



**Barcelona  
Supercomputing  
Center**  
Centro Nacional de Supercomputación



# Modeling the impact of Dust on Air Quality ~~and Climate~~

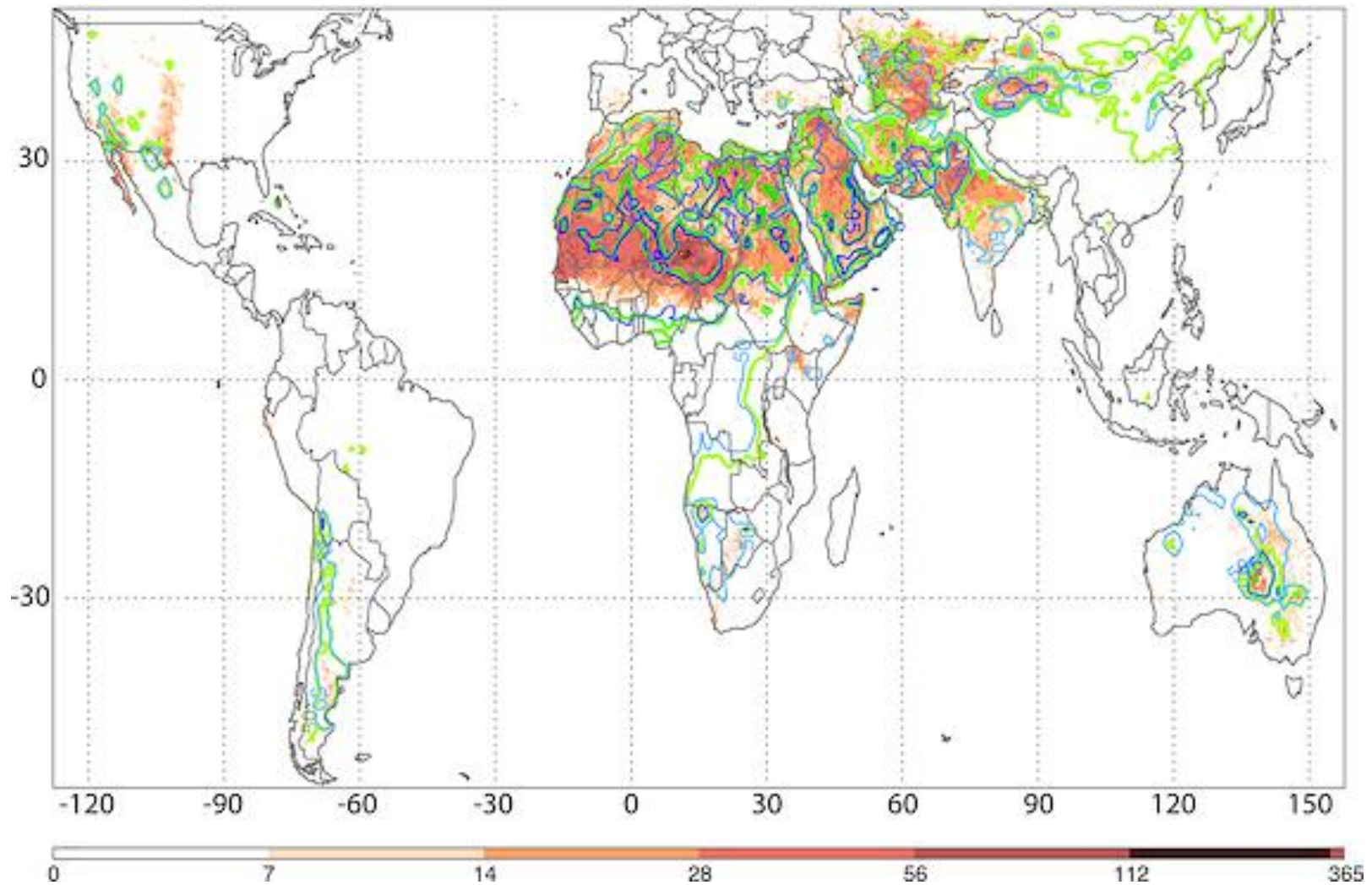
*Sara Basart ([sara.basart@bsc.es](mailto:sara.basart@bsc.es))*

*Atmospheric Composition Group, Earth  
Sciences Department*

*Barcelona Supercomputing Center*

*PSF/TAIEX Workshop on Air Pollution, Industrial, Emissions,  
Sand and Dust Storms, 21-22 November, 2017, Tehran, Iran*

# Dust global distribution



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

*Extracted from Ginoux et al. (2012, Rev. Geophys.)*

# Dust impacts

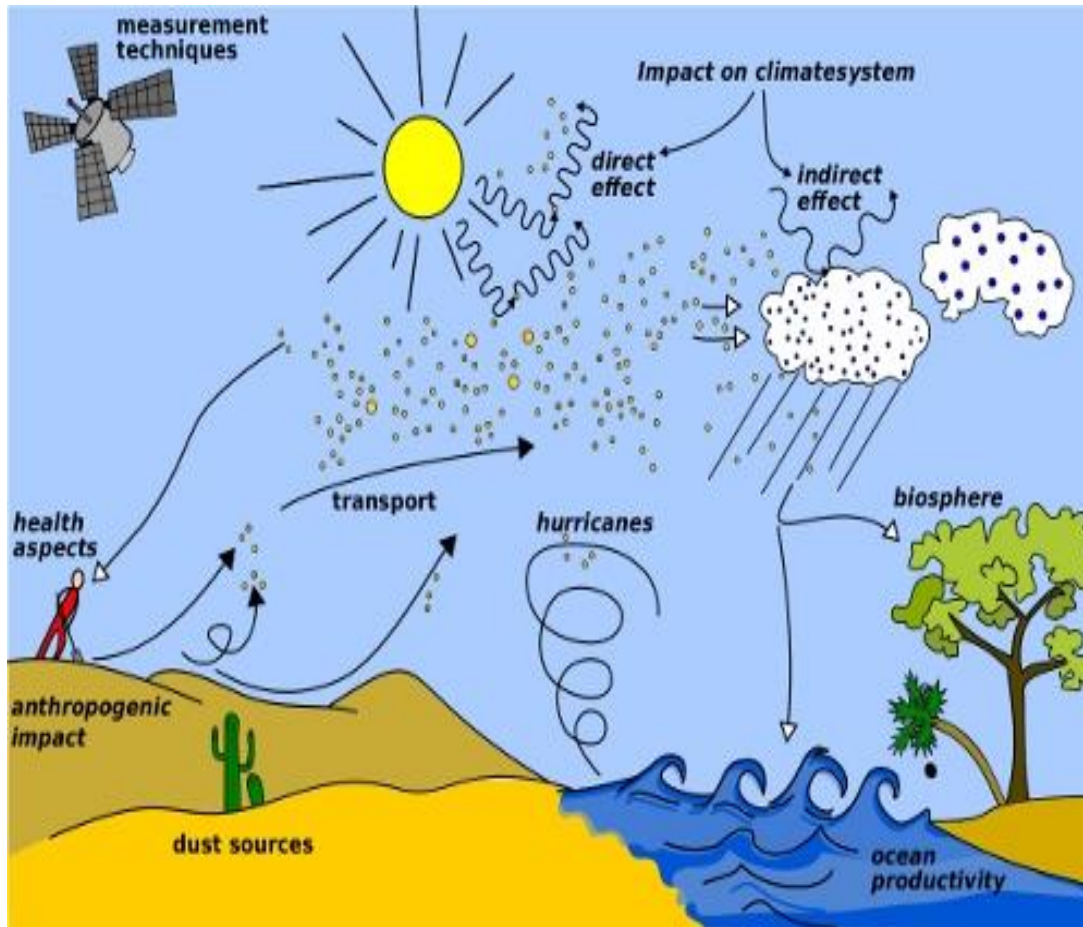


Image from WMO website  
(<http://www.wmo.int/pages/prog/arep/wwrp/new/hurricanes.html>)

## Ecosystems, meteorology and climate

- *Marine productivity*
- *Coral mortality*
- *Hurricanes formation*

## Air Quality and Human Health

- *Respiratory disease (asthma)*
- *Eye infections*
- *Meningitis in Africa*
- *Valley Fever in the Americas*

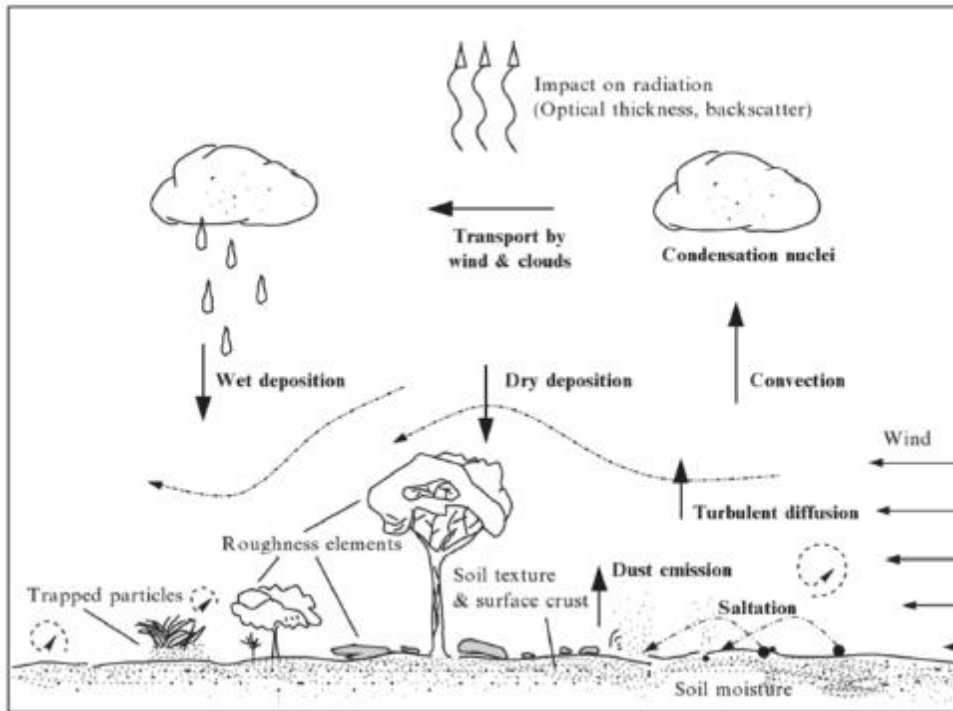
## Aviation and Ground Transportation

- *Low visibility (i.e. air disasters)*

## Agriculture and fishing

## Energy and industry

# Dust modelling

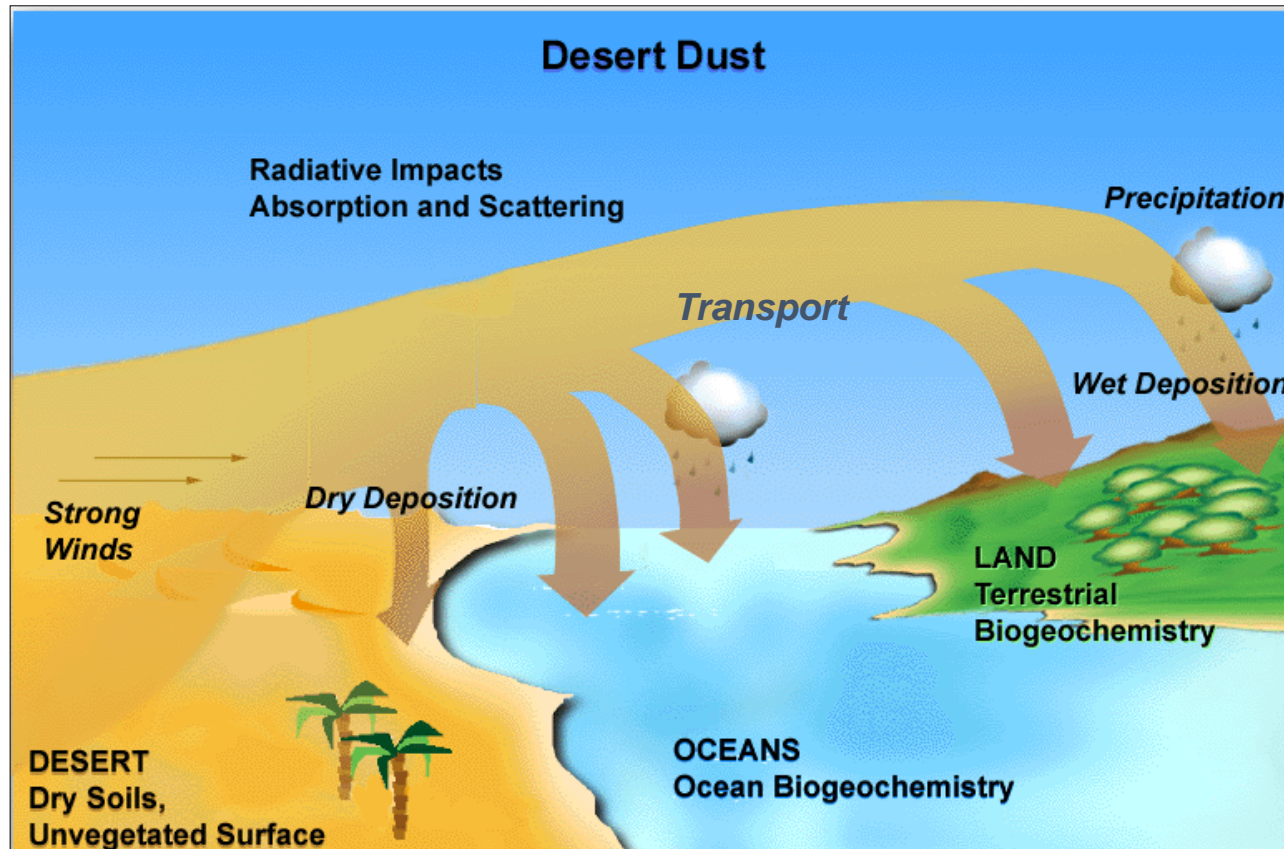


Extracted from Shao (2008)

- ✓ To **complement dust-related observations**, filling the temporal and spatial gaps of the measurements.
- ✓ To help us to understand the dust processes and their interaction with **climate** and ecosystems.
- ✓ To predict the impact of dust on surface level concentrations used as **short-term forecasting tools** (3-5 days ahead)

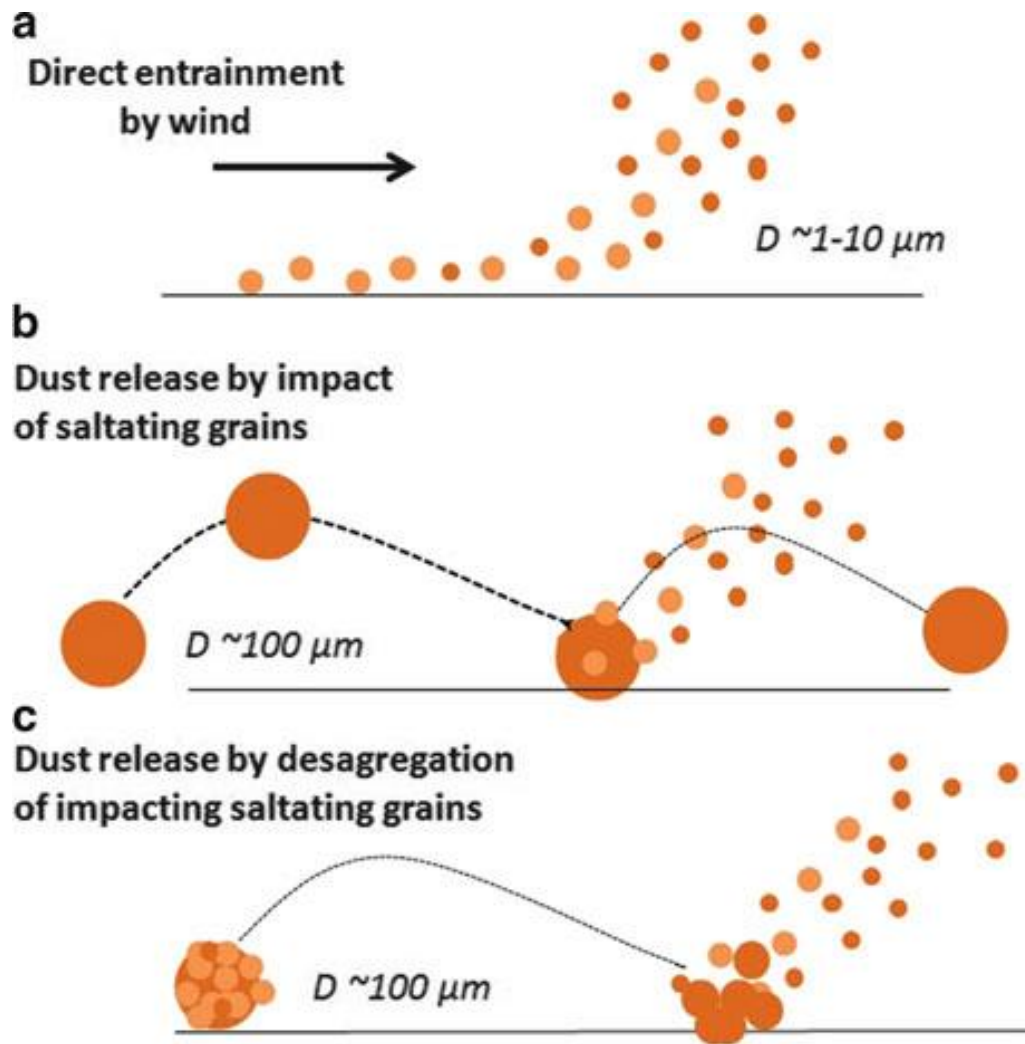
Dust forecasting models do **not** take account dust **resuspension**

# Dust modelling requires the representation of sources, transport and sinks



Dust transport is a global phenomenon. However, dust emission is a threshold phenomenon, sporadic and spatially heterogeneous, that is locally controlled on small spatial and temporal scales.

# Dust emission mechanisms



*Emitted dust mass*

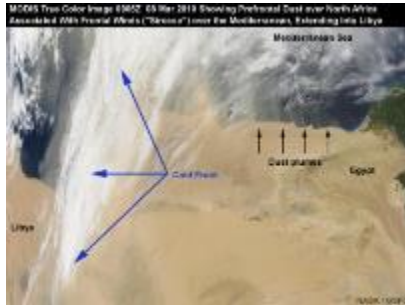
*&*

*Size distribution*

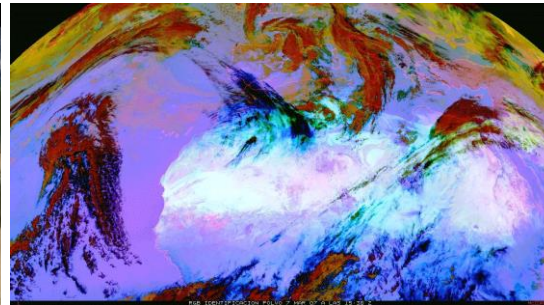
# Associated meteorological processes

**Synoptic dust storms** (large scale weather systems)

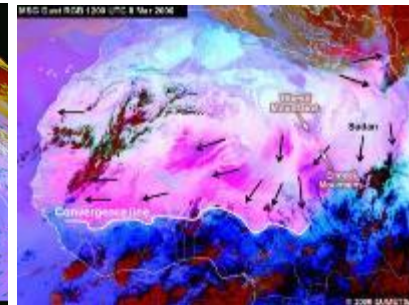
**Well captured by models.**



*Pre-frontal winds*



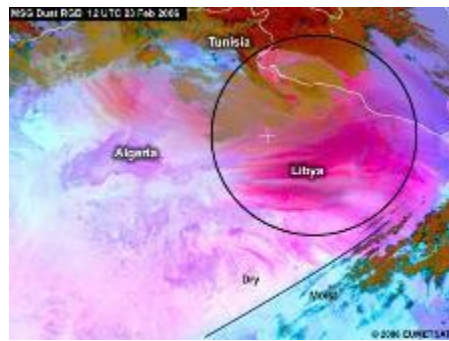
*Post-frontal winds*



*Large-scale trade winds*

**Meso-micro scale dust storms**

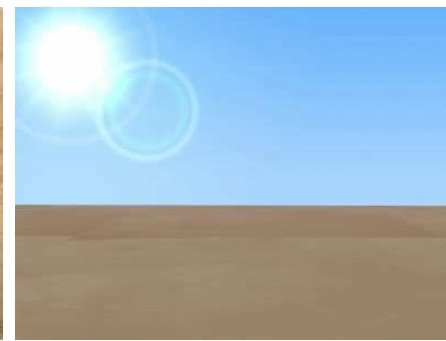
**Poorly captured by models.**



*Downslope winds*



*Gap flow*



*Dust devils*



*Haboobs (moist convection)*

# Soil size distribution

Main landscapes of the **North Africa** (Photos from Callot et al. 2000) :



A) Central part of Saharan Atlas. In the background, mountains, and in front, an overgrazed plain;

B) Northern part of Saharan Atlas. Esparto grass steppe degraded by a strong anthropic action. The sandy soil disappears, denuding the sandstone substratum;

C) The Great Hamada south-west of El-Abiodh-Sidi-Cheikh;

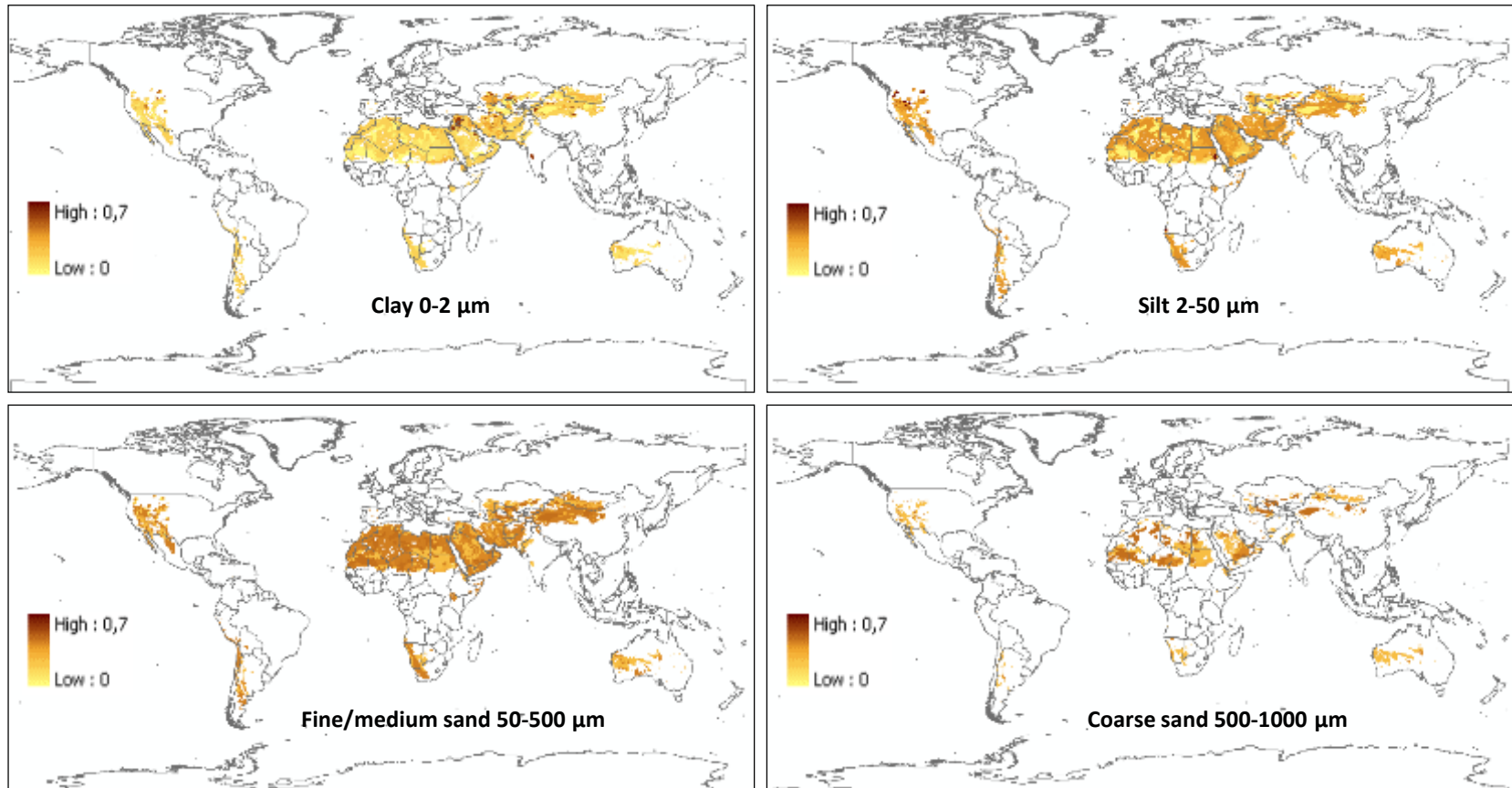
D) Daïa in the Mechfar, at Hassi Cheikh well;

E) North-east of the Great Western Erg: coarse sand interdune corridor with deflation cauldron and palaeolake deposits;

F) North-east of the Great Western Erg: great coarse sand dome dunes, covered by fine sand active dunes.



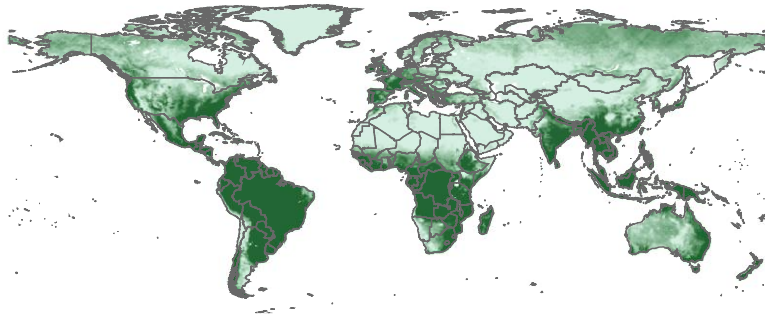
# Soil size distribution derived from soil texture



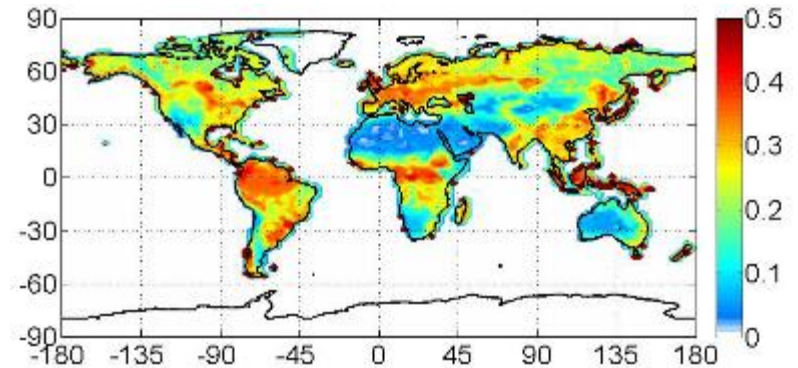
STASGO-FAO database

# Vegetation, roughness, soil moisture

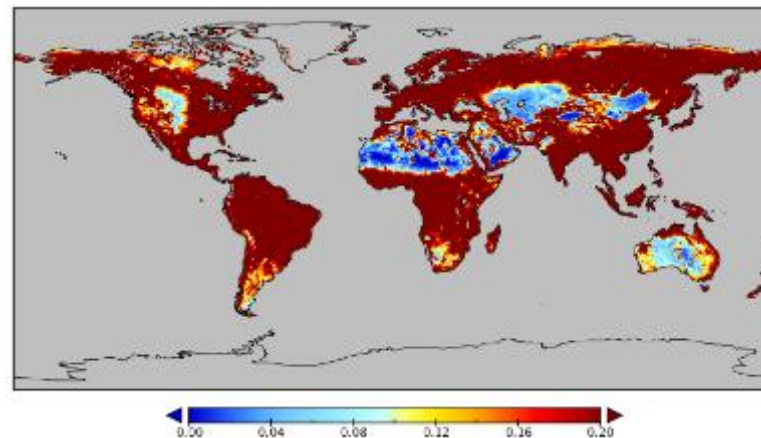
Vegetation fraction  
(MODIS)



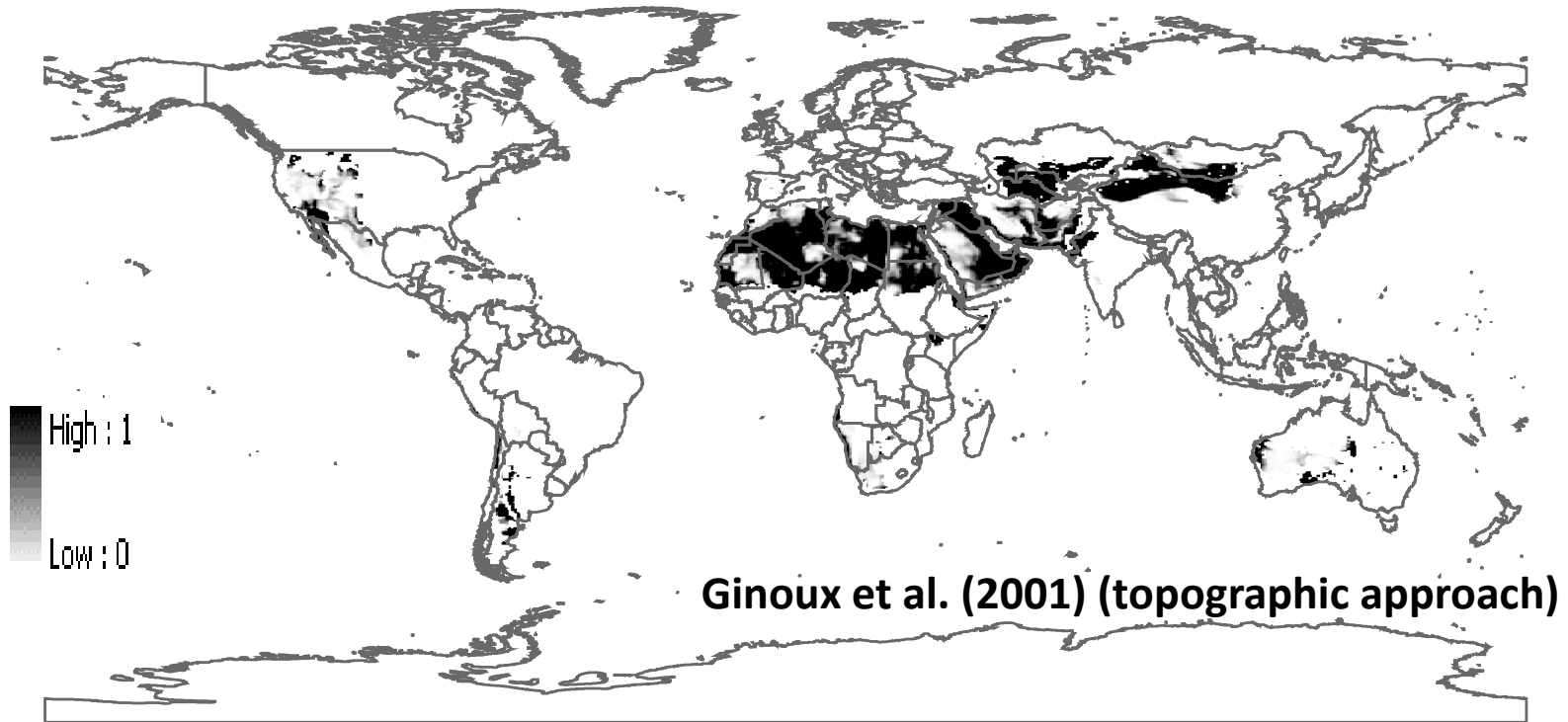
Soil moisture  
(model based)



Roughness length  
(ASCAT + PARASOL)



# Source mapping: why?

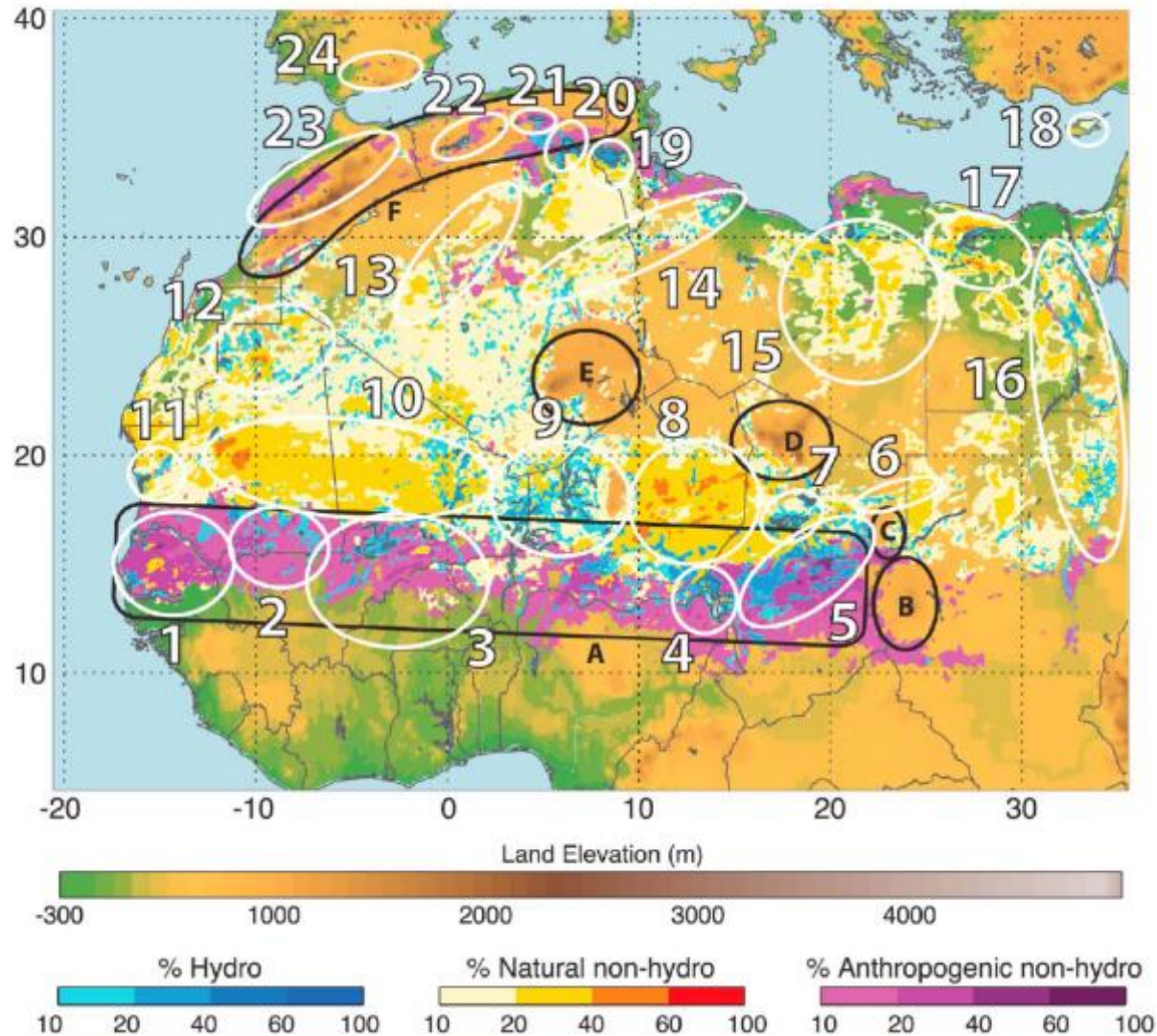


$$S = \left( \frac{z_{\max} - z_i}{z_{\max} - z_{\min}} \right)^5$$

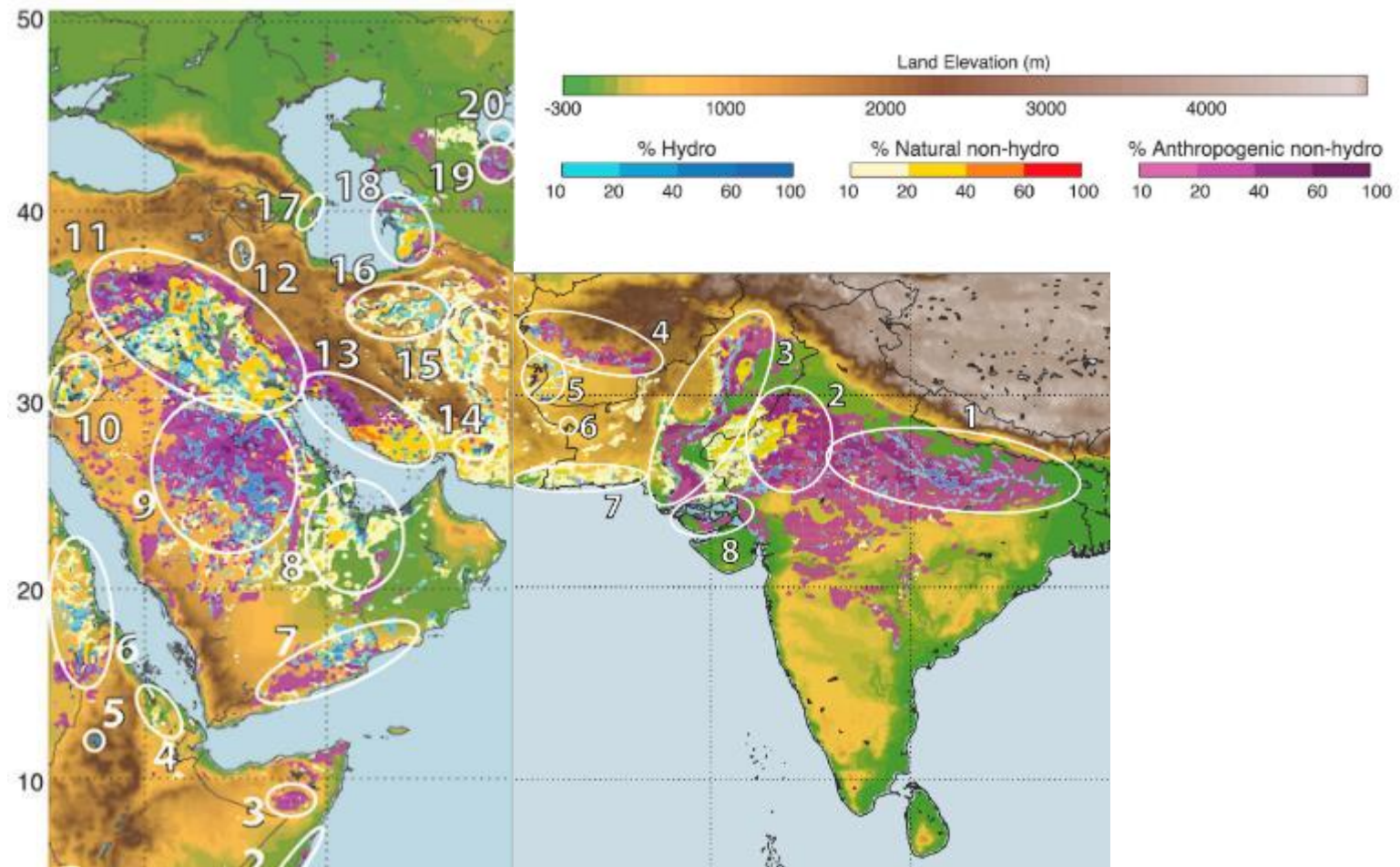
S: probability to have accumulated sediments in the grid cell i of altitude  $z_i$

best fit with the sources identified by Prospero et al. 2000

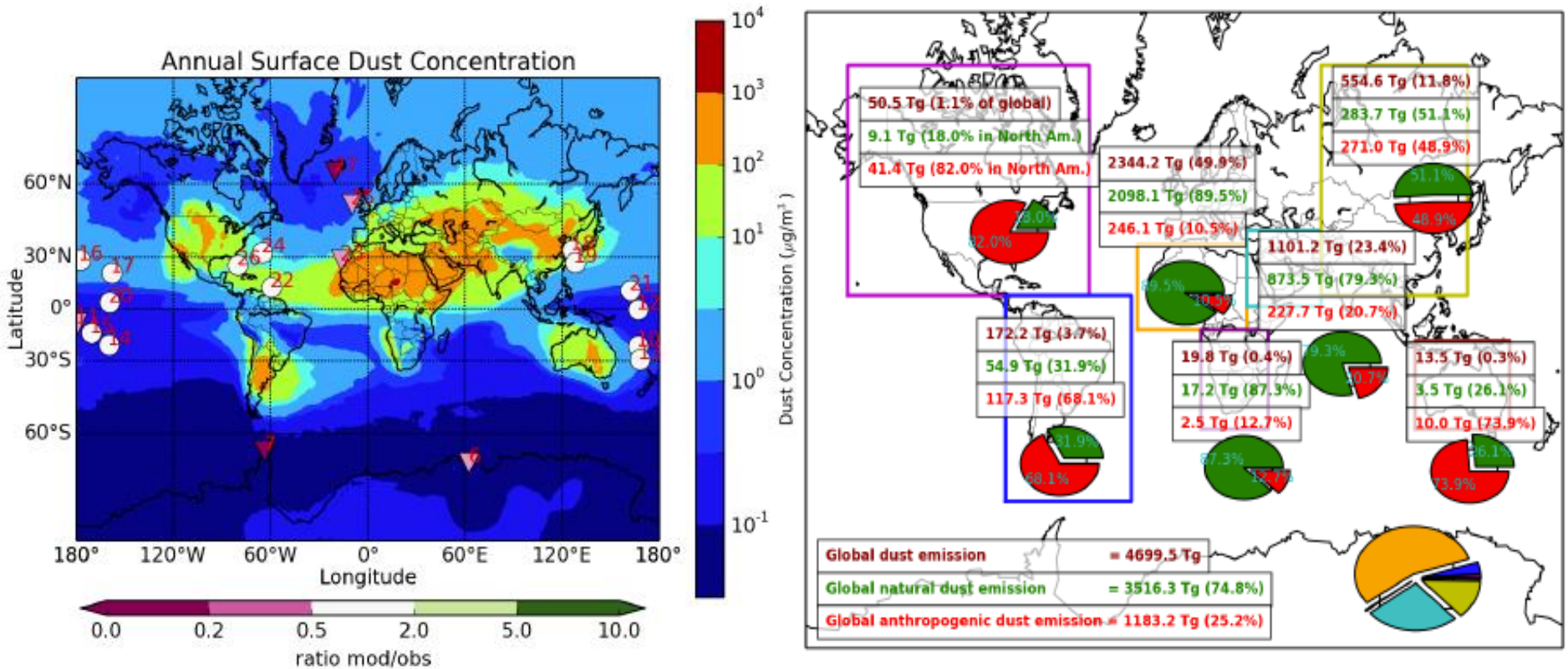
# High resolution Natural and anthropogenic dust sources



# High resolution Natural and anthropogenic dust sources



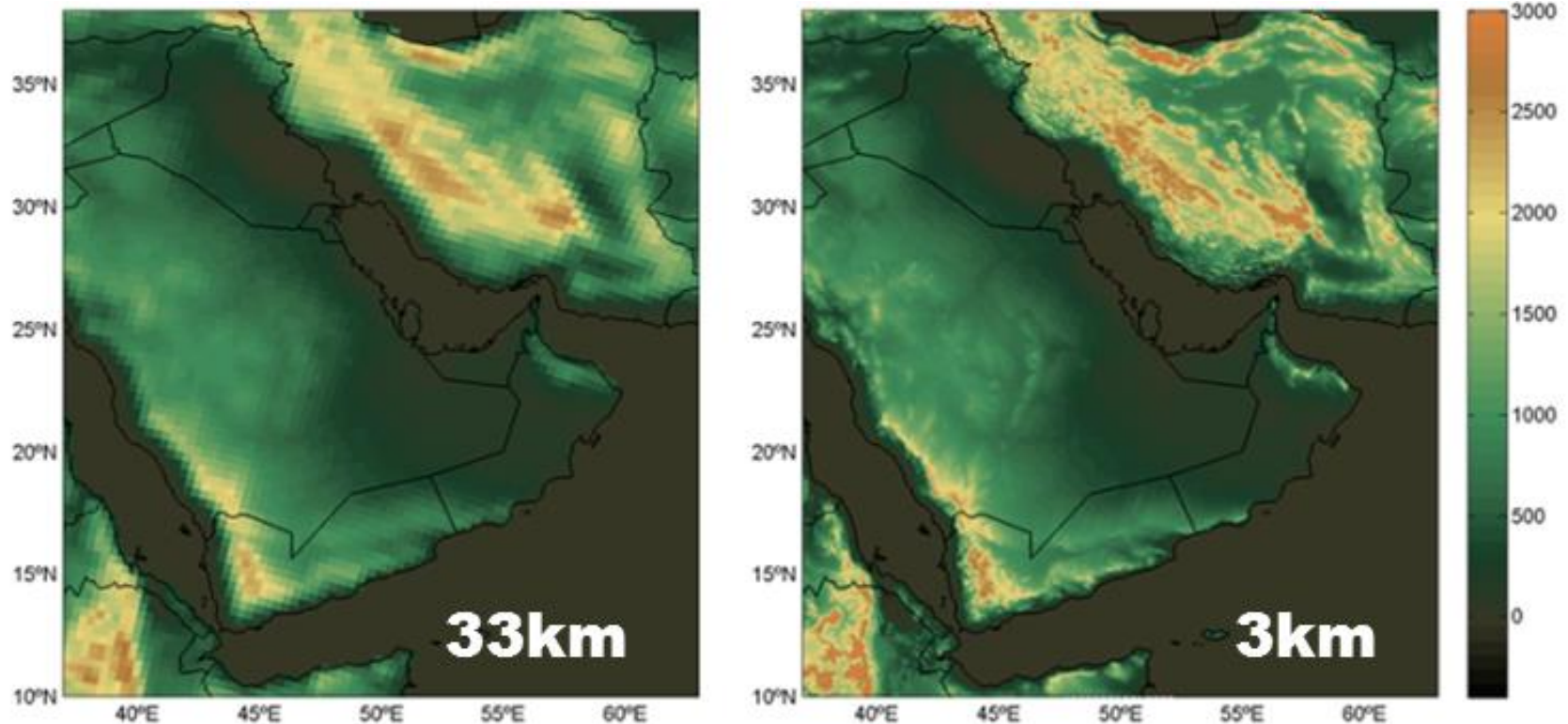
# Current quantification natural vs anthropogenic



# Major challenge for modeling



# Topographical impacts on dust transport



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

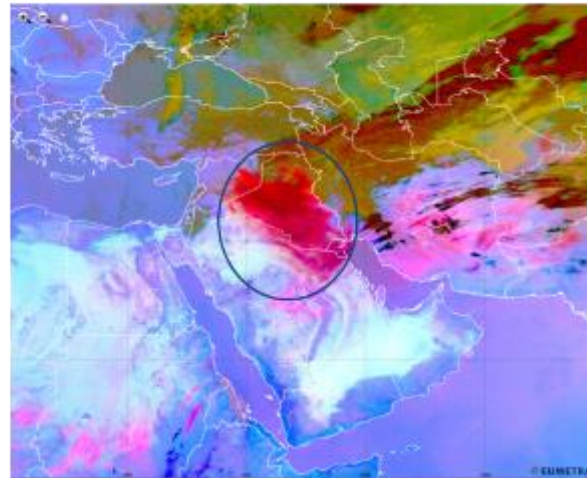
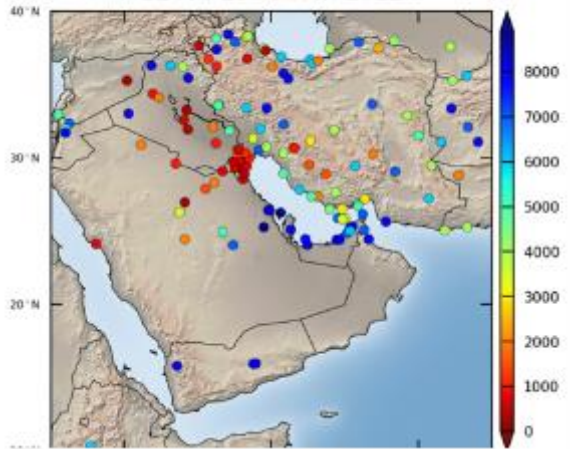
*Model configuration: LR (0.33°, ~33km), HR (0.03°, ~3km), 40 levels, FNL as meteo. Initial conditions  
Forecast time: 10 – 21 March 2012*



# Topographical impacts on transport

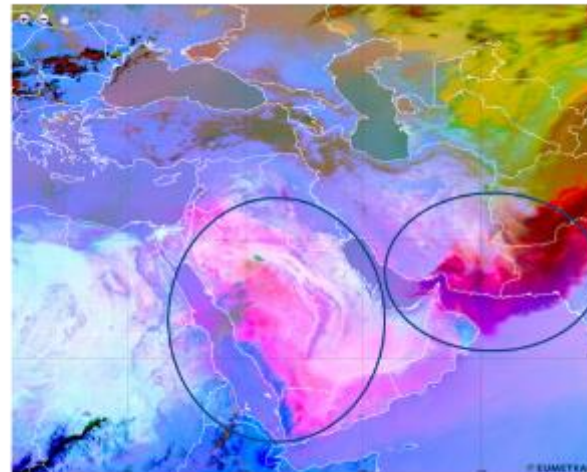
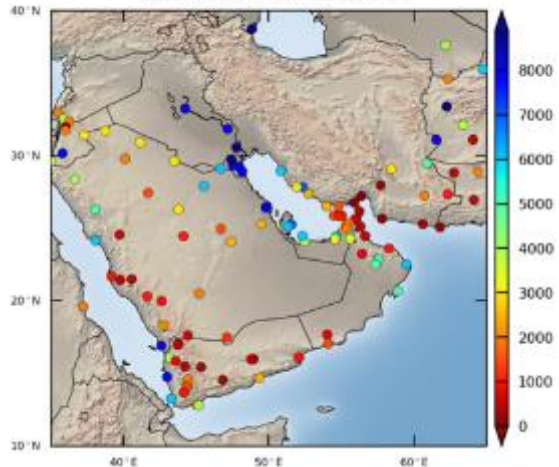
## Dust event on March 2012

VISIBILITY (meters)  
12UTC 17 MARCH 2012



Dust emission in Iraq

VISIBILITY (meters)  
12UTC 19 MARCH 2012

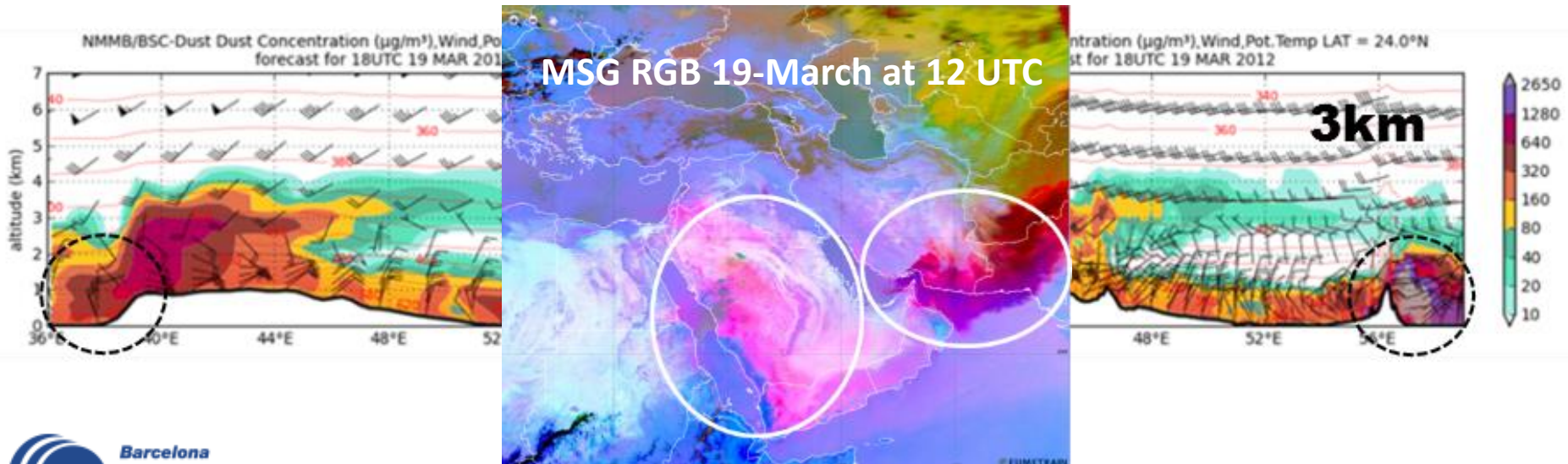
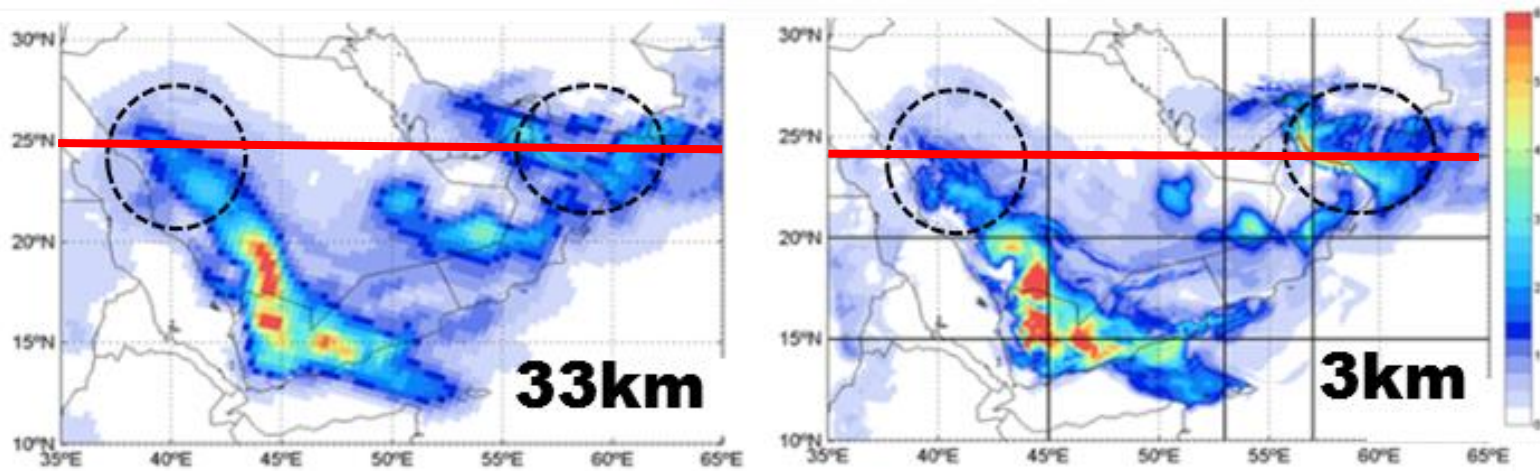


Dust from Iran and  
Afganisthan/Iran  
border reaches Oman  
coasts

Dust from Iraq  
reaches Yemen

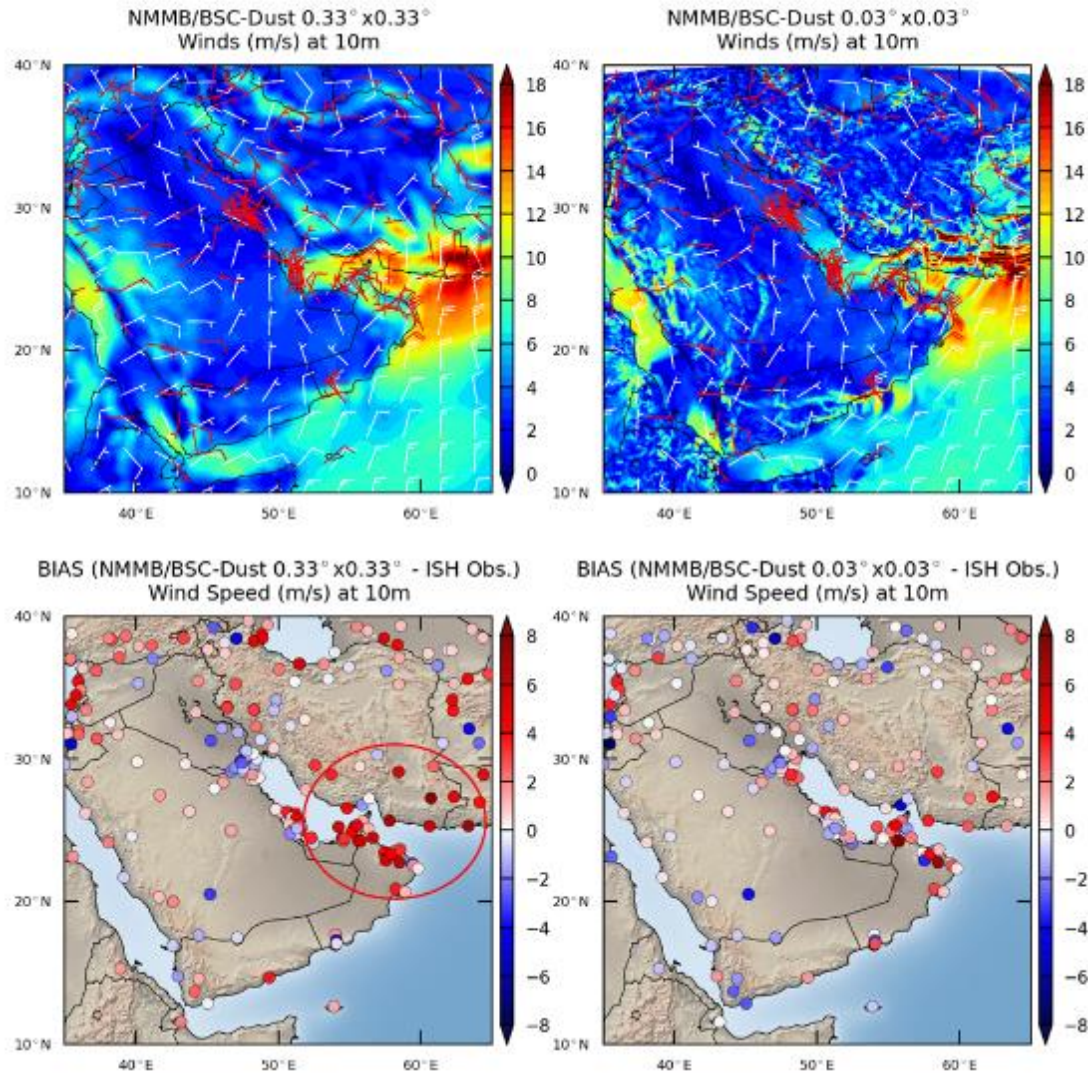
# Topographical impacts on dust transport

NMMB/BSC-Dust 19-March-2012 18UTC



# Topographical impacts on dust transport

NMMB/BSC-Dust 19-March-2012 21UTC



# Iranian Haboob: Teheran 2<sup>nd</sup> June 2014

## Ongoing Study Case

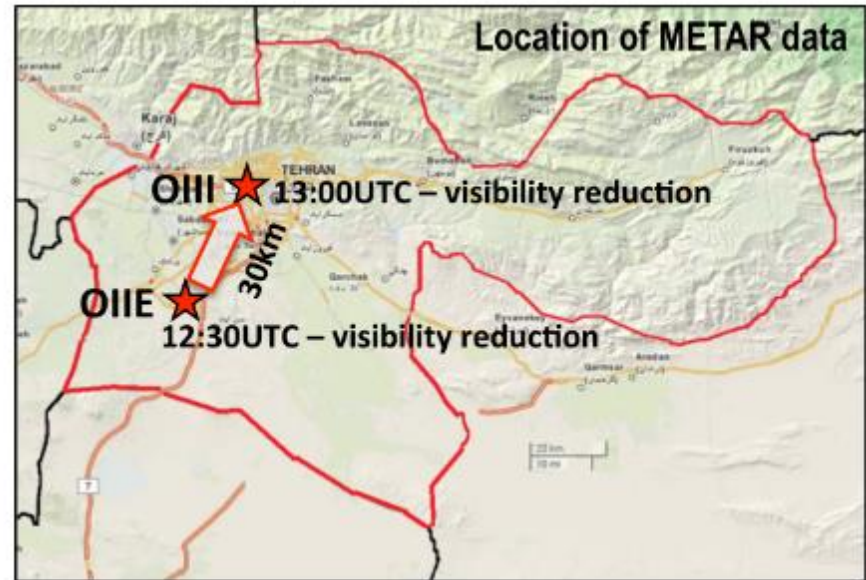


The event was local (several 100km), intense (several  $1000\mu\text{g}/\text{m}^3$  PM10) & short lived (few hours) dust storms

# Iranian Haboob: Teheran 2<sup>nd</sup> June 2014

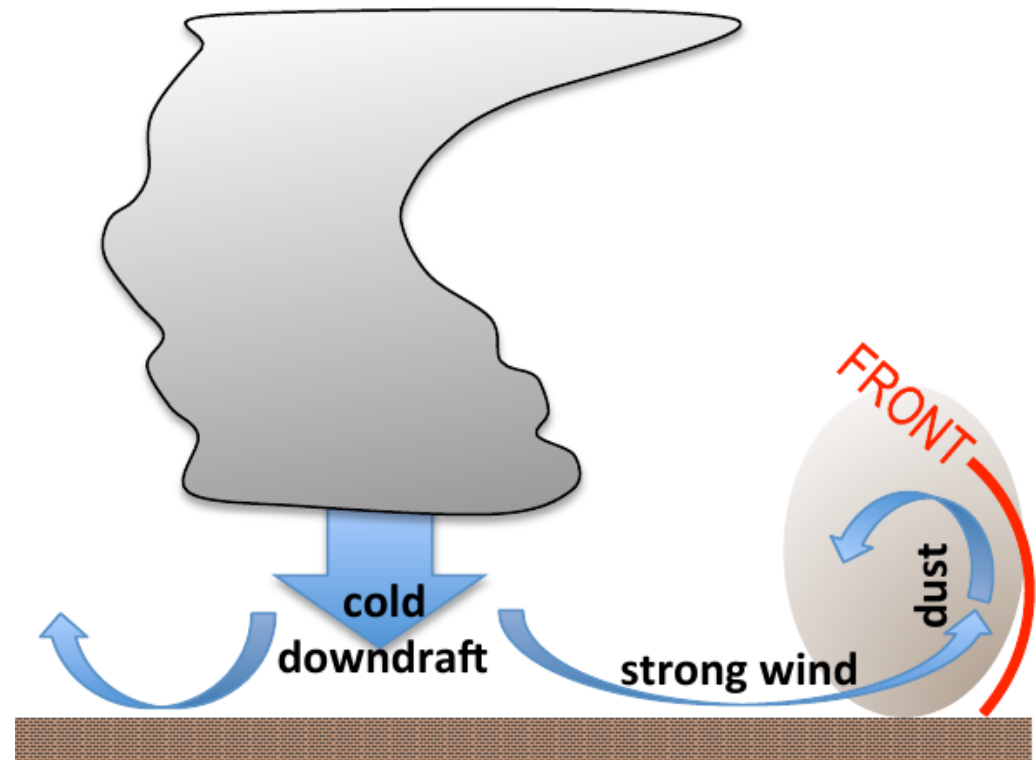
## Information from reports

- 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 18°C in several min;
- at least 5 deaths, 82 injured; multiple vehicle collision;



# Iranian Haboob: Teheran 2<sup>nd</sup> 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.

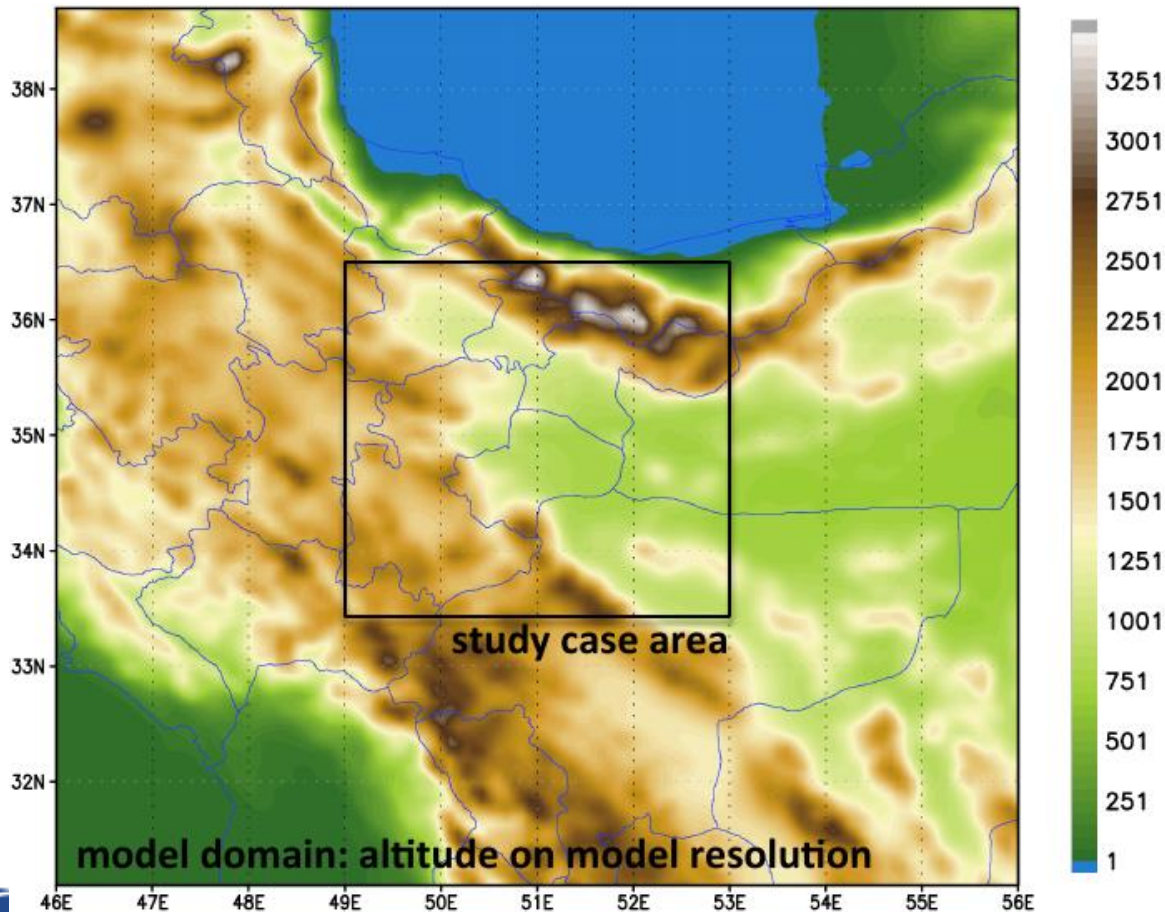
# Iranian Haboob: Teheran 2<sup>nd</sup> June 2014

**DREAM – SEEVCCC:** NMME atmospheric driver (Vukovic et al. 2014 – HR simulation)  
(Perez et al. 2006, Nickovic 2001)

Model domain: lat 31N-39N, lon 46E-56E; Model resolution: 1/40 horizontal (~4km); 60 vertical levels

Forecast time: 12UTC 01 June 2014 – 00UTC 03 June 2014 (36h)

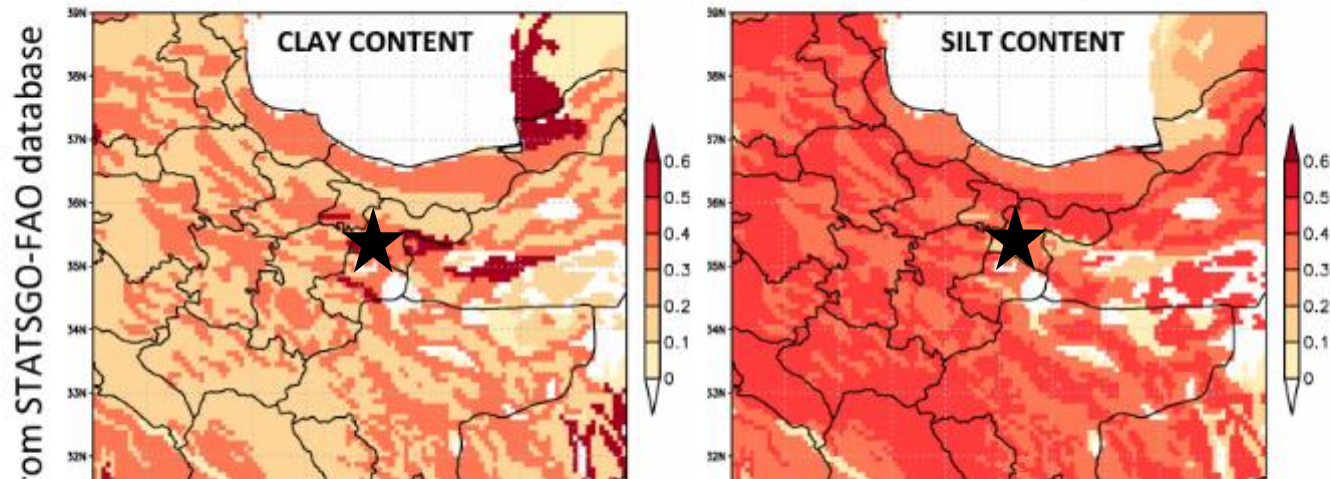
Time of the event: about 12-15 UTC 02 June 2014



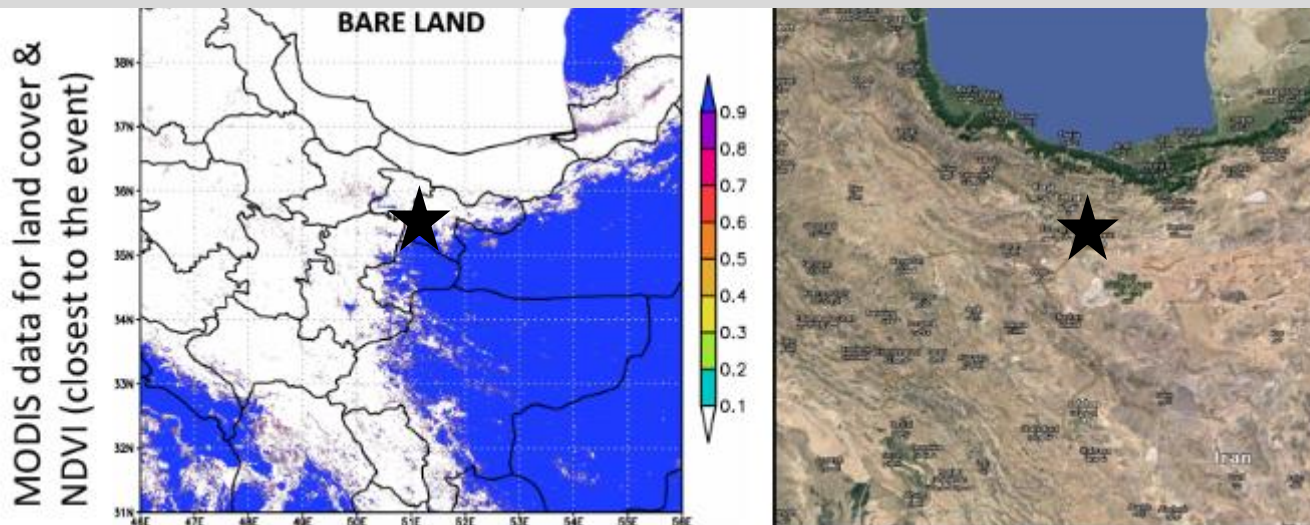
The main goal:  
To create tool for forecast of  
intense local short lived dust  
storms in service of warning  
system.

# Iranian Haboob: Teheran 2<sup>nd</sup> June 2014

clay size particles source potential = (clay content)\*(bare land)  
silt size particles source potential = (silt content)\*(bare land)



High-resolution dust modelling ↔ High-resolution updated land databases

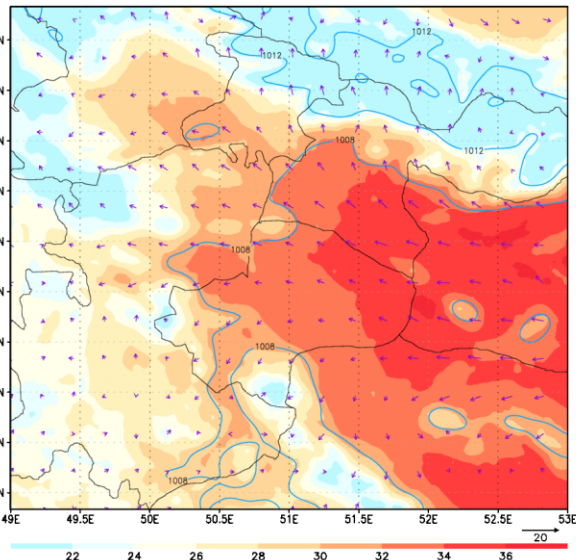




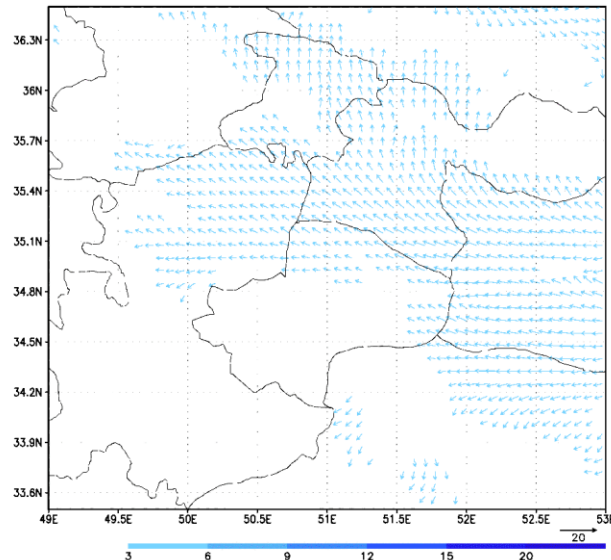
# Iranian Haboob: Teheran 2<sup>nd</sup> June 2014

## NMME-DREAM (SEEVCCC) simulation results for the period 06-20 UTC 2014

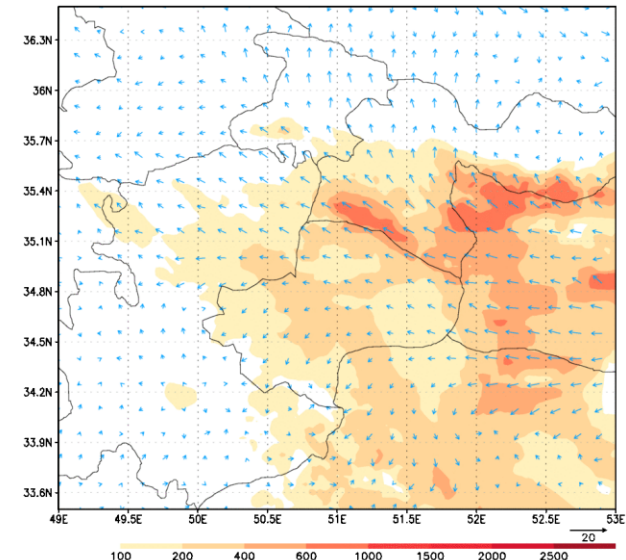
DREAM8 forecast: T2m [°C] PSL [mb] and 10m wind [m/s]  
Forecast base time: 01JUN2014 12UTC Valid: 02JUN2014 06UTC (+18h forecast)



DREAM8 forecast: 10m wind [m/s]  
Forecast base time: 01JUN2014 12UTC Valid: 02JUN2014 06UTC (+18h forecast)



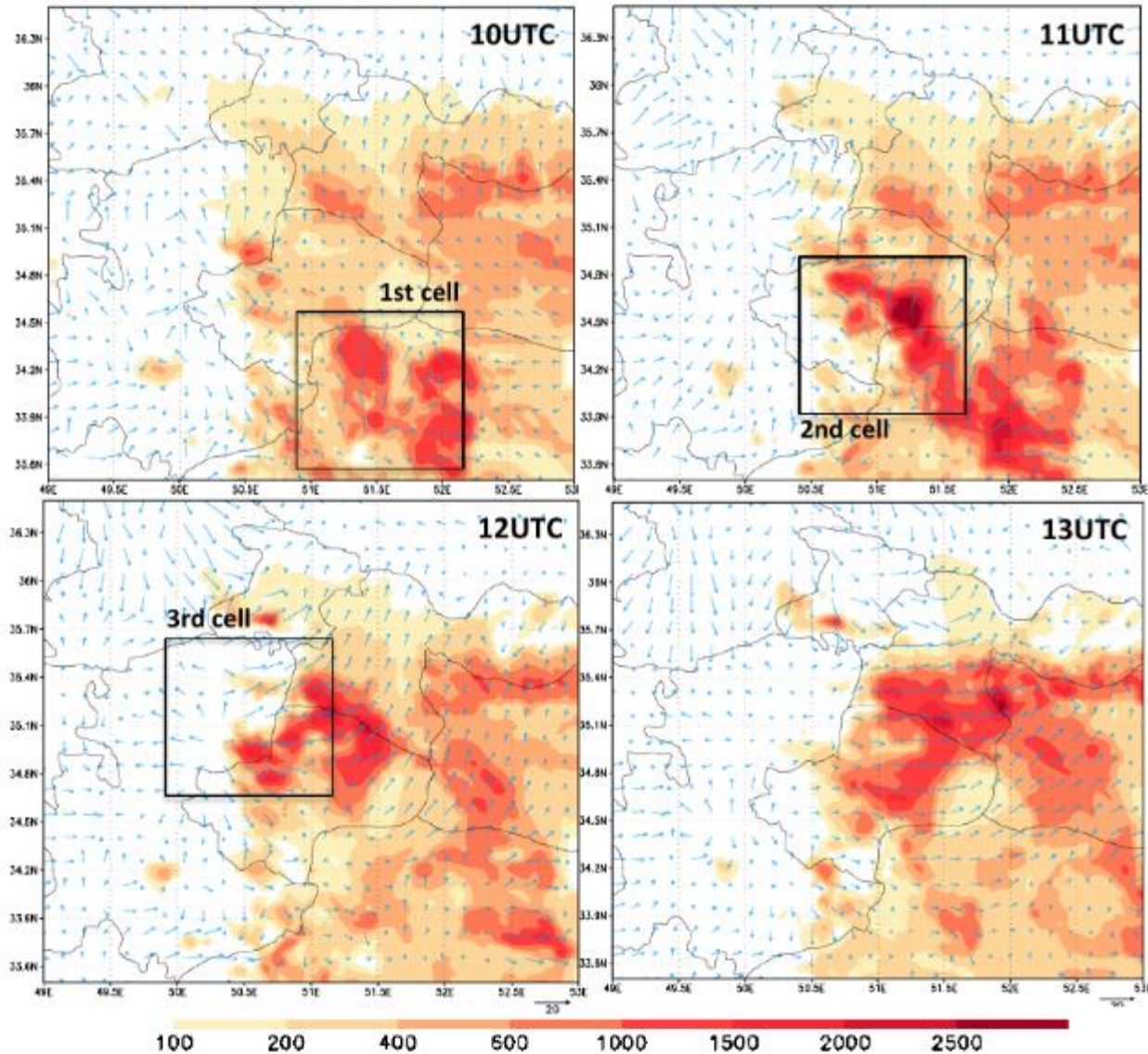
DREAM8 forecast: DNC - Surface dust number conc [1/cm³] and 10m wind [m/s]  
Forecast base time: 01JUN2014 12UTC Valid: 02JUN2014 06UTC (+18h forecast)



# Iranian Haboob: Teheran 2<sup>nd</sup> June 2014

DNC  
(surface)  
Dust Number  
Concentration  
*number of dust  
particles in cm<sup>3</sup>*

Dust uplift and  
transport  
controlled with  
three main cells.



# 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

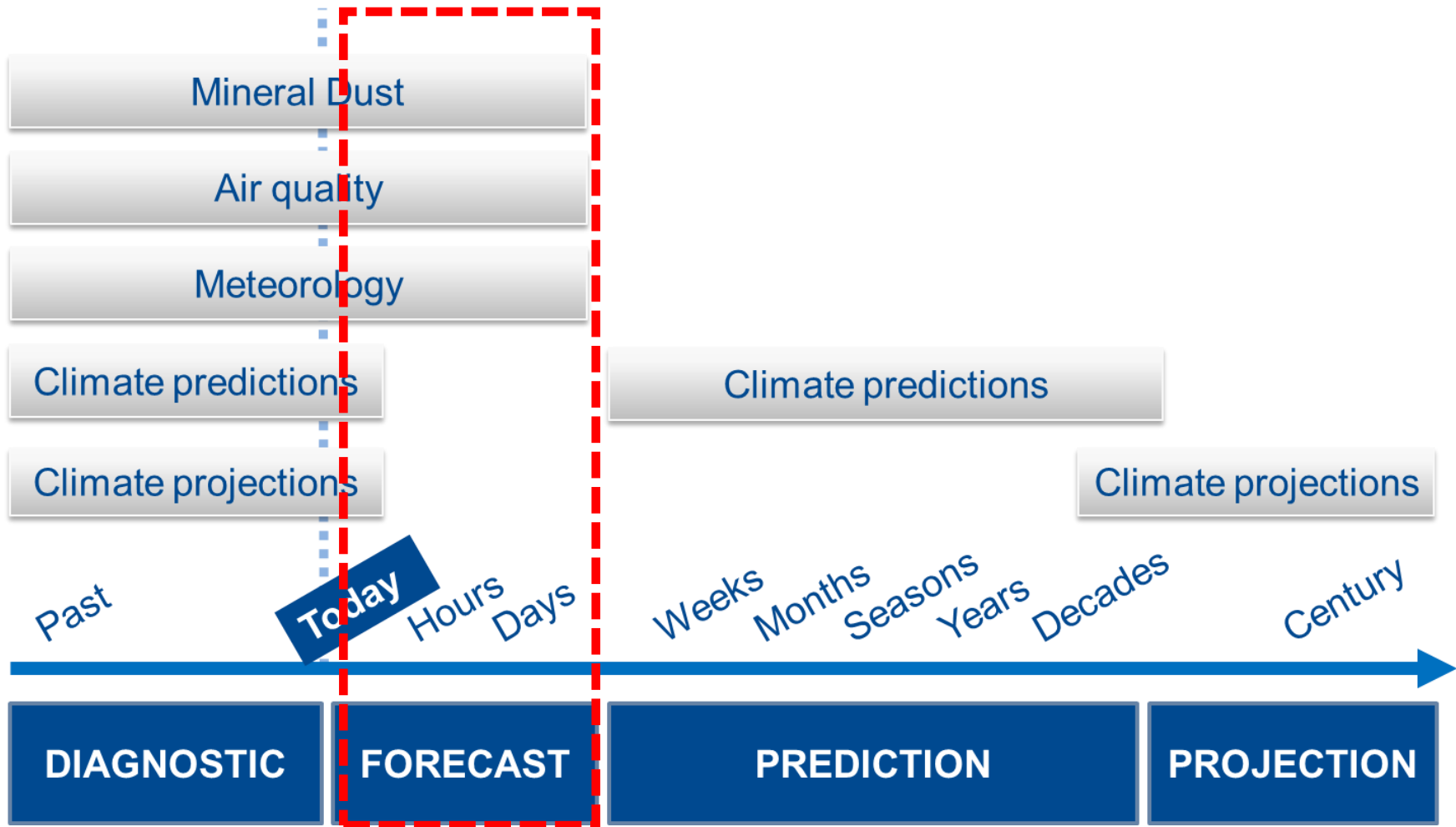
Earth system  
services

Climate  
prediction

Atmospheric  
composition

Computational  
Earth sciences

# BSC Earth Sciences Department



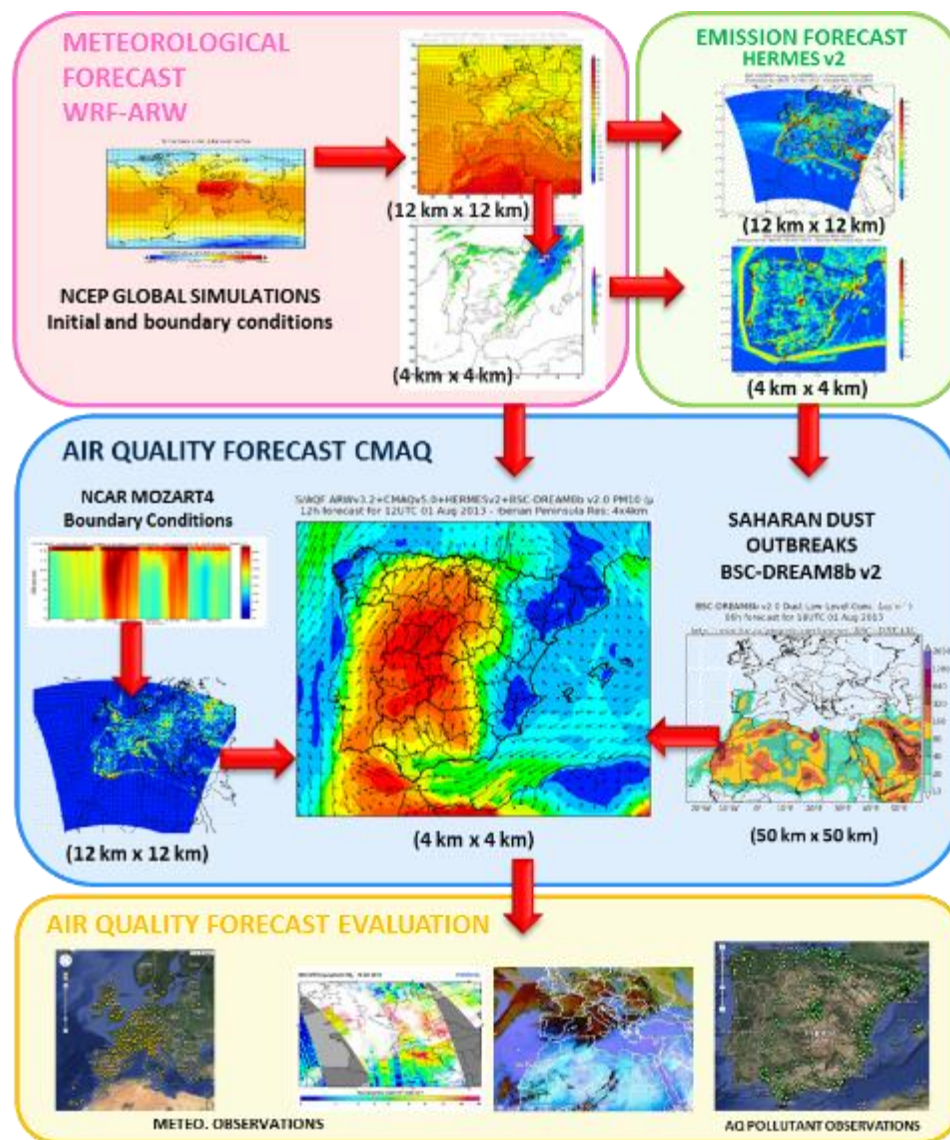
# Air Quality Modelling in EU/Spain

## 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)



CONSEJO DE MEDIO AMBIENTE Y ORDENACIÓN DEL TERRITORIO



GOBIERNO DE ESPAÑA



Gobierno de Canarias

Consejería de Educación, Universidades y Sostenibilidad



Generalitat de Catalunya

Departament de Territori i Sostenibilitat

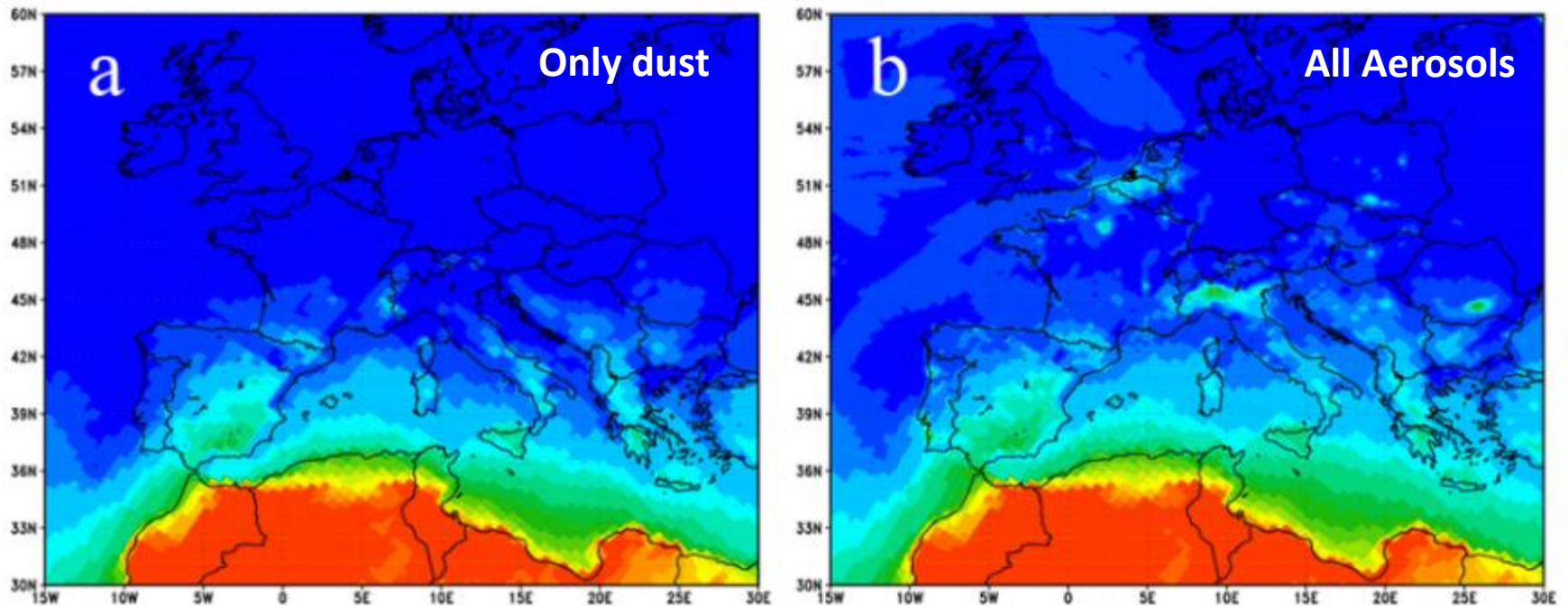


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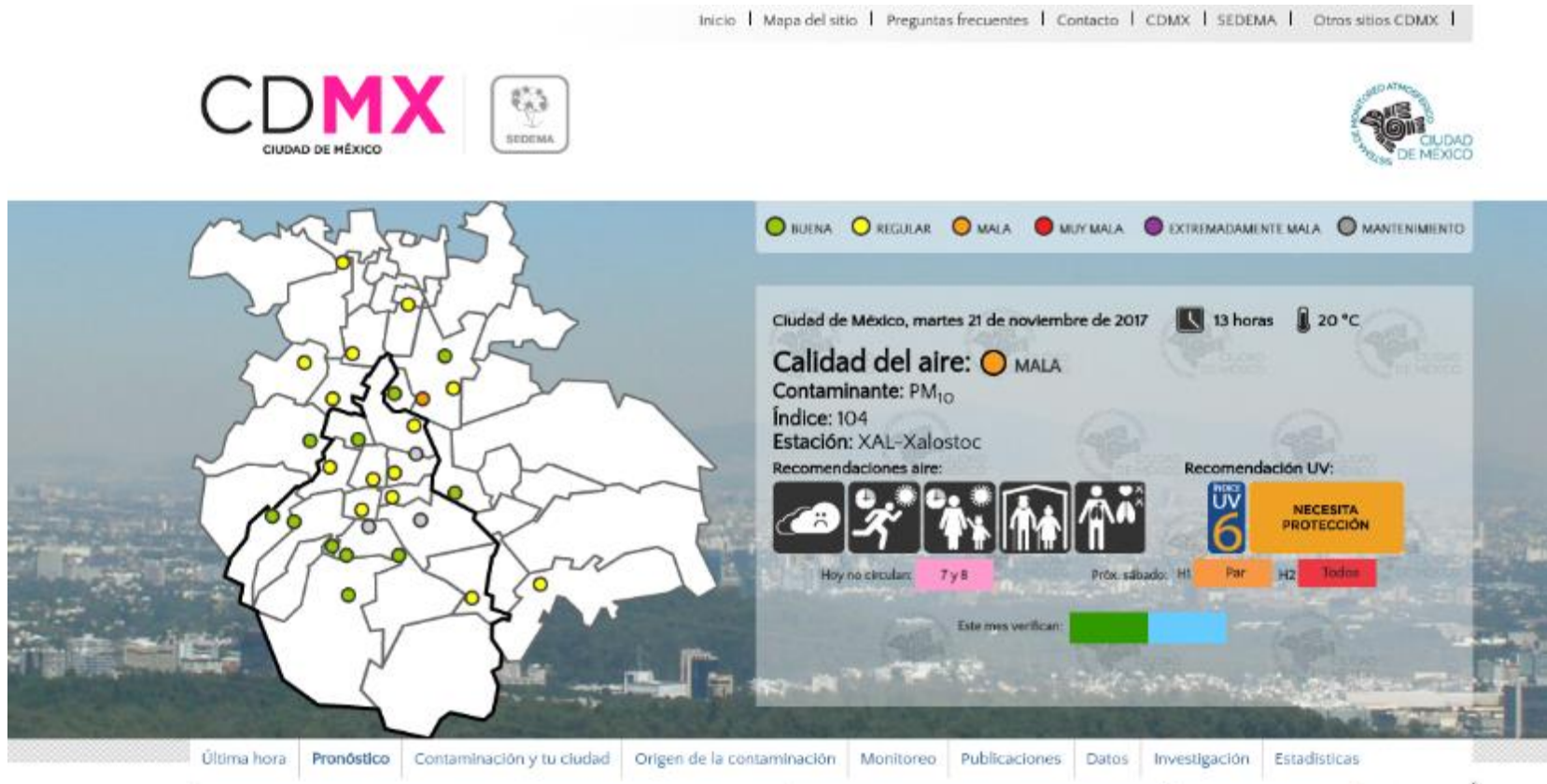
# Air Quality Modelling in EU/Spain

Number of the days exceeding the EU PM10 daily limit value ( $>50 \mu\text{g}/\text{m}^3$ ) for 2004 based on CALIOPE results



(Basart et al., ACP, 2012)

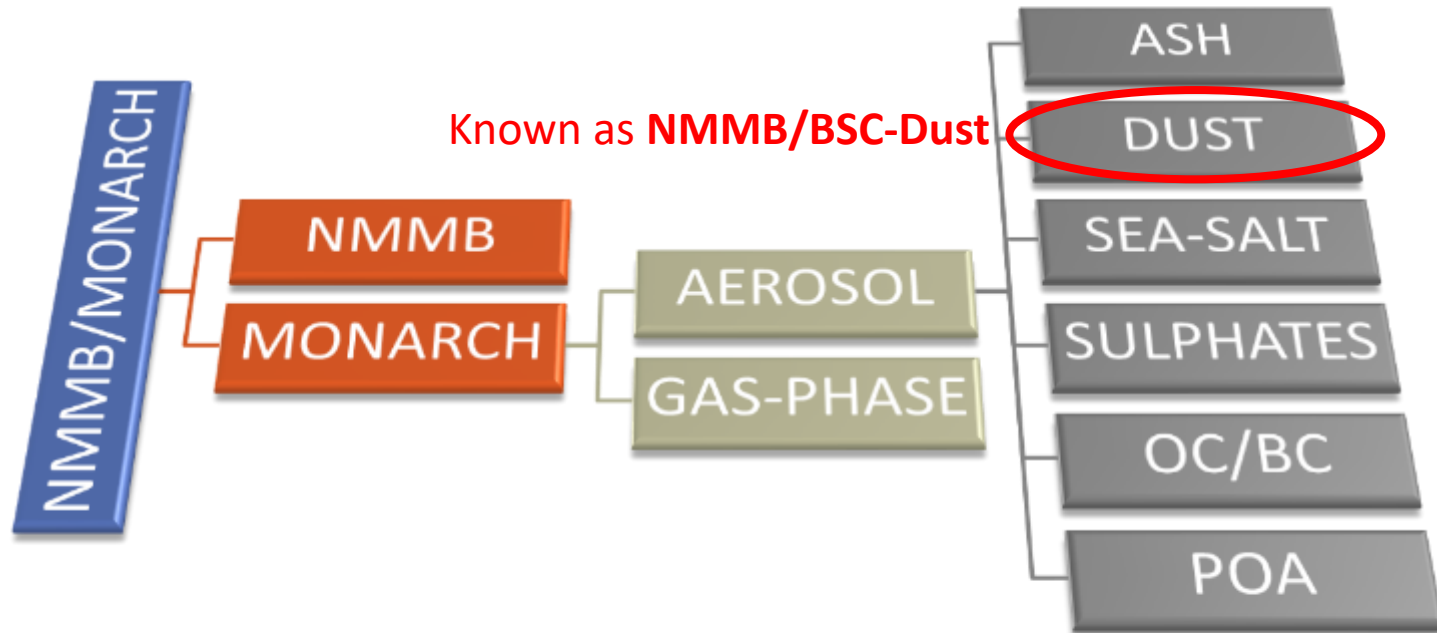
# Air Quality Modelling in Mexico



<http://www.aire.cdmx.gob.mx/default.php>

# NMMB-MONARCH: Atmospheric Composition and Air Quality

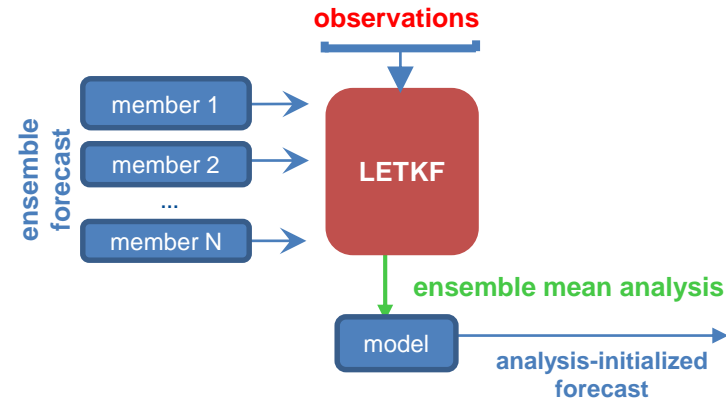
- The main system is build on the **meteorological driver NMMB**
- **Multiscale**: global to regional scales allowed (nesting capabilities)
- **Nonhydrostatic** dynamical core: single digit kilometre resolution allowed
- Fully **on-line** coupling: weather-chemistry feedback processes allowed
- Enhancement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





# NMMB-MONARCH: Dust Data Assimilation

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

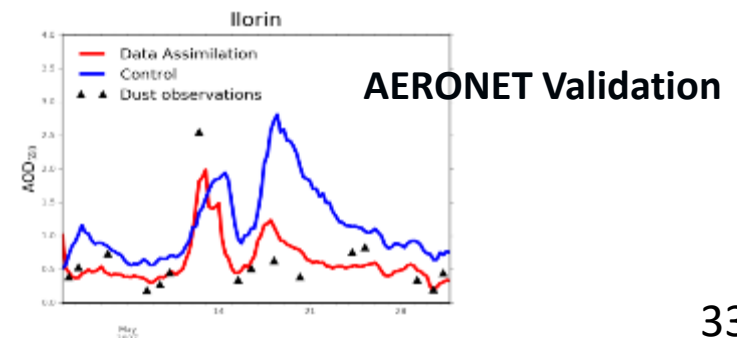
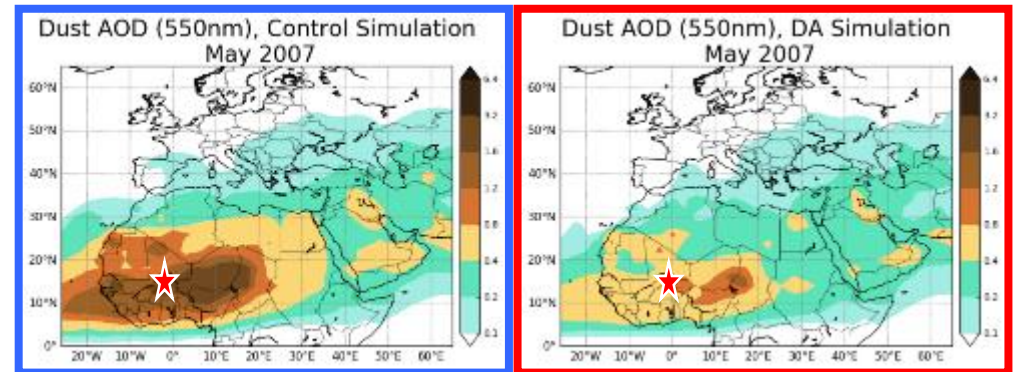


## Mineral dust application

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, 2017)*



# HERMES 3.0: A multiscale emission modelling

- A **stand-alone tool** for simulating **emissions** on a **user-defined grid for global, regional and urban** air quality models.
- Users can **select, combine and scale multiple inventories** through a flexible configuration file to obtain **hourly gridded emissions**.

## Emission data library

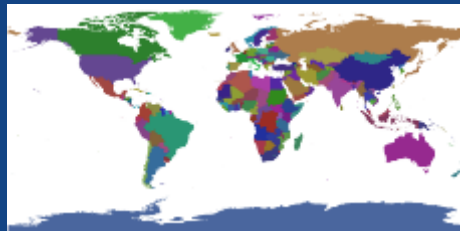
- Multiple **global and regional emission inventories**
- **Online emissions:**
  - Biogenic (MEGAN), lightning, ocean
- Spanish bottom-up emission inventory (street level emissions)



(...)

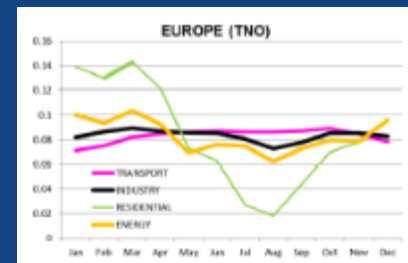
## Conservative regridding

- **User-defined grid:**
  - Regular lat-lon
  - Rotated lat-lon
  - LCC
- **Masking and scaling factors to combine and update emission inventories**



## Vertical, temporal, speciation

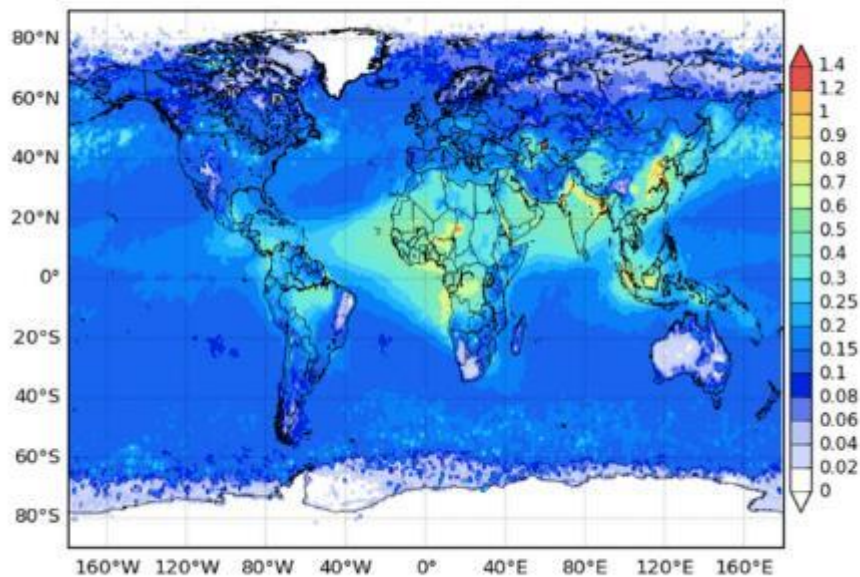
- **Vertical profiles:**
  - Point sources, biomass burning, air traffic
- **Temporal profiles:**
  - Monthly, weekly and daily factors per sector
- **VOC and PM2.5 speciation:**
  - CB05, SAPRC99, AERO5, AERO6



# Multiscale forecast modelling: Atmospheric Composition and Air Quality

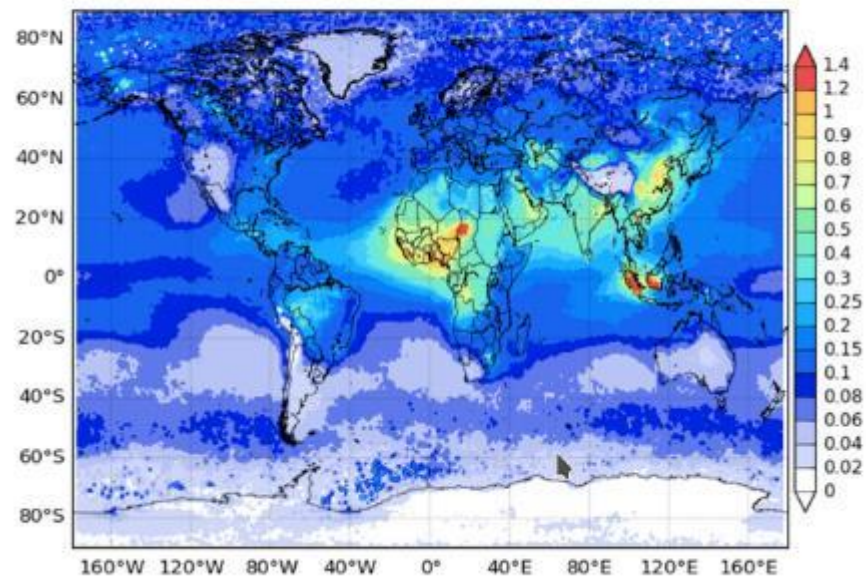
## OBSERVATIONS

MODIS/Terra AOD550 Collection 6 Level 3  
2015



## MODEL

NMMB-MONARCH-b015 AOD550  
2015



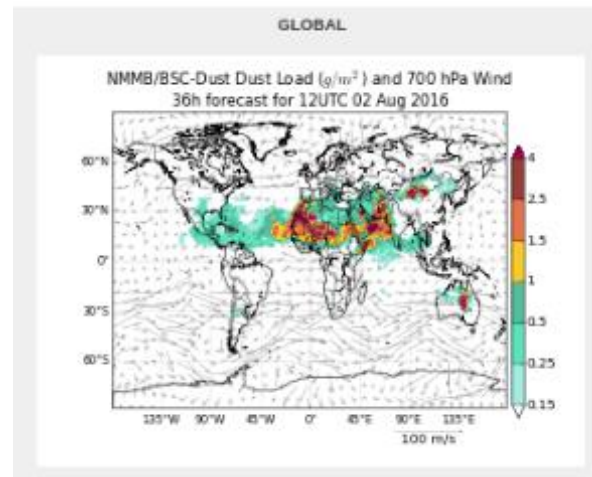
Annual average of Aerosol Optical Depth (AOD) at 550nm for 2015

# Mineral dust Services

## BSC dust operational forecast (global and regional domains)

<http://www.bsc.es/ESS>

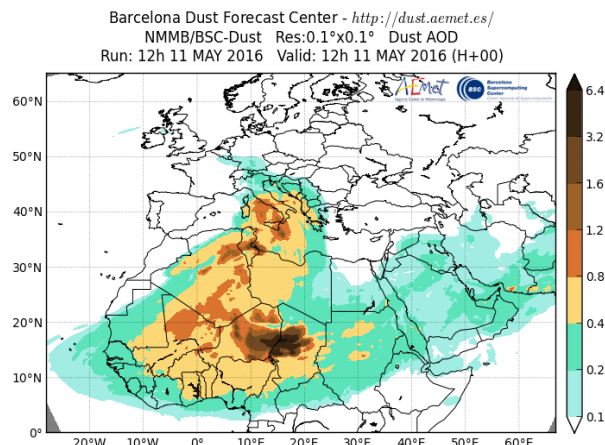
✓ Contribution to the **ICAP** multi-model ensemble (global) <http://icap.atmos.und.edu>



## WMO Dust Centers

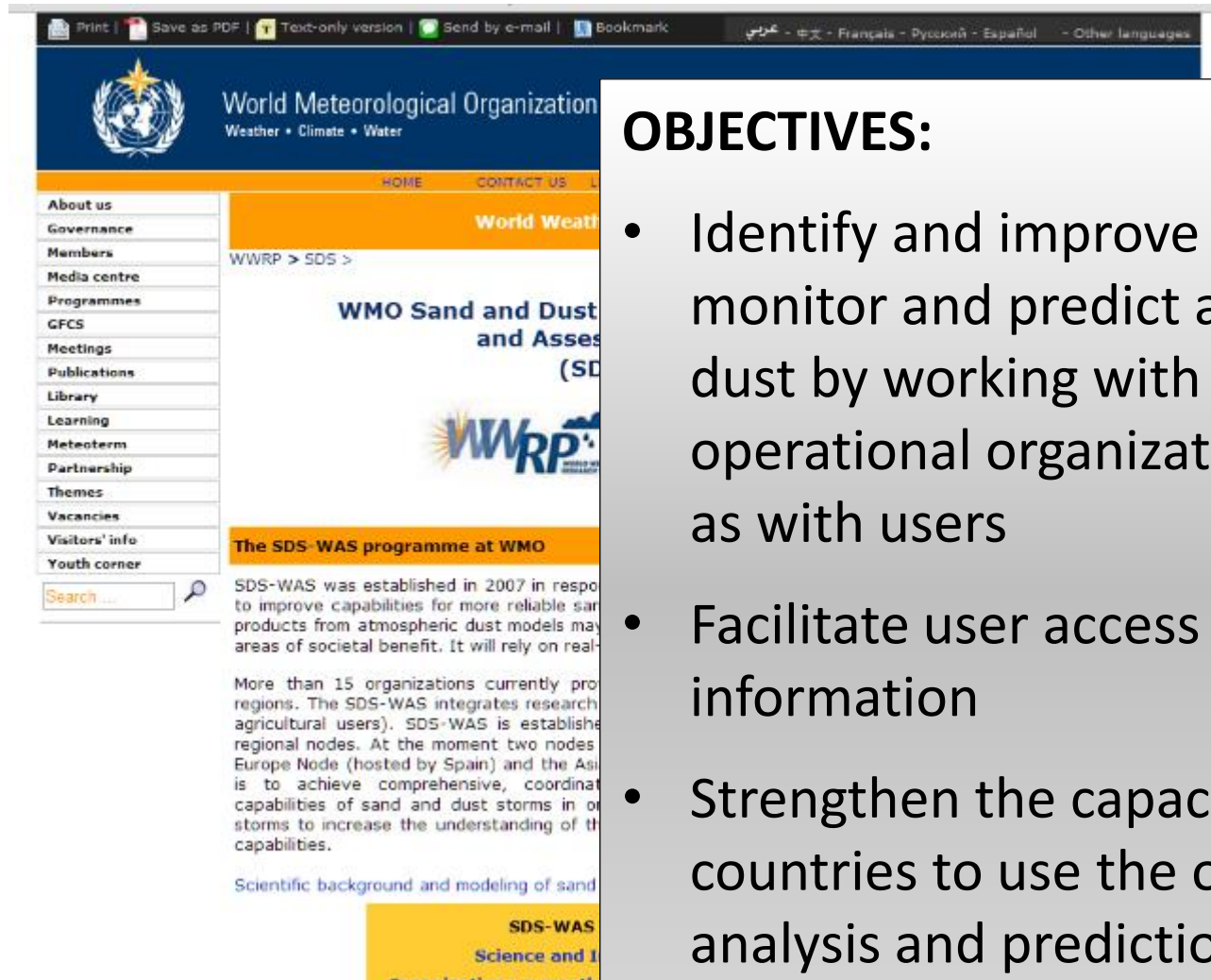
**SDS-WAS. North Africa, Middle East and Europe Regional Center.** <http://sds-was.aemet.es> started in 2010 – **Research**

**Barcelona Dust Forecast Center.** [@Dust\\_Barcelona](https://twitter.com/Dust_Barcelona)  
First specialized WMO Center for mineral dust prediction.  
<http://dust.aemet.es> started in 2014 - **Operational**





# The WMO SDS-WAS project

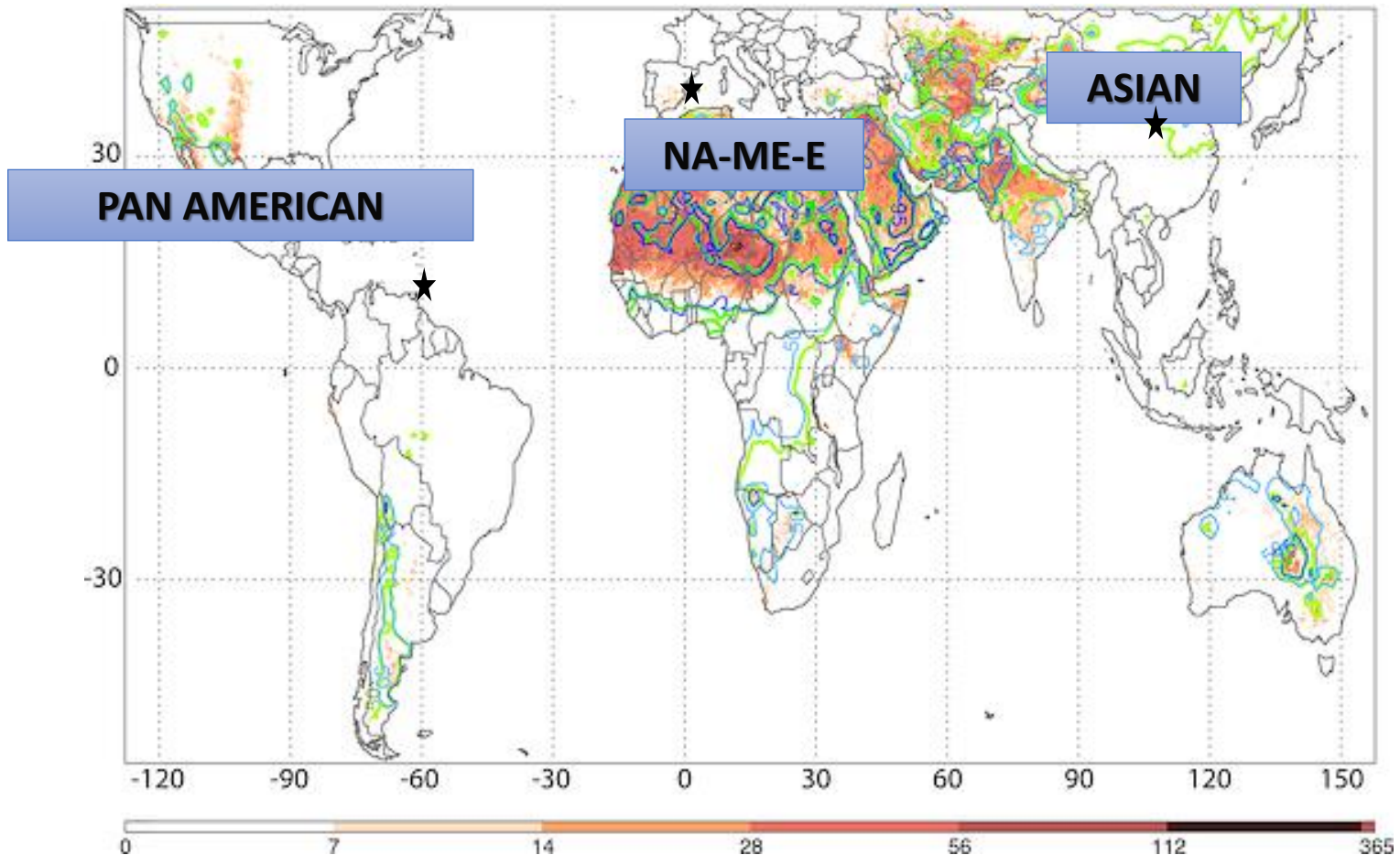


The screenshot shows the WMO website interface. At the top, there is a navigation bar with the WMO logo and the text "World Meteorological Organization Weather • Climate • Water". Below this, there are links for "HOME" and "CONTACT US". A sidebar on the left contains a menu with items like "About us", "Governance", "Members", "Media centre", "Programmes", "GFCS", "Meetings", "Publications", "Library", "Learning", "Meteo-term", "Partnership", "Themes", "Vacancies", "Visitors' info", and "Youth corner". The main content area features a header "World Weather" and a sub-header "WWRP > SDS >". The main title is "WMO Sand and Dust and Assessment (SD)". Below this, there is a section titled "The SDS-WAS programme at WMO" with a yellow background. The text describes the establishment of SDS-WAS in 2007 to improve capabilities for more reliable sand products from atmospheric dust models in areas of societal benefit. It mentions that more than 15 organizations currently participate in the project across various regions. The SDS-WAS integrates research and operational users and is established through regional nodes, currently including the Europe Node (hosted by Spain) and the Asia Node. The project aims to achieve comprehensive, coordinated capabilities of sand and dust storms in order to increase the understanding of their capabilities. At the bottom of the page, there is a section titled "SDS-WAS Science and Information" with a yellow background.

## 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  $\geq 0.5$  (blue), and OMI (2004–2006) aerosol index  $\geq 0.5$  (green). The isocontours of TOMS and OMI have been removed over oceans for clarity.*

# SDS-WAS NAMEE RC

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## NORTHERN AFRICA-MIDDLE EAST-EUROPE (NA-ME-E) REGIONAL CENTER

WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS)

WMO SDS WAS || Asia Regional Center || America Regional Center

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Oct 23, 2017 - Oct 25, 2017 — Istanbul, Turkey

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### Northern Africa-Middle East-Europe (NA-ME-E) Regional Center

by Francisco Fontcava — last modified May 26, 2012 03:33 PM

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**Portal manual**

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**Dust forecasts**

Compared Dust Forecasts

Forecast Evaluation



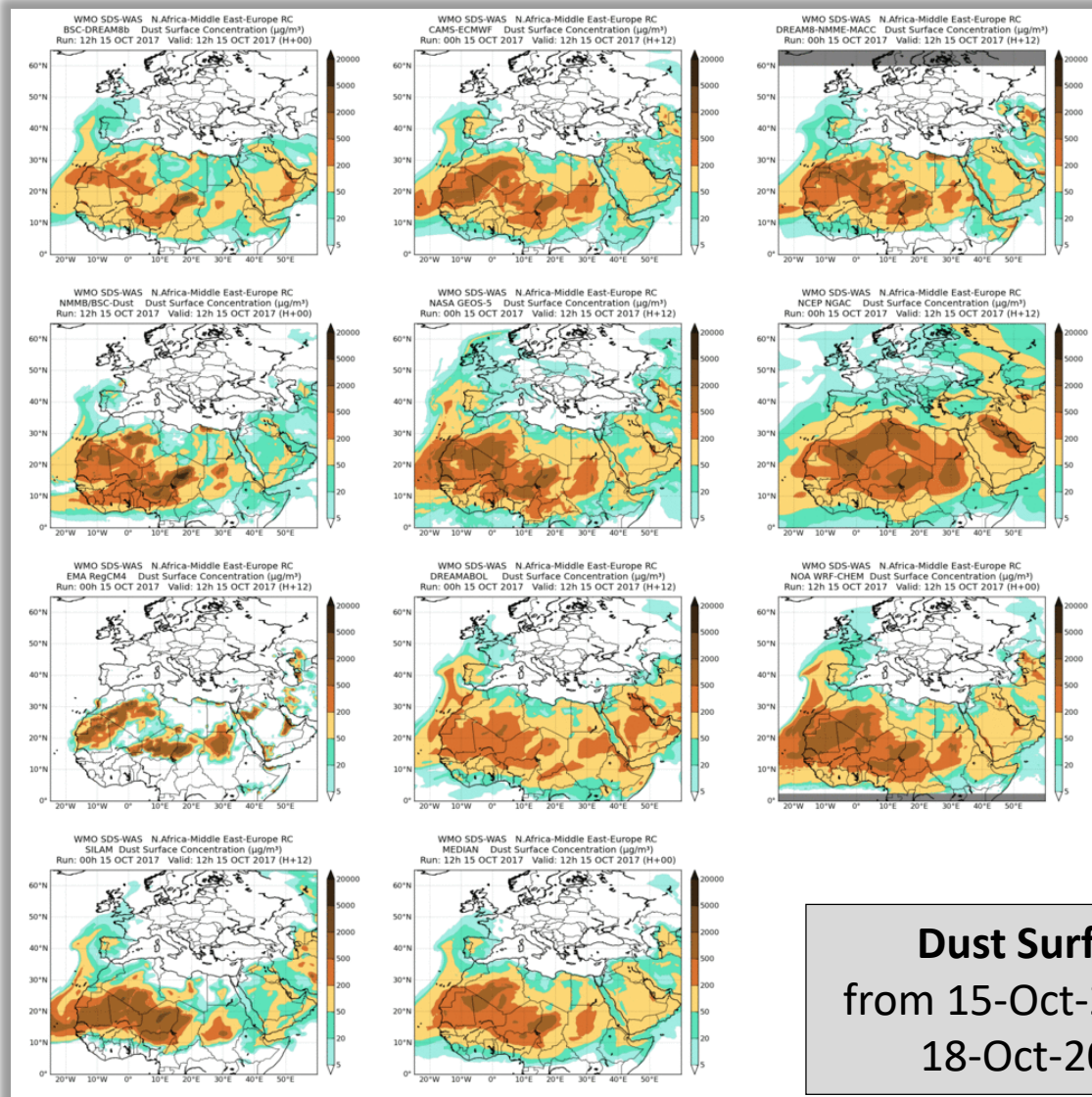
# SDS-WAS NAMEE: Dust Forecasts

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



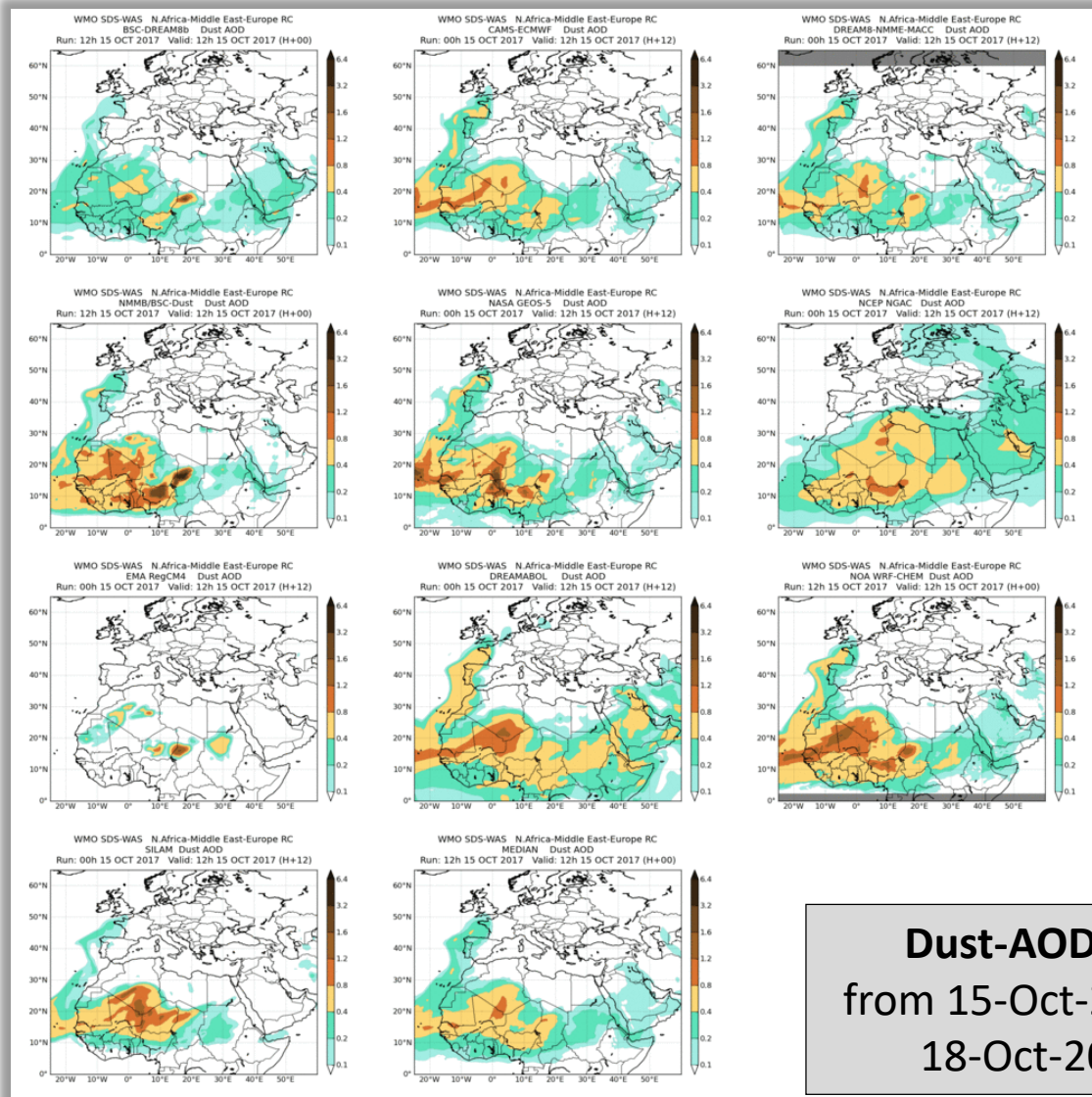
MODEL	RUN TIME	DOMAIN	DATA ASSIMILATION
BSC-DREAM8b	12	Regional	No
CAMS ECMWF	00	Global	MODIS AOD
DREAM8-NMME	00	Regional	CAMS analysis
NMMB/BSC-Dust	00	Regional	No
MetUM	12	Global	MODIS AOD
GEOS-5	00	Global	MODIS reflectances
NGAC	00	Global	No
RegCM4 EMA	00	Global	No
DREAMABOL	12	Regional	No
WRF-CHEM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

# SDS-WAS NAMEE: Joint Visualization



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

# SDS-WAS NAMEE: Joint Visualization

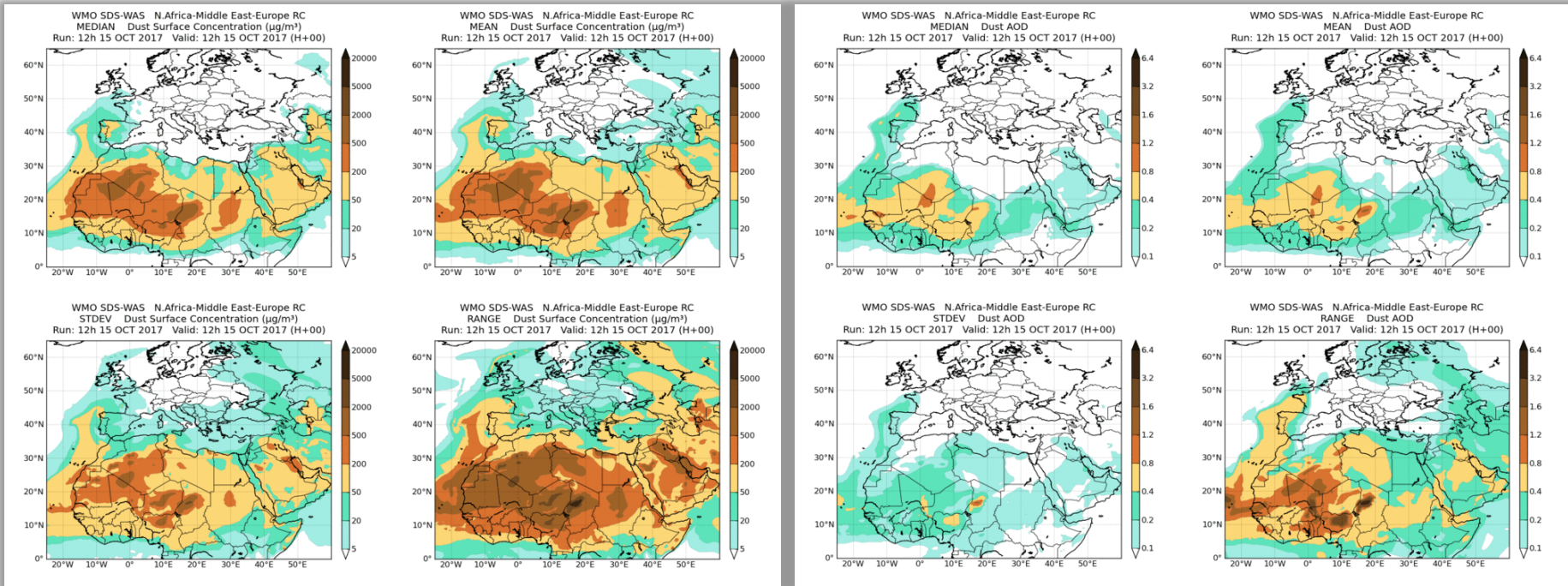


**Dust-AOD at 550nm**  
from 15-Oct-2017 12:00 to  
18-Oct-2017 00:00

# 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: Files Download

BSC-DREAMb v2.0	<a href="#">PUBLIC Files</a> <a href="#">RESTRICTED Files</a>	<a href="#">Model website</a>	
CAMS-ECMWF	<a href="#">PUBLIC Files</a> <a href="#">RESTRICTED Files</a>	<a href="#">Model website</a>	
DREAM-NMME-MACC	<a href="#">PUBLIC Files</a> <a href="#">RESTRICTED Files</a>	<a href="#">Model website</a>	

	Title	Size	Modified
NMME-BSC-I			
NASA-GEOS-5	<b>latest</b> - <i>(download all)</i>	4.0 kB	Oct 19, 2017 10:40 PM
NCEP-NGAC	<b>2017</b> - <i>(download all)</i>	4.0 kB	Oct 03, 2017 10:40 PM
	<b>2016</b> - <i>(download all)</i>	4.0 kB	Dec 03, 2016 10:40 PM
DREAMABO1	<b>2015</b> - <i>(download all)</i>	4.0 kB	Mar 07, 2016 12:49 PM
	<b>2014</b> - <i>(download all)</i>	4.0 kB	Mar 07, 2016 12:49 PM
EMA-RegCM4	<b>2013</b> - <i>(download all)</i>	4.0 kB	Mar 07, 2016 12:49 PM
	<b>2012</b> - <i>(download all)</i>	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: DOD Model Evaluation

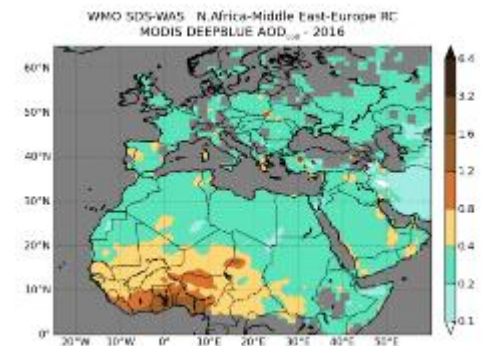
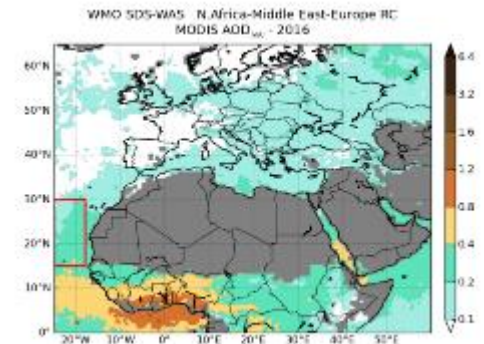
- Evaluation with AERONET data
  - Graphical NRT Evaluation by site
  - Evaluation scores monthly/seasonal/annual and sites



- 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

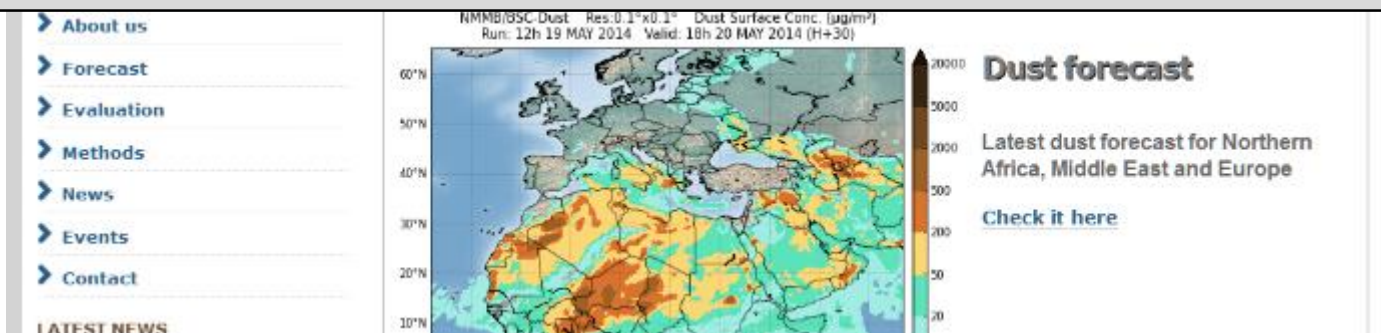


<http://sds-was.aemet.es/forecast-products/forecast-evaluation>

# Barcelona Dust Forecasting Center



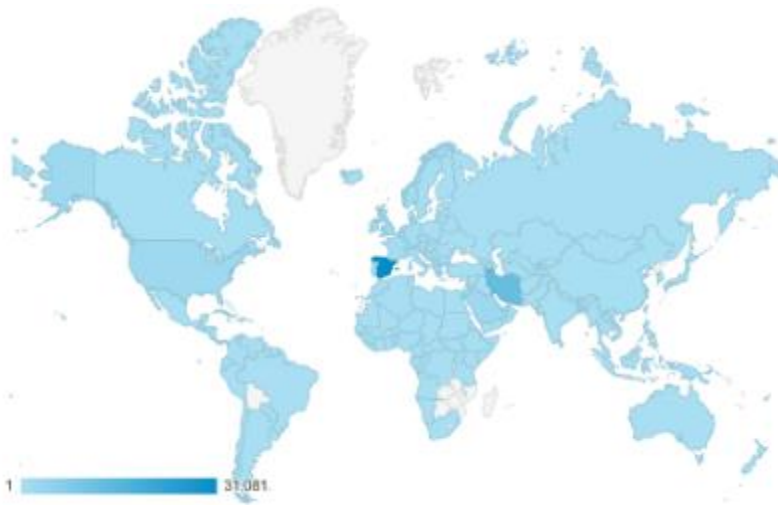
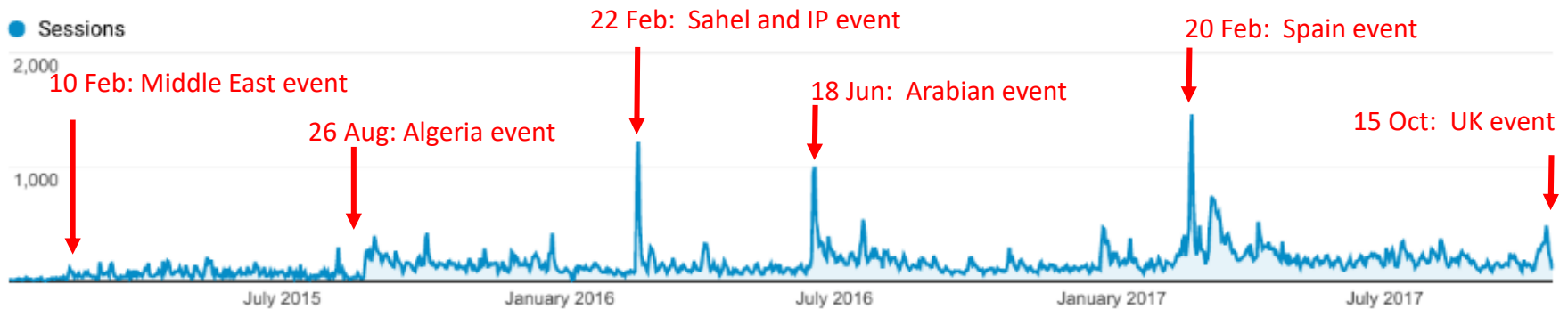
***In 2014, the First Specialized Center for Mineral Dust Prediction of WMO is created***  
***NMMB/BSC-Dust selected to provide operational forecasts for NAMEE region***



# Barcelona Dust Forecasting Center

Website visits: 1 January 2015 – 20 October 2017

<http://dust.aemet.es/>



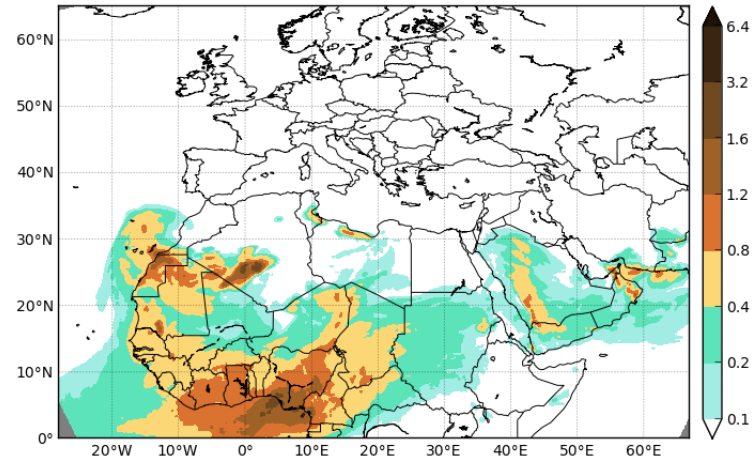


# Operational Products

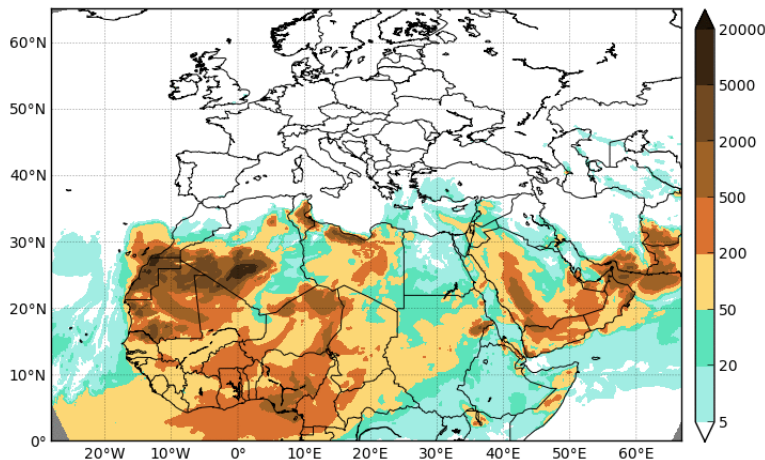
## 72-hours forecasts of:

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

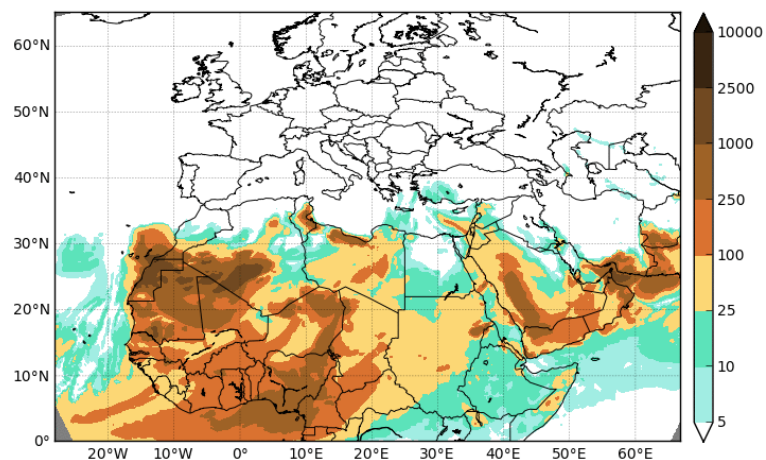
Barcelona Dust Forecast Center  
NMMB/BSC-Dust Res:0.1°x0.1° Dust AOD  
Run: 12h 07 MAR 2015 Valid: 12h 07 MAR 2015 (H+00)



Barcelona Dust Forecast Center  
NMMB/BSC-Dust Res:0.1°x0.1° Dust Surface Conc. ( $\mu\text{g}/\text{m}^3$ )  
Run: 12h 07 MAR 2015 Valid: 12h 07 MAR 2015 (H+00)



Barcelona Dust Forecast Center  
NMMB/BSC-Dust Res:0.1°x0.1° Dust Surface Ext. ( $\text{Mm}^{-1}$ )  
Run: 12h 07 MAR 2015 Valid: 12h 07 MAR 2015 (H+00)



# Summary

Towards **better dust forecasts** over the Middle East:

- High-resolution and update land surface databases
  - *Identification of dust sources*
- Dust ground-based and satellite observations
  - *Model Evaluation and Data Assimilation*

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



# Thank you

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[sara.basart@bsc.es](mailto:sara.basart@bsc.es)