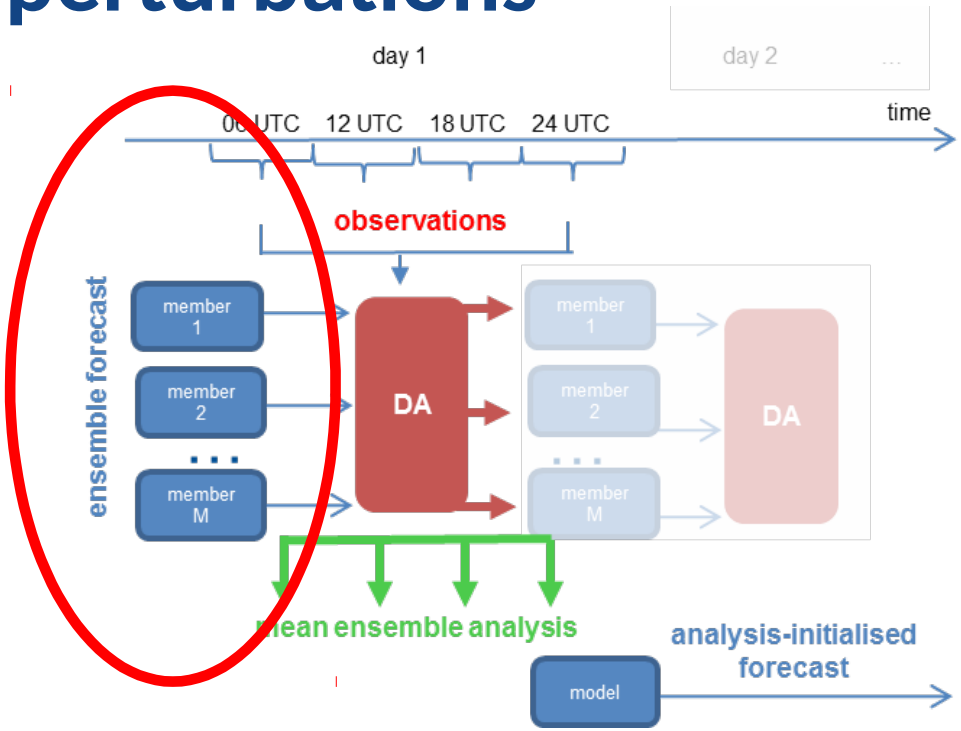
The implementation of the **ensemble forecast** is based on known uncertainties in the physical parametrizations of the dust scheme (*imperfect model scenario assumption*)



NMMB-MONARCH: Data Assimilation Ensemble perturbations

The ensemble forecast has been designed considering model uncertainties with respect to:

- **surface winds,**
- **soil humidity,**
- **vertical flux distribution at sources,**



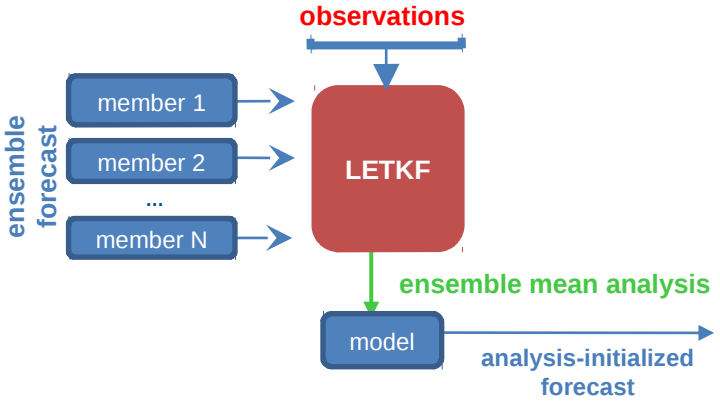
by perturbing:

1. the threshold friction velocity which is soil moisture-dependent, and determines the velocity above which the soil particles begin to move in horizontal saltation flux;

2. the vertical flux of dust in each of the eight dust transport bins

NMMB-MONARCH: Data Assimilation

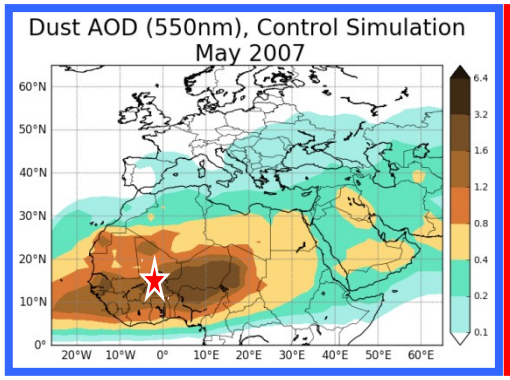
NMMB-MONARCH coupled with a Local Ensemble Transform Kalman Filter (**LETKF**) for the assimilation of aerosol optical depth observations

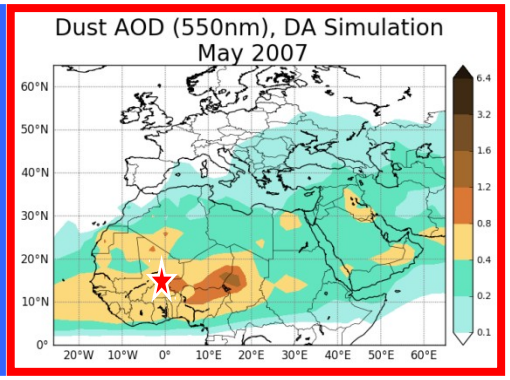


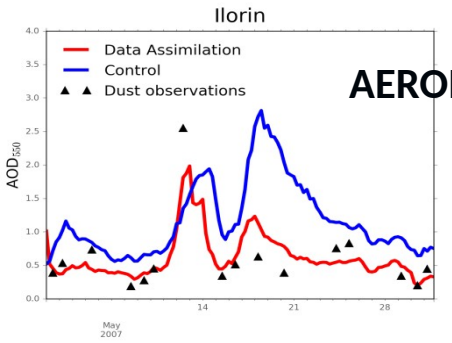
Mineral dust application
The ensemble forecast is based on uncertainties in the dust emission scheme

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

(DiTomaso et al., GMD, 2016)





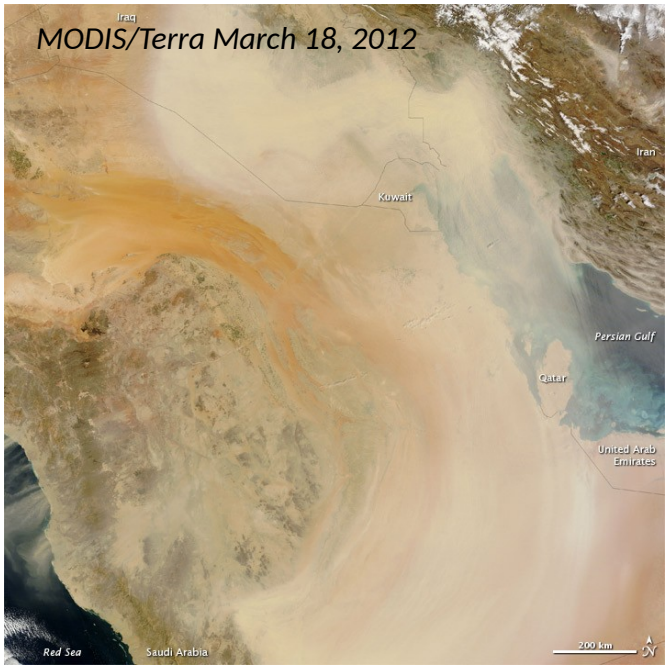


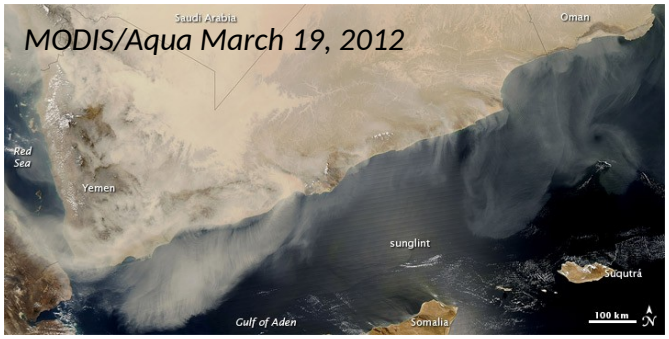
AERONET Validation

Mineral Dust modelling: Topography

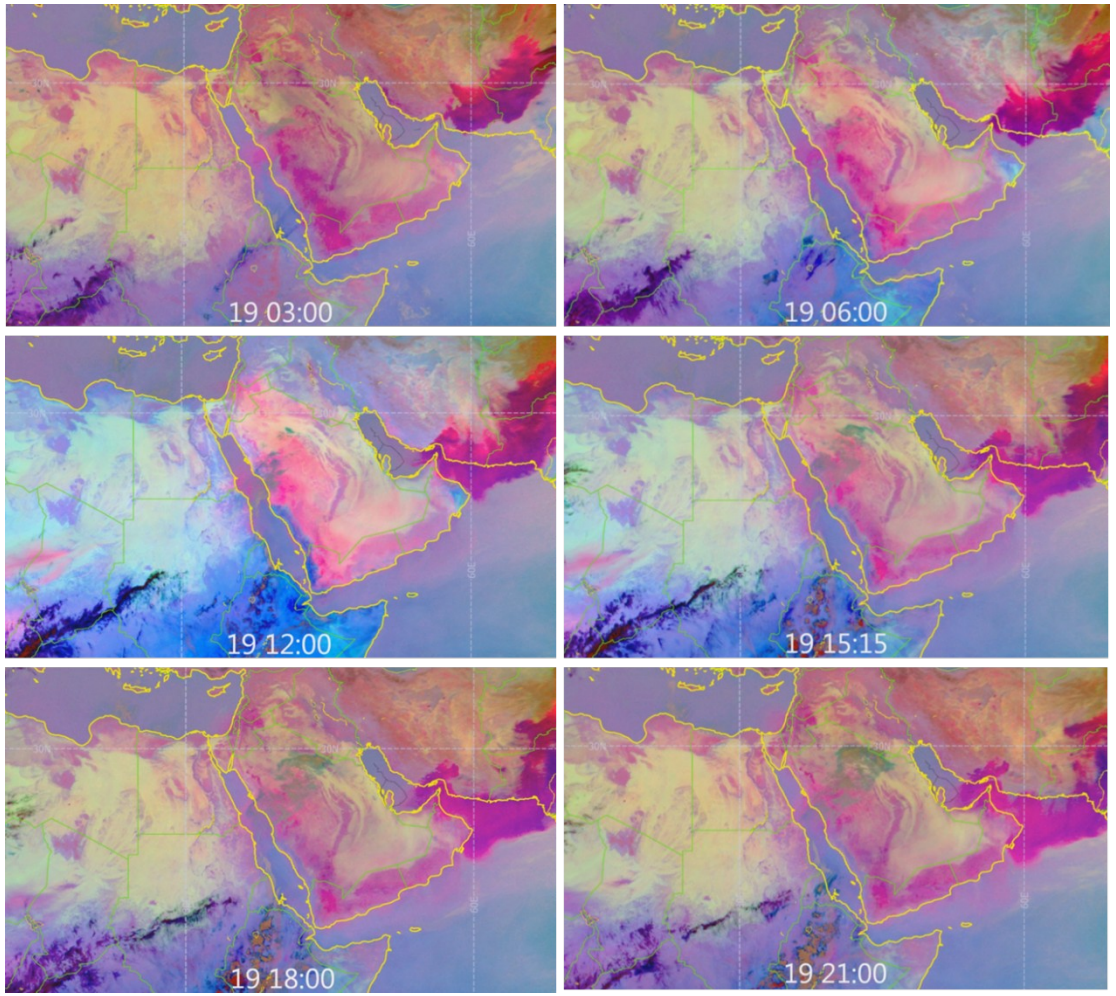
Mineral Dust modelling: Topography

Impact of the topography on dust transport



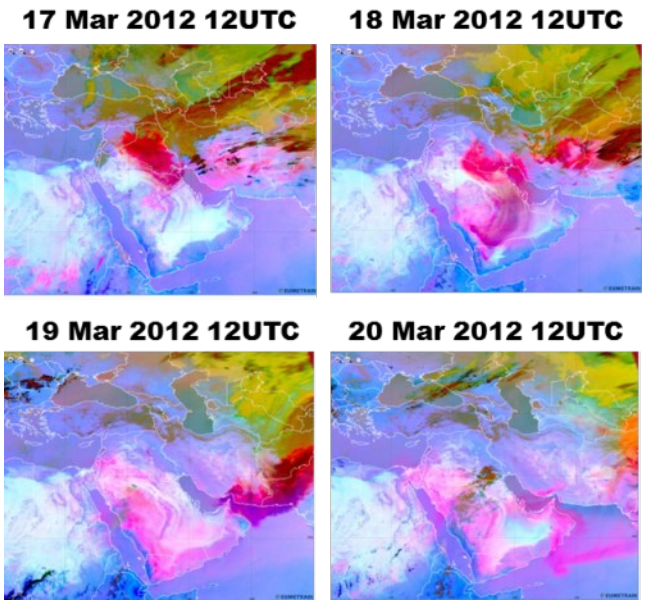


MSG/RGB March 19, 2012

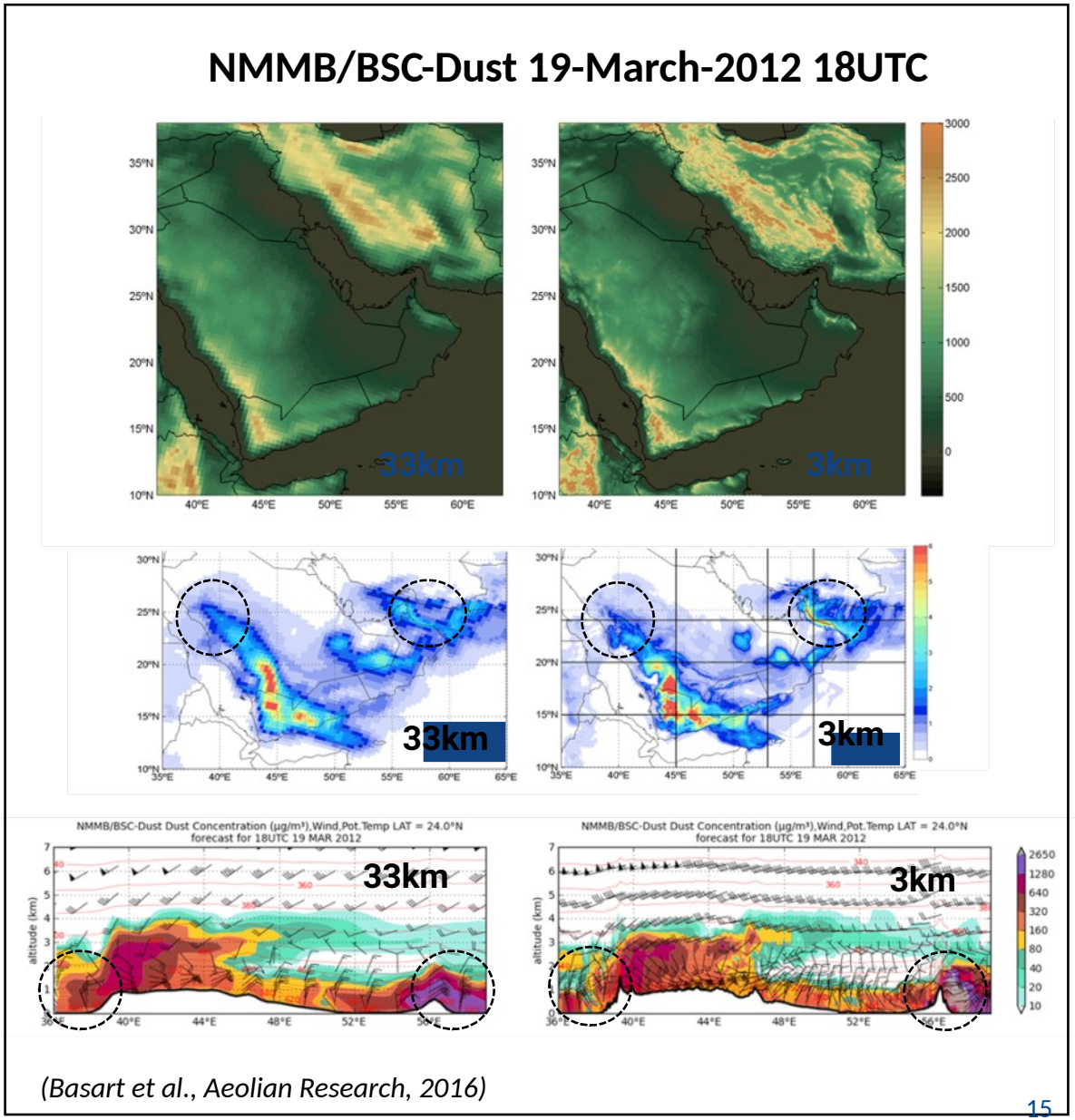


(Basart et al., Aeolian Research, 2016)

Mineral Dust modelling: Topography

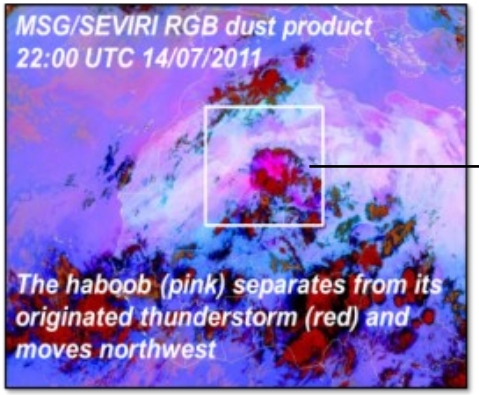


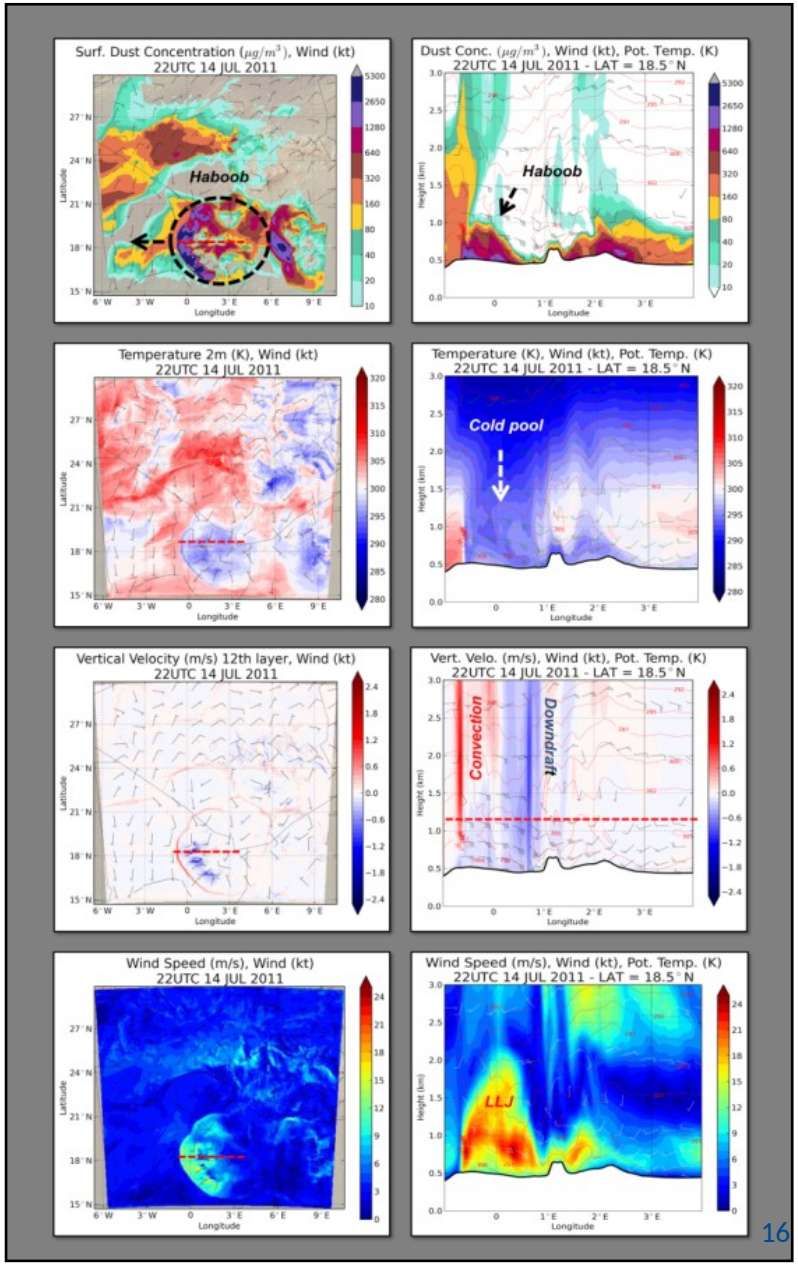
Two simulations using the **NMMB/BSC-Dust** model demonstrates results demonstrate how the dust prediction in the vicinity of complex terrains improves using high-horizontal resolution simulations.



(Basart et al., Aeolian Research, 2016)

Mineral Dust modelling: Haboobs





MODEL CONFIGURATION
Study domain: *6°W-10°E to 15°N-31°N*
Study period: *from 14 to 15 July 2011*
Horizontal resolution: *0.03°x0.03° (about 3 km)* → ***allowing explicit convection***
Vertical resolution: *60σ-layers (12-15σ-layers in the first 1000 m)*
Cold start *(No data assimilation)*

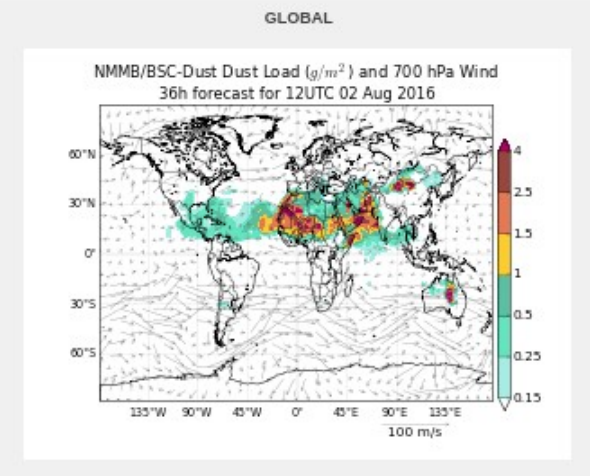
(Vendrell et al., in preparation)

Mineral dust Services

BSC dust operational forecast (global and regional domains)

http://www.bsc.es/ESS

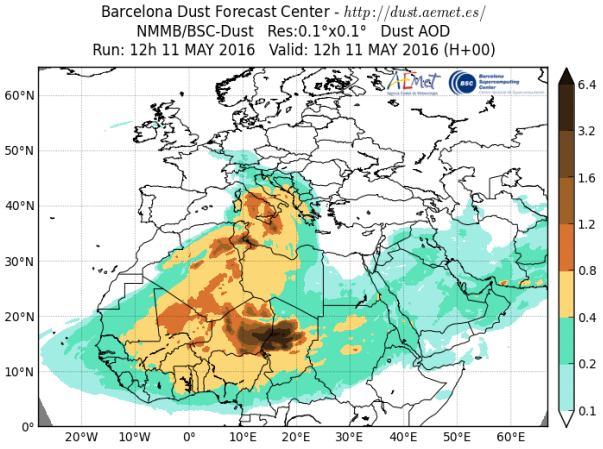
✓ *Contribution to the **ICAP** multi-model ensemble (global) http://icap.atmos.und.edu*



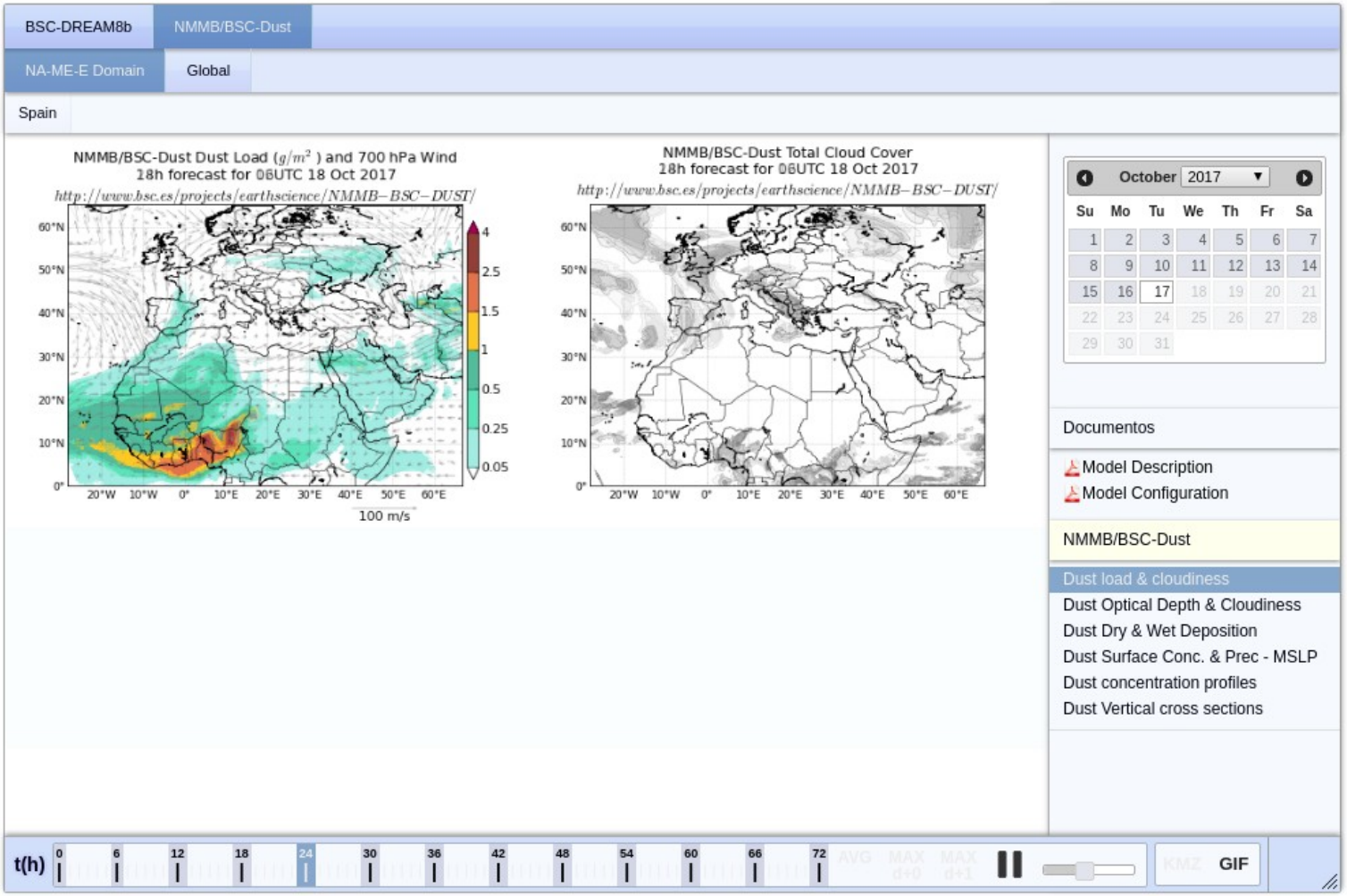
WMO Dust Centers

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

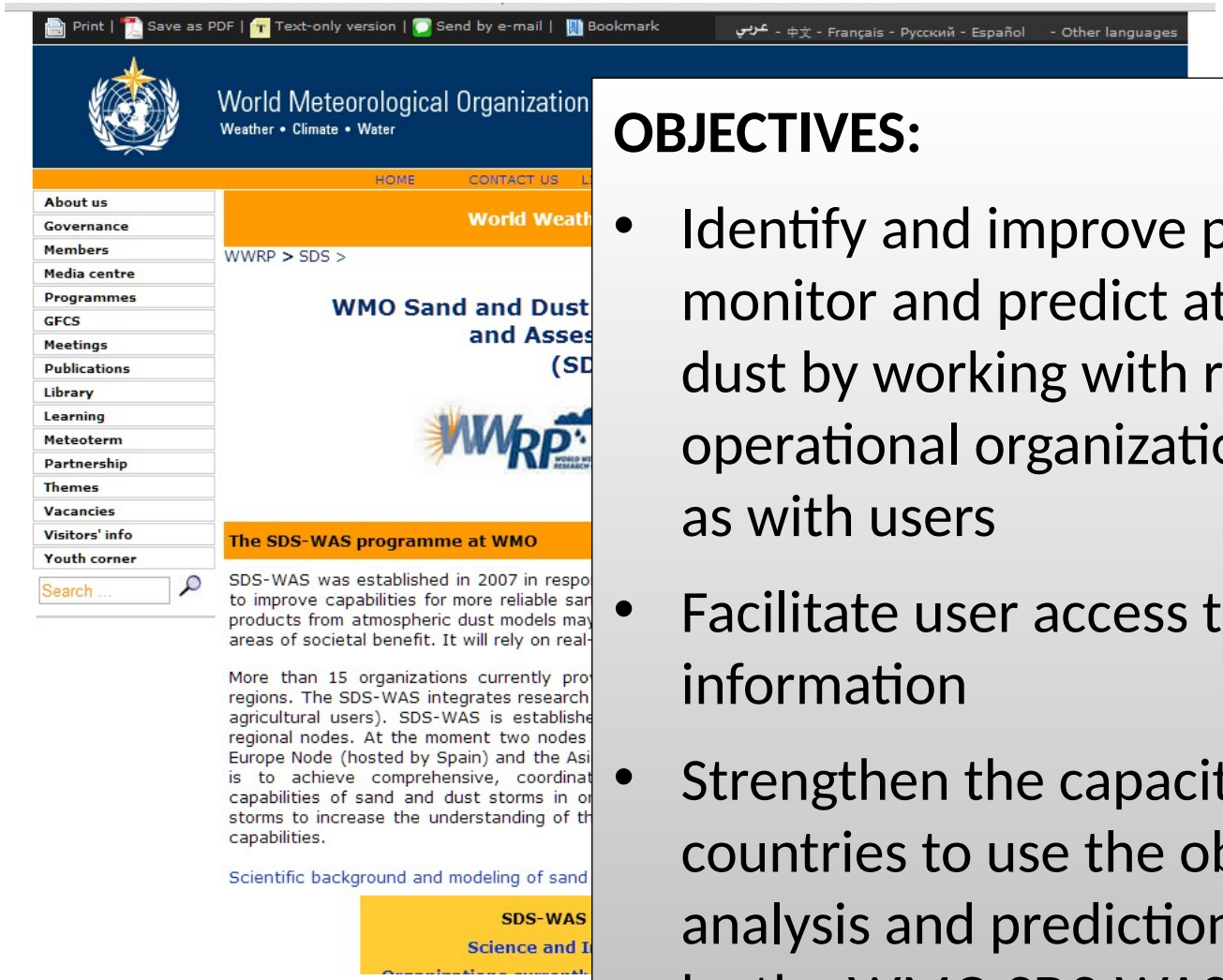


BSC dust operational forecast



http://www.bsc.es/ESS

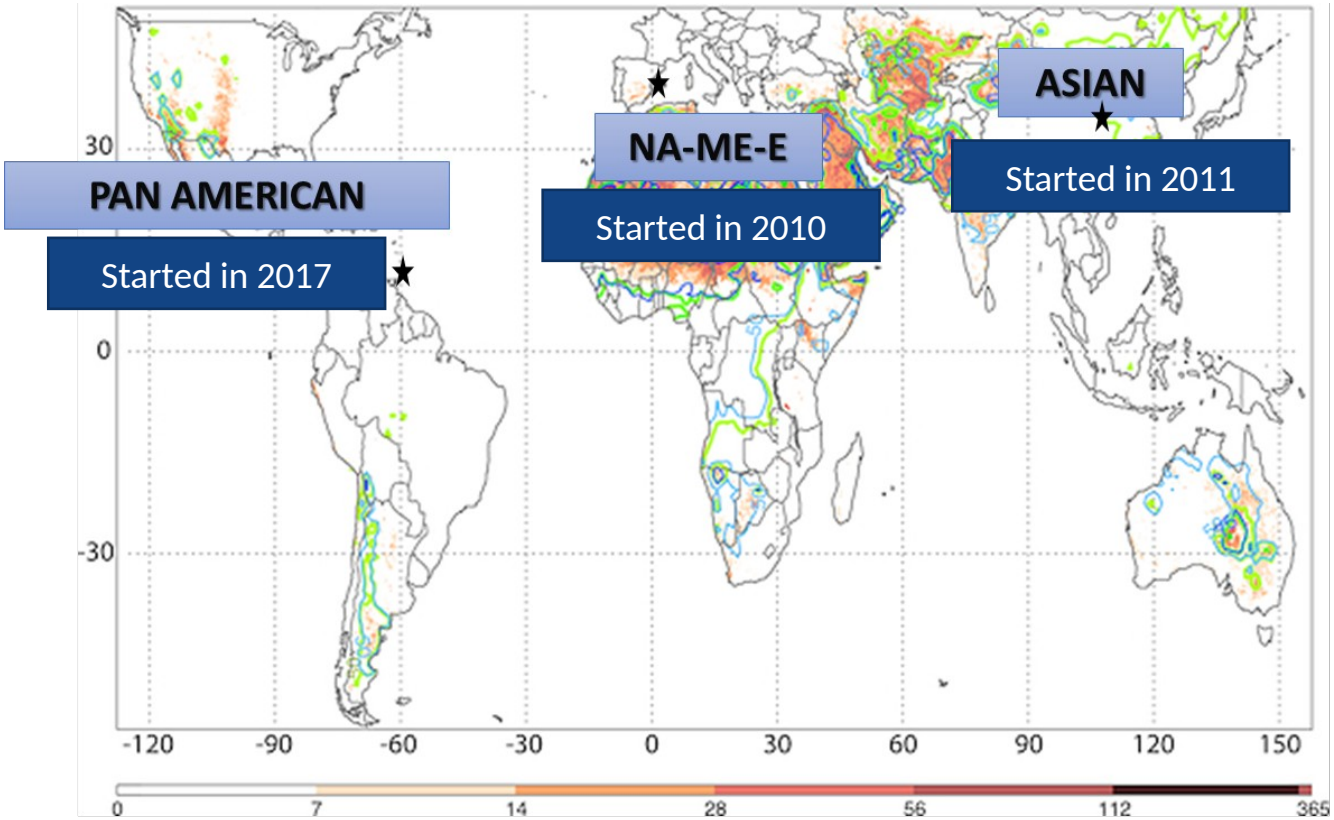
The WMO SDS-WAS project



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

SDS-WAS and the Regional Nodes/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.)

WORLD METEOROLOGICAL ORGANIZATION

SDS-WAS NAMEE RC

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-D			
NASA-GEOS-5			
NCEP-NGAC			
DREAMABOL			
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.

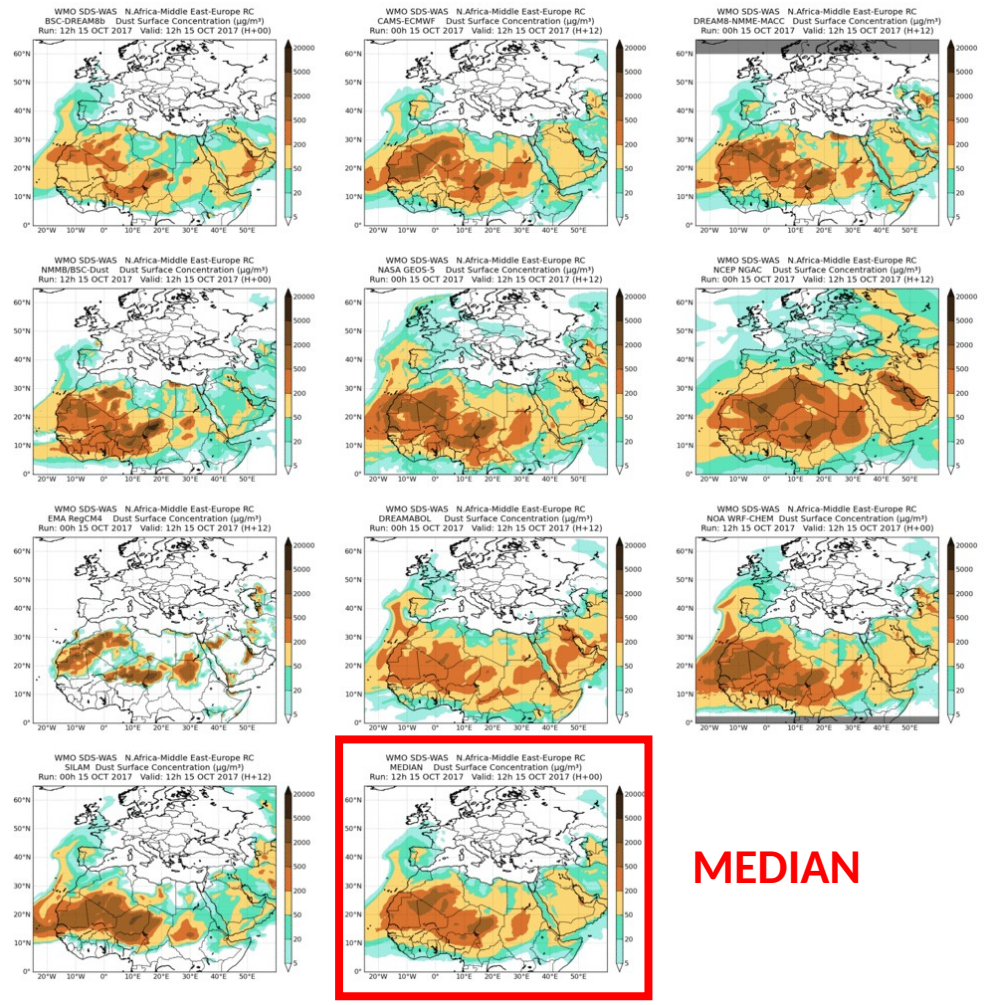
Needed registered user!

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

SDS-WAS Multi-model

SDS-WAS product

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



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

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Agencia Estatal de Meteorología

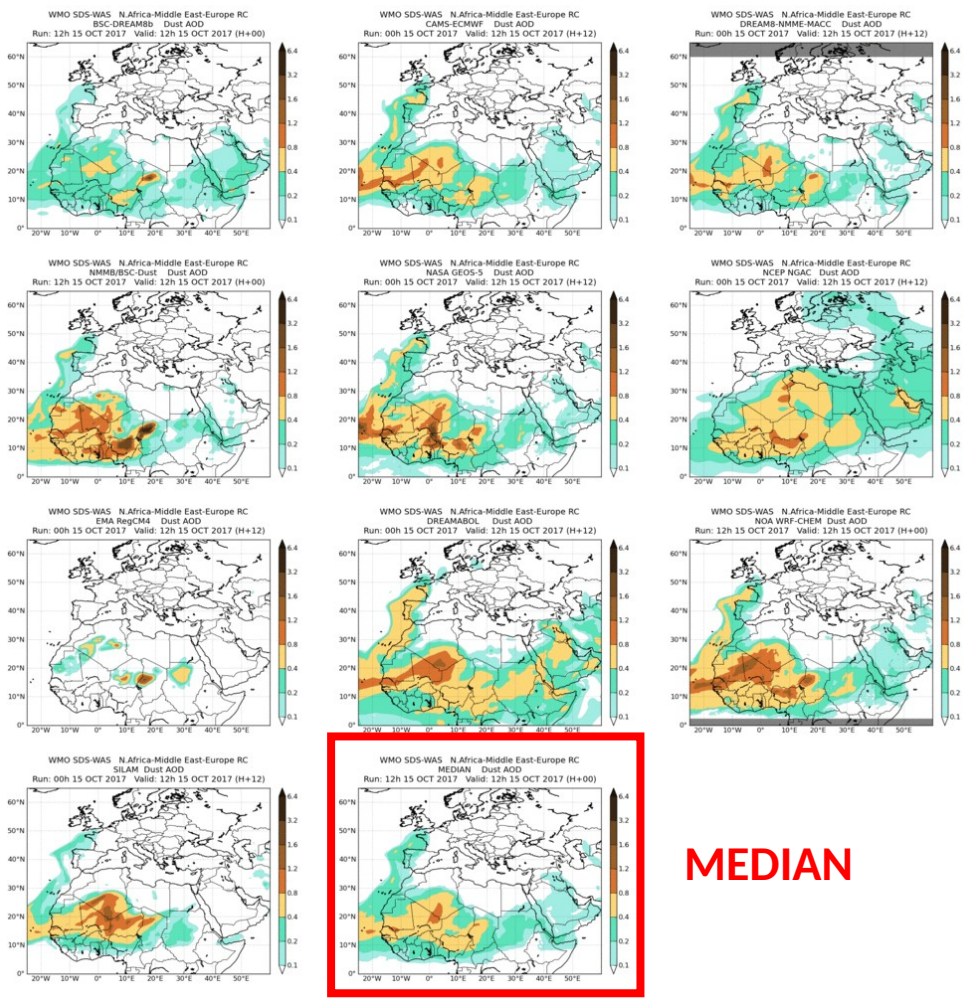
http://sds-was.aemet.es/

SDS-WAS Multi-model

SDS-WAS product

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

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

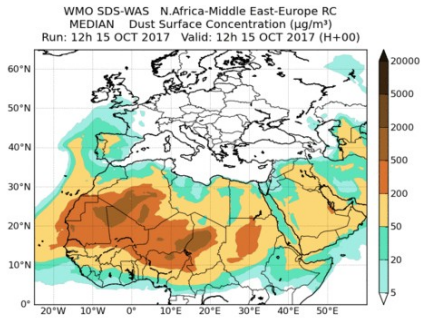


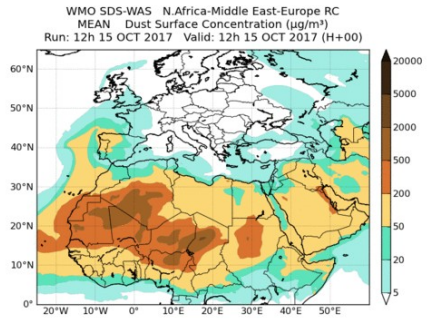
MEDIAN

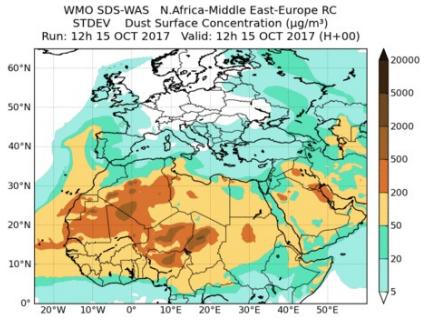
http://sds-was.aemet.es/

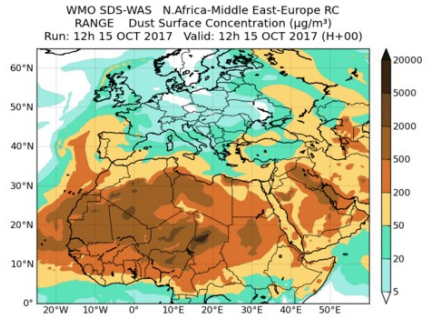
SDS-WAS NAMEE: Multi-model

Surface concentration

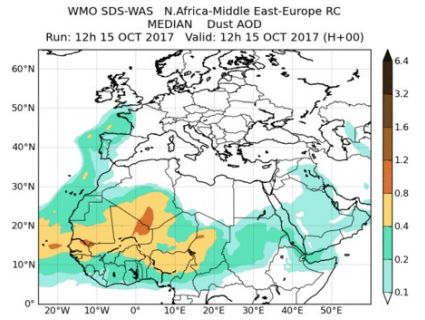


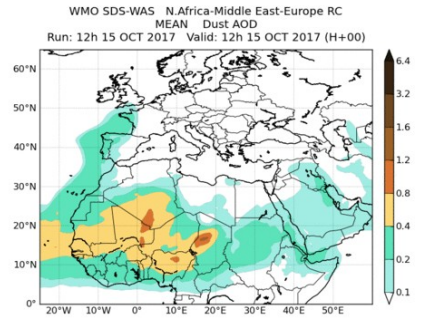


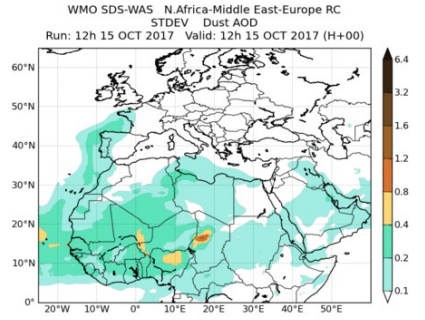


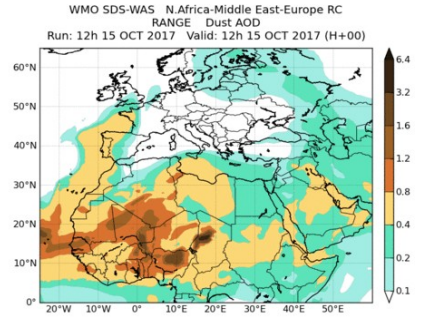


Dust AOD at 550nm









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

Model outputs are bi-linearly interpolated to a common 0.5°x0.5° grid mesh. Then, different multi-model products are generated:

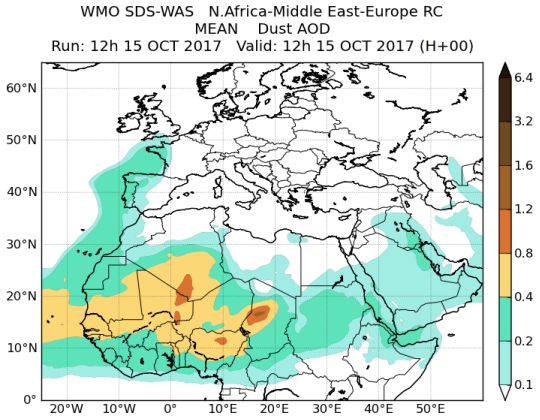
CENTRALITY: median - mean

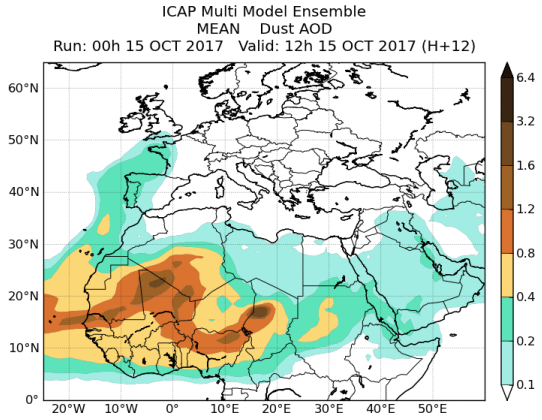
SPREAD: standard deviation – range of variation

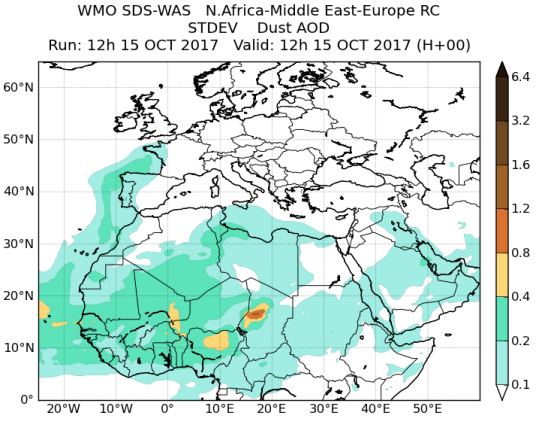
SDS-WAS NAMEE: Multi-model - ICAP

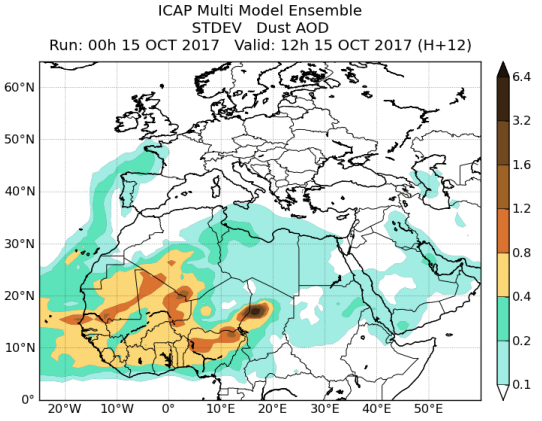
Only global models!

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





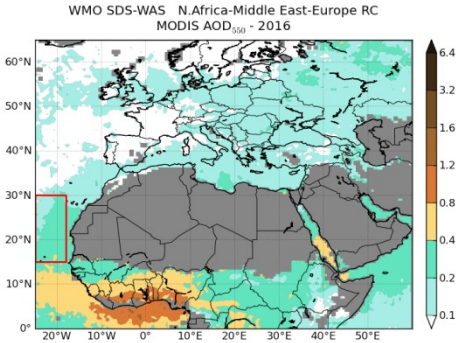




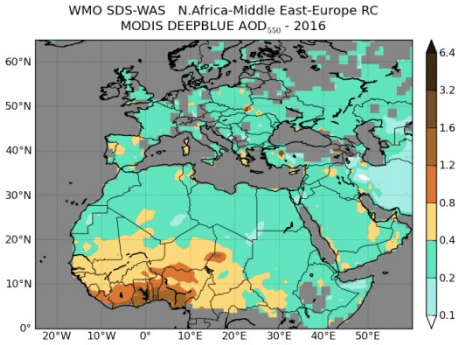
SDS-WAS NAMEE: DOD Model Evaluation

- **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

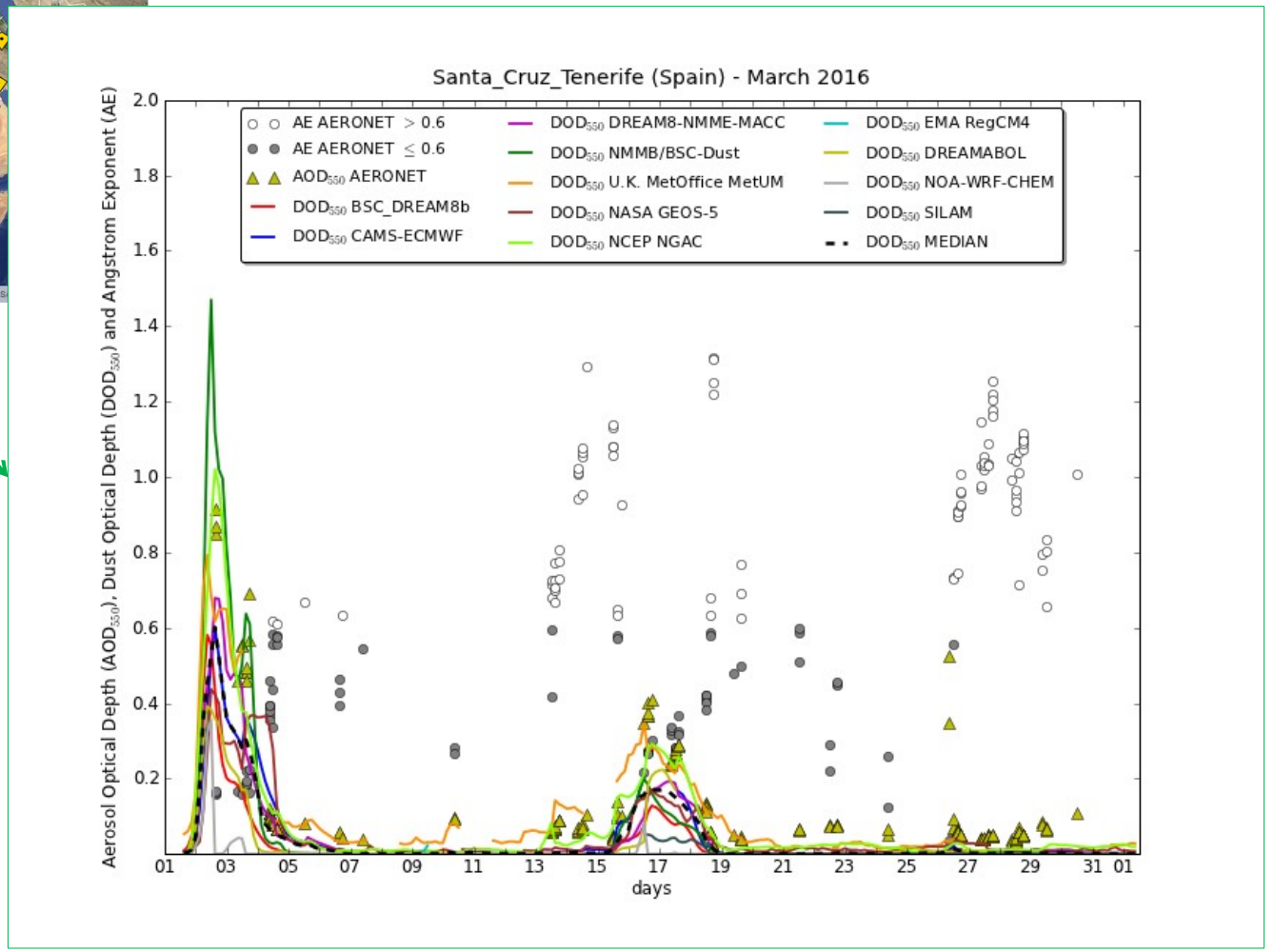


- **Evaluation of dust models with MODIS Deep Blue retrievals**
  - Evaluation scores monthly/seasonal/annual



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

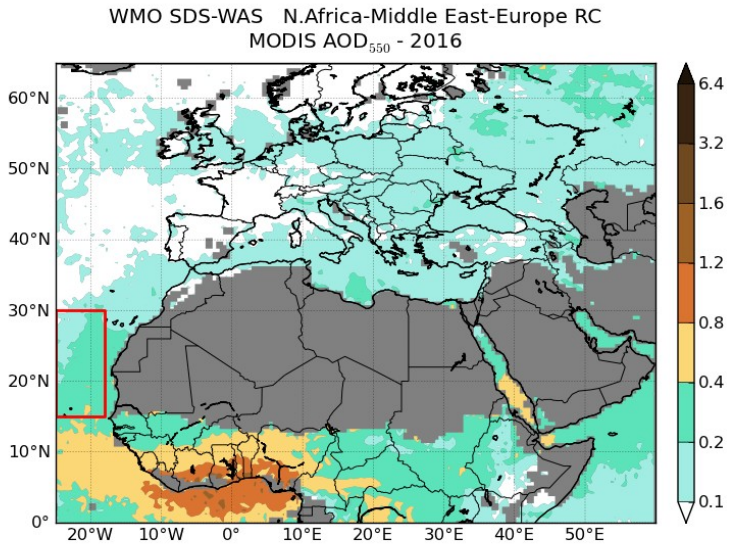
ROOT MEAN SQUARE ERROR

	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

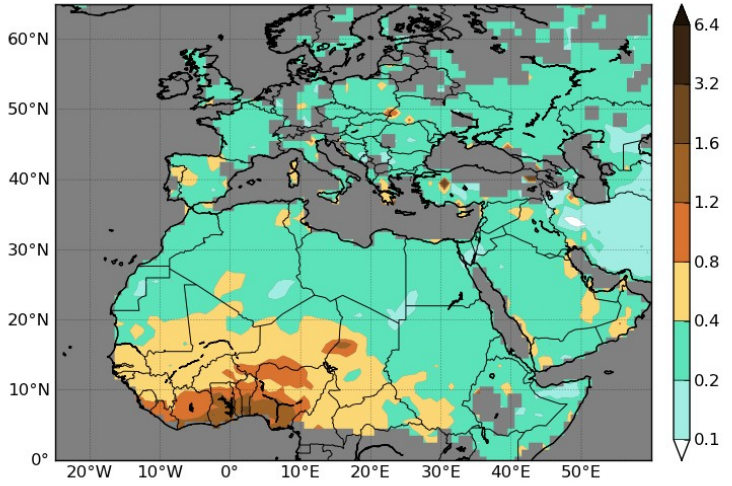
CORRELATION COEFFICIENT

	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



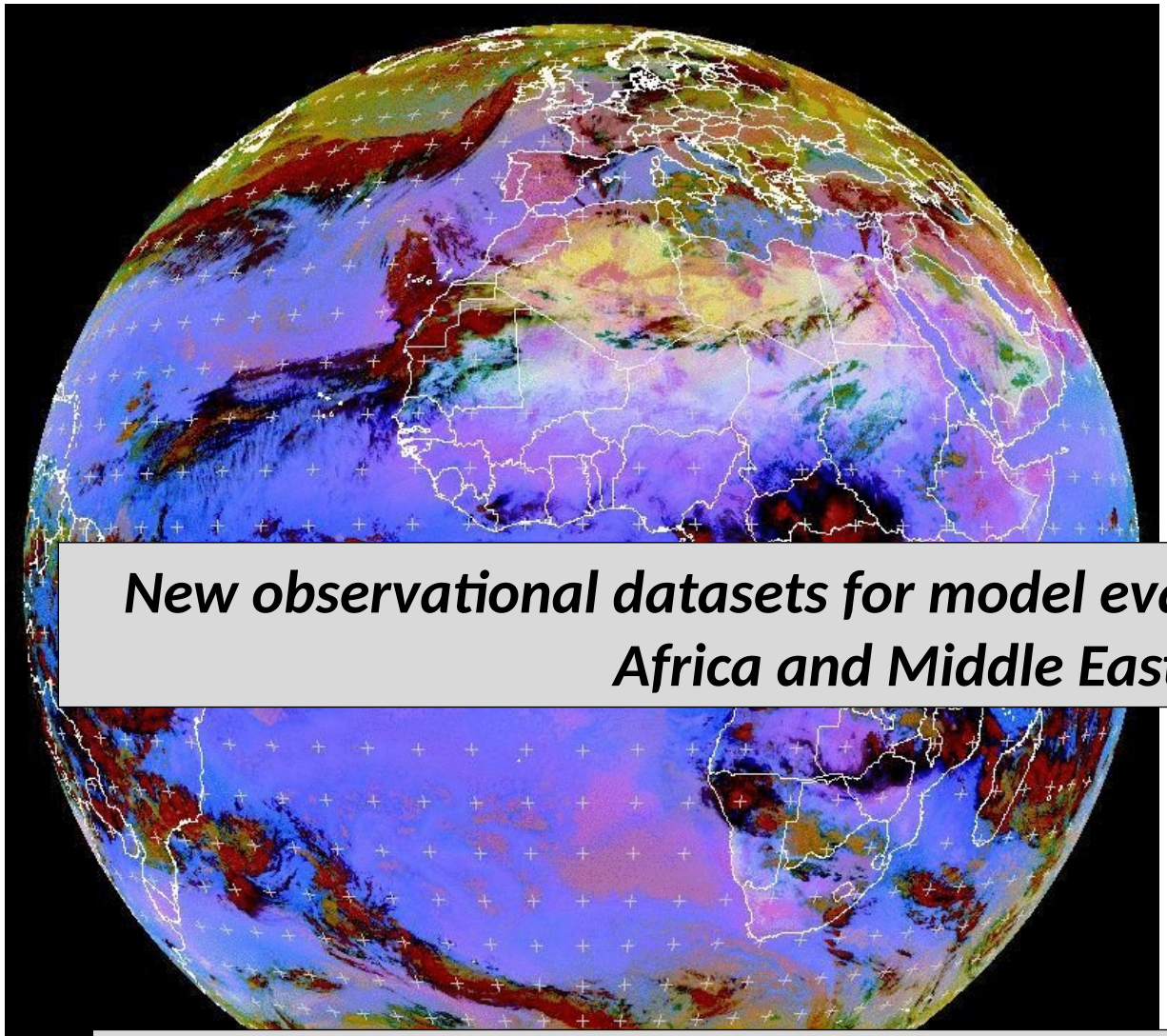
	BIAS	ROOT MEAN SQUARE ERROR	CORRELATION COEFFICIENT	FRACTIONAL GROSS ERROR	NUMBER OF CASES
BSC_ DREAM8b	-0.16	0.26	0.70	0.97	18493
NMMB/BSC-Dust	-0.11	0.22	0.72	0.83	18293
NCEP NGAC	0.08	0.21	0.79	0.51	18465
EMA RegCM4	0.03	0.35	0.34	1.11	8039
DREAMABOL	-0.06	0.27	0.51	0.84	17834
NOA-WRF-CHEM	-0.00	0.18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

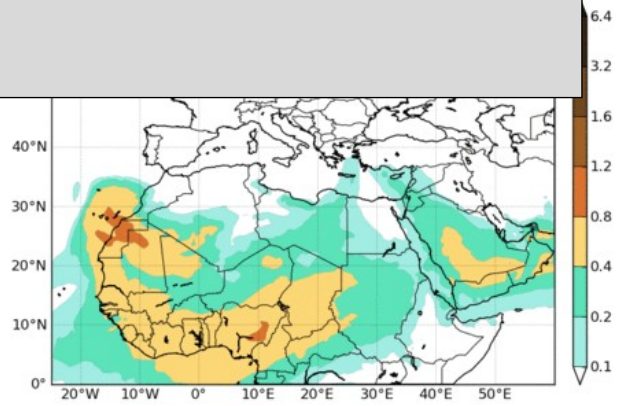
SDS-WAS NAMEE: Model Evaluation



EUMETSAT

7 March 2015

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

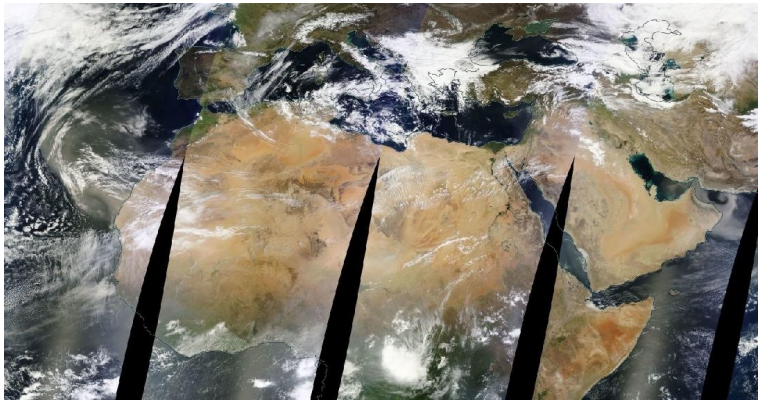


NOTE: There is available an historical archive of the MSG RBG dust products.

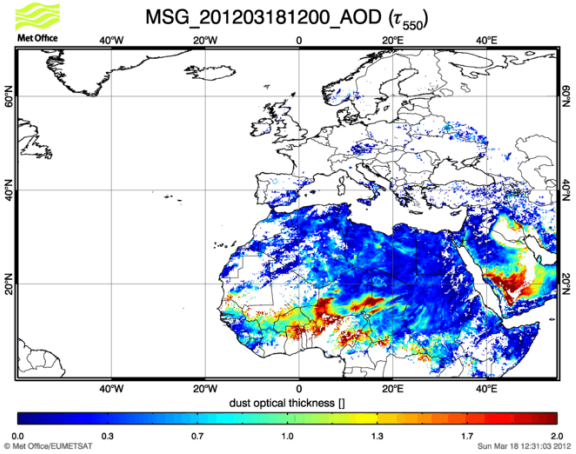
SDS-WAS NAMEE: Model Evaluation

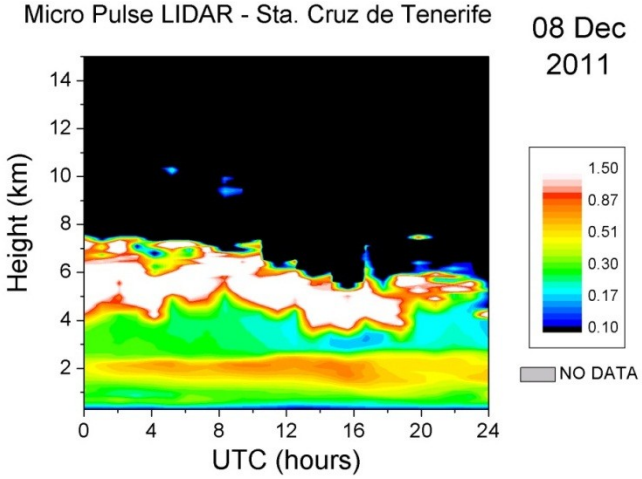
New observational datasets for model evaluation in Northern Africa and Middle East

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



MODIS composite 8th March 2015 from EOSDIS World Viewer





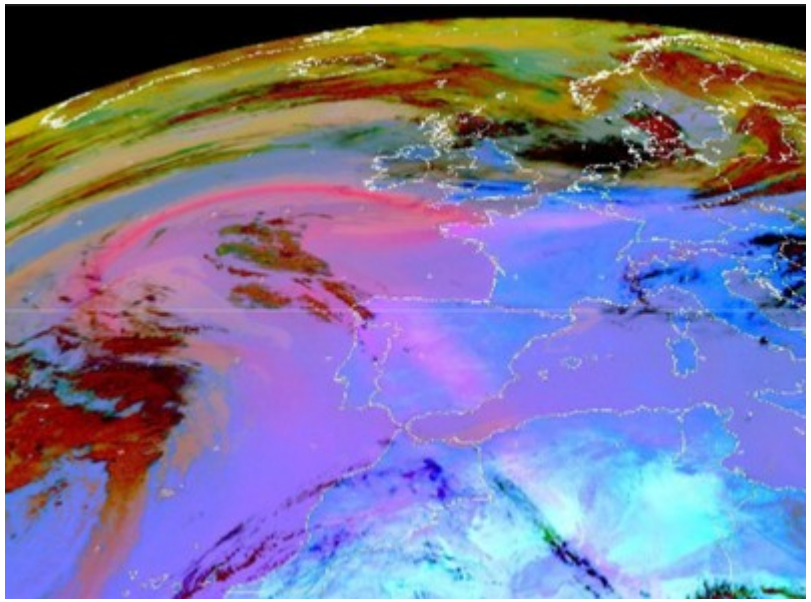
http://sds-was.aemet.es/

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Agencia Estatal de Meteorología

SDS-WAS NAMEE: Studies

Model Intercomparison: European dust outbreak on April 2011



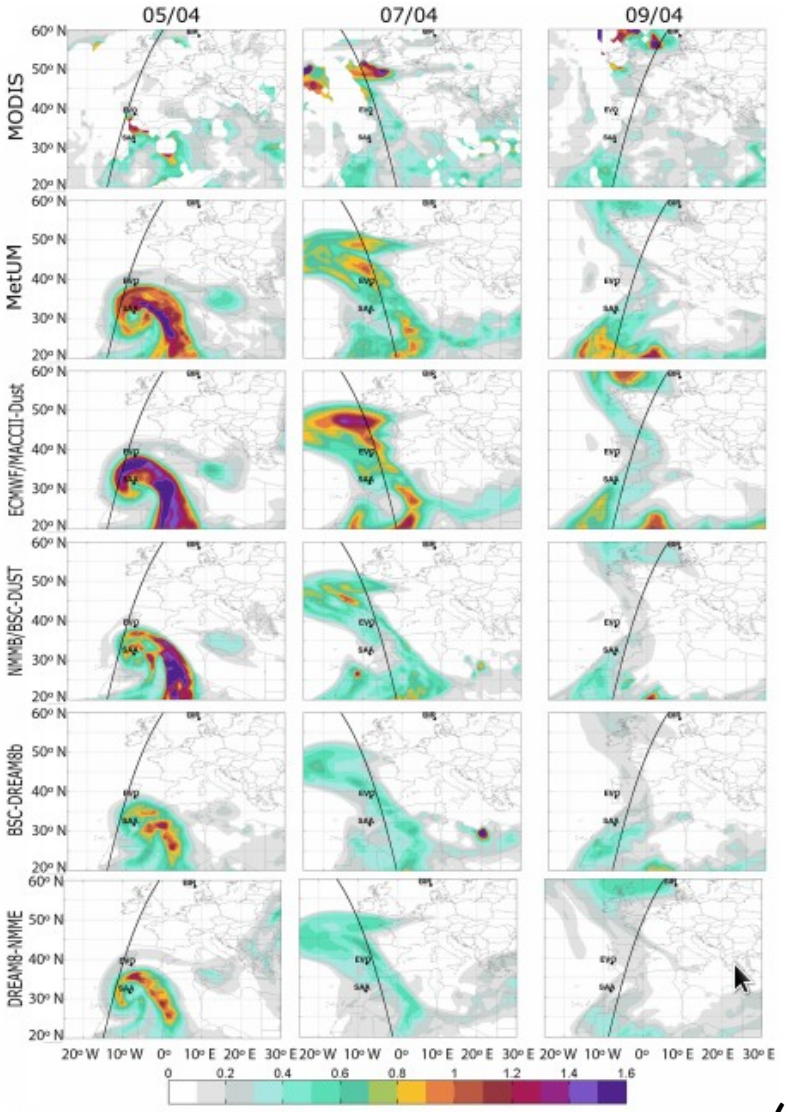
MSG/SEVIRI RGB product 7 April
Courtesy of EUMETSAT

- 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

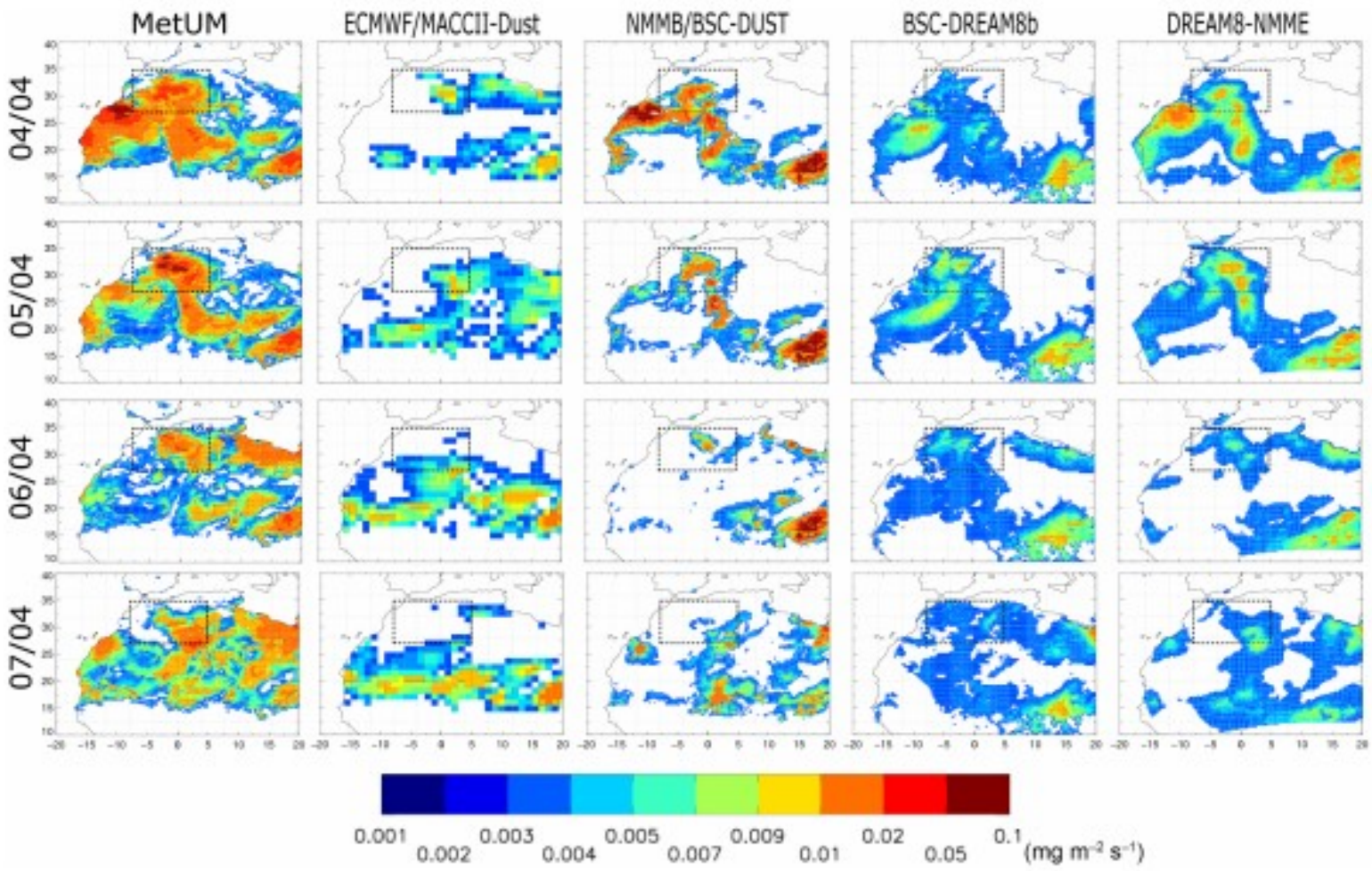
Model Intercomparison: European dust outbreak on April 2011 – DOD



(Huneeus et al., ACP, 2016)

SDS-WAS NAMEE: Studies

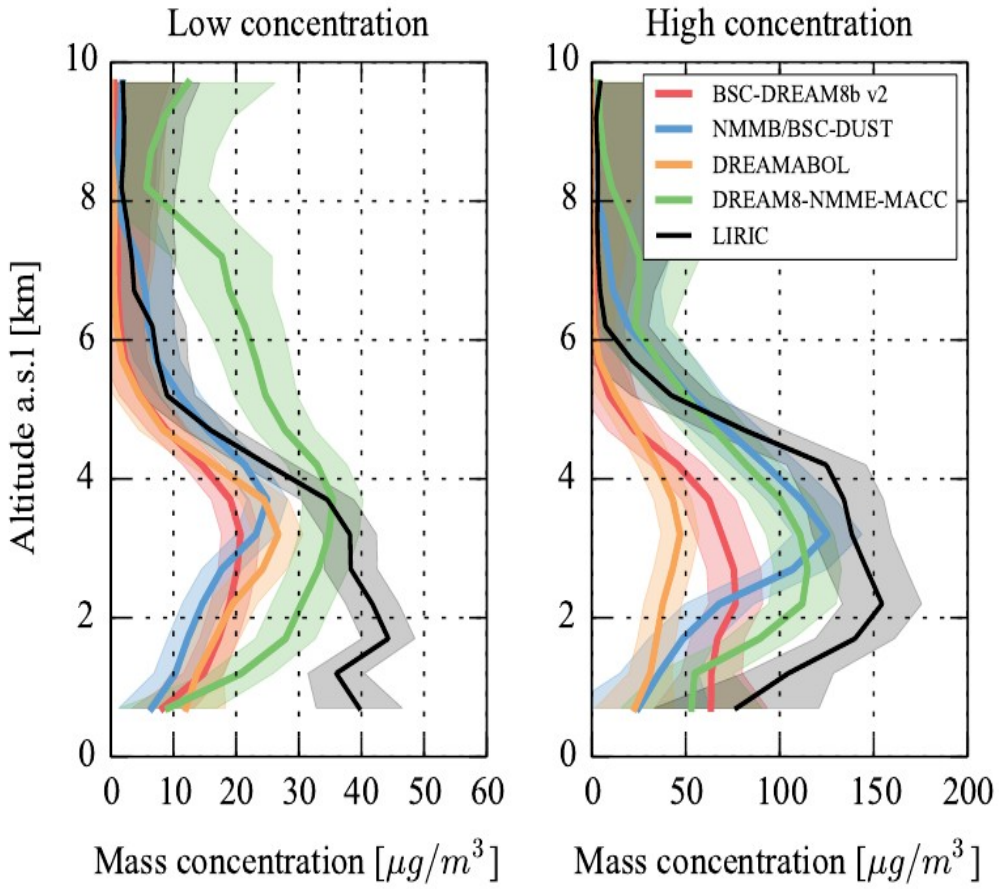
Model Intercomparison: European dust outbreak on April 2011 - Emissions



(Huneeus et al., ACP, 2016)

SDS-WAS NAMEE: Studies

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



(Binietoglou et al., ATM, 2015)

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.

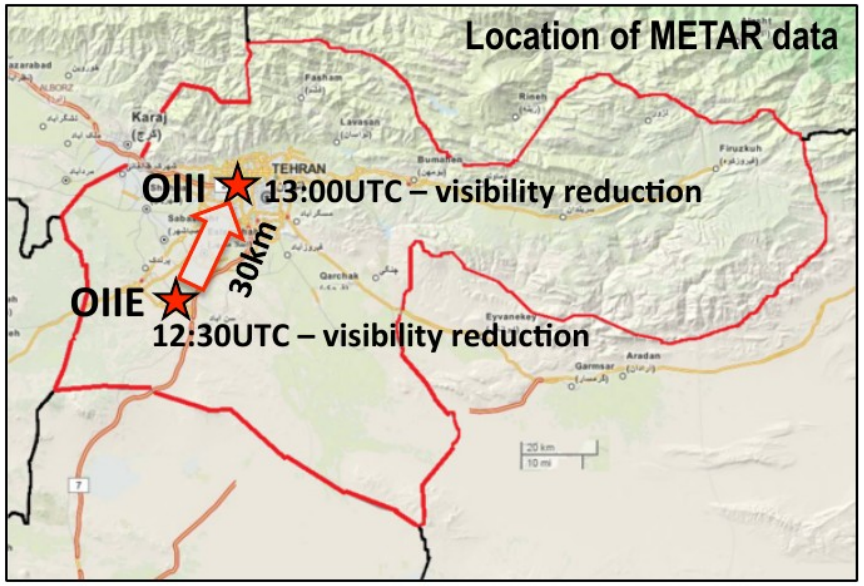
Based on public news, the dust storm caused several deaths, reduction of visibility to several tenths meters in the city, and adverse disturbance of the public traffic. The blowing wind reached 110 km/h.

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.

Iranian Haboob: Teheran 2nd June 2014

Information from reports

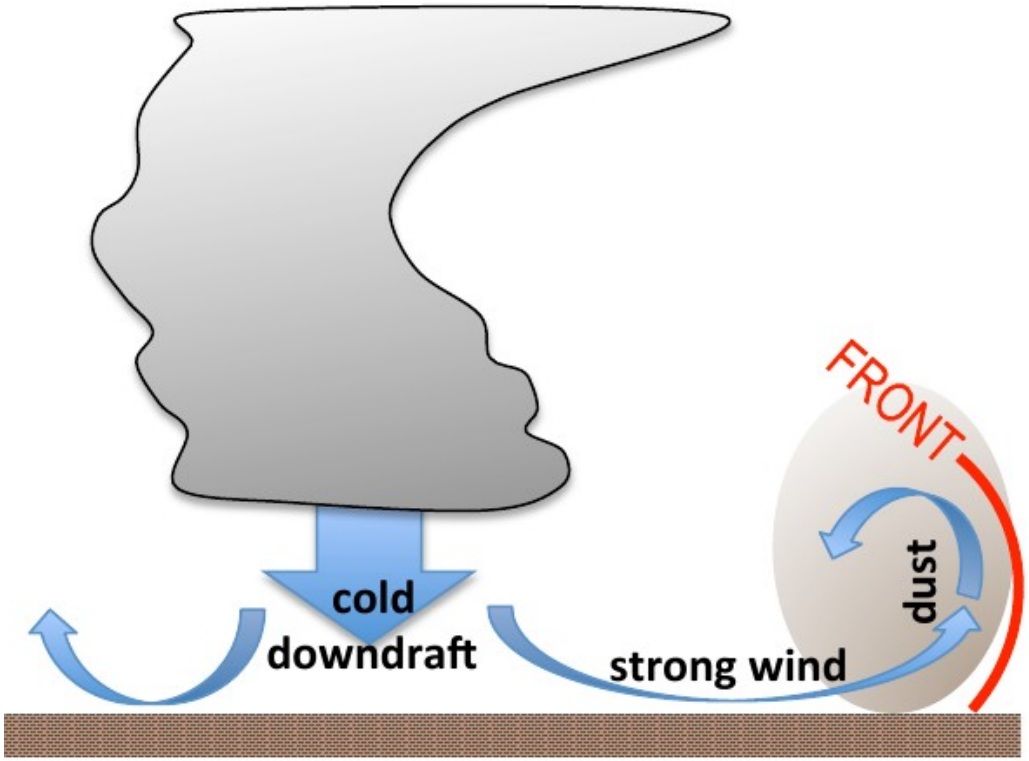
- reached city at 5.30 p.m. local time;
- passing of the sand storm over the fixed site lasted about 15min;
- storm duration less than 2h;
- reduction of visibility to ~10m; wind velocity reached 110 km/h;
- temperature dropped from 33 to 18ºC in several min;
- at least 5 deaths, 82 injured; multiple vehicle collision;



(Vukovic et al., in preparation)

Iranian Haboob: Teheran 2nd 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;



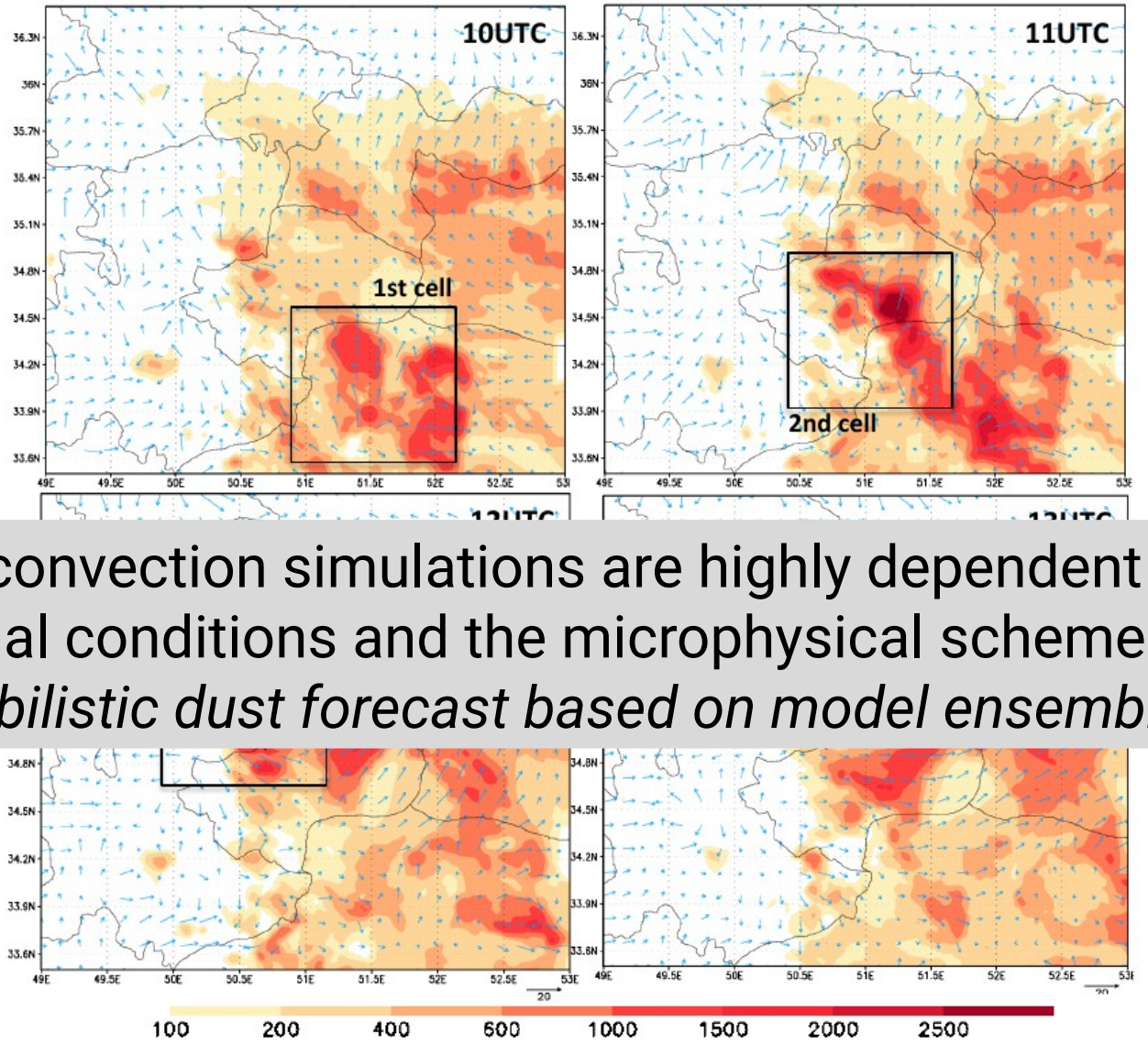
Expected: high wind speed, drop in temperature, rise in humidity, rise in pressure, reduction of visibility.

(Vukovic et al., in preparation)

Iranian Haboob: Teheran 2nd June 2014

DNC
(surface)
Dust Number
Concentration
number of dust particles in cm^3

Dust uplift and transport controlled with three main cells.



Explicit convection simulations are highly dependent on the initial conditions and the microphysical scheme
→ *Probabilistic dust forecast based on model ensembles*

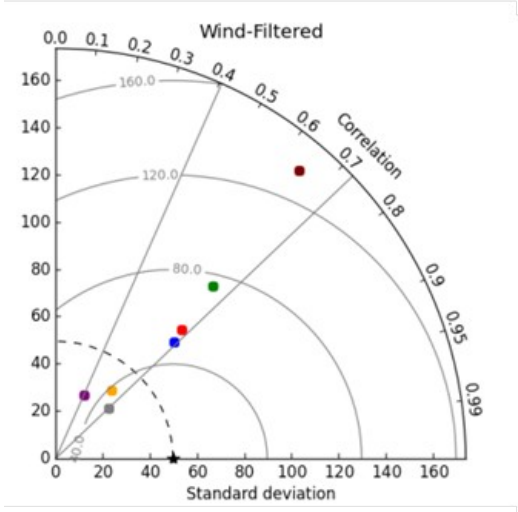
(Vukovic et al., in preparation)

SDS-WAS NAMEE: PM10 Evaluation

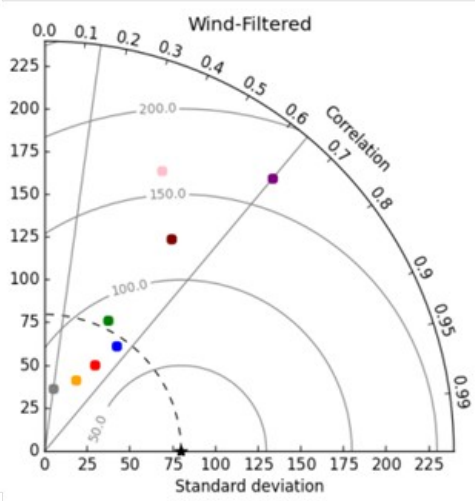
AMMA network: PM10 in Sahel for the year 2013

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.*

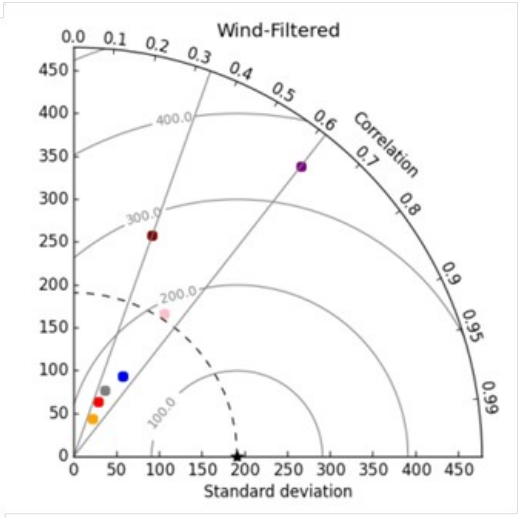
M'Bour-Senegal

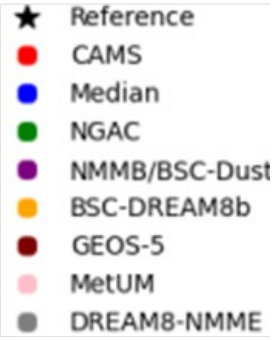


Cinzana-Mali



Banizoumbou-Niger



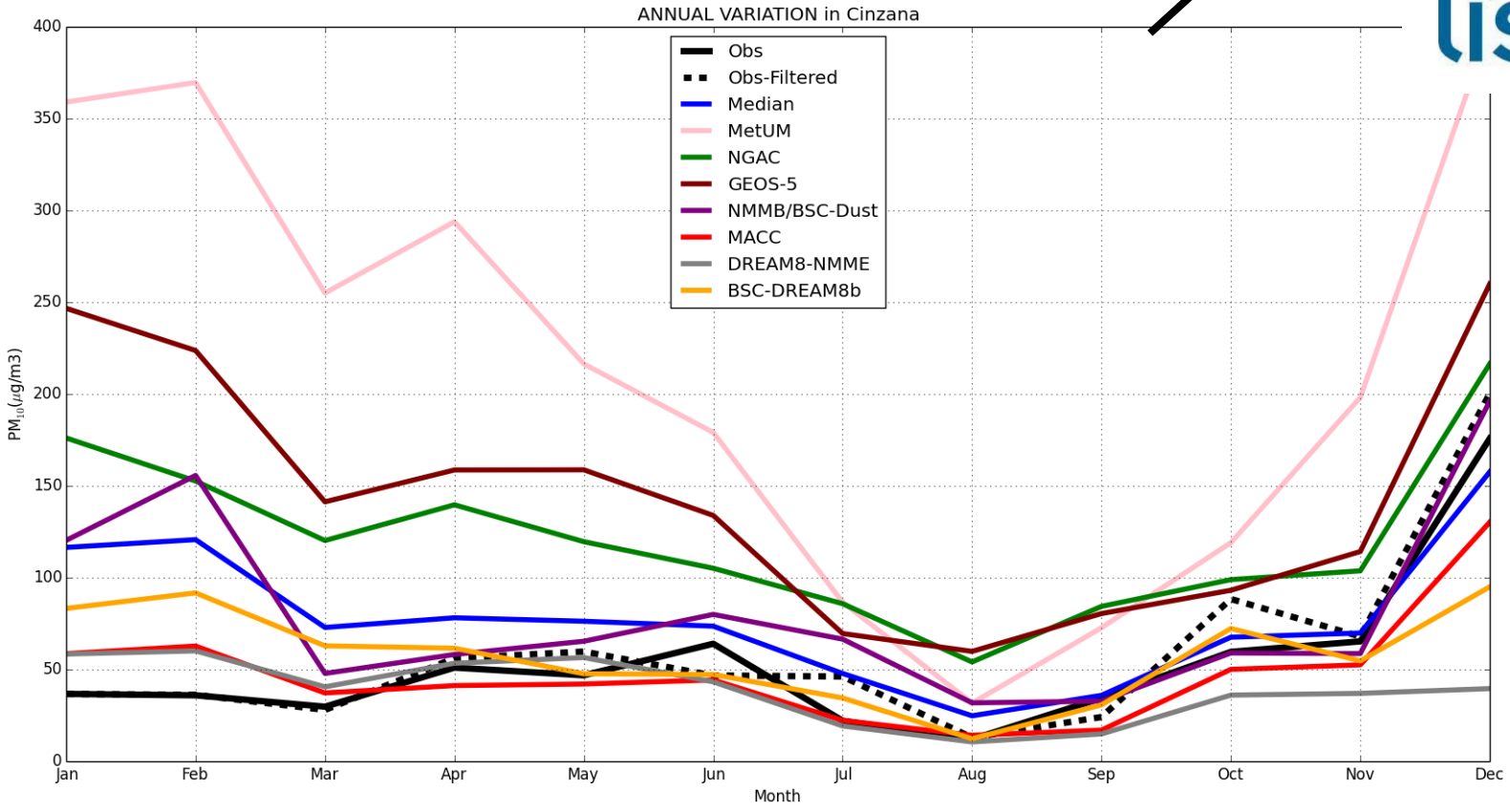


AMMA (Marticorena et al., 2010)

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

SDS-WAS NAMEE: PM10 Evaluation

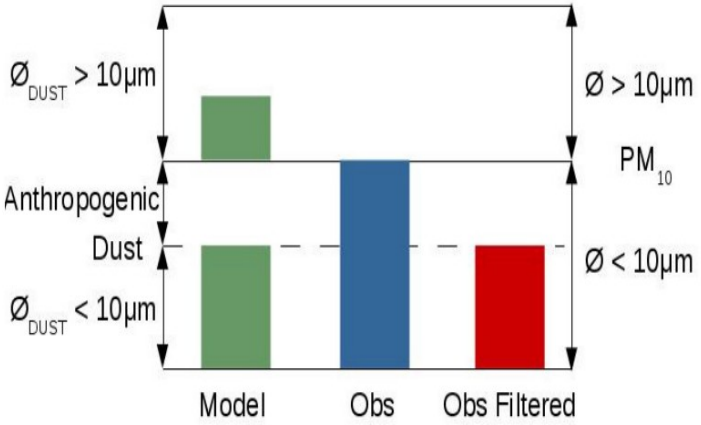
AMMA network: PM10 in Sahel for the year 2013



SDS-WAS NAMEE: PM10 Evaluation

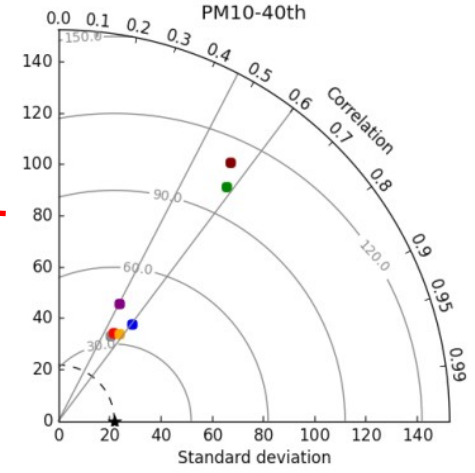
AQ network: Canary Islands 2013-2014

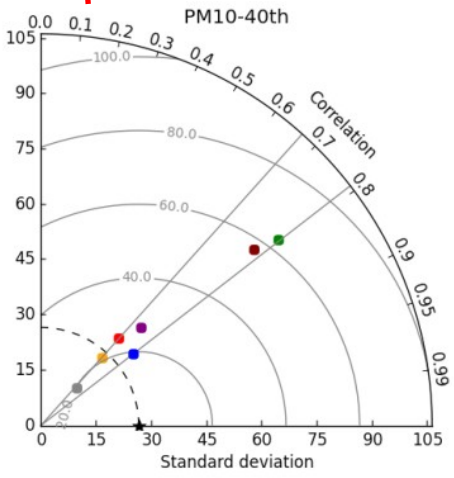
Not all PM10 is dust: *Local sources*
Dust filter: *Moving 40th percentile of 30 days, 15 days before and 15 days after (Escudero at al. 2007).*

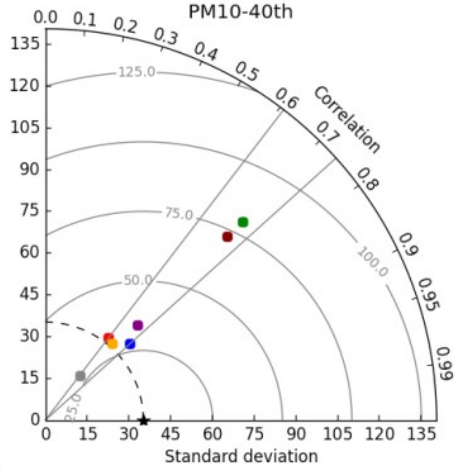


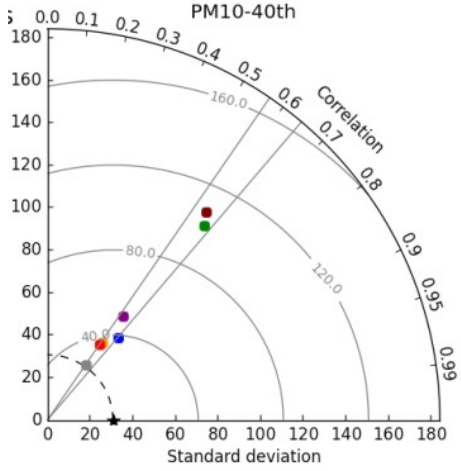
SDS-WAS NAMEE: PM10 Evaluation

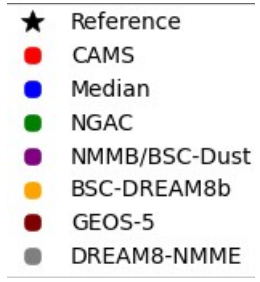
AQ network: Canary Islands 2013-2014











Supercomputing Center
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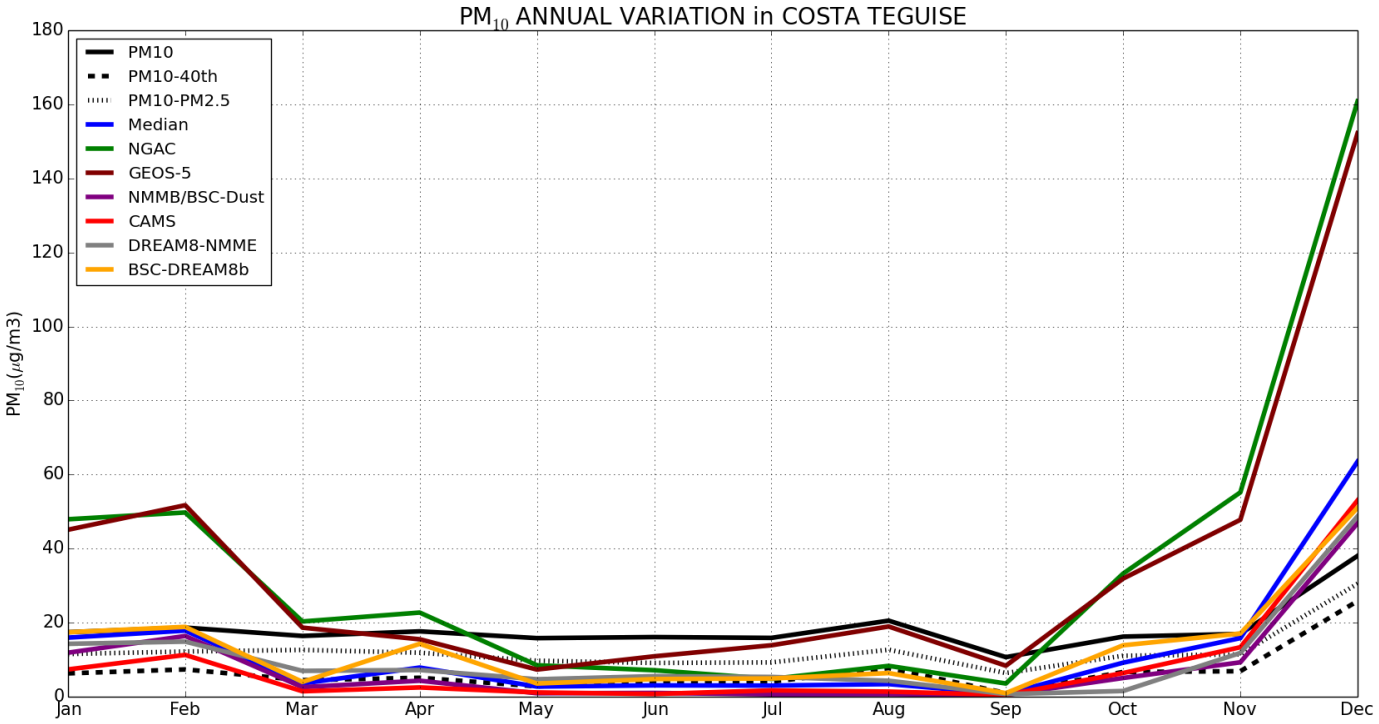
Agencia Estatal de Meteorología

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

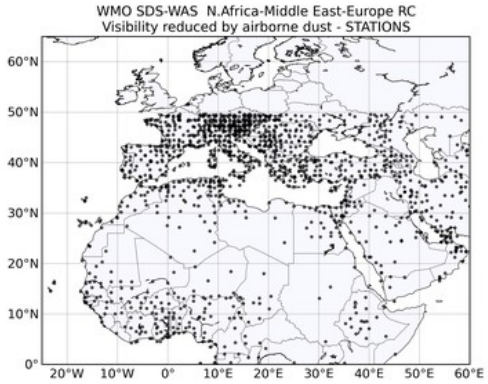
SDS-WAS NAMEE: PM10 Evaluation

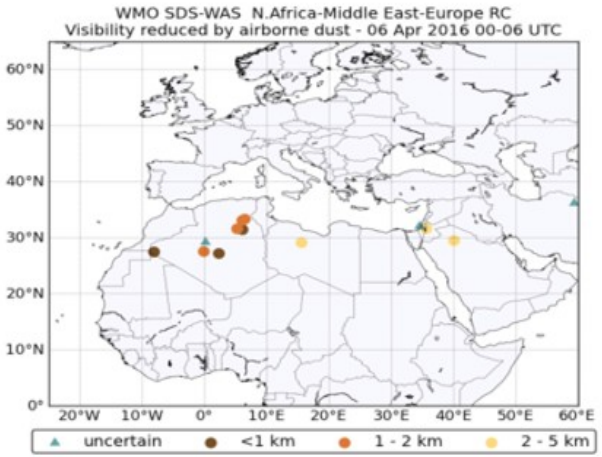
AQ network: Canary Islands 2013-2014

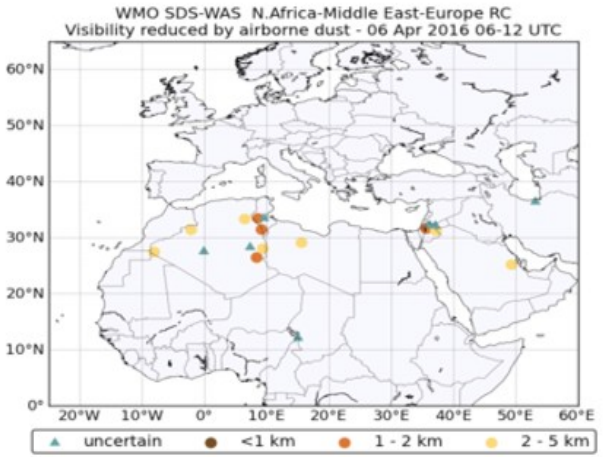


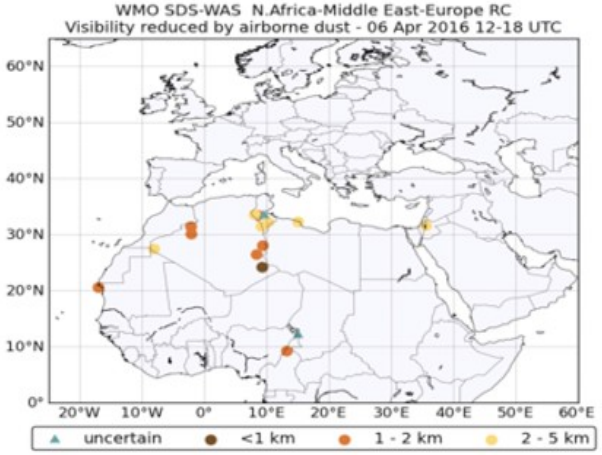
SDS-WAS NAMEE: Visibility vs Surf. Conc.

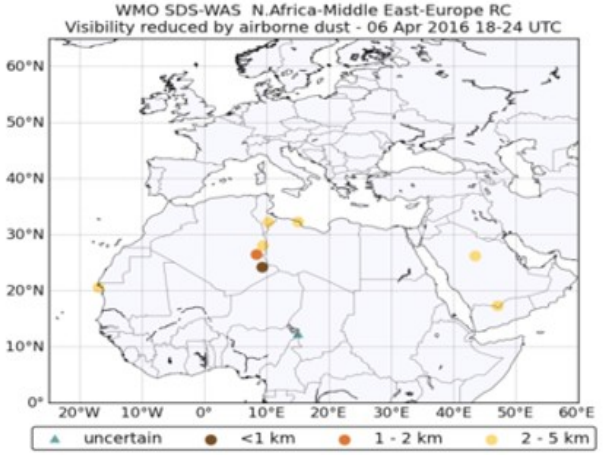
NRT visibility evaluation: 6th April 2016 0-12UTC





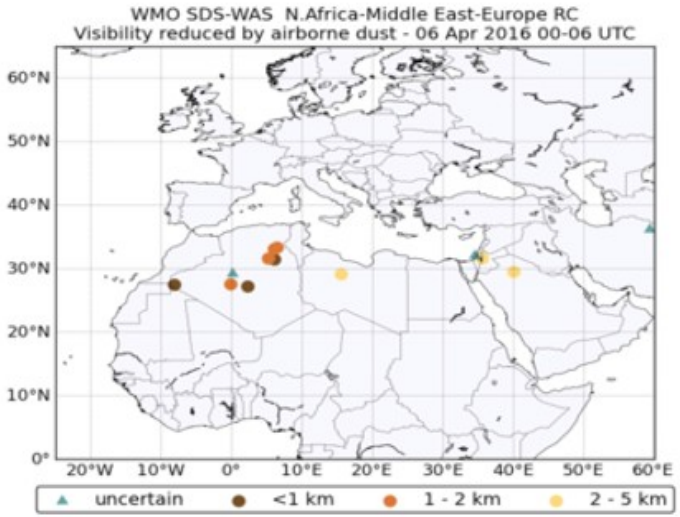


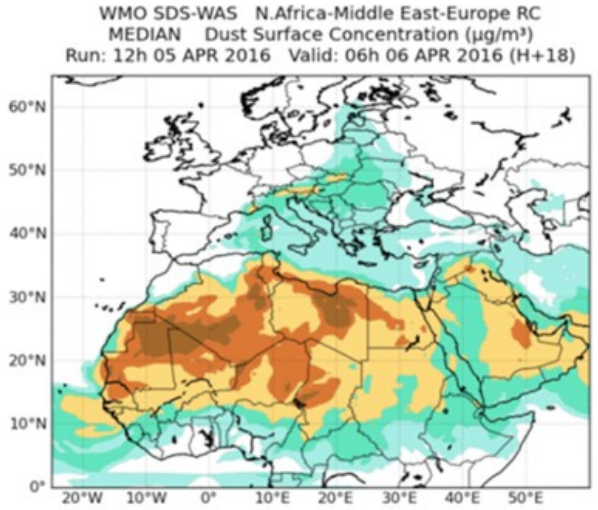


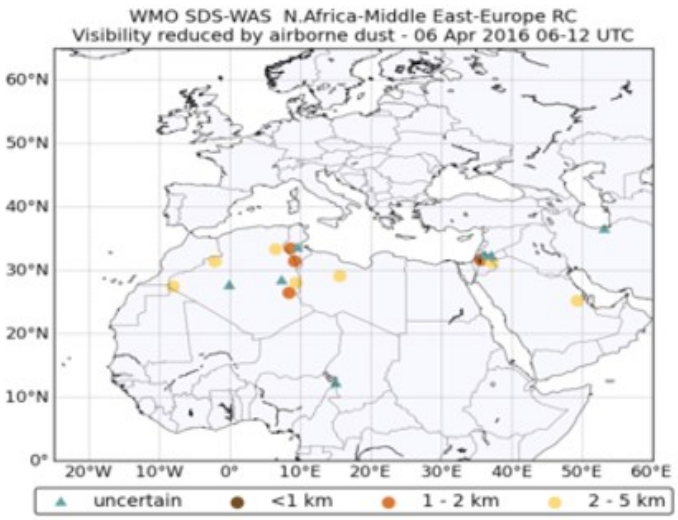


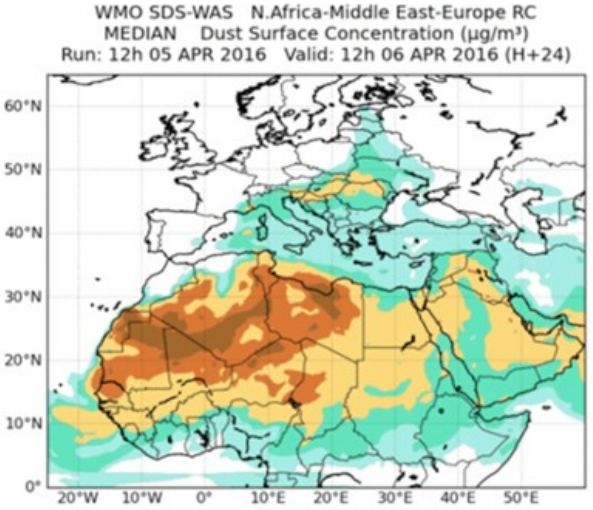
SDS-WAS NAMEE: Visibility vs Surf. Conc.

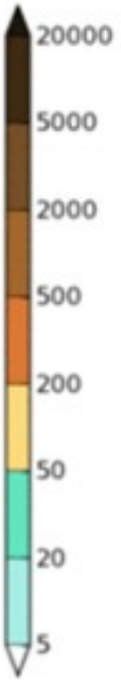
NRT visibility evaluation: 6th April 2016 0-12UTC











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Centro Nacional de Supercomputación

Agencia Estatal de Meteorología

World Meteorological Organization

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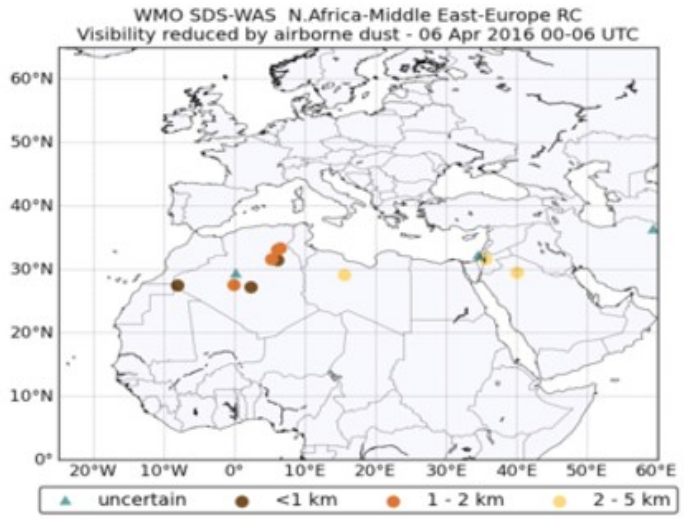
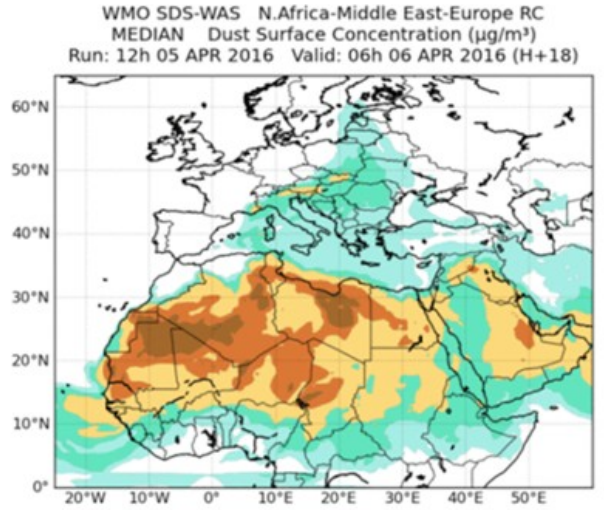
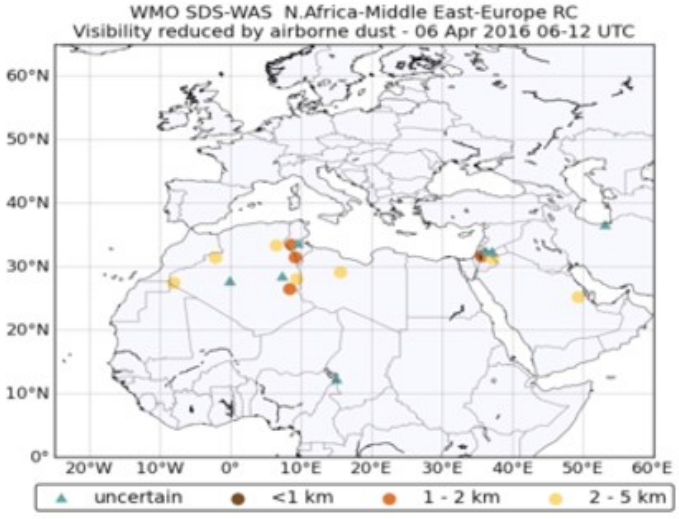
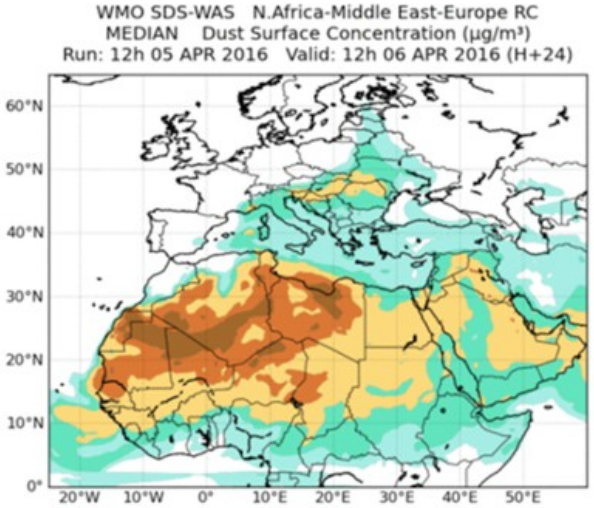
SDS-WAS NAMEE: Visibility vs Surf. Conc.

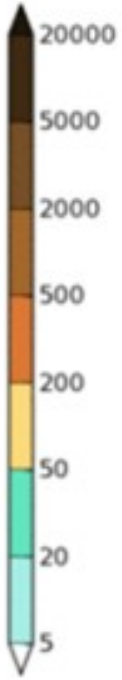
NRT visibility evaluation: 6th April 2016 0-12UTC











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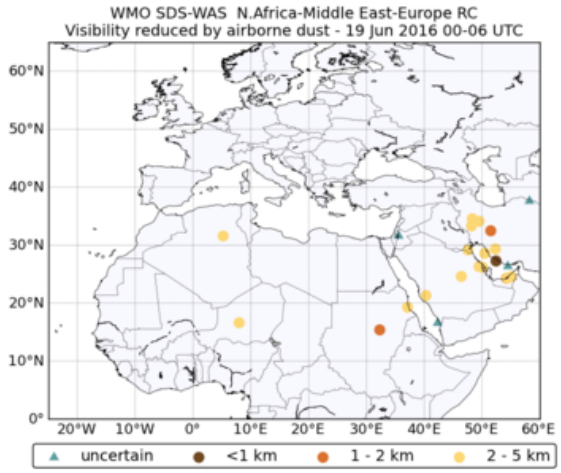
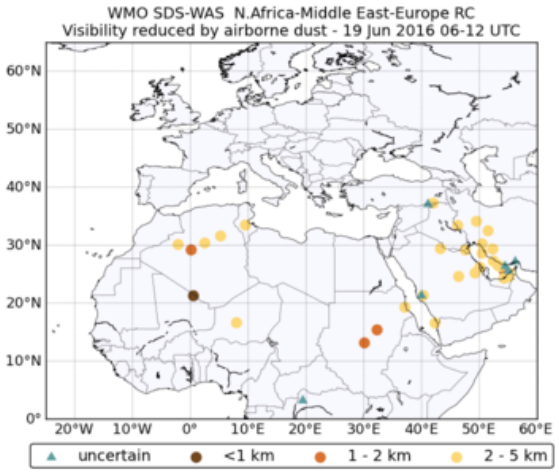
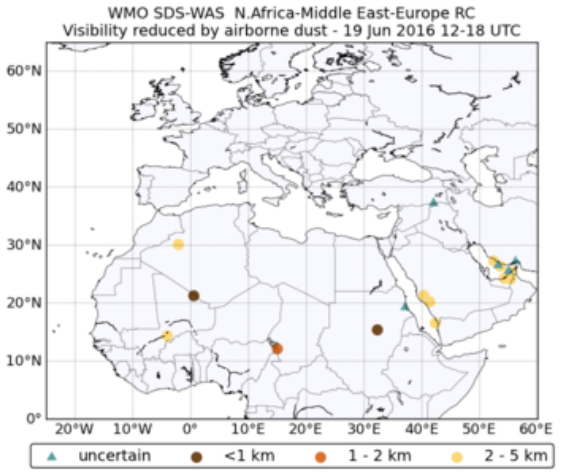
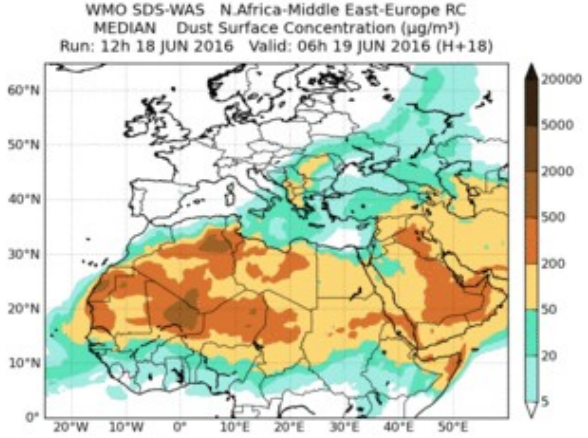
SDS-WAS NAMEE: Visibility vs Surf. Conc.

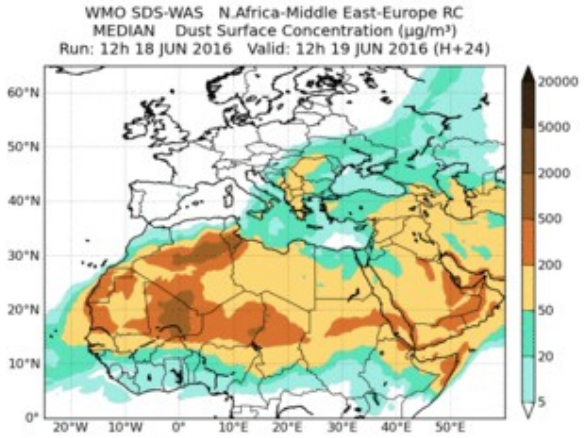
NRT visibility evaluation: 19th june 2016

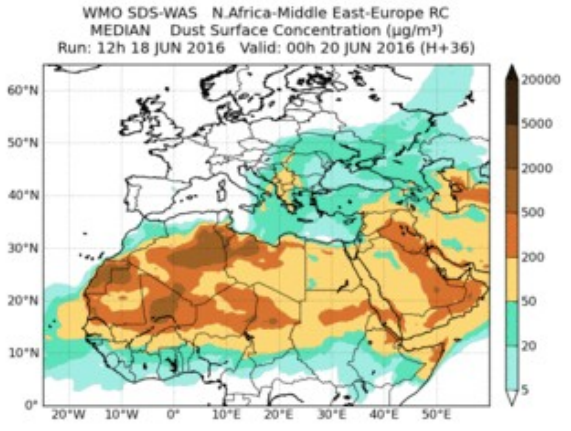






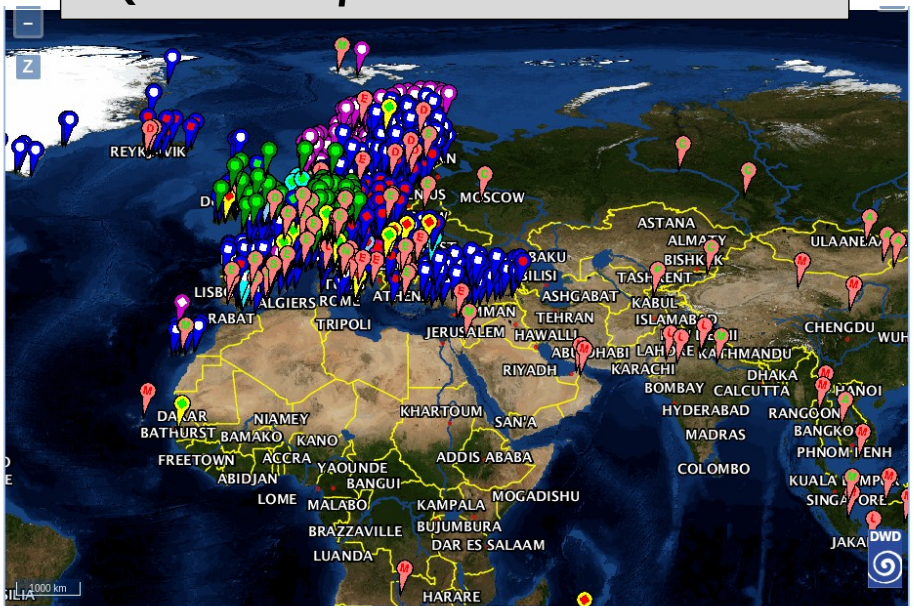




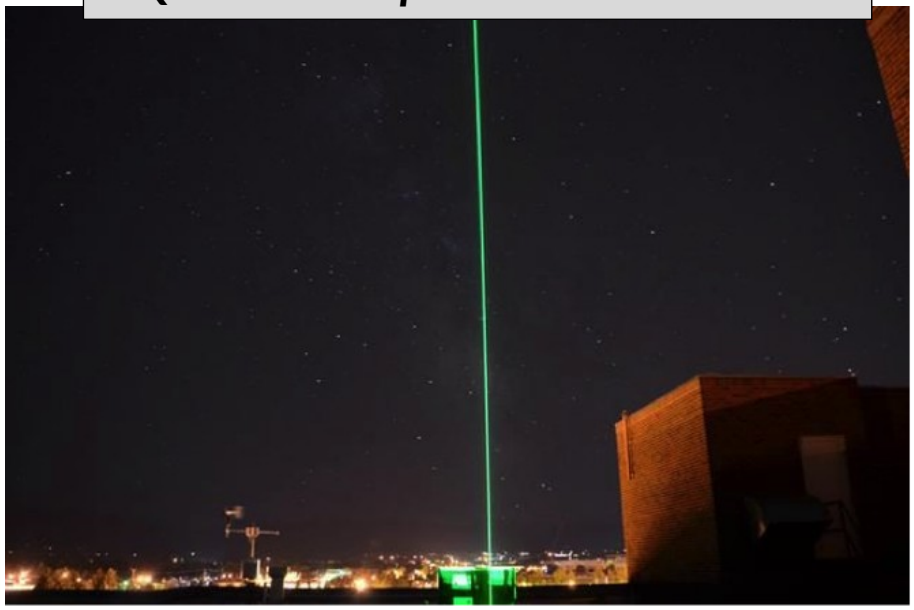


SDS-WAS NAMEE: Dust Profiles Evaluation

+ High density of stations
- Qualitative products



- 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

OBSERVATIONS

Extinction profiles at 12UTC
available in a window of 24 hours

3 ceilometers
1 lidar

SDS-WAS MODELS

- **BSC-DREAM8b**
- **NMMB/BSC-Dust**
- **CAMS**
- **DREAM8-NMME**
- ....

```
2016040512_3H_BSC_DREAM8B_profiles{
dimensions:
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      station = 67 ;
      lev = 24 ;
char station_name(station, strlen) ;
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      station_name:long_name = "station long name" ;
      station_name:units = "-" ;
char station_code(station, codlen) ;
      station_code:missing_value = -9999. ;
      station_code:long_name = "station code" ;
      station_code:units = "-" ;
double time(time) ;
```

Data format
Exchange operational protocol includes 72 hours forecasts

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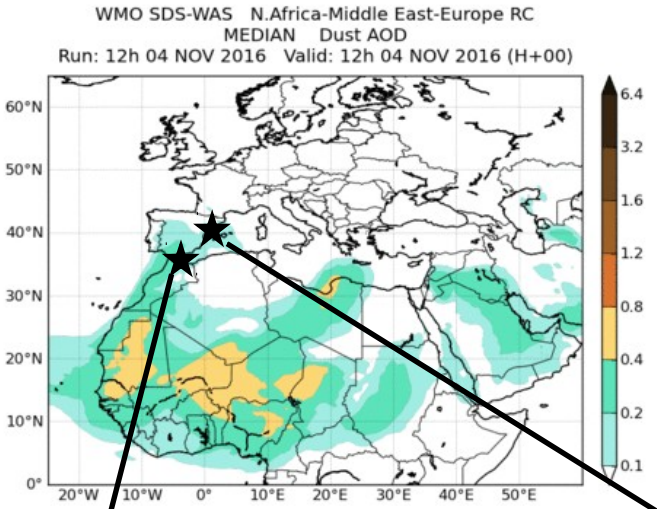
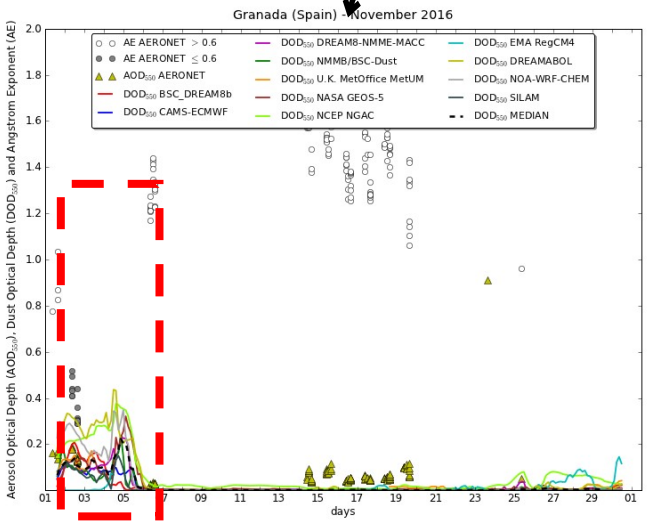
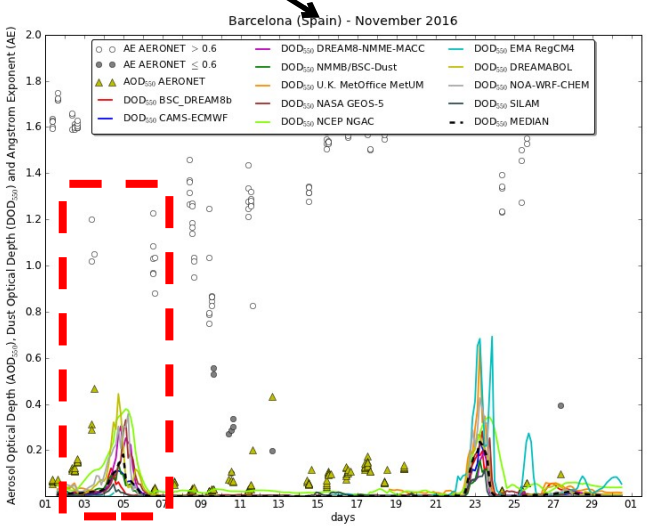
SDS-WAS NAMEE: Dust Profiles Evaluation

W. Mediterranean dust event: 2 - 5 November 2016



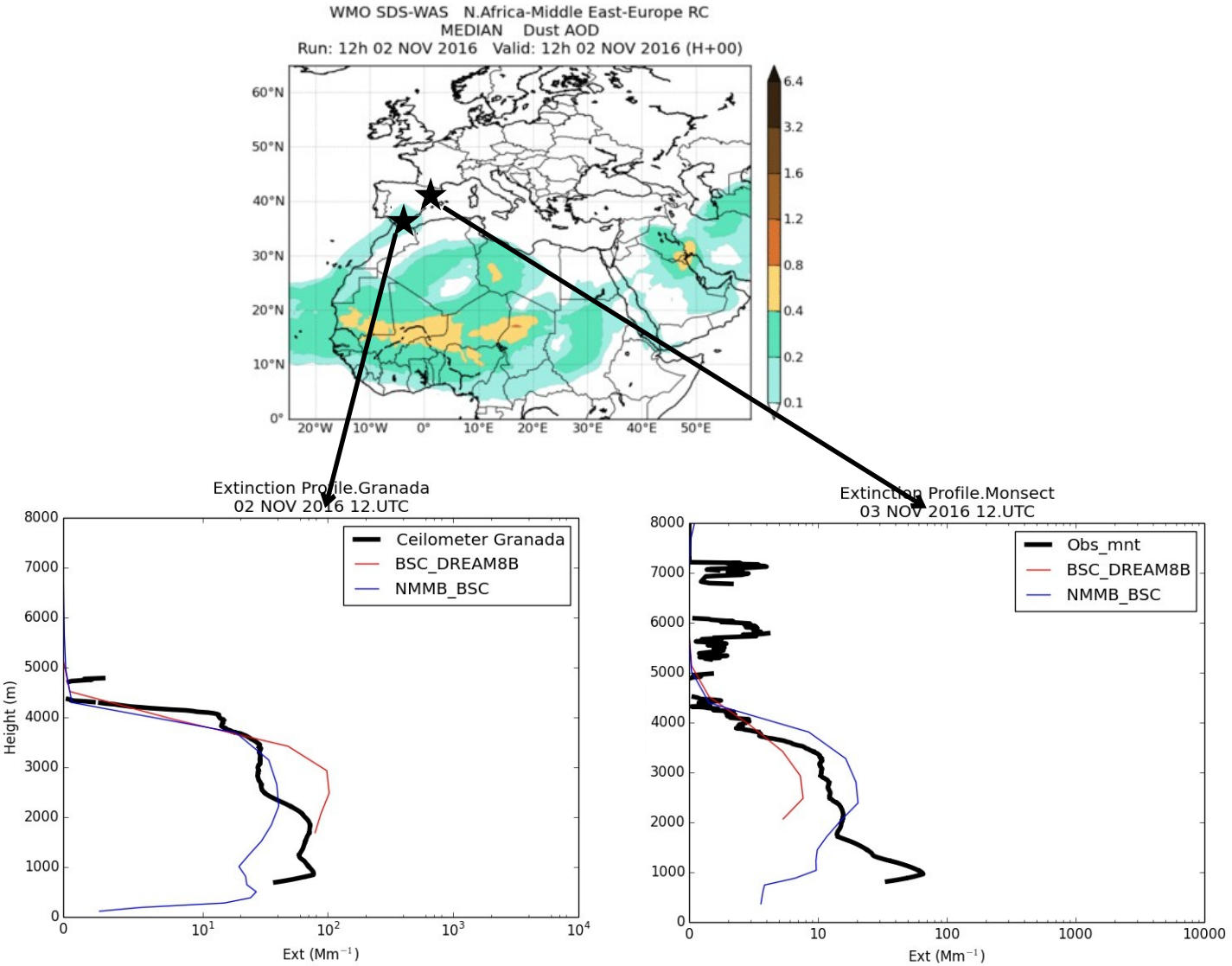
AERONET





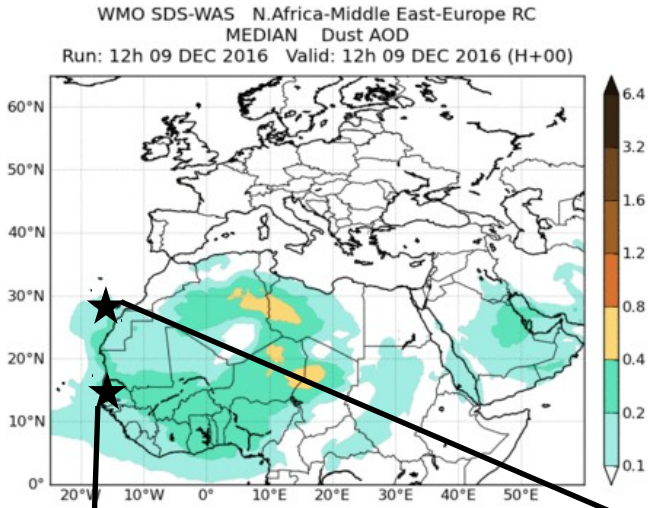
SDS-WAS NAMEE: Dust Profiles Evaluation

Atlantic dust event: 2 - 5 November 2016



SDS-WAS NAMEE: Dust Profiles Evaluation

Atlantic dust event: 9 - 12 December 2016



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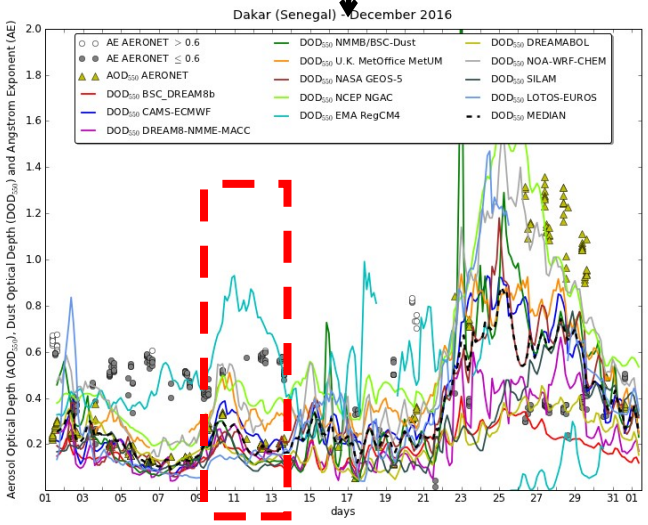
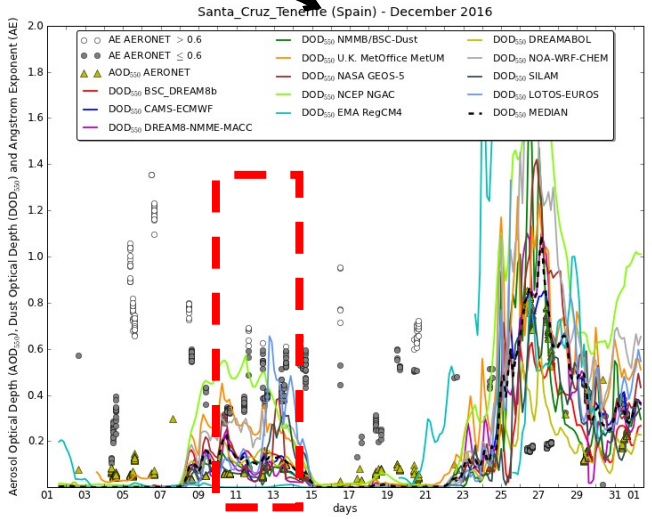
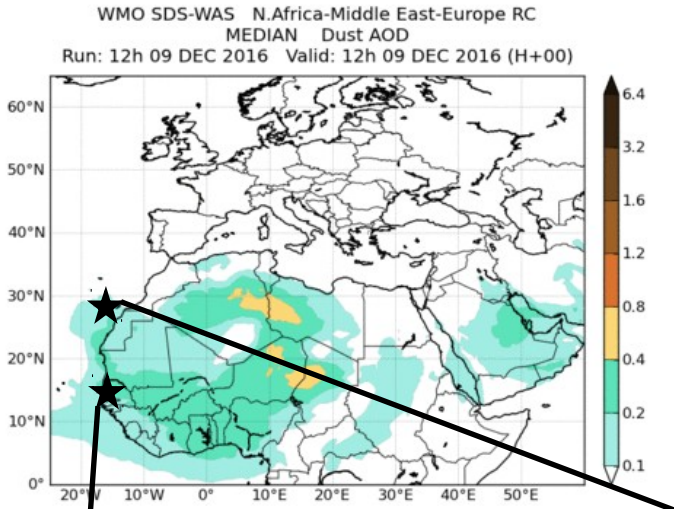
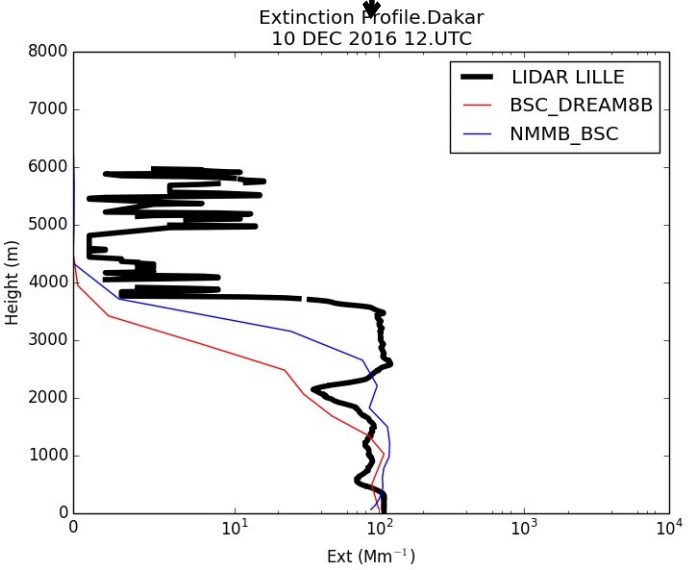


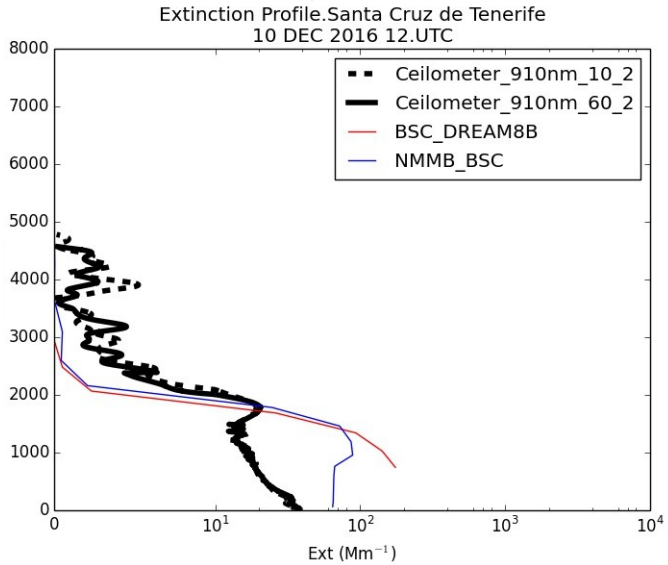


SDS-WAS NAMEE: Dust Profiles Evaluation

Atlantic dust event: 9 - 12 December 2016

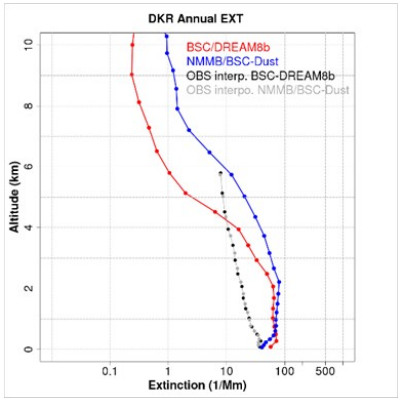


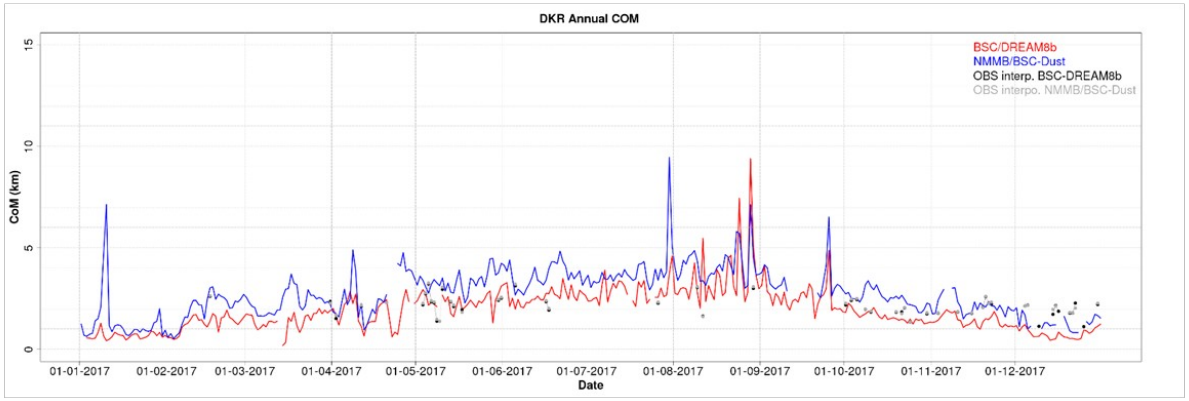


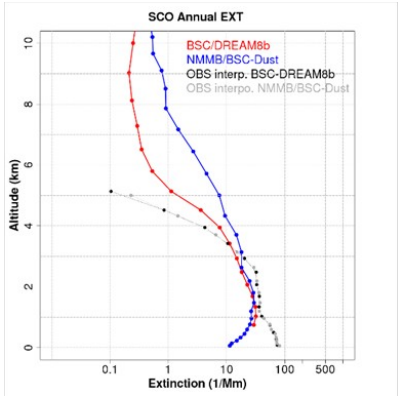


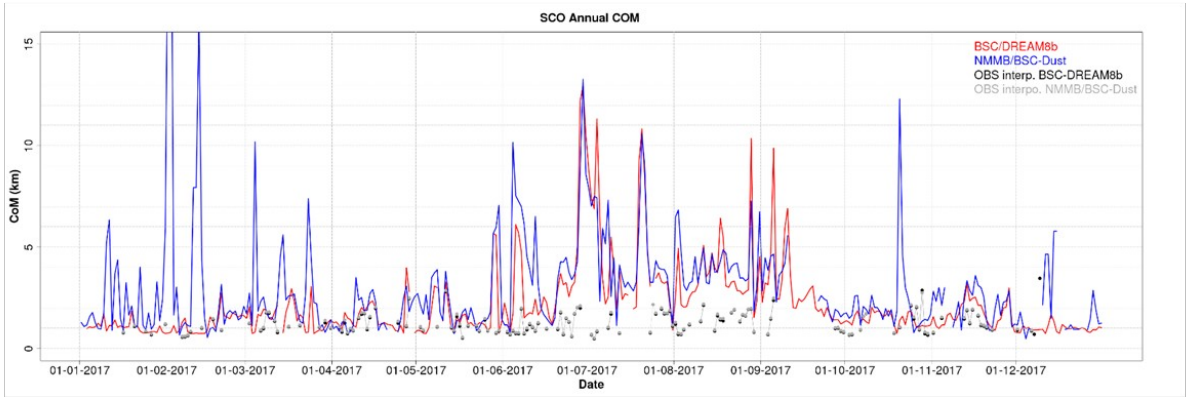
SDS-WAS NAMEE: Dust Profiles Evaluation

Skills scores: Preliminary results for the year 2017





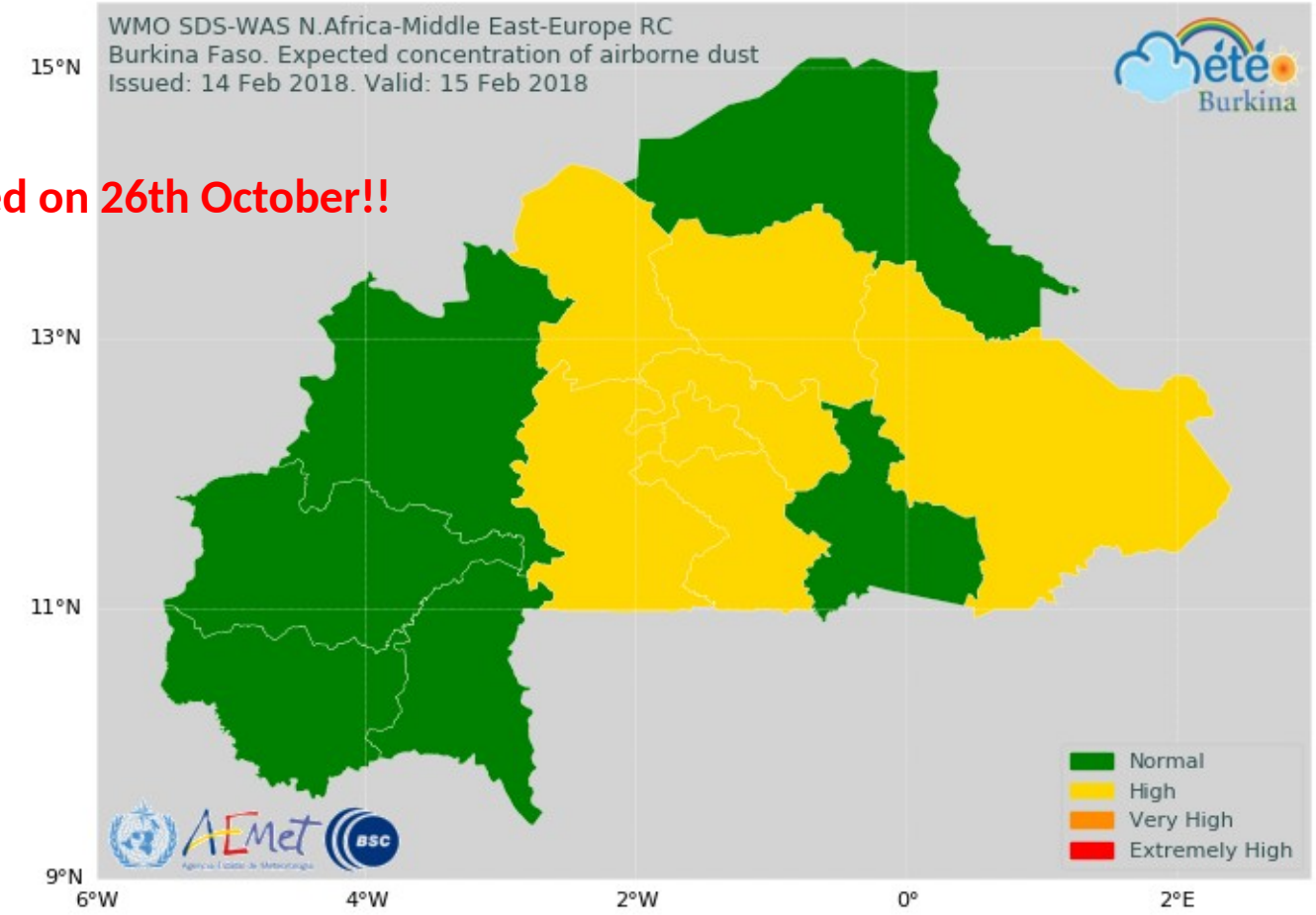




http://sds-was.aemet.es/projects-research/evaluation-of-model-derived-dust-vertical-profiles

SDS-WAS NAMEE:
Early Warning System for Burkina Faso

Launched on 26th October!!



https://sds-was.aemet.es/forecast-products/burkina-faso-warning-advisory-system

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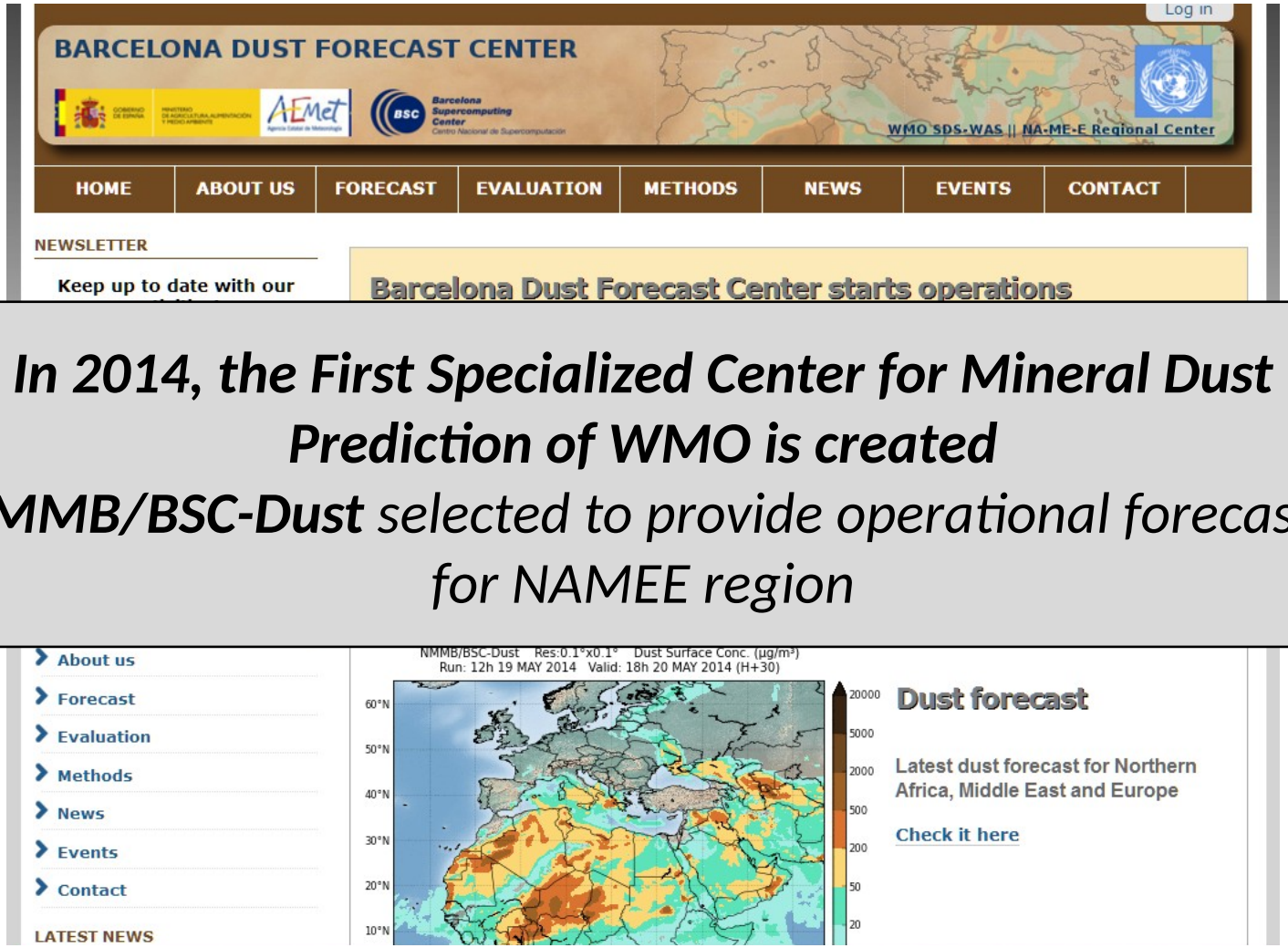
Centro Nacional de Supercomputación
AEMet Agencia Estatal de Meteorología
World Meteorological Organization

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

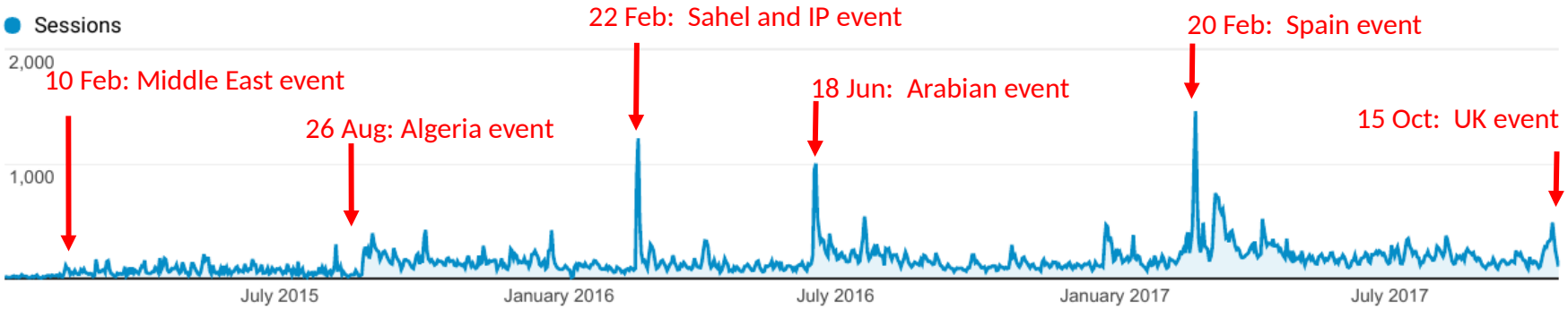
@Dust_Barcelona

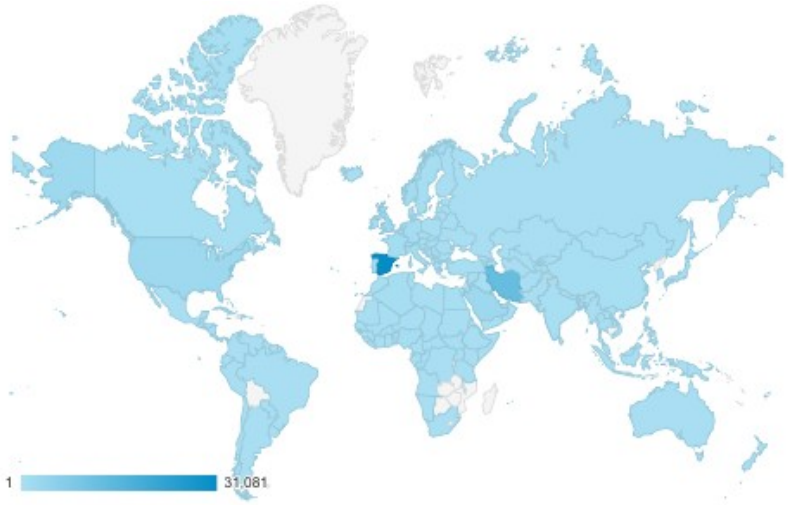
http://dust.aemet.es/

Barcelona Dust Forecasting Center

Website visits: 1 January 2015 – 20 October 2017

http://dust.aemet.es/





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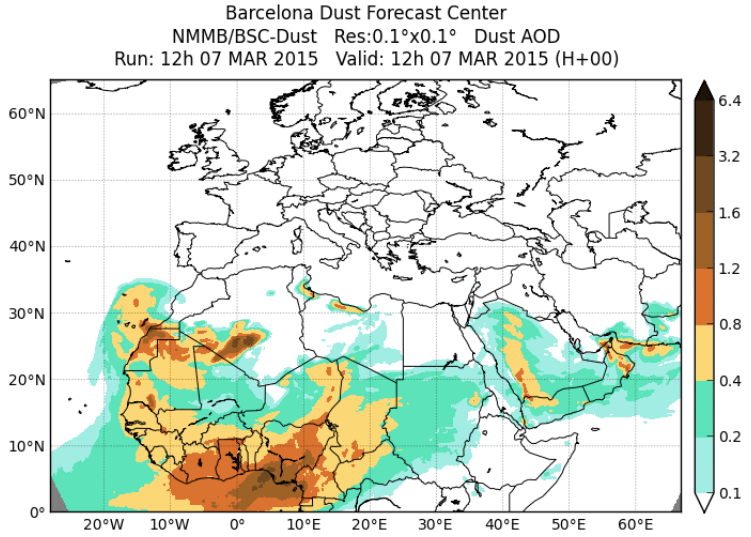
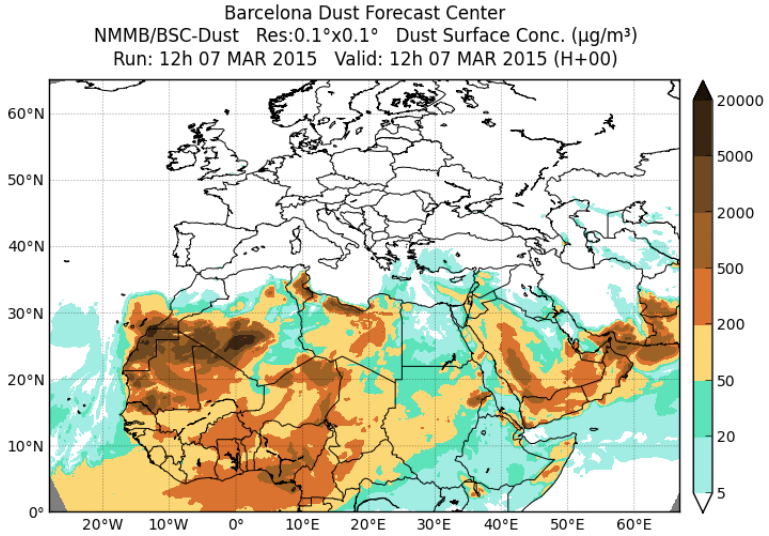
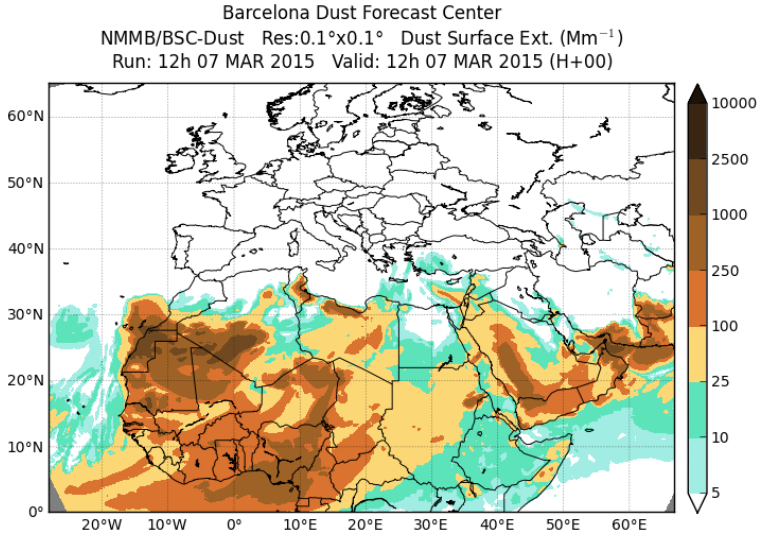
BDFC: Operational Products

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







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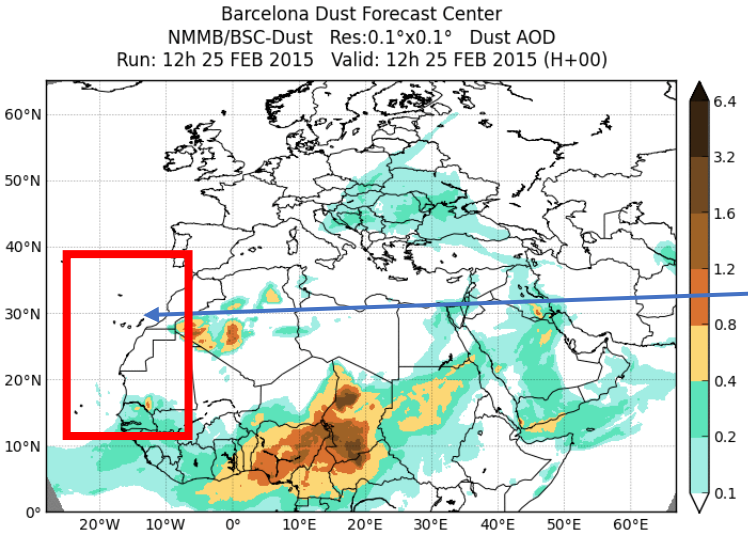
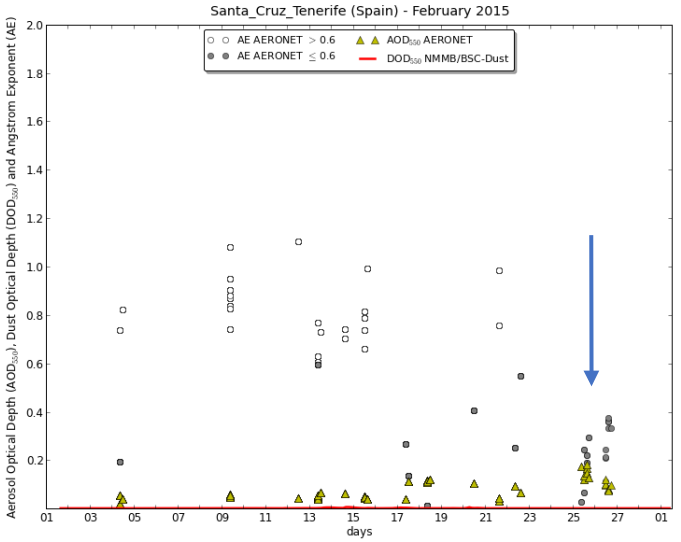
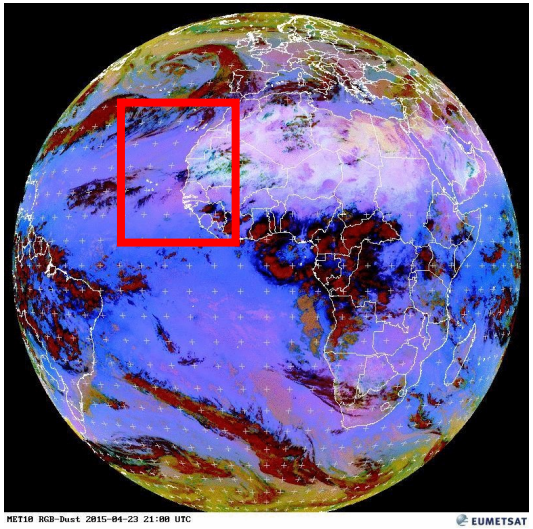
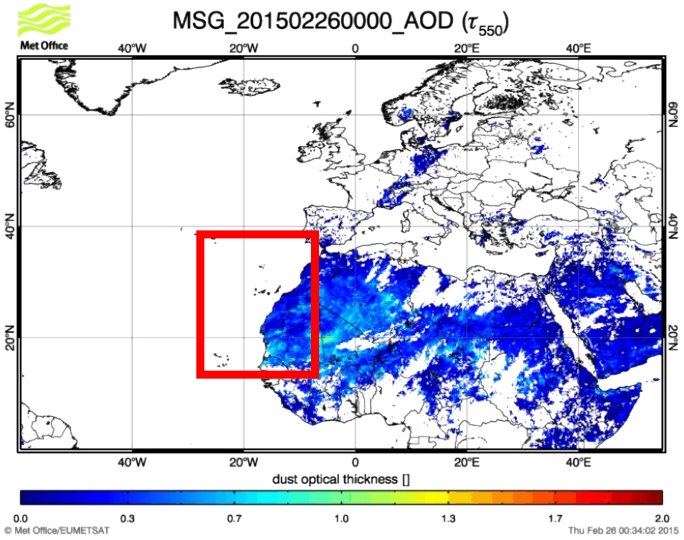
BDFC: Dust event Canary Islands Feb 2015



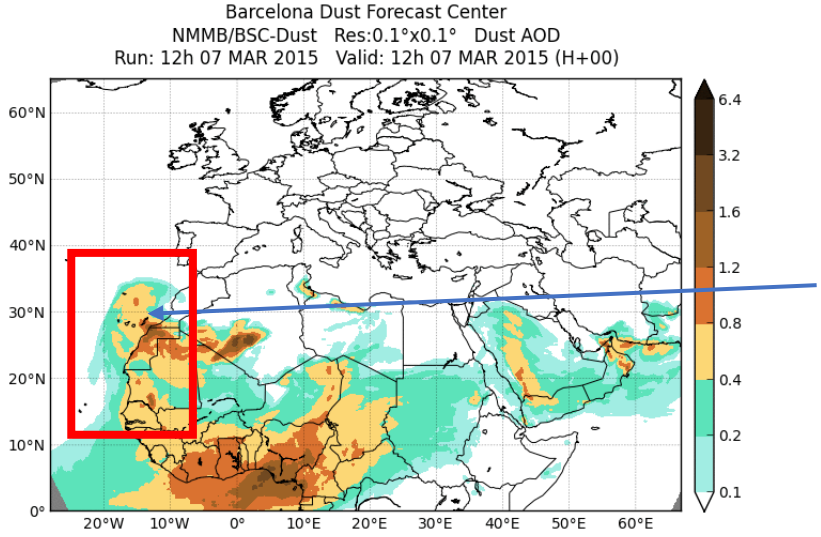


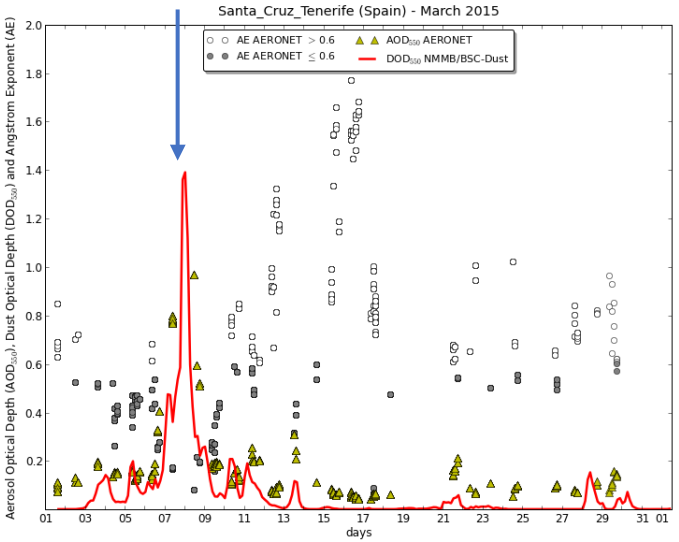


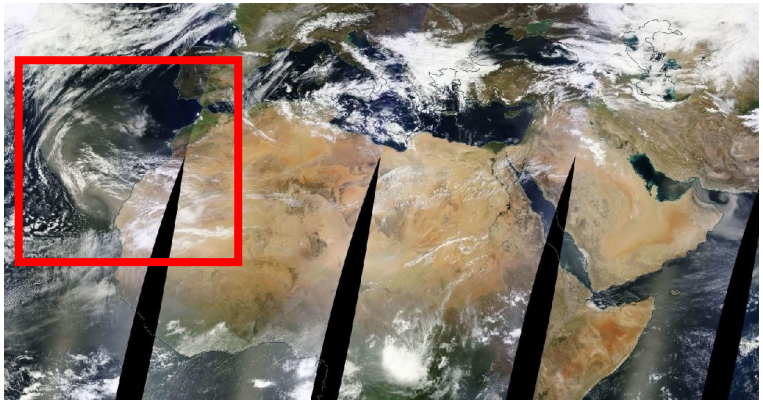


http://dust.aemet.es/

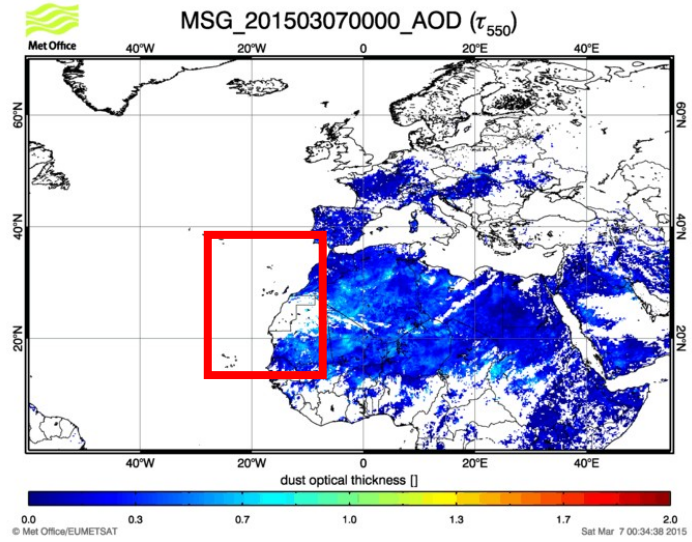
BDFC: Dust event Canary Islands Mar 2015





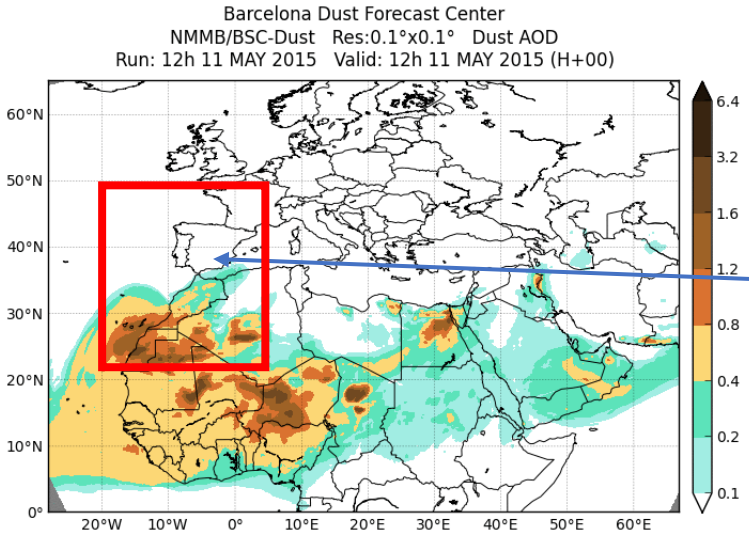


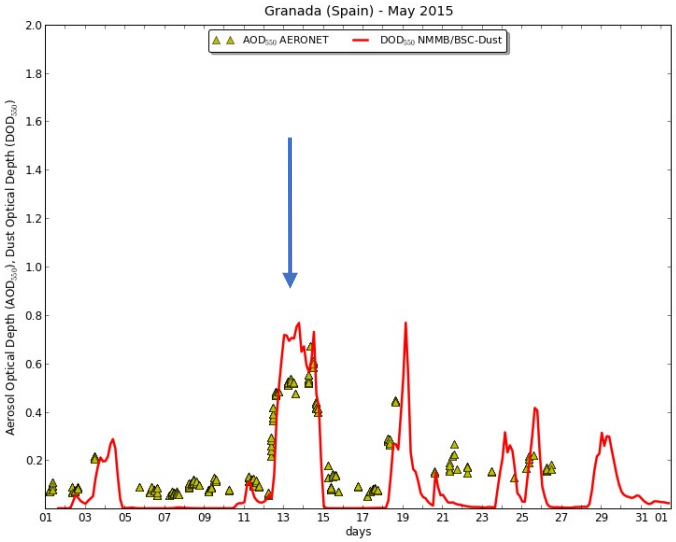
MODIS composite 8th March 2015 from EOSDIS World Viewer

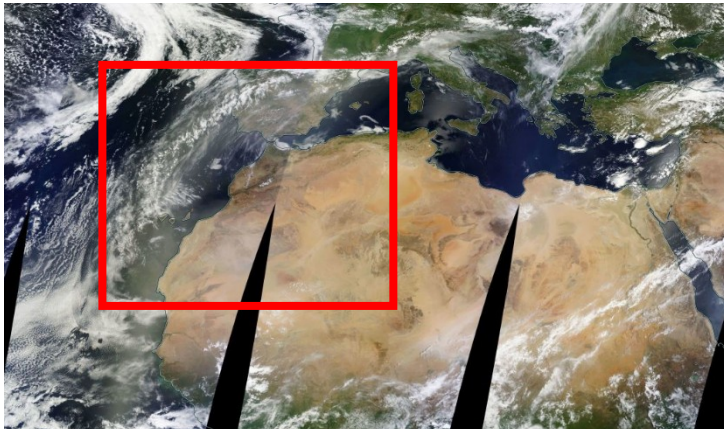


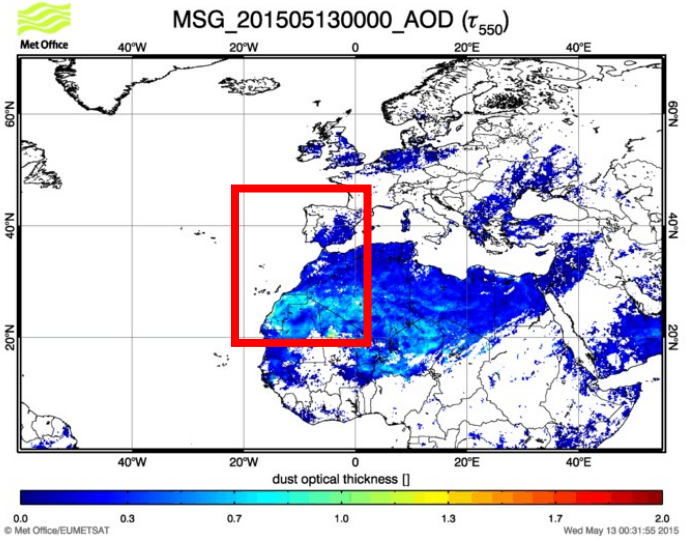
http://dust.aemet.es/

BDFC: Dust event Europe May 2015



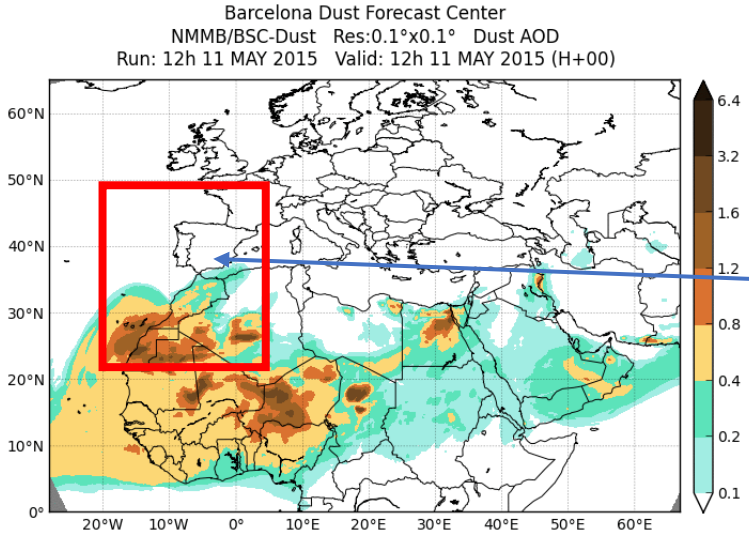


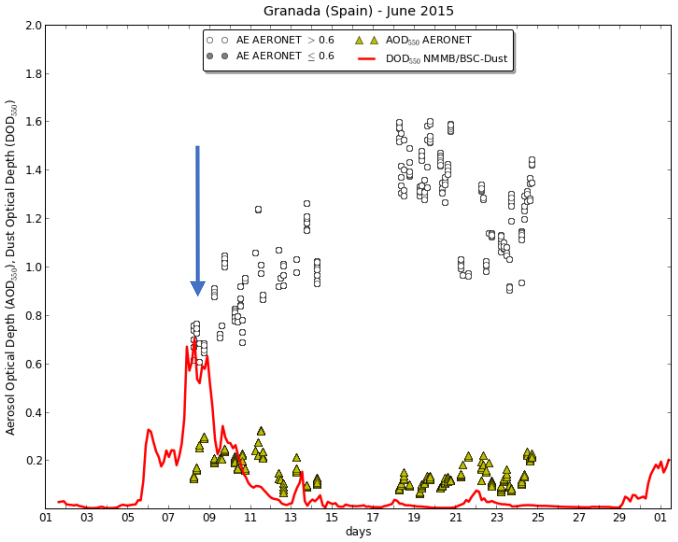


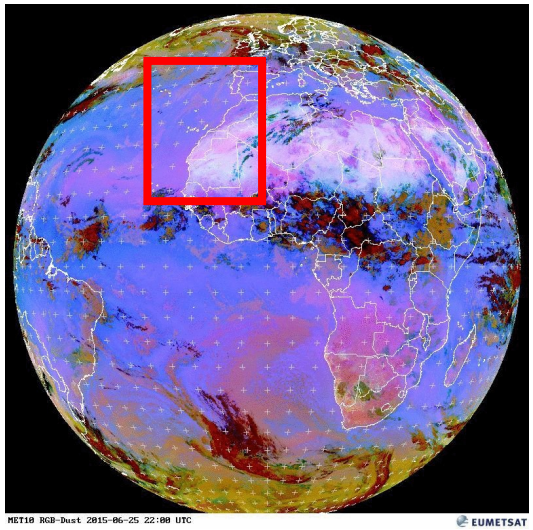


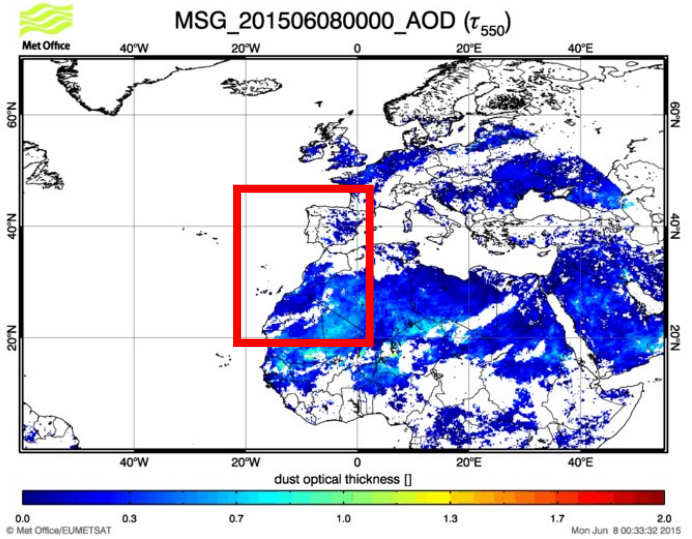
http://dust.aemet.es/

BDFC: Dust event Europe June 2015



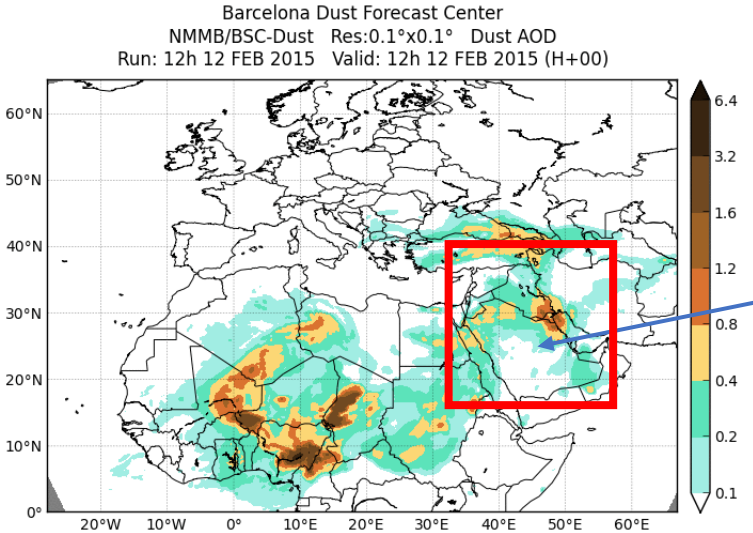


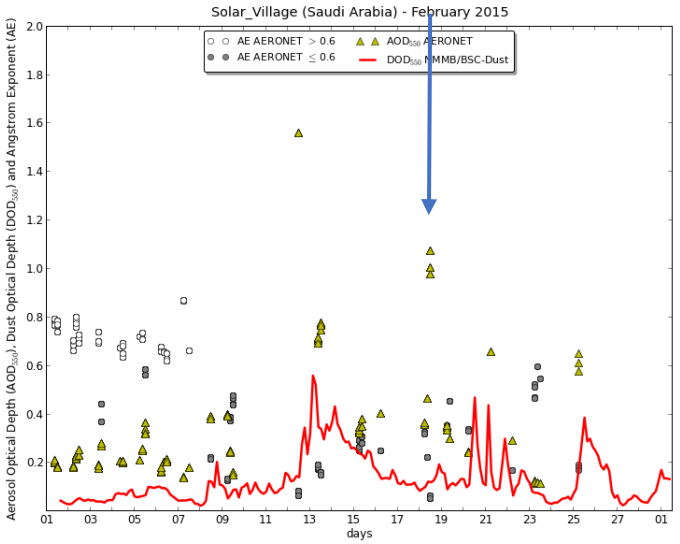


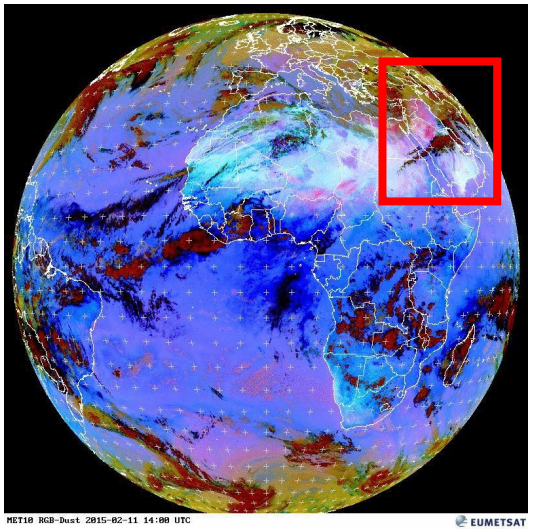


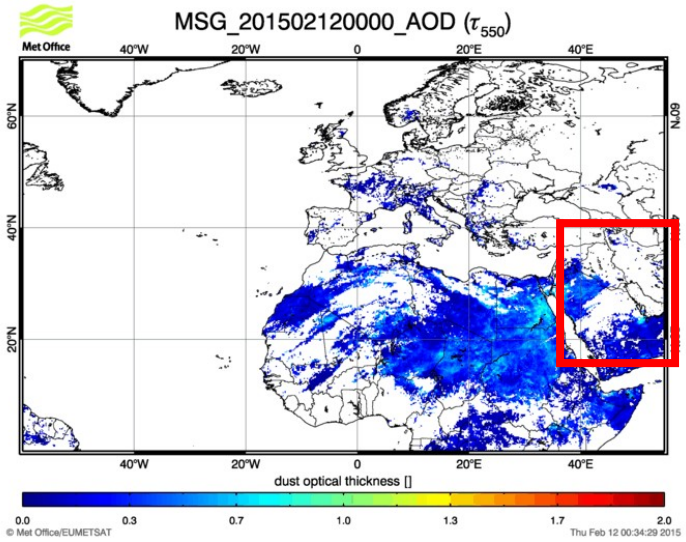
http://dust.aemet.es/

BDFC: Dust event Middle East Feb 2015



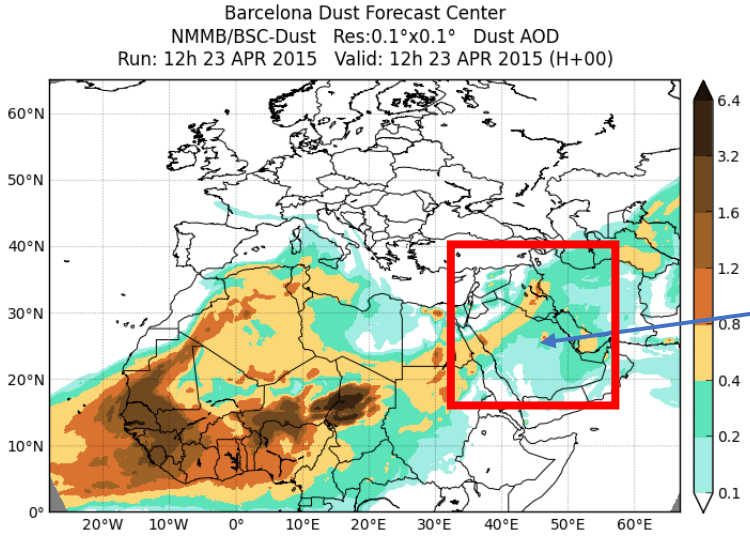


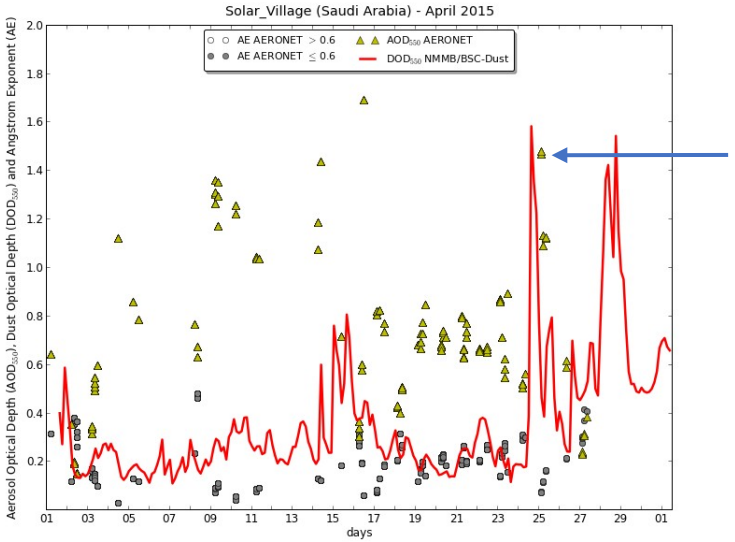


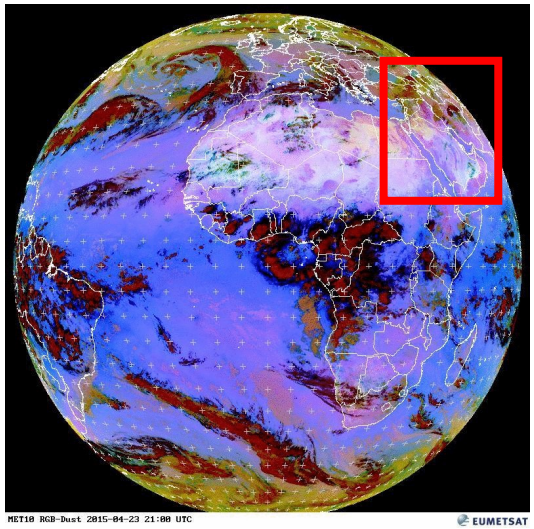


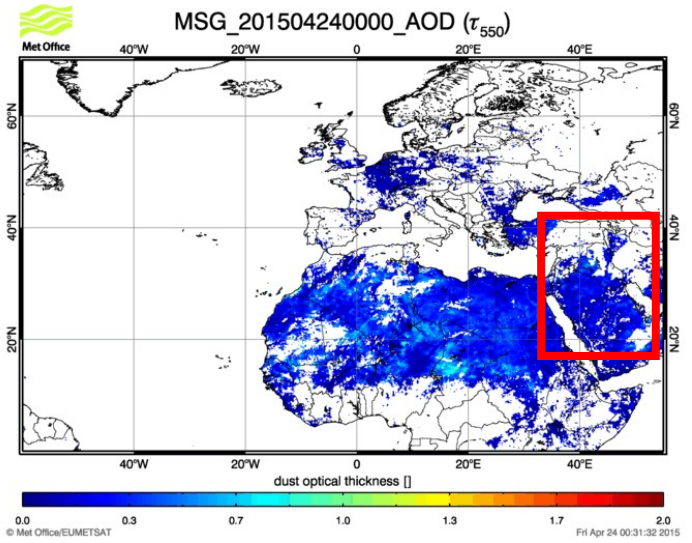
http://dust.aemet.es/

BDFC: Dust event Middle East Apr 2015









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WMO Dust Regional Centers

Lessons learnt:

- Lack of coordination between measurement and modelling groups.
  - Measurement products lack harmonised quality controls, data formats and measurements schedules
    - This is more dramatic when you consider Northern African and the Middle East where we find the deserts
- Advertise about Sand and Dust Storms
  - Enhance the visibility of the dust impacts to the society at large and the most affected socio-economic sectors in particular
- Not “really” tailored user-oriented products
  - Few existing channels of communication between scientific research and user (socio-economic) communities.

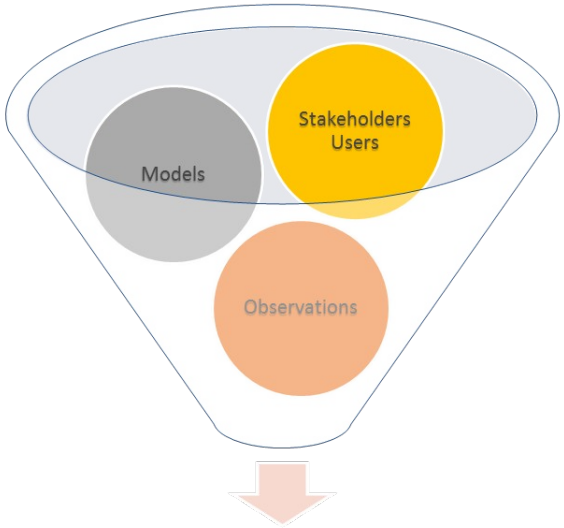
DustClim

ERA4CS European Research Area for Climate Services

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

- SDS is a serious hazard for life, health, environment and economy
- Lack of dust observations (past trends and current conditions)

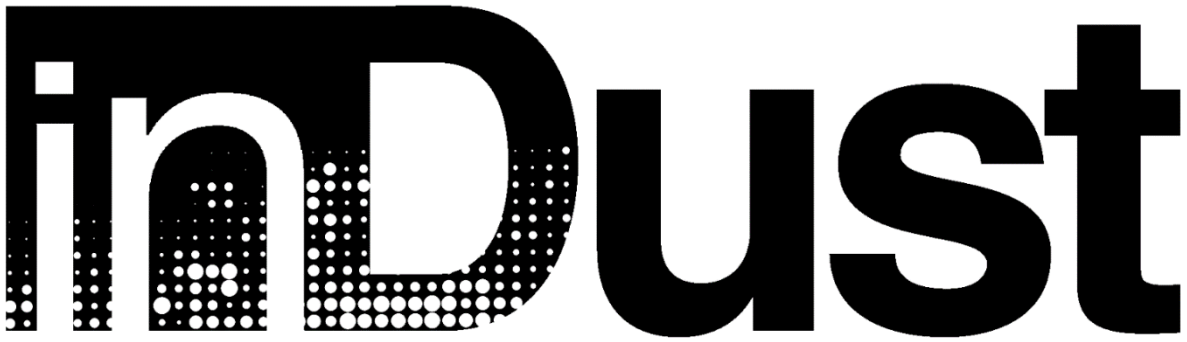
GOAL: Develop **dust-related services** to specific socio-economic sectors based on an advanced **dust reanalysis** for the NAMEE region



Dust-related Climate Services

BSC AEMet Agencia Estatal de Meteorología cnrs

International Network to Encourage the Use of Monitoring and Forecasting Dust Products



COST Action CA16202

cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Background

- Sand and Dust Storms (SDS) play a significant role in different aspects of weather, climate and atmospheric chemistry and represent a **serious hazard** for life, health, property, environment and economy.
- Understanding, managing and mitigating SDS **risks** and **effects** requires fundamental and cross-disciplinary knowledge.

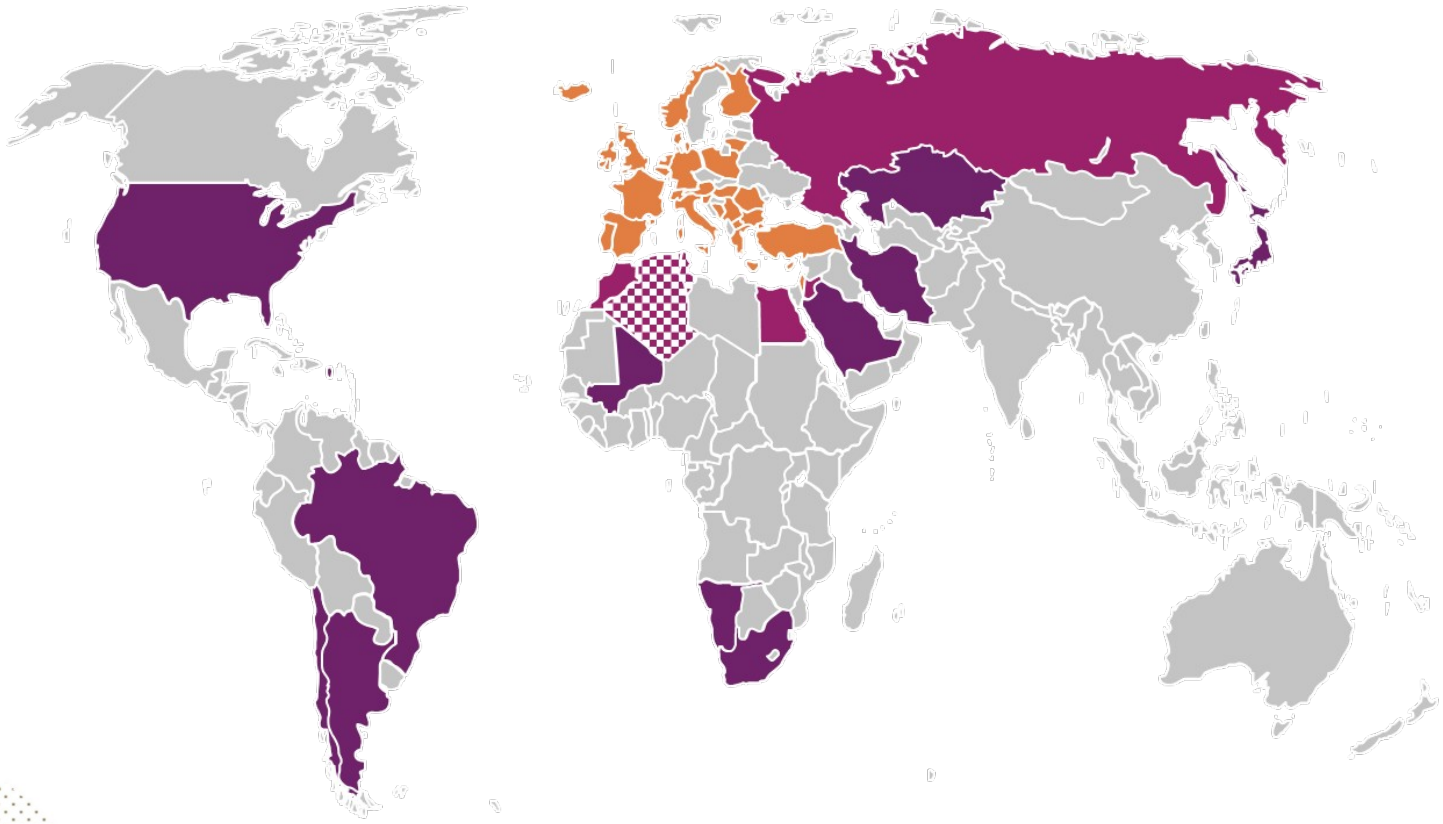
Tehran, Iran, June 2014

Our goals

- To establish a network involving research institutions, service providers and potential end users of
- To
- To assist the diverse socio-economic sectors affected by the presence of high concentrations of airborne mineral dust.

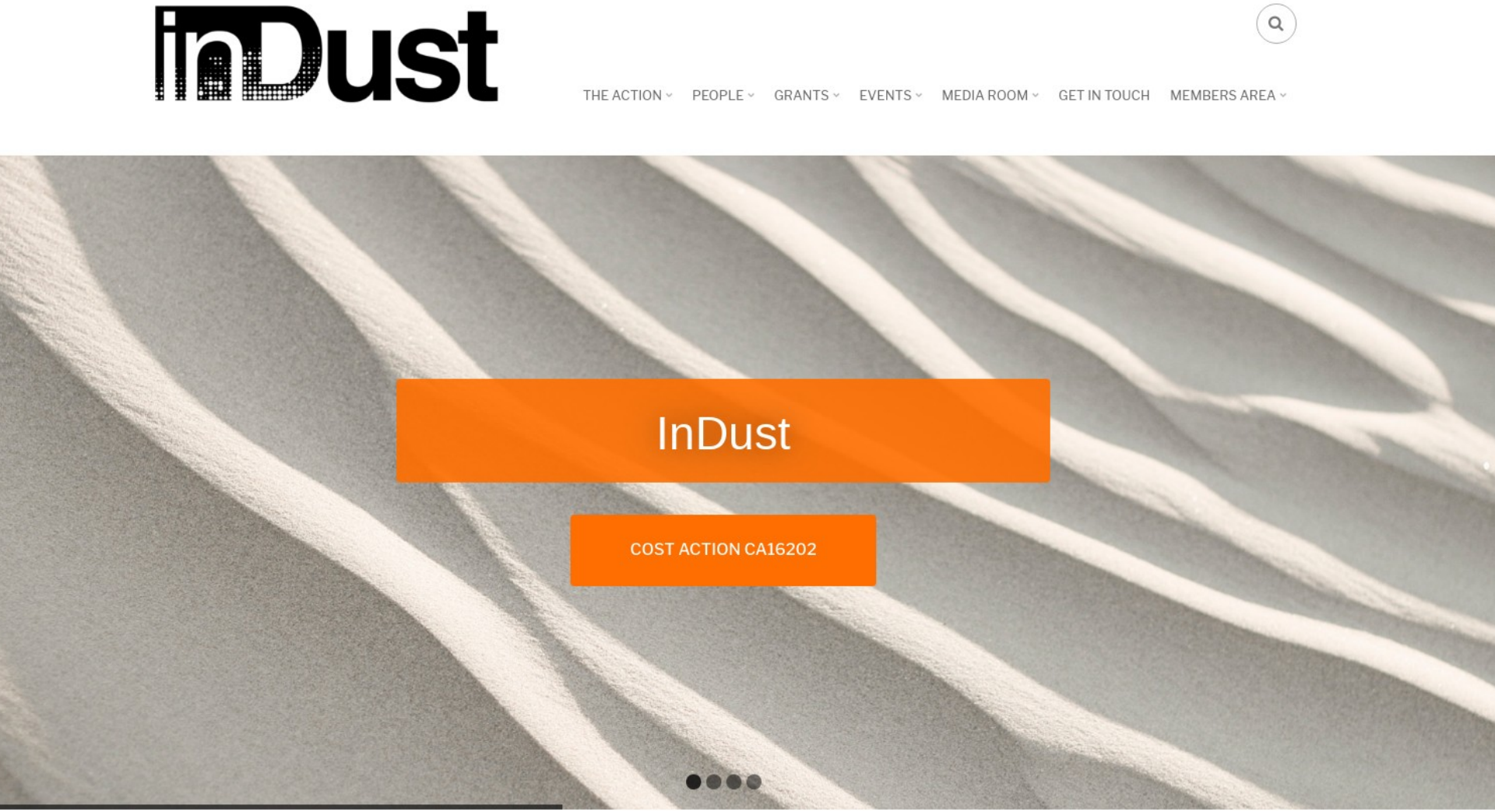
inDust is looking for dust user-oriented services

inDust Countries



- COST countries (in total 29)
- Near-Neighbour Countries (Egypt, Jordan, Lebanon, Morocco, Russia, *Algeria*)
- International Partner Countries
  International organisation (WMO, *ECMWF*)

www.cost-indust.eu
Contact: cost-indust@bsc.es



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AXA Research Fund

EXCELENCIA SEVERO OCHOA

inDust

AEMet Agencia Estatal de Meteorología

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