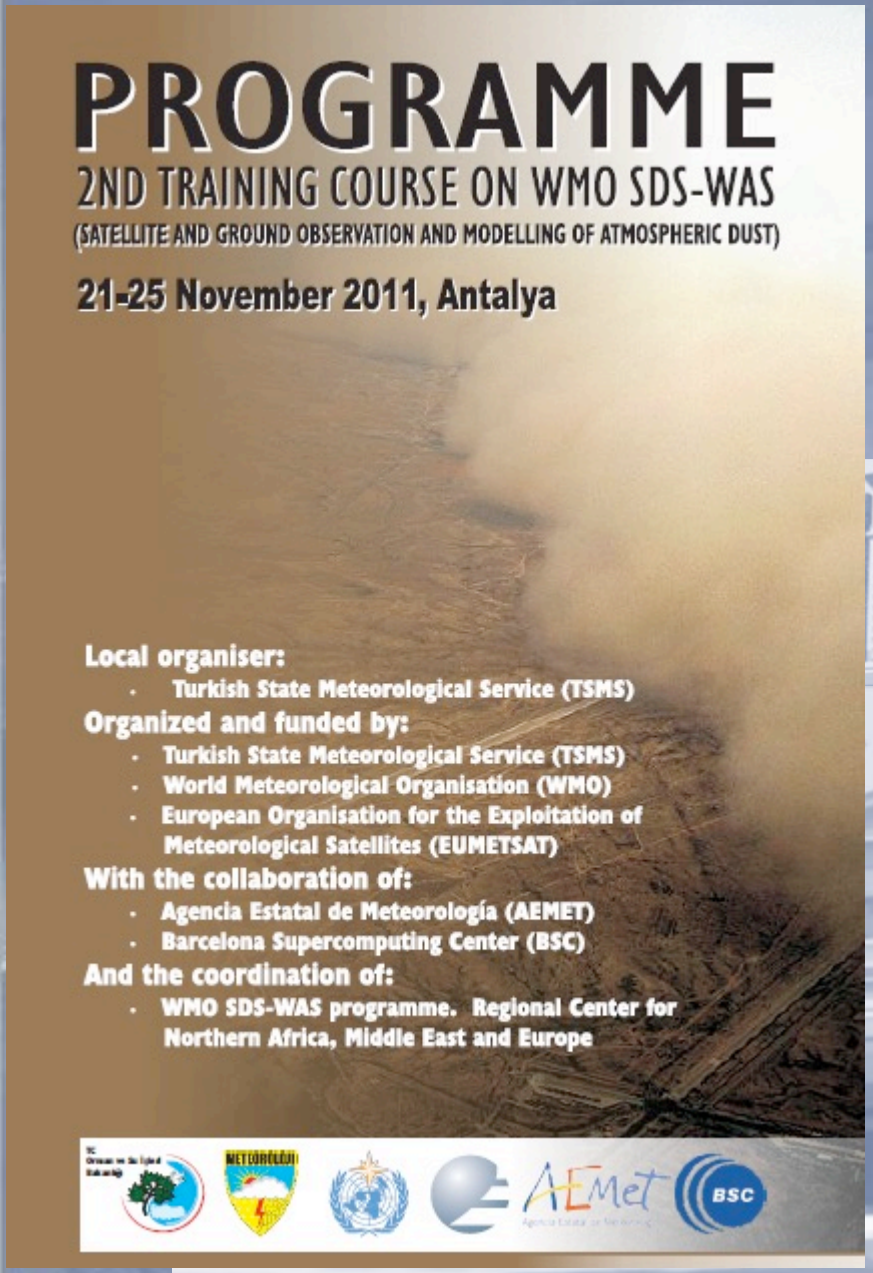

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Dust Modelling

Prof. Dr. J.M. Baldasano

Earth Sciences Department, Barcelona Supercomputing Center (BSC-CNS), Barcelona, Spain
Environmental Modeling Laboratory, Technical University of Catalonia (UPC), Barcelona, Spain

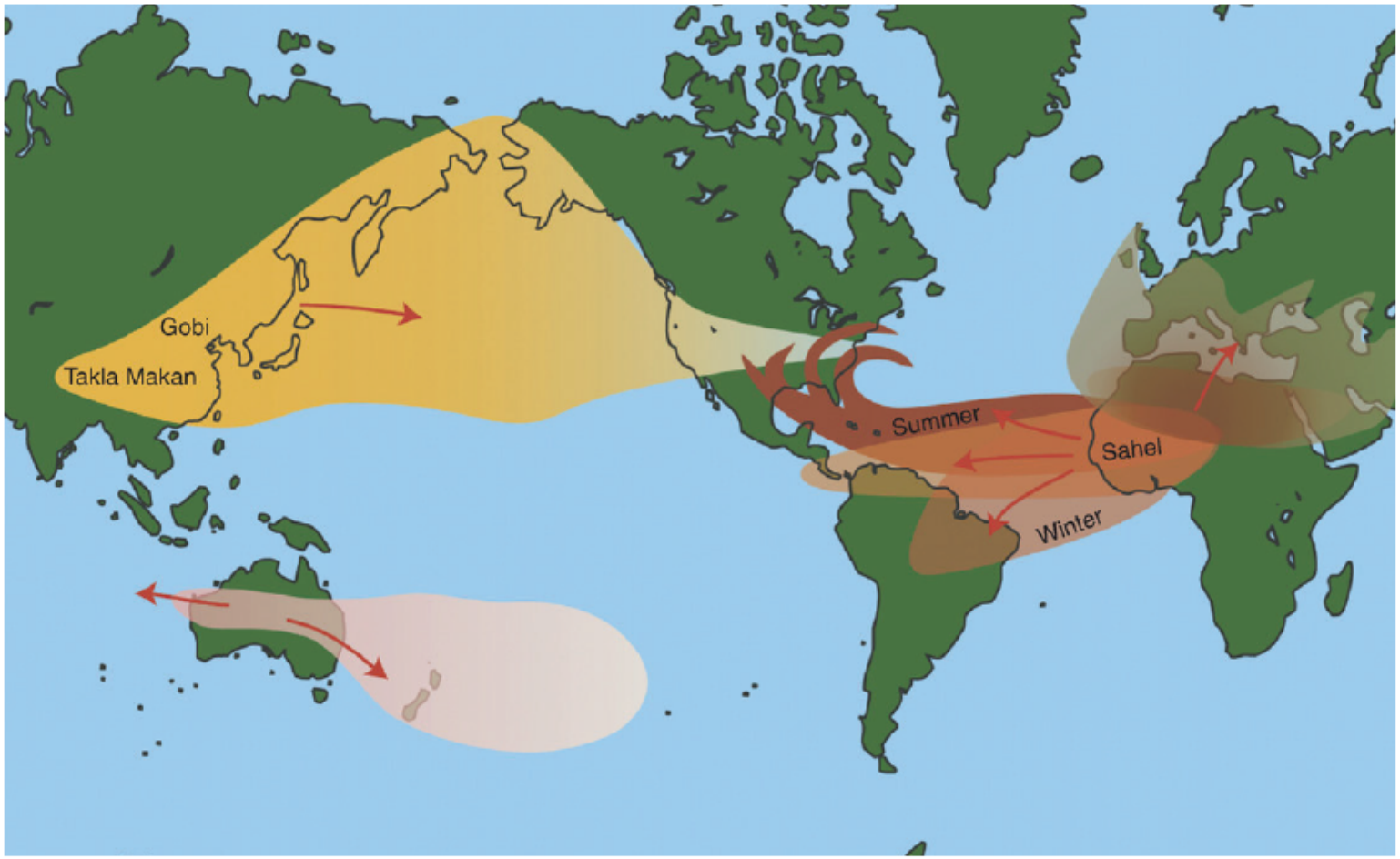


Figure 1.5: Principal pathways of the two major global dust transport systems. The African dust exerts a strong seasonal component with summer trade winds carrying the dust towards North America and the Caribbean and winter dust flow shifted to South America and the Amazon rainforest. Throughout the year, dust storms from northern Africa cross into the Mediterranean and Europe. Asian dust from the Gobi is transported to the Pacific mainly during dust events in spring. Extracted from Kellogg and Griffin [2006].

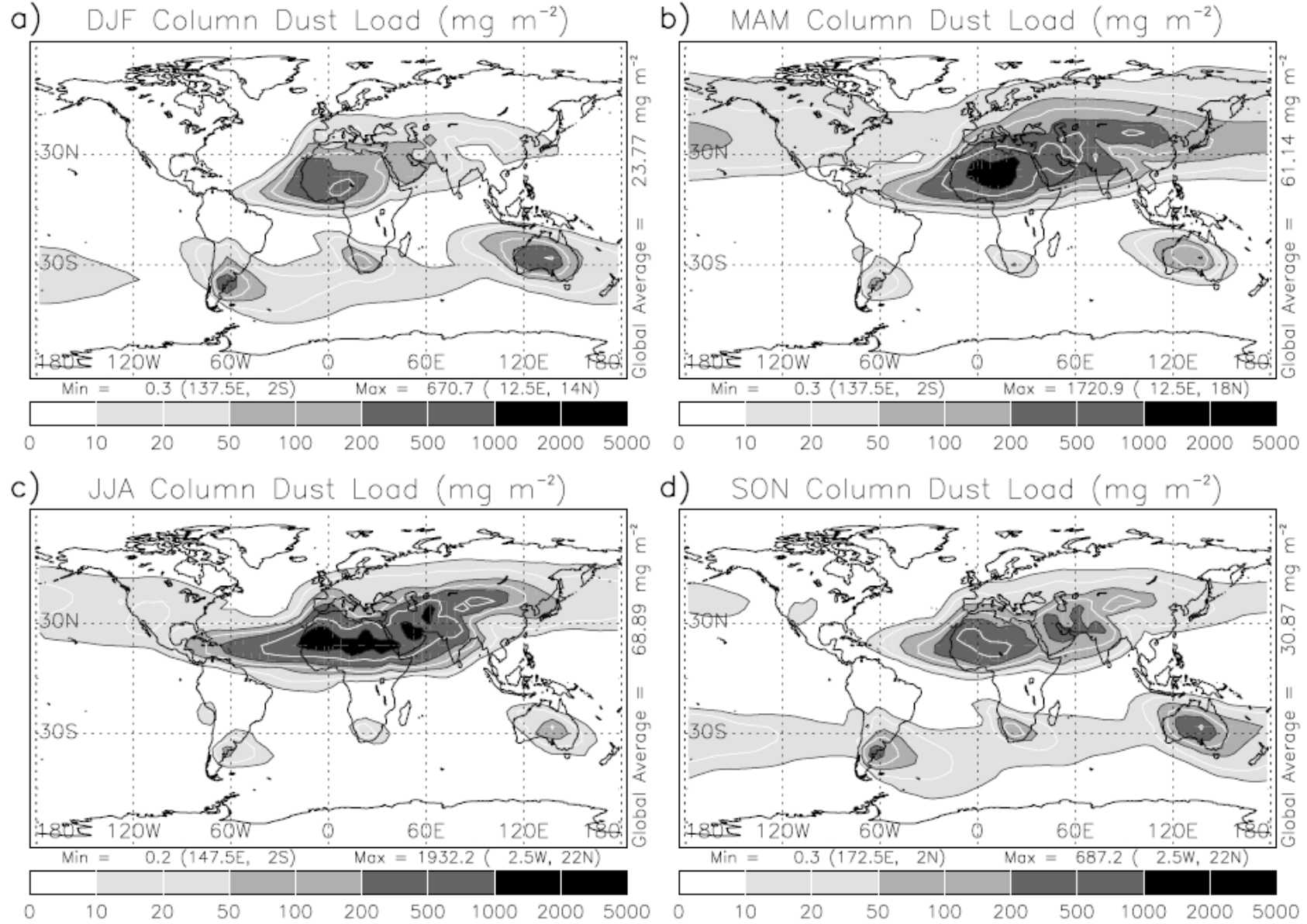


Figure 1.4: Global column dust load for winter (DJF), spring (MAM), summer (JJA), and fall (SON), derived from model estimates and experimental results. Extracted from Cakmur et al. [2006].

Complexity of dust cycle

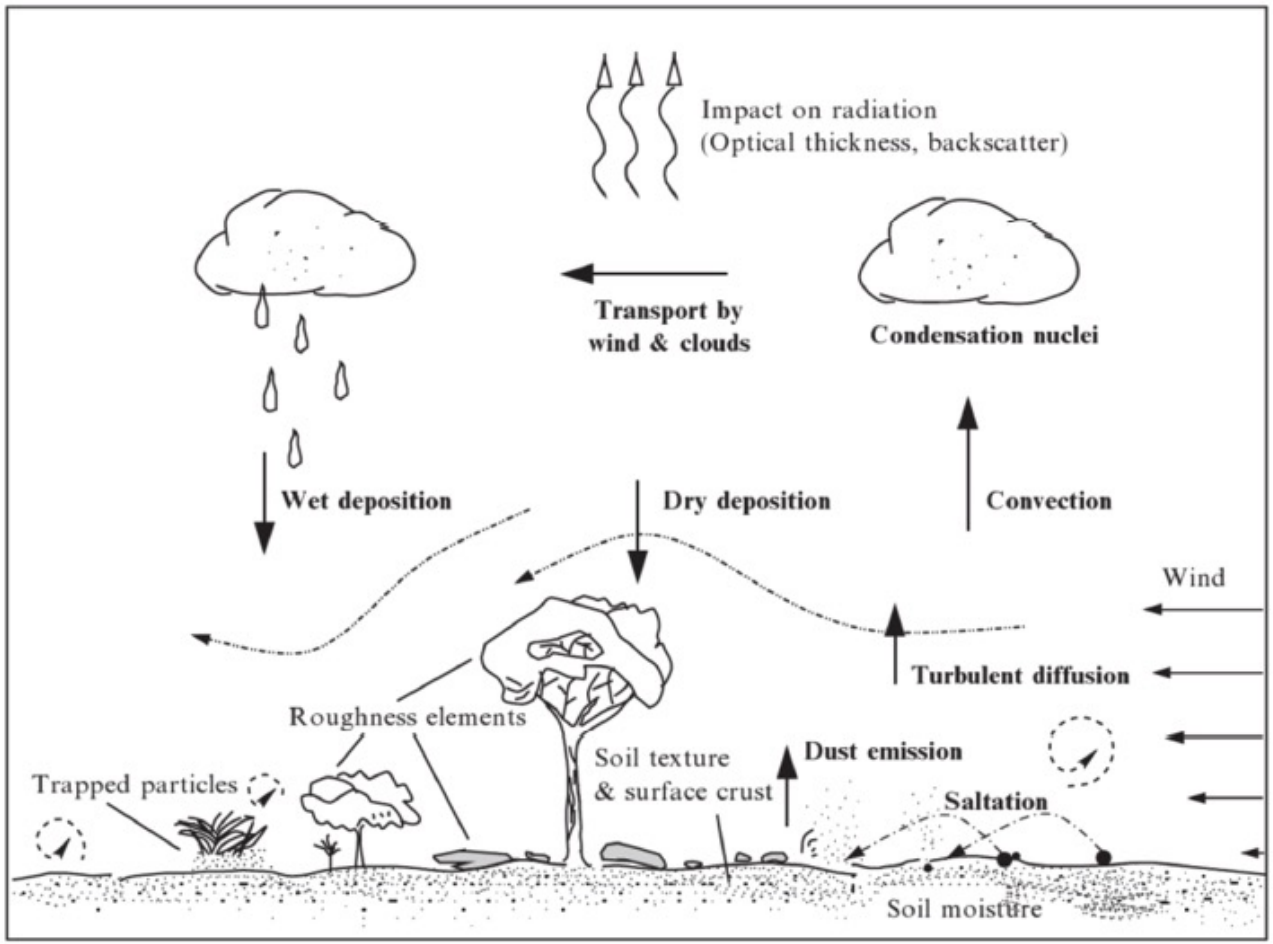
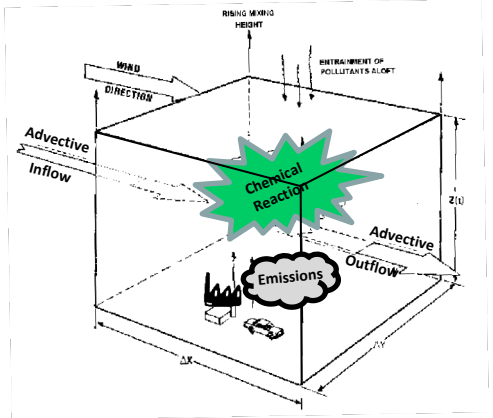


Figure 1.8: An illustration of the phases of the dust cycle: entrainment, transport and deposition. Atmospheric conditions, soil properties, land-surface characteristics and landuse practice control the erosion process. Extracted from Shao (2008).

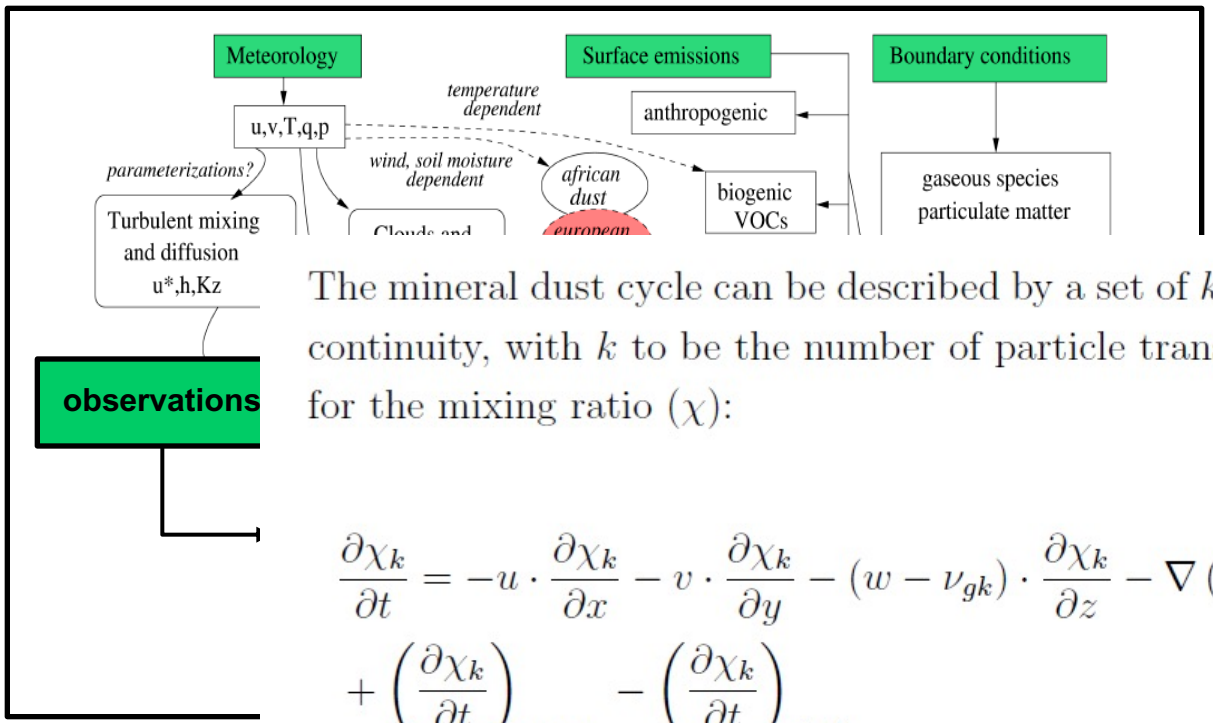
How do we model ?

Numerical Deterministic

- Mathematical representation of processes that affect air pollution.
- Requires a system of models to simulate: the **emissions**, **transport** (adv. & diff.), **chemical transformation** (gas, aerosol, aq. phase), and **removal** (wet & dry deposition) of air pollution.



Modelling system flowchart



Model evaluation

- Determining the suitability of a model for a specific application & configuration.

The mineral dust cycle can be described by a set of k independent equations of mass continuity, with k to be the number of particle transport bins, as exemplary shown for the mixing ratio (χ):

$$\frac{\partial \chi_k}{\partial t} = -u \cdot \frac{\partial \chi_k}{\partial x} - v \cdot \frac{\partial \chi_k}{\partial y} - (w - \nu_{gk}) \cdot \frac{\partial \chi_k}{\partial z} - \nabla \left(K_H \cdot \nabla \chi_k \right) - \frac{\partial}{\partial z} \left(K_Z \cdot \frac{\partial \chi_k}{\partial z} \right) + \left(\frac{\partial \chi_k}{\partial t} \right)_{source} - \left(\frac{\partial \chi_k}{\partial t} \right)_{sink} \quad (1.1)$$

Schematic for Global Atmospheric Model

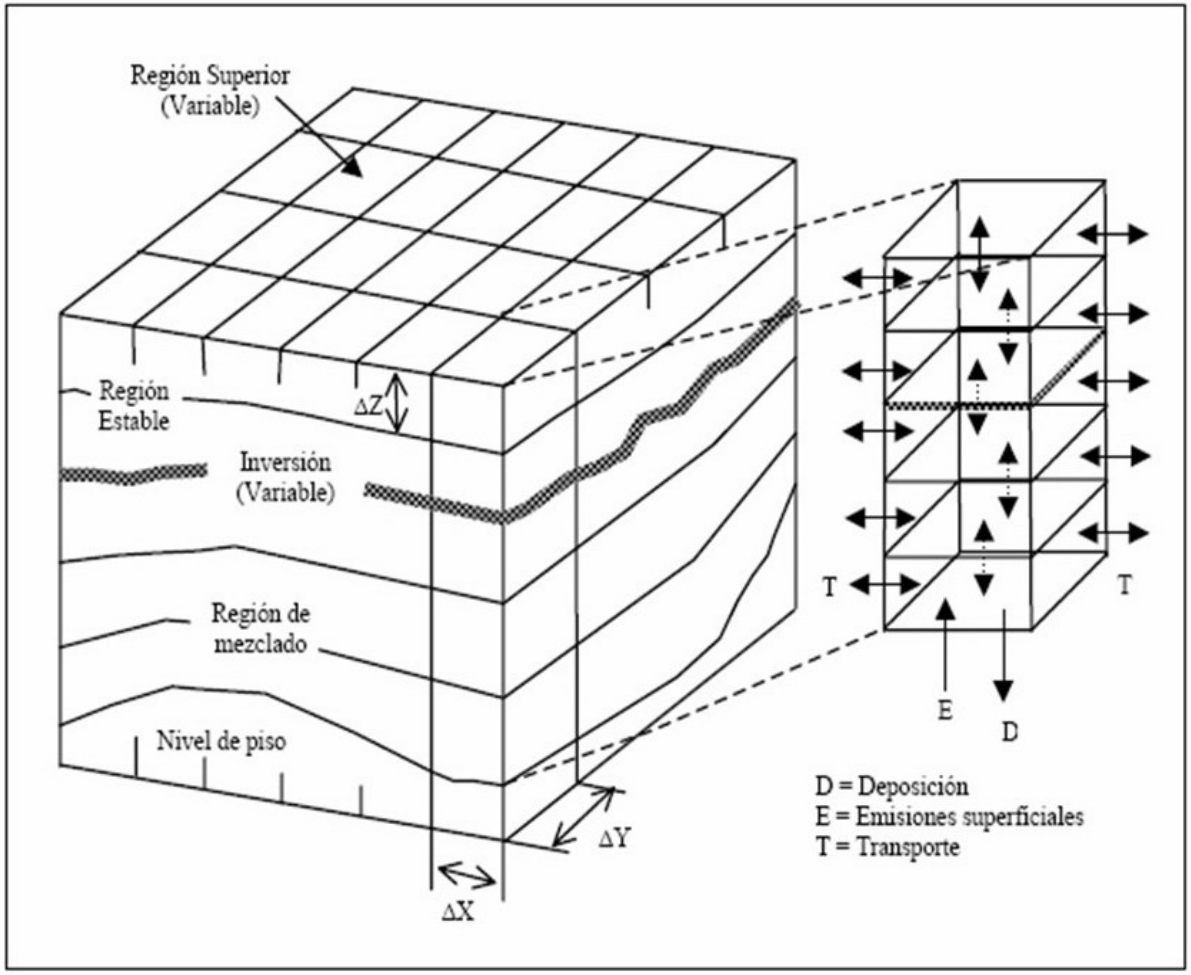
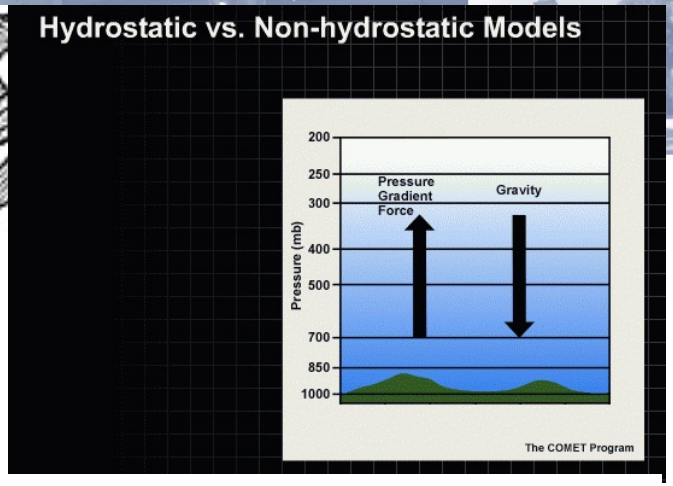
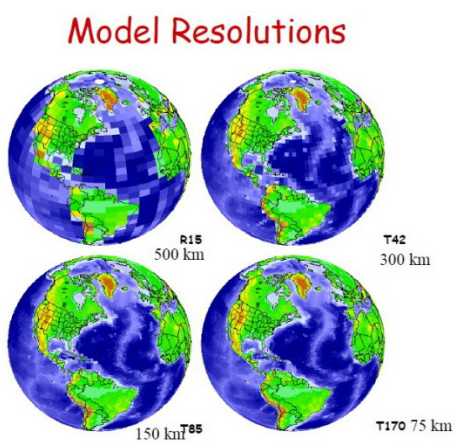
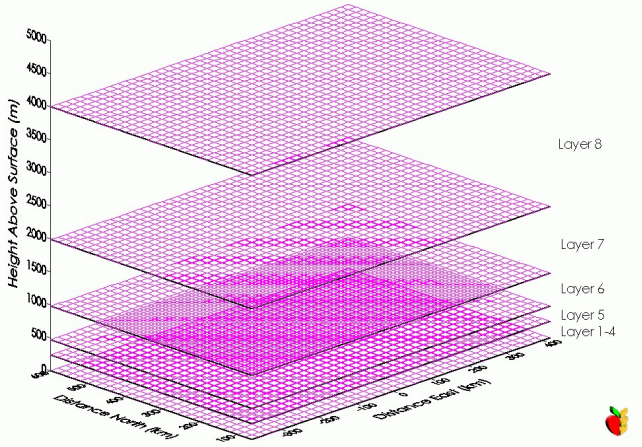
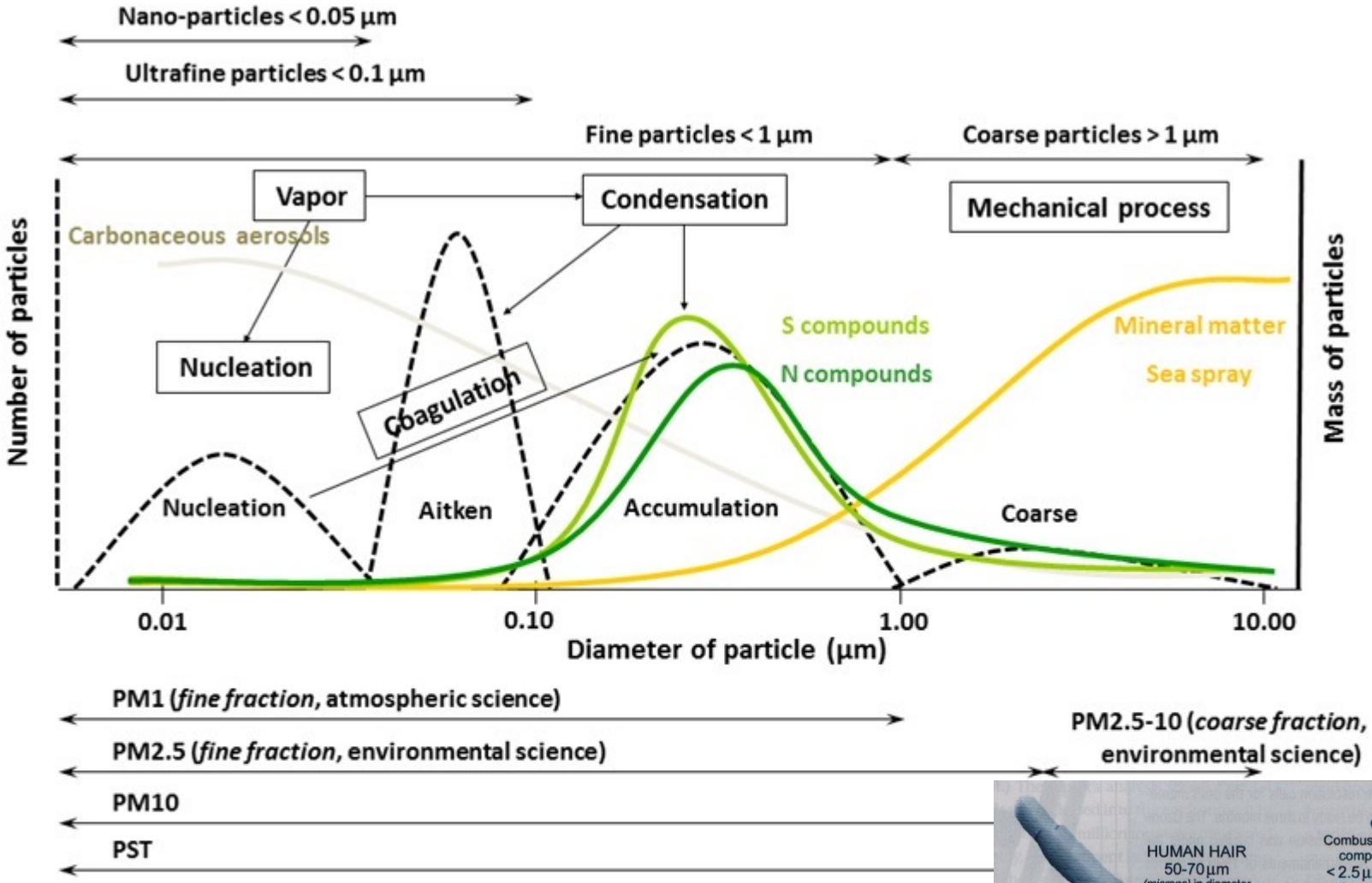


Figura 3. Representación esquemática de un mallado para un modelo Euleriano









PM1 (*fine fraction*, atmospheric science)

PM2.5 (*fine fraction*, environmental science)

PM2.5-10 (*coarse fraction*, environmental science)

PM10

PST

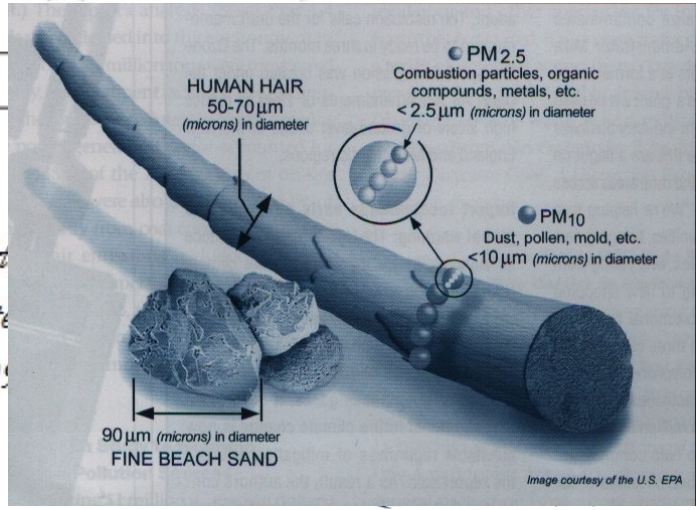


Figure 1.1 *Relationship between particulate matter (PM), size, number of part*
chemical mass composition (solid line). Aerosol physical processes are represente
Warneck (1988) and Harrison and van Grieken (19

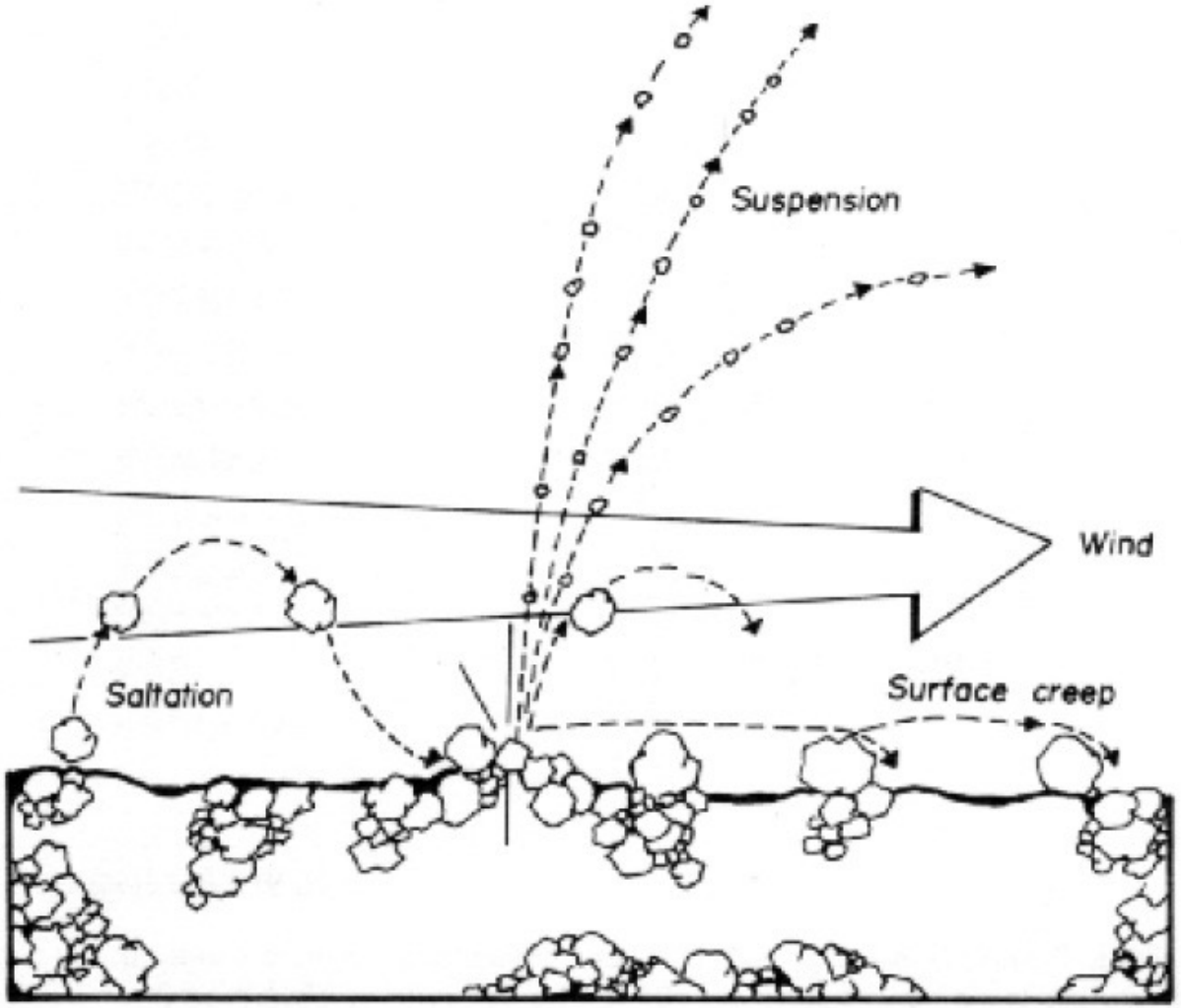


Figure 2.5: Scheme of the major wind erosion processes with saltation, creeping and suspension (due to sandblasting) in dependency of wind speed. The image is taken from www.extension.purdue.edu/extmedia/AY/AY-271.html.

Dust models

Model	Typical resolution	Emission	Transport bins	Remarks
MATCH-DEAD	research only	MB95	flexibel (0.1-10 μm)	offline
CMA-RDCM5	research only	CH04	flexibel (0.1-10 μm)	offline
COSMO-MUSCAT-DES	research only	MB95	5 (0.1-24 μm)	rad. feedb.
DTA-CARMA	100 km/21 z	IW82	8 (0.1-5 μm)	offline
NOGAPS-NAAPS	1x1°/24 z	W88	bulk (1 μm)	offline
JMA-MASINGAR	1.25x1.25°	TF94	10 (0.1-10 μm)	online
RAMS-CFORS	80 km/22 z	MB95	12 (0.1-25 μm)	offline
CHIMERE-DUST	1x1°/15 z	AG01/MB95	4-30 (0.18-126 μm)	online
ECMWF-IFS	1x1°/91 z	GX01	3 (0.03-20 μm)	online
LMDzT-INCA	3.75x2.5°/19 z	G00	3 (0.01-42.3 μm)	online
Meteo-France MOCAGE	0.1x0.1°/47 z	MB95	5 bins	online
TAU-DREAM	0.33x0.33°/24 z	SH93/N01	4 (0.7-38 μm)	online
SKIRON	0.25x0.25°/38 z	SH93/N01	8 (0.1-10 μm)	online
BSC-DREAM8b	0.33x0.33°/24 z	SH93/N01	8 (0.1-10 μm)	rad. feedb.

Table 1.2: Overview of all dust models which are currently available. The following acronyms for the emission schemes applied: W88 = [Westphal et al., 1988], IW82 = [Iversen and White, 1982], CH04 = [Cheng et al., 2004], TF94 = [Tegen and Fung, 1994], SH93 = [Shao et al., 1993], G00 = [Guelle et al., 2000], N01 = [Nickovic et al., 2001], and GX01 = [Ginoux et al., 2001]. Model references are given in the text.

http://www.wmo.int/sdswas; http://sds-was.aemet.es/

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  - PARASOL
  - METAR
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- Reanalysis
- Data access

Forecasts & Products

Dust Forecasts are produced with atmospheric transport models.

Results of dust transport simulations are by no means observations and can only be used as advisory information.

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  - METEO-FRANCE
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  - TAU-DREAM
  - NAAPS
- Near real time observations
  - AERONET
  - MODIS
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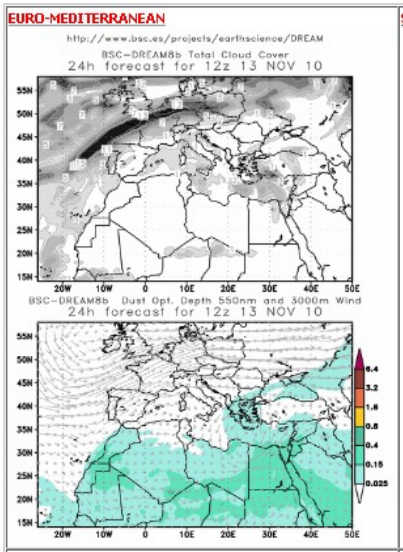

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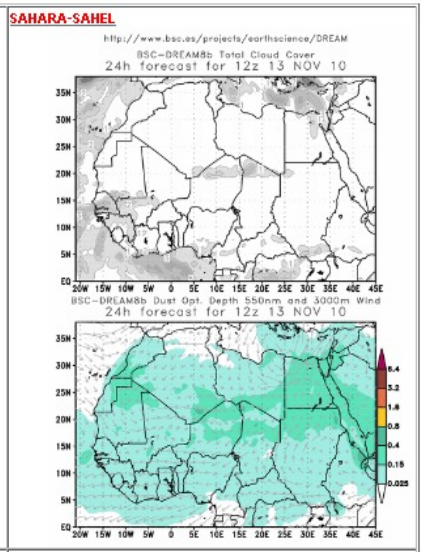

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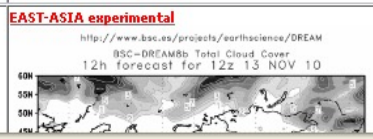
EAST-ASIA experimental



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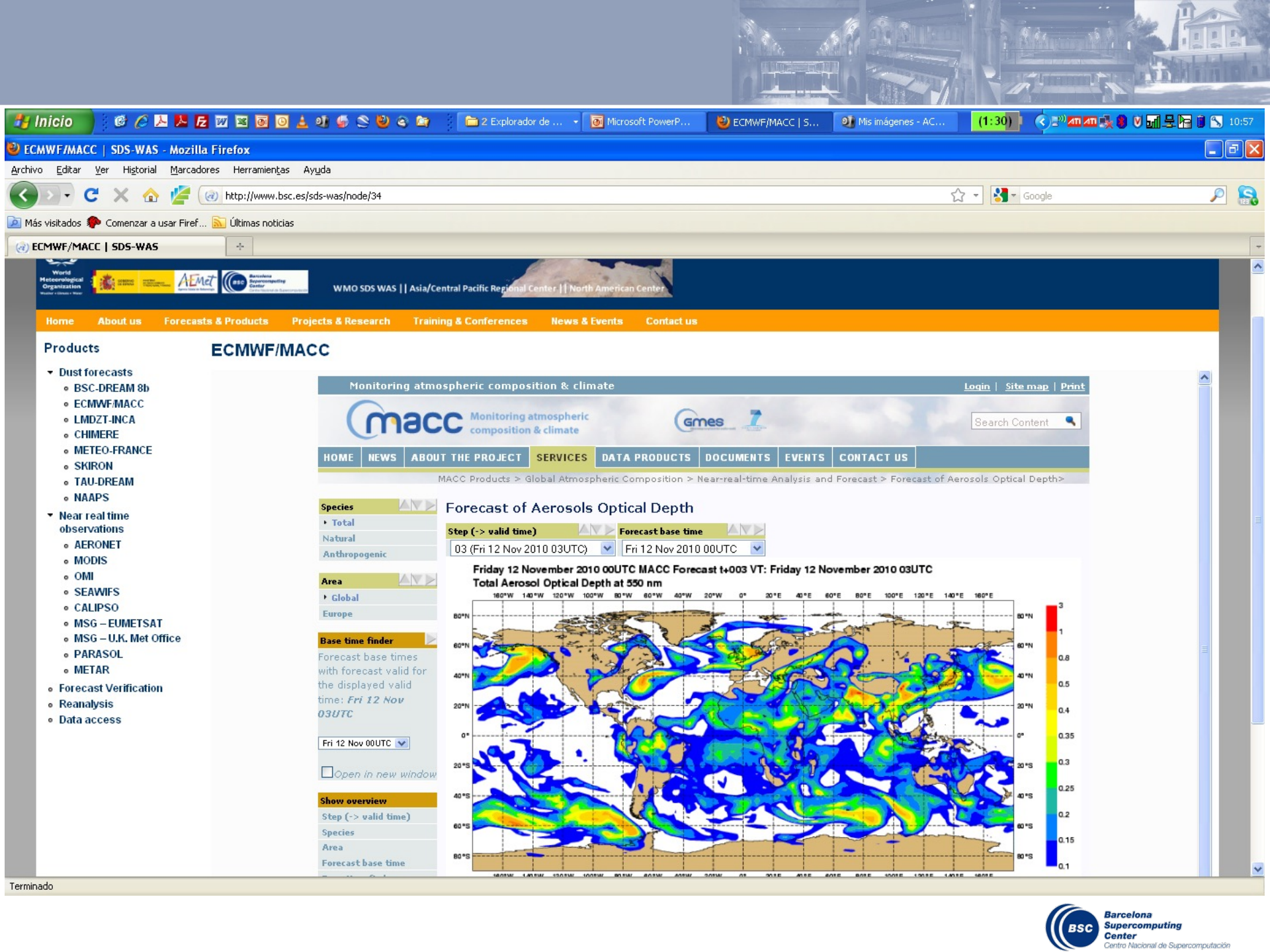

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  - ECMWF/MACC
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  - TAU-DREAM
  - NAAPS
- Near real time observations
  - AERONET
  - MODIS
  - OMI
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  - CALIPSO
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  - METAR
- Forecast Verification
- Reanalysis
- Data access

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INCA — EXPERIMENTAL CHEMICAL WEATHER FORECAST CATALOGUE

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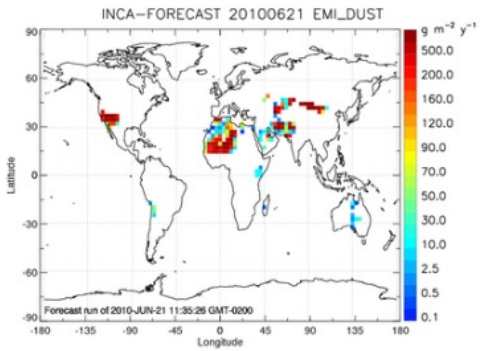
- limit choices -> FORECAST

Data Source -> INCA-ECMWF_latest

Species -> DUST = DUST

Parameter -> EMI = emission rate

Region -- Forecast date -> WORLD | 2010 | DAY-J0



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  - NAAPS
- Near real time observations
  - AERONET
  - MODIS
  - OMI
  - SEAWIFS
  - CALIPSO
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  - MSG – U.K. Met Office
  - PARASOL
  - METAR
- Forecast Verification
- Reanalysis
- Data access

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Chimere DUST [Model web site]

Date and parameter

2008 2009 2010

- o HORIZONTAL MAPS
  - dust load [g/m2]
  - conc.surf. [ug/m3]
  - AOT
  - U10m (m/s)
  - conv.precip. (mm/h)
  - Emissions (g/cm2/day)
  - Dry dep. (g/m2/midday)
  - Wet dep. (g/m2/midday)
- o SLICES
  - south - north
    - conc. (17W) [ug/m3]
    - conc. (0W) [ug/m3]
  - west- east
    - conc. (14N) [ug/m3]

01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

January February March April May June July August September October November

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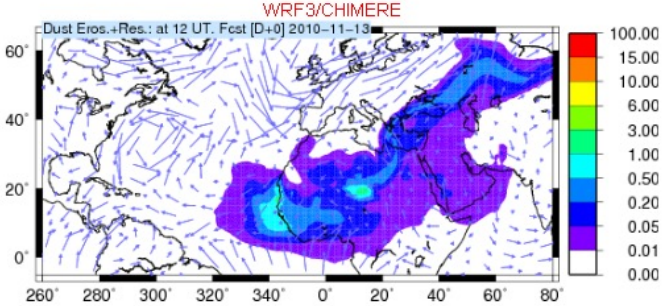
MM5/CHIMERE-DUST

WRF3/CHIMERE



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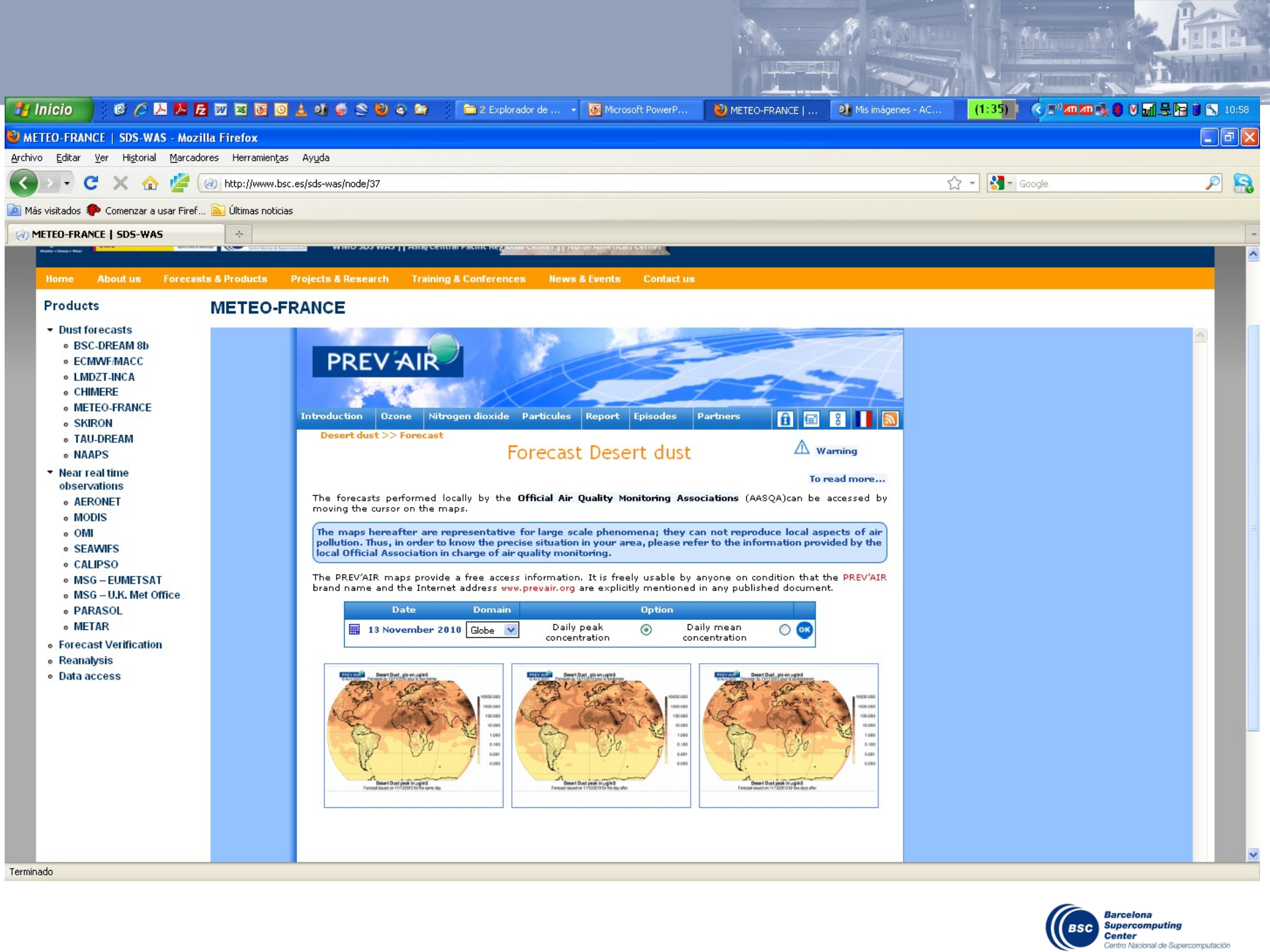

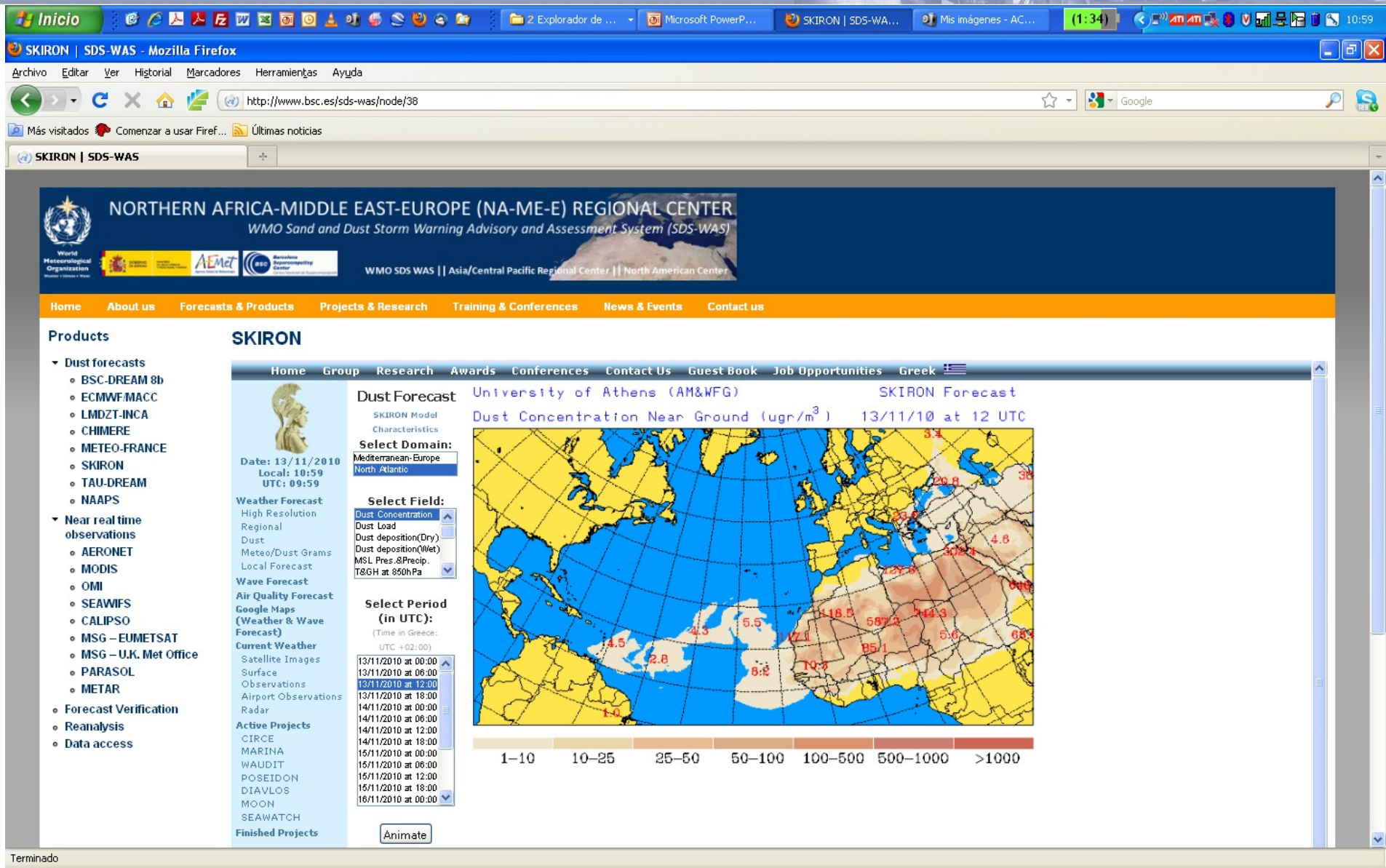
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CHIMERE
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SKIRON
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NAAPS
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MODIS
OMI
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Current Weather
Satellite Images
Surface Observations
Airport Observations
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Dust Forecast
SKIRON Model Characteristics
Select Domain:
Mediterranean-Europe
North Atlantic
Select Field:
Dust Concentration
Dust Load
Dust deposition(Dry)
Dust deposition(Wet)
MSL Pres.&Precip.
T&GH at 850hPa
Select Period (in UTC):
(Time in Greece: UTC +02:00)
13/11/2010 at 00:00
13/11/2010 at 06:00
13/11/2010 at 12:00
13/11/2010 at 18:00
14/11/2010 at 00:00
14/11/2010 at 06:00
14/11/2010 at 12:00
14/11/2010 at 18:00
15/11/2010 at 00:00
15/11/2010 at 06:00
15/11/2010 at 12:00
15/11/2010 at 18:00
16/11/2010 at 00:00
Animate
University of Athens (AM&WFG)
SKIRON Forecast
Dust Concentration Near Ground (ugr/m3)
13/11/10 at 12 UTC
1–10
10–25
25–50
50–100
100–500
500–1000
>1000
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  - METEO-FRANCE
  - SKIRON
  - TAU-DREAM
  - NAAPS
- Near real time observations
  - AERONET
  - MODIS
  - OMI
  - SEAWIFS
  - CALIPSO
  - MSG – EUMETSAT
  - MSG – U.K. Met Office
  - PARASOL
  - METAR
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- Reanalysis
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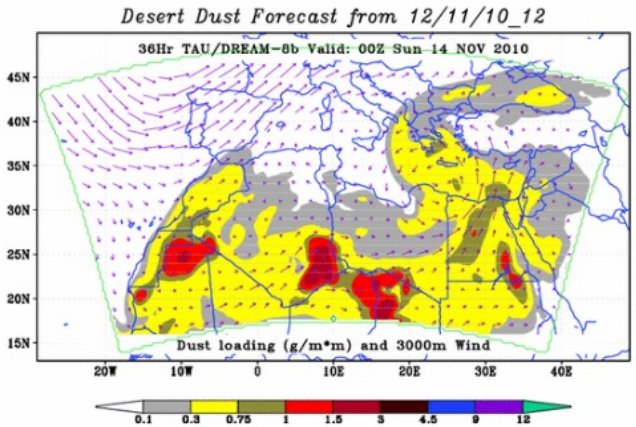

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Europe, the Middle East, and North Africa
WEST-EAST (35N) cross-section (animation)
Evolution of dust over Israel
Surface dust concentration in Israel
Evolution of dust over Rome (Italy)
Past days
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  - SKIRON
  - TAU-DREAM
  - NAAPS
- Near real time observations
  - AERONET
  - MODIS
  - OMI
  - SEAWIFS
  - CALIPSO
  - MSG – EUMETSAT
  - MSG – U.K. Met Office
  - PARASOL
  - METAR
- Forecast Verification
- Reanalysis
- Data access

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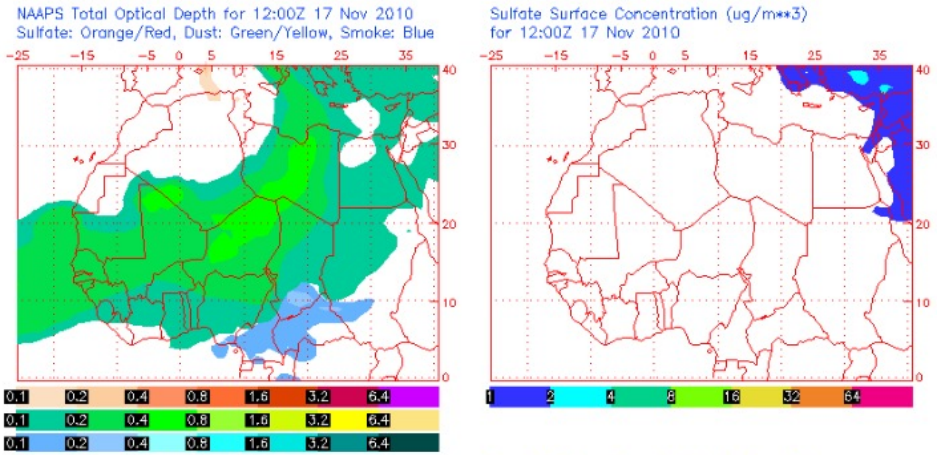
The Naval Research Laboratory (NRL) in Monterey, CA, has developed a near-operational system for predicting the distribution of tropospheric aerosols, **NAAPS** (Navy Aerosol Analysis and Prediction System) Global Aerosol Model. The NRL version uses global meteorological fields from the Navy Operational Global Atmospheric Prediction System (NOGAPS) (Hogan and Rosmond, 1991; Hogan and Brody 1993) analyses and forecasts on a 1 X 1 degree grid, at 6-hour intervals and 24 vertical levels reaching 100 mb. The original model used northern hemispheric, 12-hourly ECMWF fields on a 2.5 X 2.5 degree grid.



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Dust Forecasts for the Asian Region

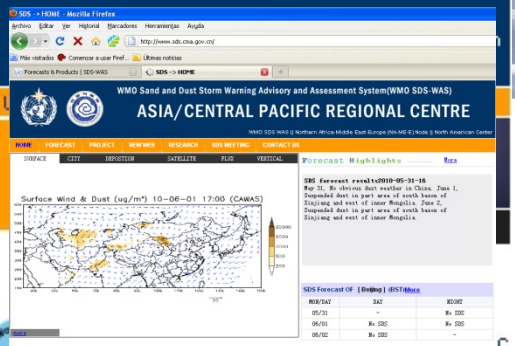
Regional Dust Models

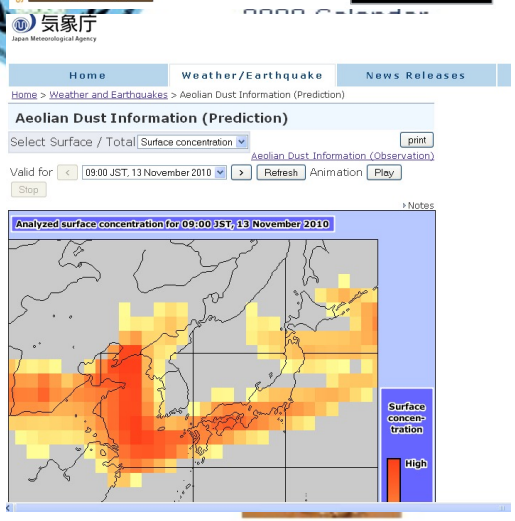
- China Meteorological Authority
- Japan Meteorological Authority
- Barcelona Supercomputer Centre

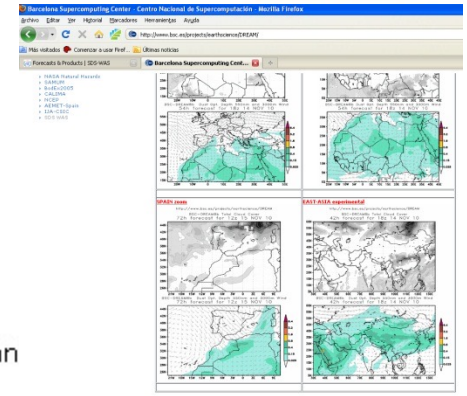
Global Dust Models

- ECMWF
- NRL Monterey

Note: SDS-WAS Portal for the Asian SDS-WAS Node is under development an posted when ready

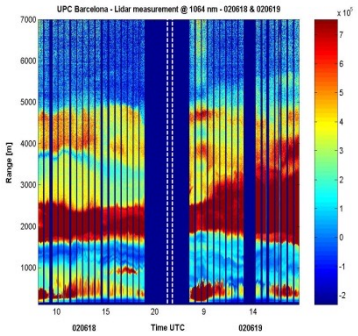


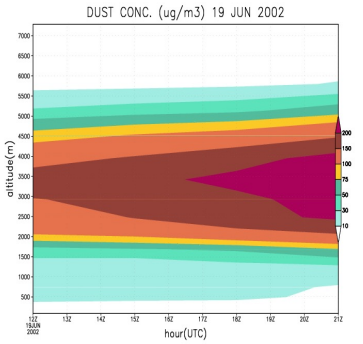




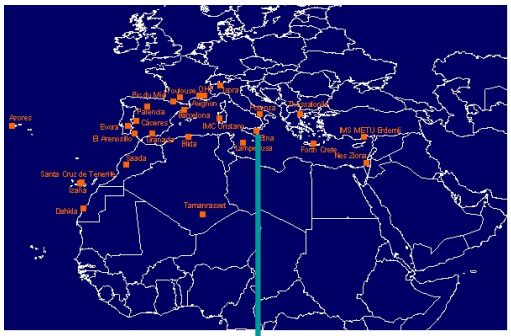
Dust forecast evaluation

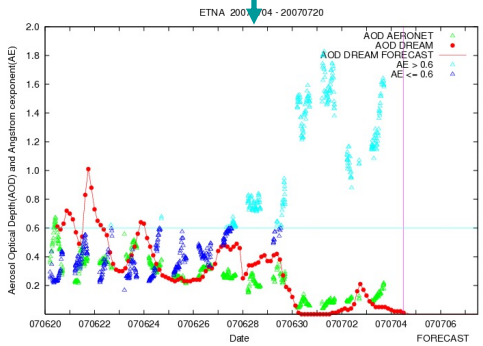
Lidars - EARLINET



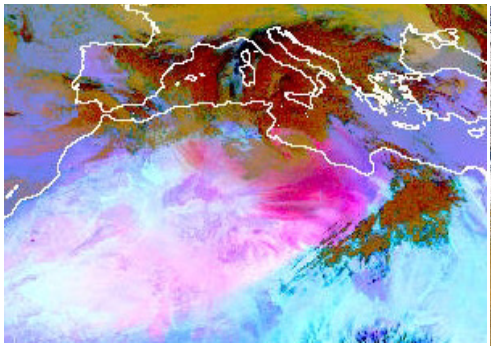


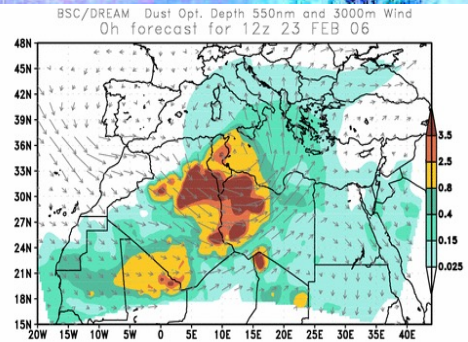
AERONET - ONLINE



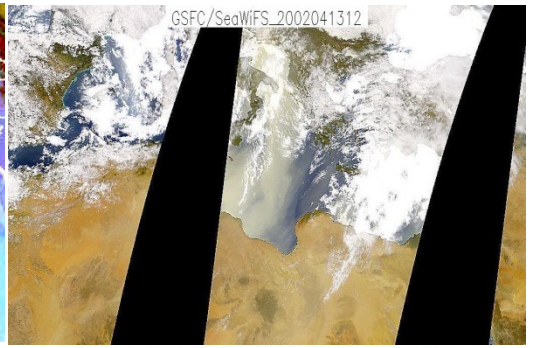


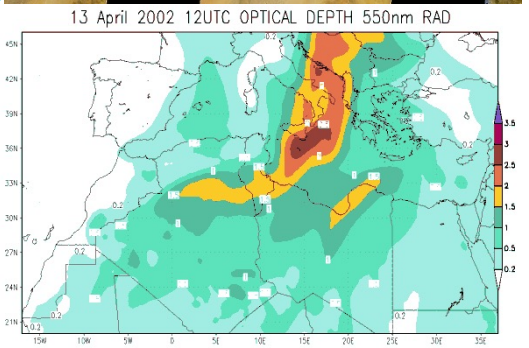
Meteosat Second Generation





SeaWIFS





Model has shown good agreement with observations in a number of studies of single events (e.g., *Ansmann et al.*, 2003, *Papayannis et al.,* 2005; Balis et al., 2006; *Pérez et al*., 2006a;b; *Jiménez et al,* 2006 ….)

NRT evaluation

Barcelona Supercomputing Center - Centro Nacional de Supercomputación - Mozilla Firefox

Archivo Editar Ver Historial Marcadores Herramientas Ayuda

http://www.bsc.es/plantillaH.php?cat_id=522

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Home > Earth Sciences > Mineral dust forecast system > BSC-DREAM8b Forecast > North Africa - Europe - Middle East Domain > Daily Verification

- Air quality
- Meteorological modelling
- Mineral dust forecast system
  - BSC-DREAM8b Forecast
    - North Africa - Europe - Middle East Domain
      - Euro-Mediterranean
      - Sahara-Sahel
      - Spain
      - Daily Verification
    - Asia Domain
    - BSC-DREAM8b Model Info

Daily Verification

AERONET Verification | MSG Verification | MODIS Real-Time

Sites Back to Map Archive Plot info

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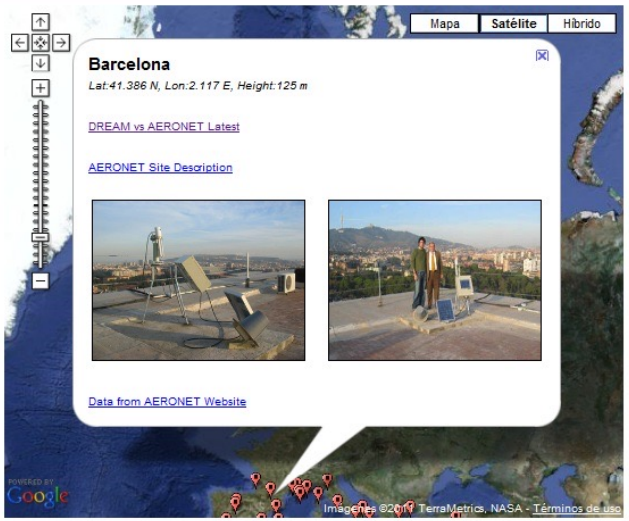

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      - Euro-Mediterranean
      - Sahara-Sahel
      - Spain
      - Daily Verification
    - Asia Domain
    - BSC-DREAM8b Model Info
    - Current and future developments
    - Source Code
    - News
  - SAMUM Forecasts
- Climate change
- Geophysical Flows
- CALIOPE Project
- SDS-WAS
- NMMB/BSC Project
- Software
- Earth Sciences Seminars

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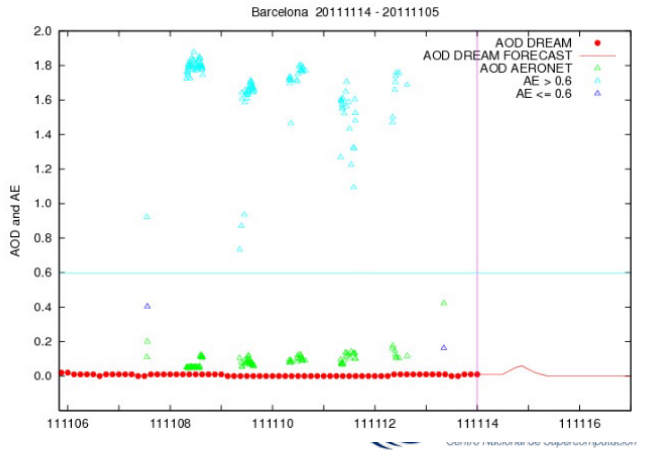
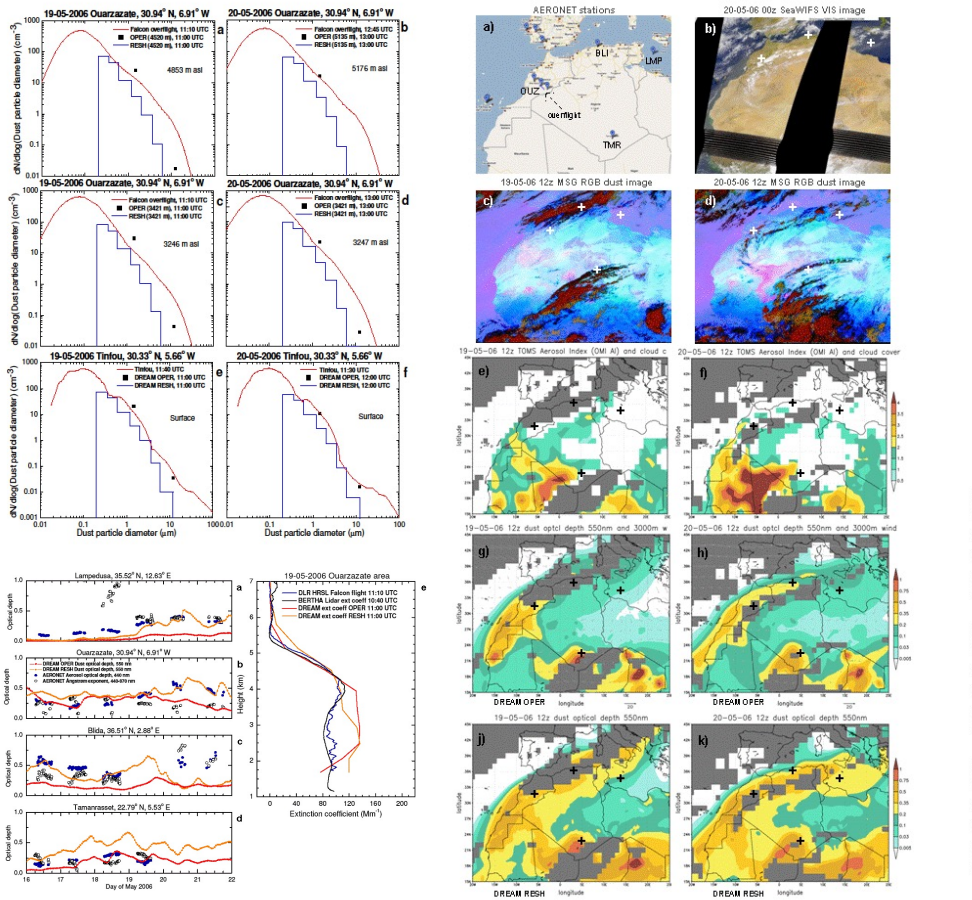


BSC-DREAM8b assessment

- BSC-DREAM8b validation activites

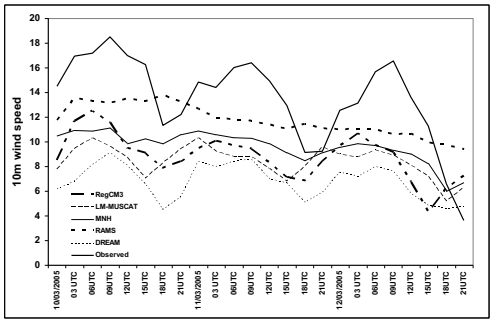
→ SAMUM-I comparison [Haustein et al., 2009]



→ BoDEx intercomparison [Todd et al., 2008]

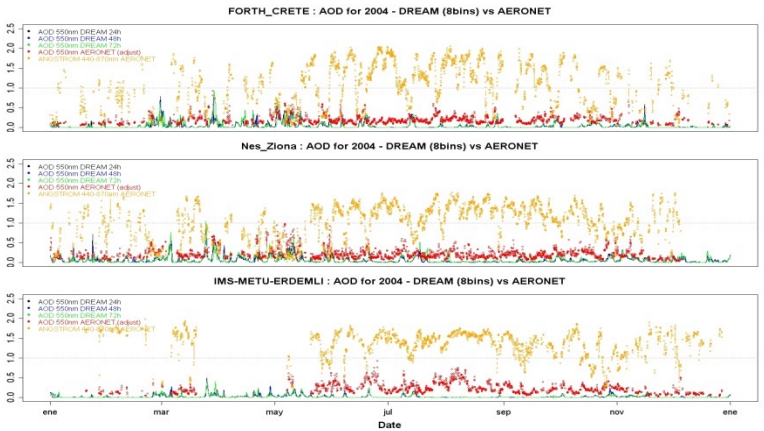
Regional model intercomparison in the Bodélé

RegCM3
LM-MUSCAT
Meso-NH
RAMS-DPM
BSC/DREAM



→ AERONET comparison

Ongoing evaluation (**Basart et al 2009**)
Full year 2004 valiadation of **BSC-DREAM8b versus AERONET**



Previous work: NMMB/BSC-DUST

- Eta/DREAM model [Nickovic et al., 2001]
- Eta/BSC-DREAM8b regional dust forecast model [Pérez et al., 2006]
  http://www.bsc.es/projects/earthscience/DREAM
- NMMB introduction
  - The NCEP-ETA weather forecast model is replaced by a state-of-the-art regional/global model with improved dynamics and physics:

→ ***NCEP-NMMb***

[Janjic, 2005, 2007, 2009]

- ***Under development at NCEP*** *as evolution of the ETA model*
- Unified model with regional and global domain (embedded in ESMF architecture)
- Arakawa B grid and pressure-sigma hybrid coordinate [Arakawa and Lamb, 1977]
- NMMB regional will become the next-generation NCEP mesoscale model for ***operational weather forecasting in 2010***

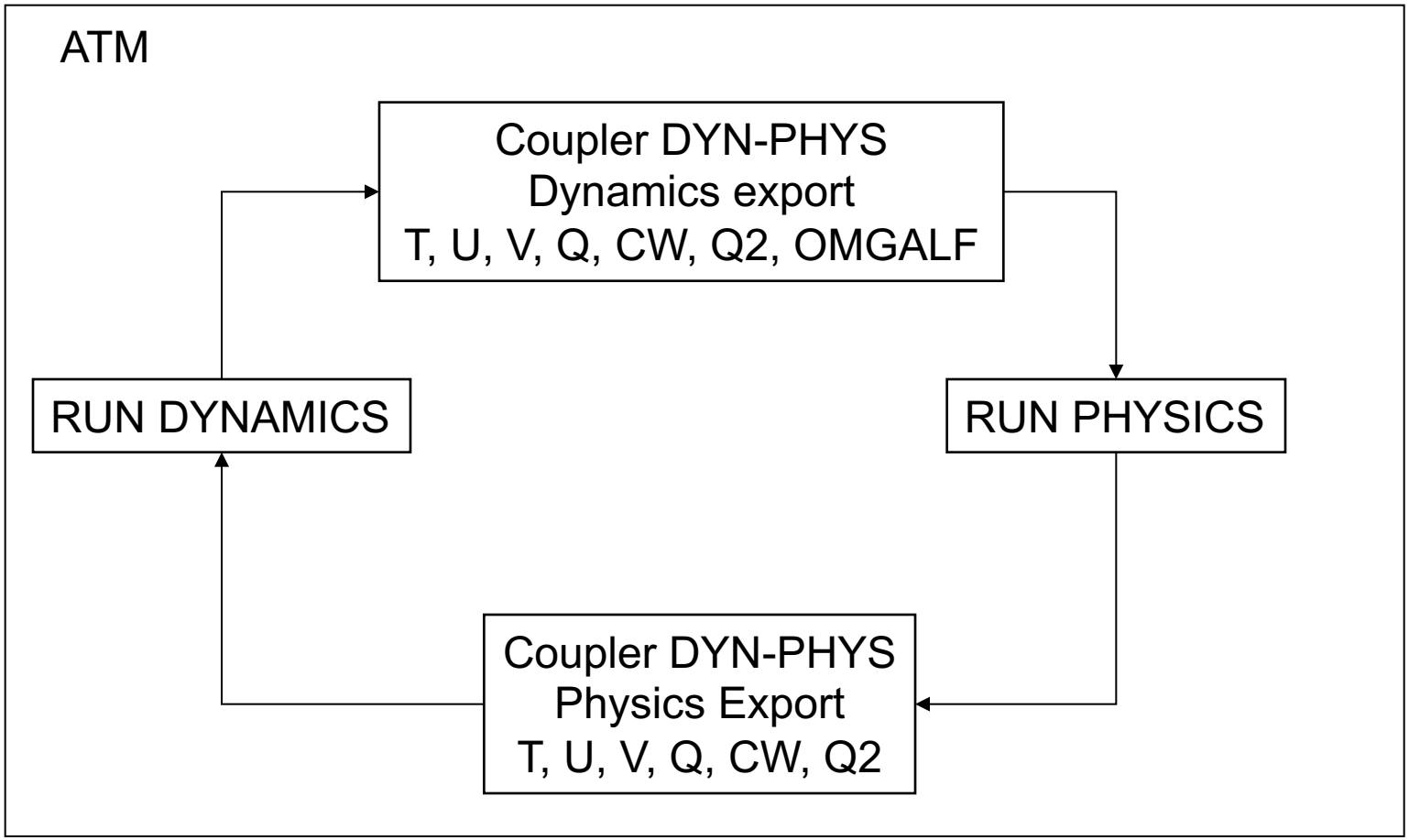
  - Global dust forecasts up to7 days at sub-synoptic resolutions:

→ ***NMMb/BSC-DUST***

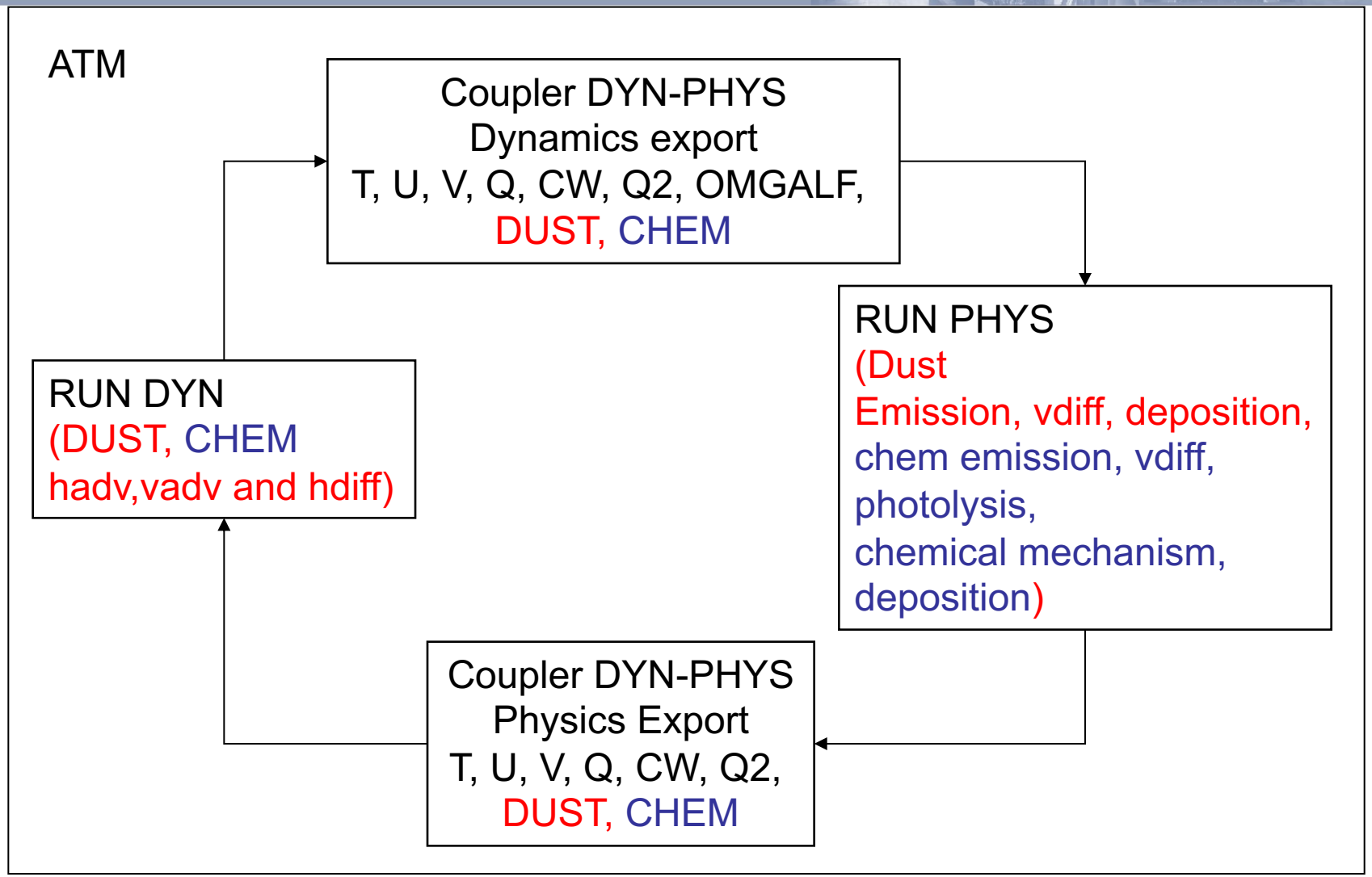
[Pérez et al., 2008, 2011; Haustein et al., 2009, 2011]

- Implementation of all common on-line dust modules for global simulations
- Nested regional domains at very high resolution will be available
- The current DREAM dust emission scheme is upgraded to a physically based scheme → ***explicitly accounting for saltation and sandblasting***
- New high resolution database for soil textures and vegetation fraction is included

Structure of NMMb using Earth System Modeling Framework (ESMF)



NMMb/BSC-DUST-CHEM using Earth System Modeling Framework (ESMF)



DUST and gas-phase CHEM modules fully embeded within the atmospheric driver

- NMMB/BSC-DUST emission scheme

→ Threshold friction velocity [Bagnold, 1941; Iversen and White, 1982; Marticorena and Bergametti, 1995]

DREAM: $u_{*total}(D,w) = u_{*dry}(D)\cdot H(w)$

NMMB-DUST : $u_{*total}(D,z_0,w) = \frac{u_{*dry}^{MB}(D)}{R(z_0,z_{0S})}\cdot H(w)$

H=Moisture correction
R=Drag partition correction

→ Horizontal flux [White, 1979]

DREAM: Implicit in vertical flux

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

s_i=relative surface area of each soil fraction

→ Vertical flux [Shao et al., 1993; Marticorena and Bergametti, 1995; Tegen et al., 2002]

DREAM: $F_S = c\cdot\delta_{DREAM}\cdot u_*^3\cdot\left(1-\frac{u_{*total}^2}{u_*}\right)$

NMMB-DUST: $F_S = c\cdot\alpha\cdot\delta\cdot G \Rightarrow (u_* \geq u_{*total})$

α=sandblasting efficiency
δ=new source function

→ Viscous sublayer effects near the surface [Janjic, 2001]

NMMB/BSC-DUST deposition scheme

- Threshold friction velocity [Bagnold, 1941; Iversen and White, 1982; Marticorena and Bergametti, 1995]
- Horizontal flux [White, 1979]
- Vertical flux [Shao et al., 1993; Marticorena and Bergametti, 1995; Tegen et al., 2002]
- Viscous sublayer effects near the surface [Janjic, 2001]

- Turbulent deposition [Giorgi, 1986] $\upsilon_{dep} = \frac{1}{\frac{1}{\upsilon_{SL}} + \frac{1}{f_{B0} \cdot \upsilon_{IL}}}$

(DREAM + NMMB-DUST)

Brownian diffusion, interception, impaction is considered

- Gravitational settling [Giorgi, 1986]

DREAM: $v_g = \frac{2 \cdot g \cdot \rho_k \cdot R_k^2}{9 \cdot \nu}$

NMMB-DUST: $v_g = \frac{2 \cdot g \cdot \rho_k \cdot R_k^2}{9 \cdot \nu} \cdot Cc$ Cc=Cunningham correction

---

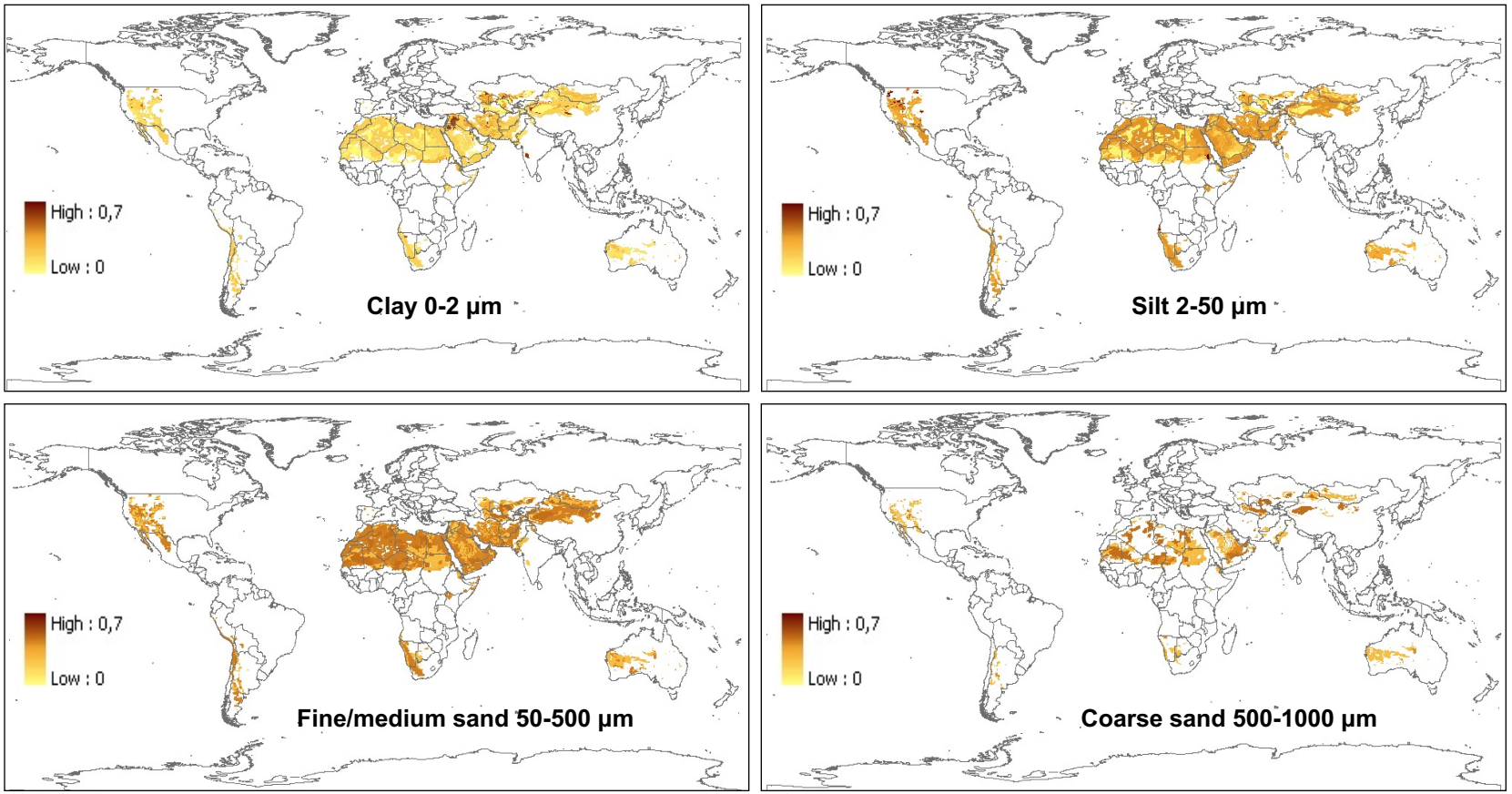
- Grid scale precipitation [Slinn, 1983; 1984]
- Convective precipitation [Loosmore and Cederwall, 2004]

NMMB-DUST:

In-cloud scavenging and **Below-cloud scavenging** (Ferrier microphysics for grid scale and BMJ microphysics for convection)

NMMB/BSC-DUST

- NMMB DUST parent soil size distribution

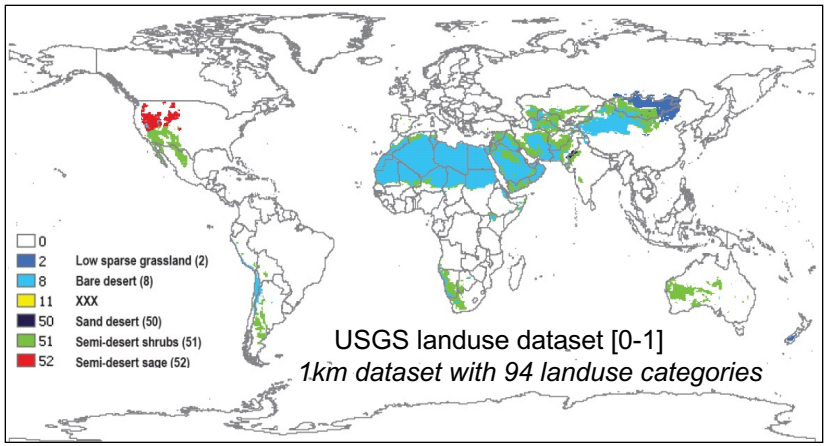


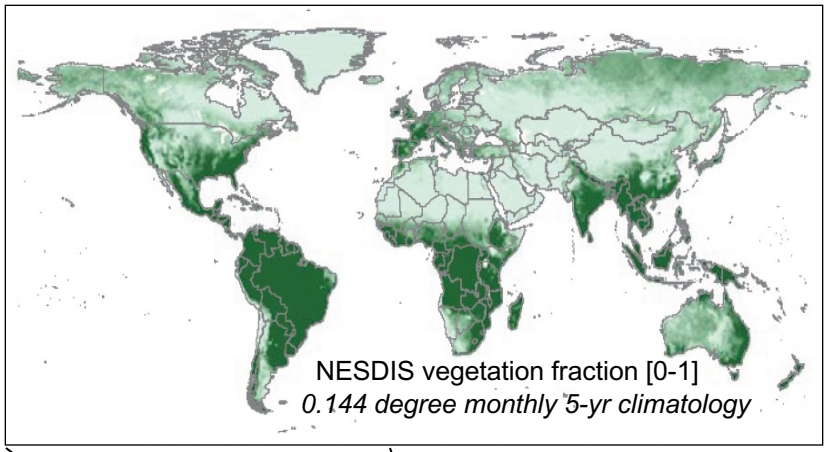
Four top soil texture classes according STASGO-FAO 1km database are converted to 4 parent soil size categories following Tegen et al. [2002]
They are used to calculate ***horizontal flux***

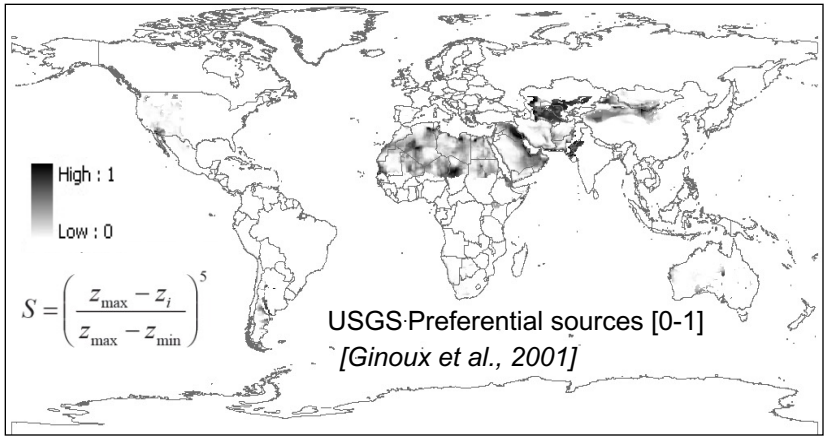
Dust ***horizontal concentration*** is calculated distributing the ***vertical flux*** of the ***first two parent soil categories*** over the ***8 model particle bins***

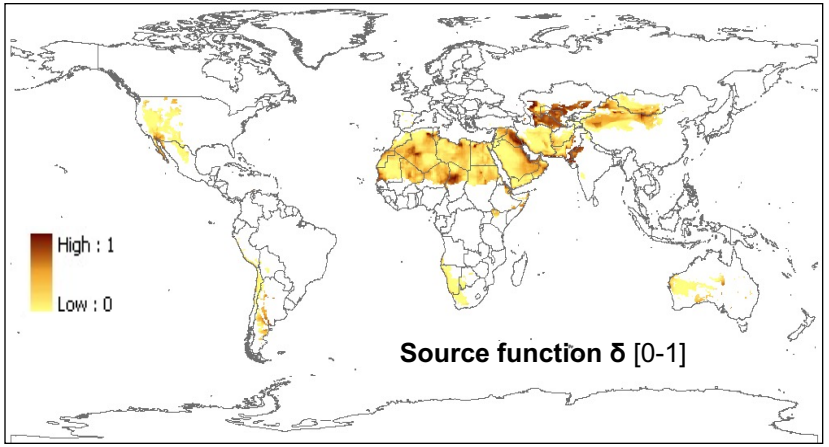
NMMB/BSC-DUST

- NMMB DUST source function





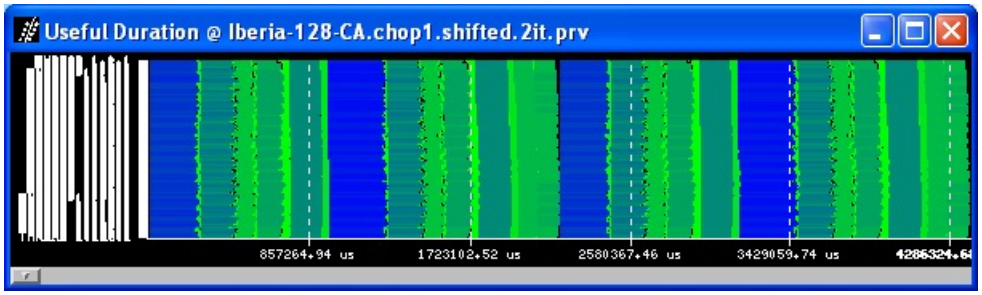




$$\delta = USGS \cdot PREF \cdot (1 - VEGFRAC) \cdot (1 - SnowCover)$$

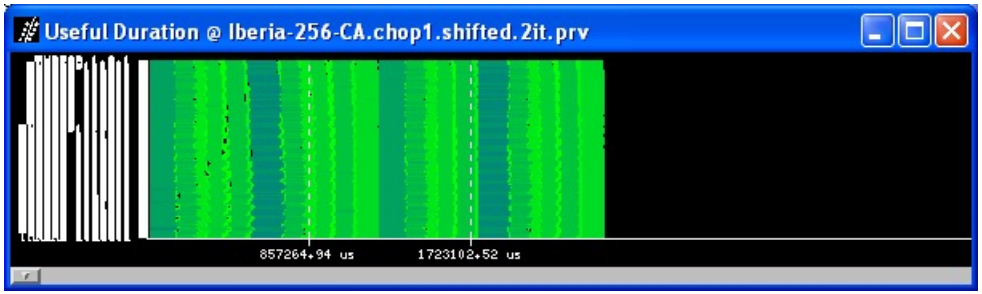
NMMB/BSC-DUST traces @ MareNostrum (REGIONAL)

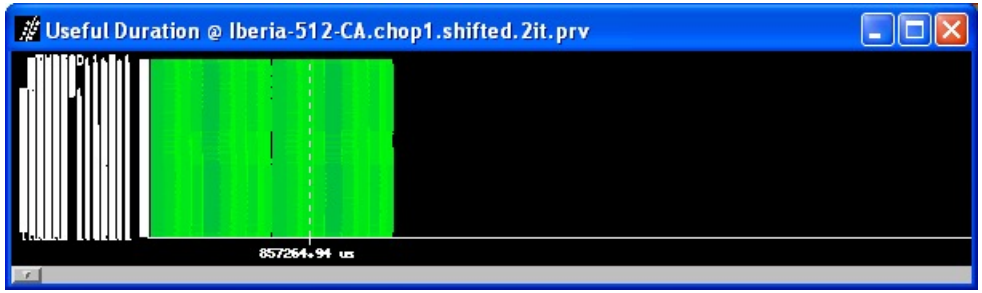
- 128 CPUs



- 256 CPUs

Computational time





Iberian Peninsula 4km

NMMB/BSC-DUST

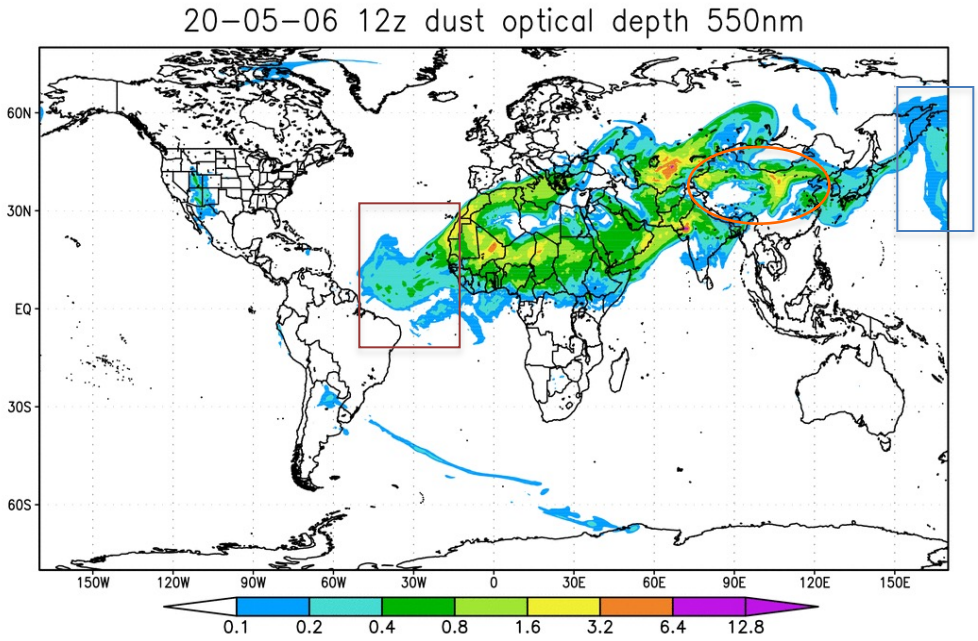
- NMMB model setup → define the simulation characteristics

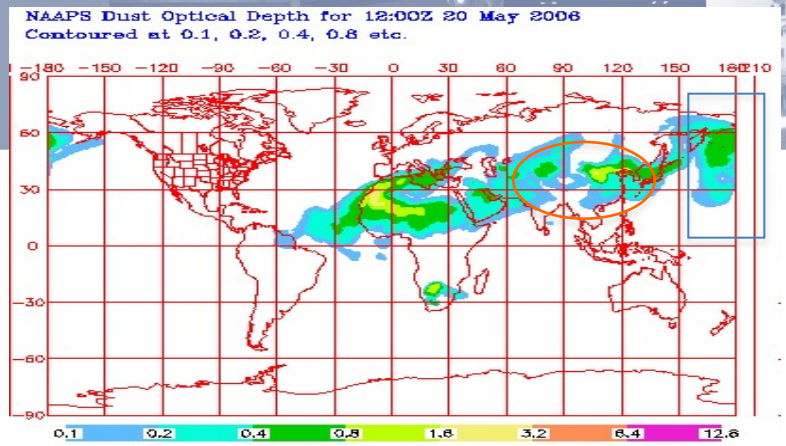
→ Global domain
→ 1º x 1º NCEP analysis meteorology data updated every 24 hours
→ Non-hydrostatic physics
→ 1/2º x 1/2º model grid resolution
→ 64 vertical (sigma) layers
→ Dust cold start period of 3 days
→ SAMUM period in May 2006
→ No wet deposition in this simulation

→ All results are preliminary!

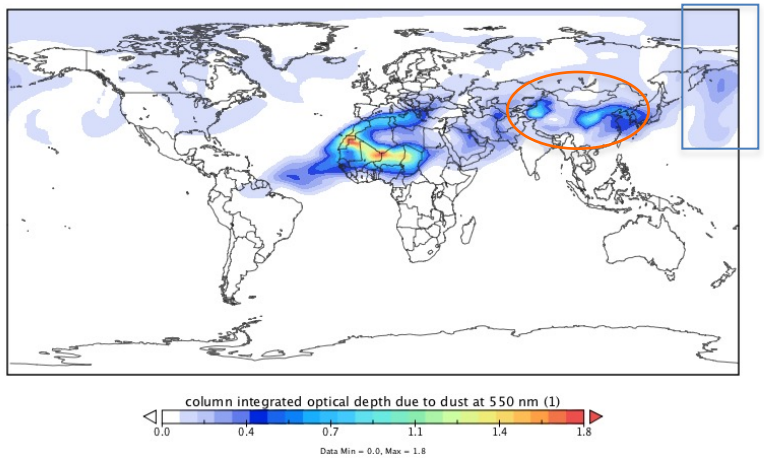
BSC - Mare Nostrum

NMMb/BSC-Dust May 20th, 2006

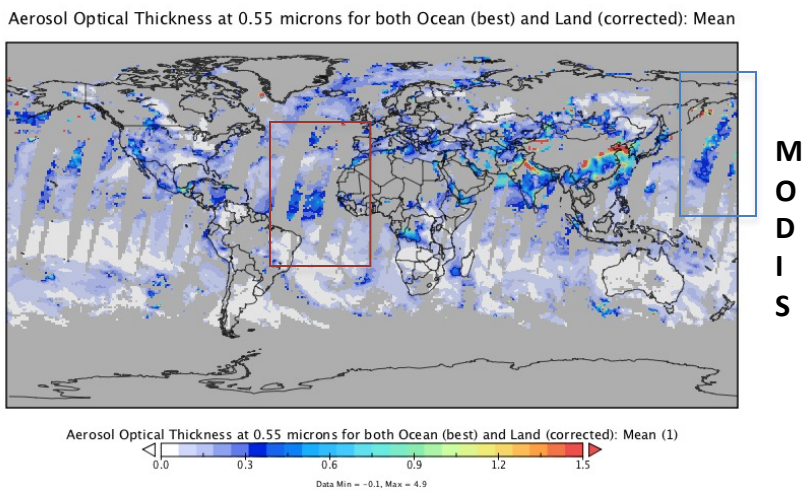




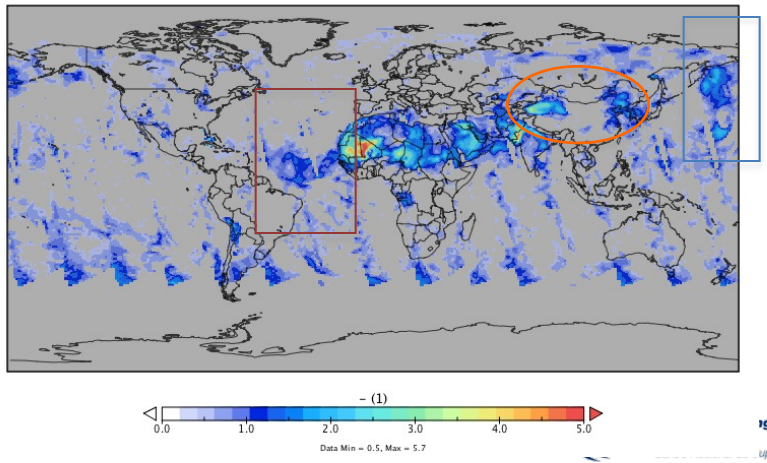
NAAPS



GOCART



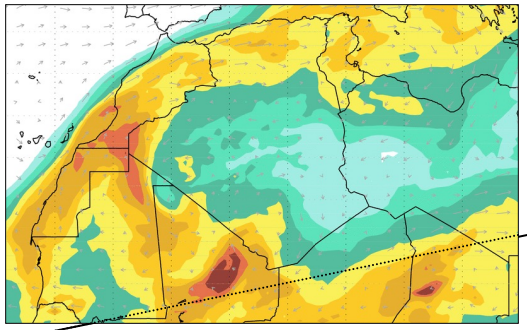
MODIS

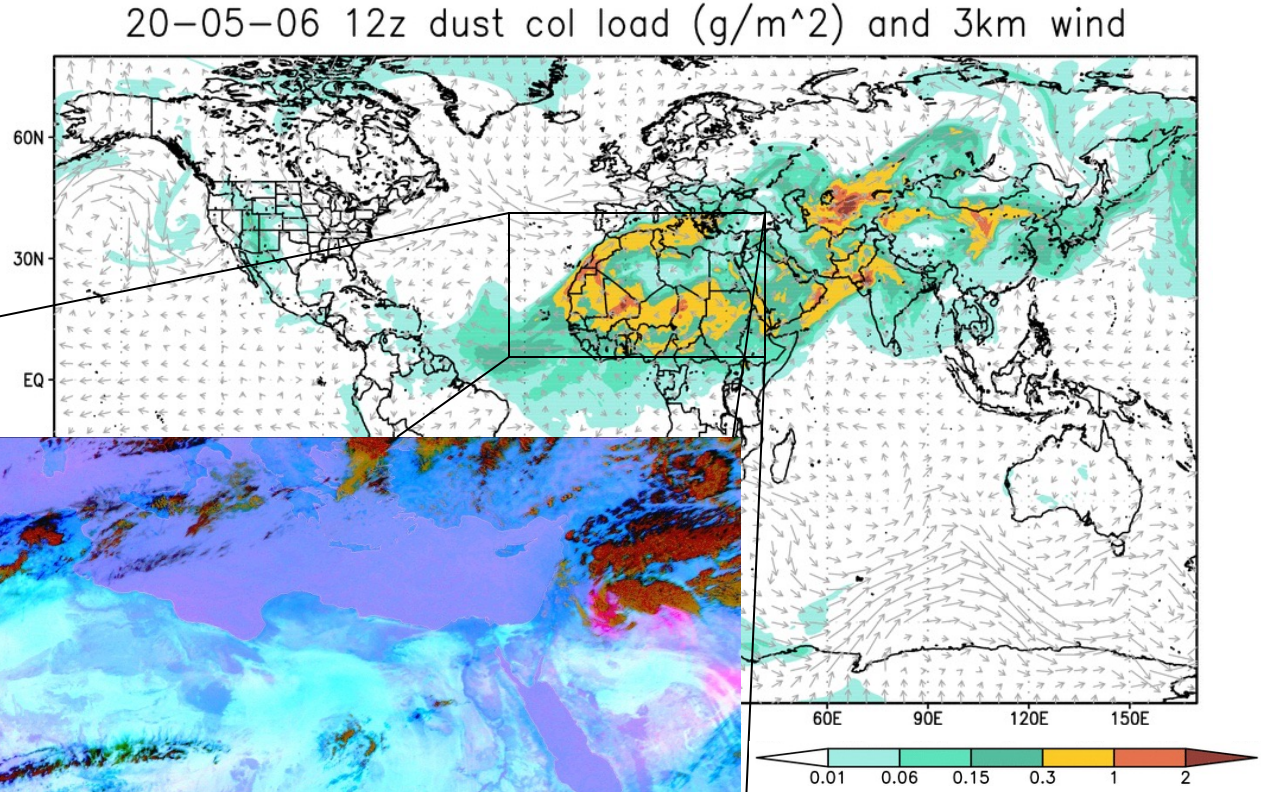


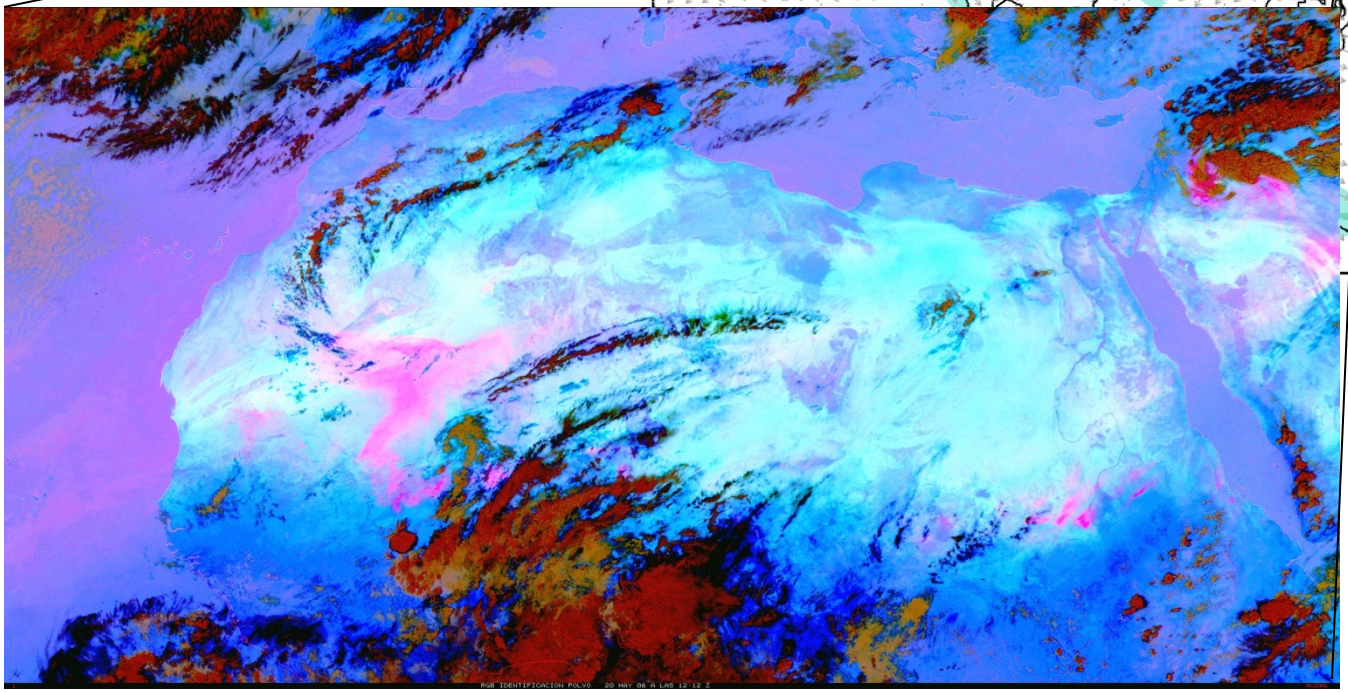
AEROSOL INDEX

NMMB/BSC-DUST

- NMMB results II







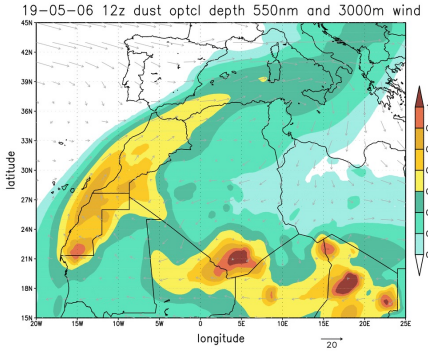
MSG dust image
20-05-06 12z

NMMB/BSC-DUST

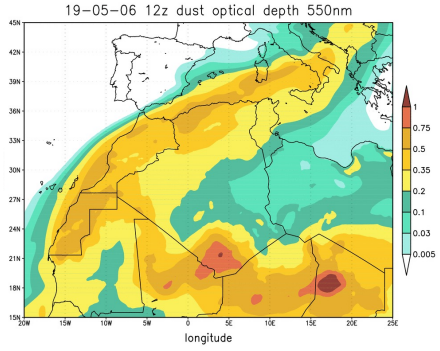
- NMMB results III

comparison dust AOD 550nm & OMI aerosol index

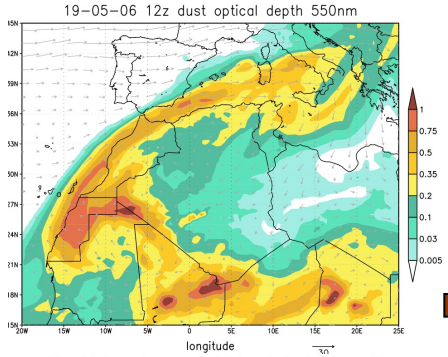
DREAM



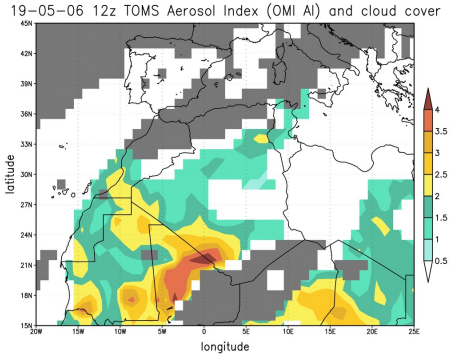
BSC-DREAM8b



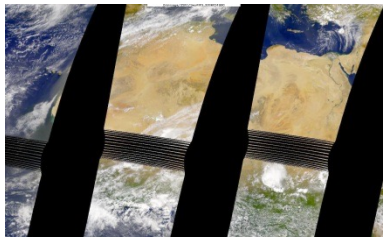
NMMB/BSC-DUST



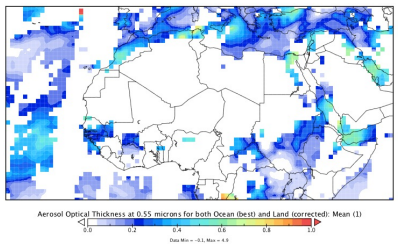
OMI AI

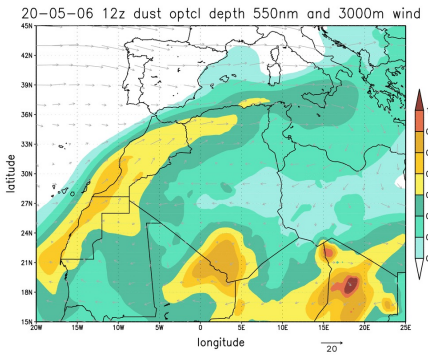


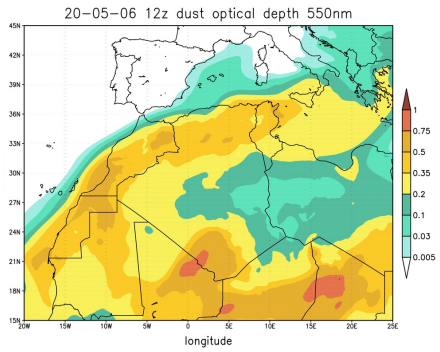
SeaWiFS image
19-05-06 00z

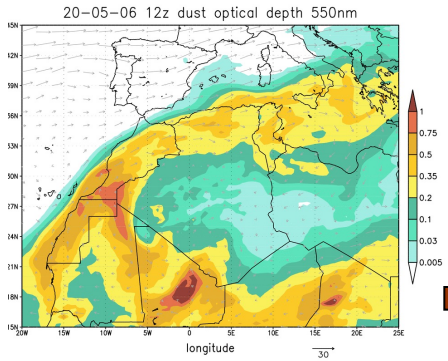


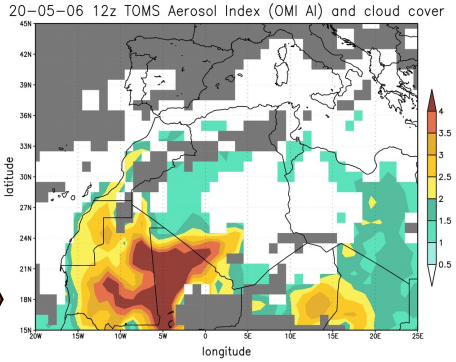
MODIS AOD
20-05-06











Moist convective event
no captured by models

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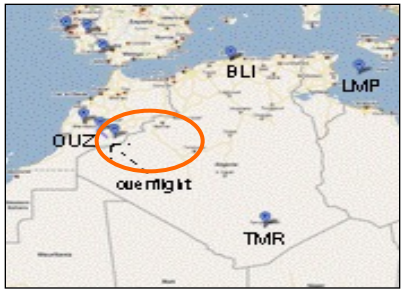
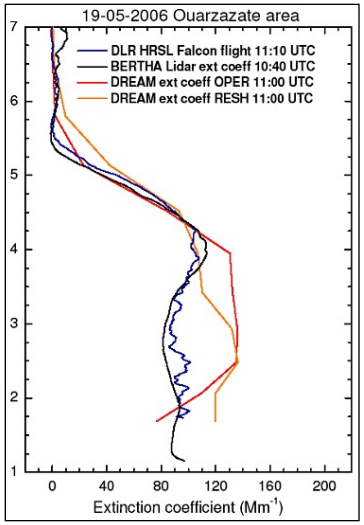
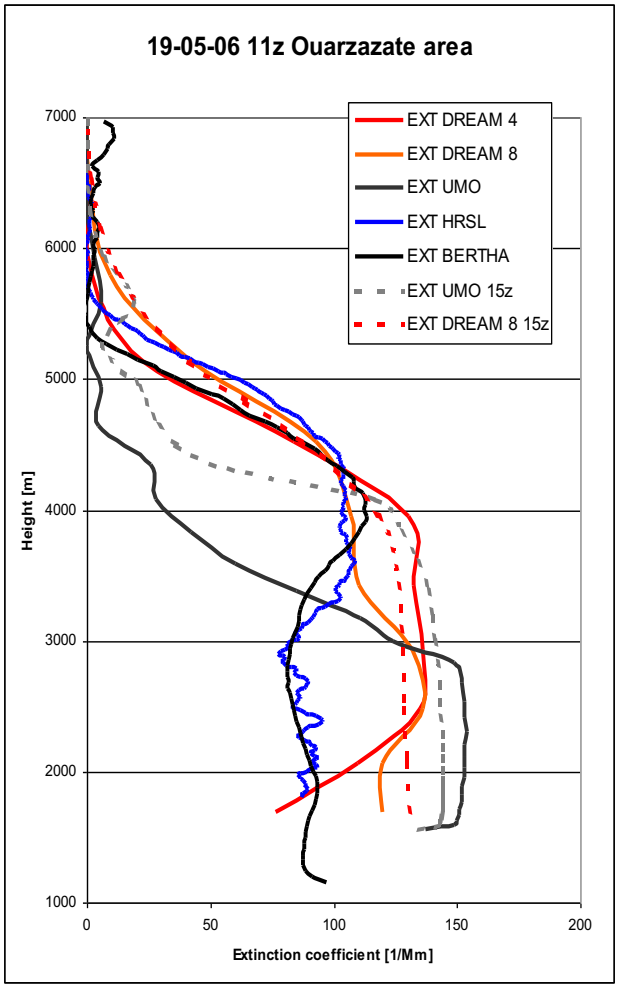
NMMB/BSC-DUST

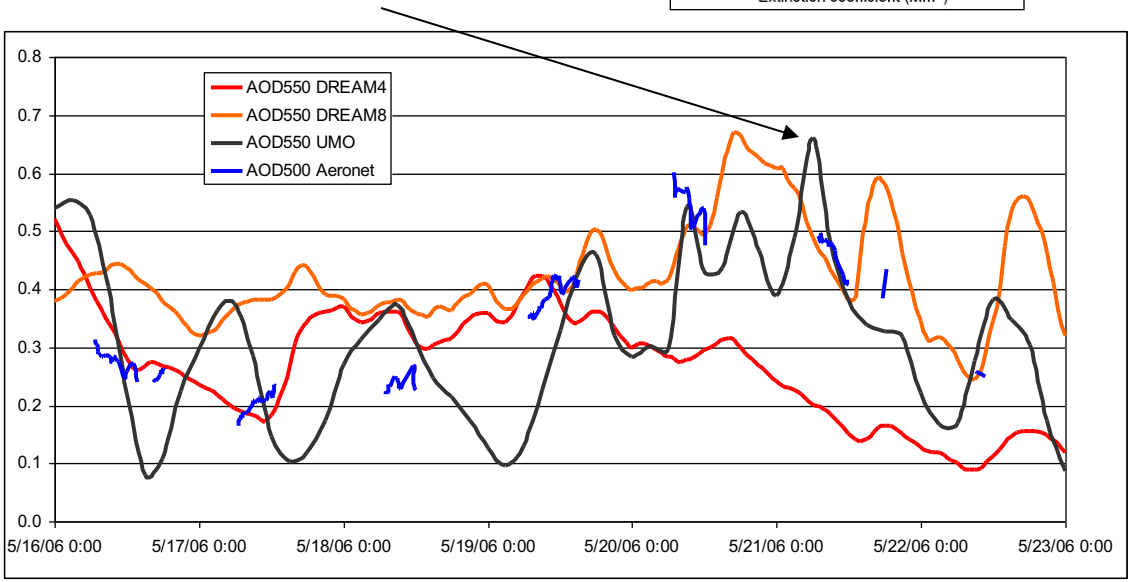
- NMMB results IV







- very pronounced diurnal dust cycle
- noticable variations in case of dust events

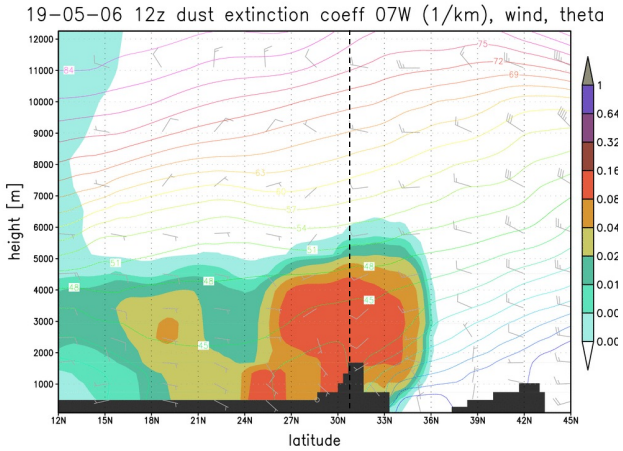


NMMb/BSC-DUST

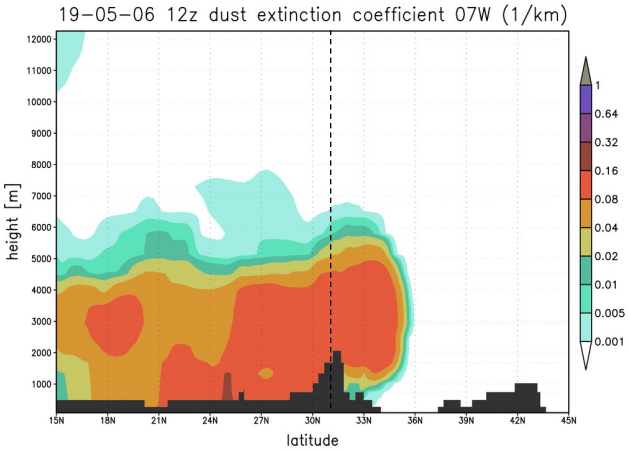
(Pérez et al., 2008; Haustein et al., 2009)

- NMMb/BSC-DUST results

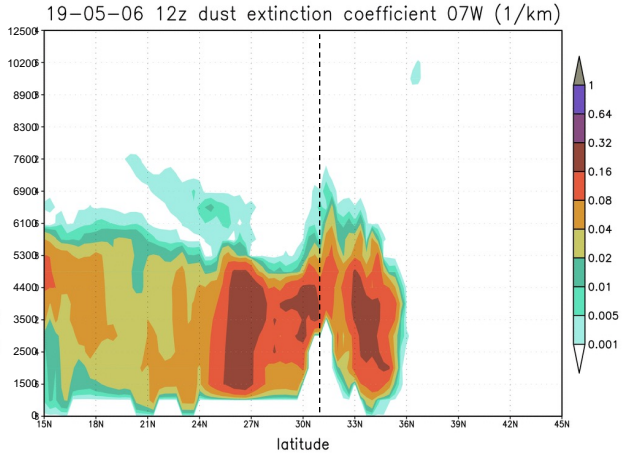
vertical cross section dust extinction coefficient (Ouarzazate)



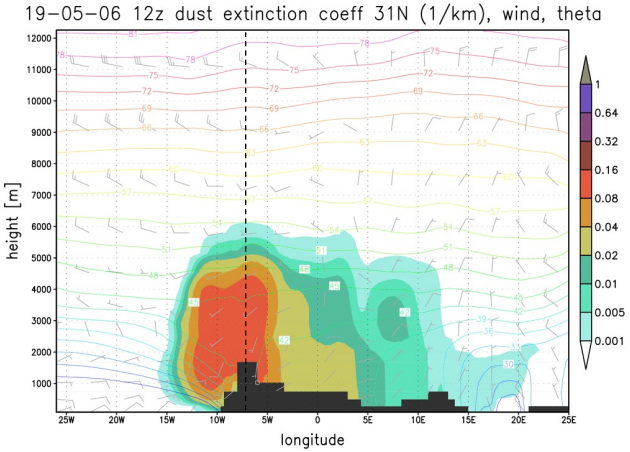
DREAM

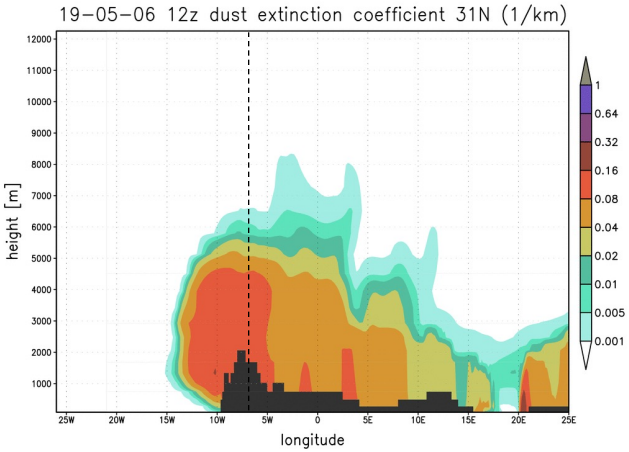


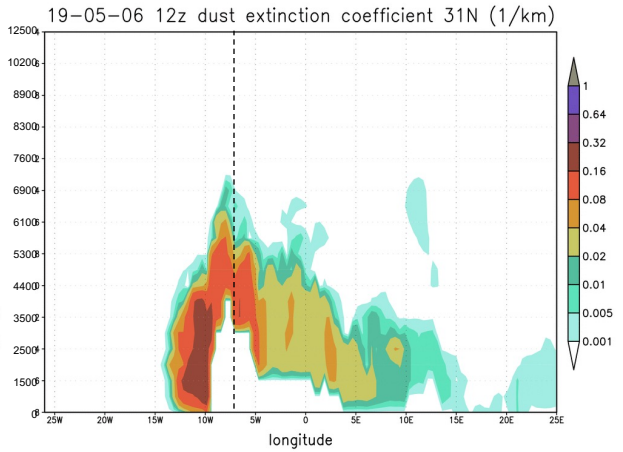
BSC-DREAM8b operational



NMMB-DUST







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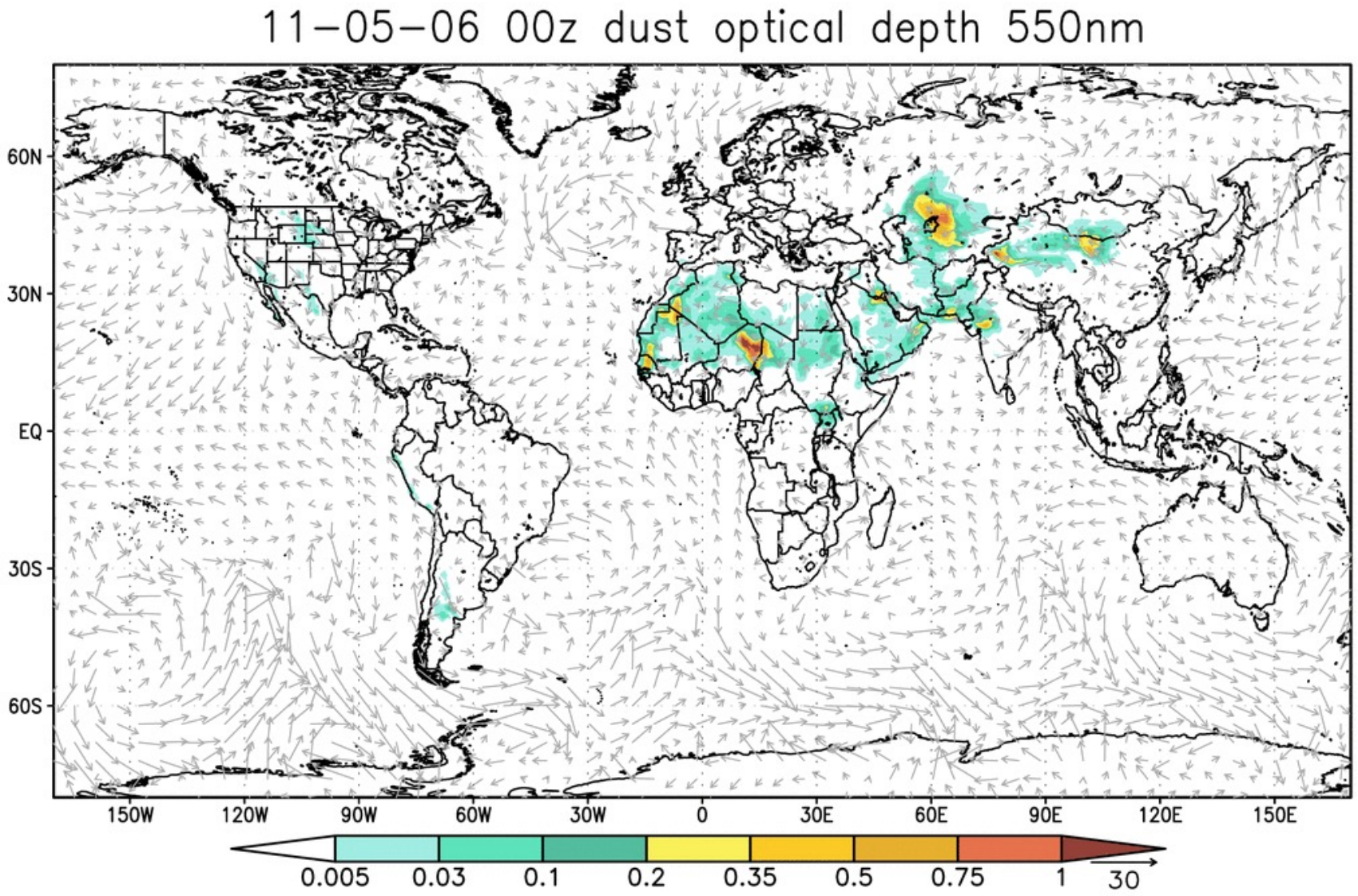
Global dust simulations with NMM/BSC-Dust
11-25 May 2006: Samum campaign period

0.3333 deg meridionally (37 km)
64 vertical levels resolution, comparable to operational GFS resolution



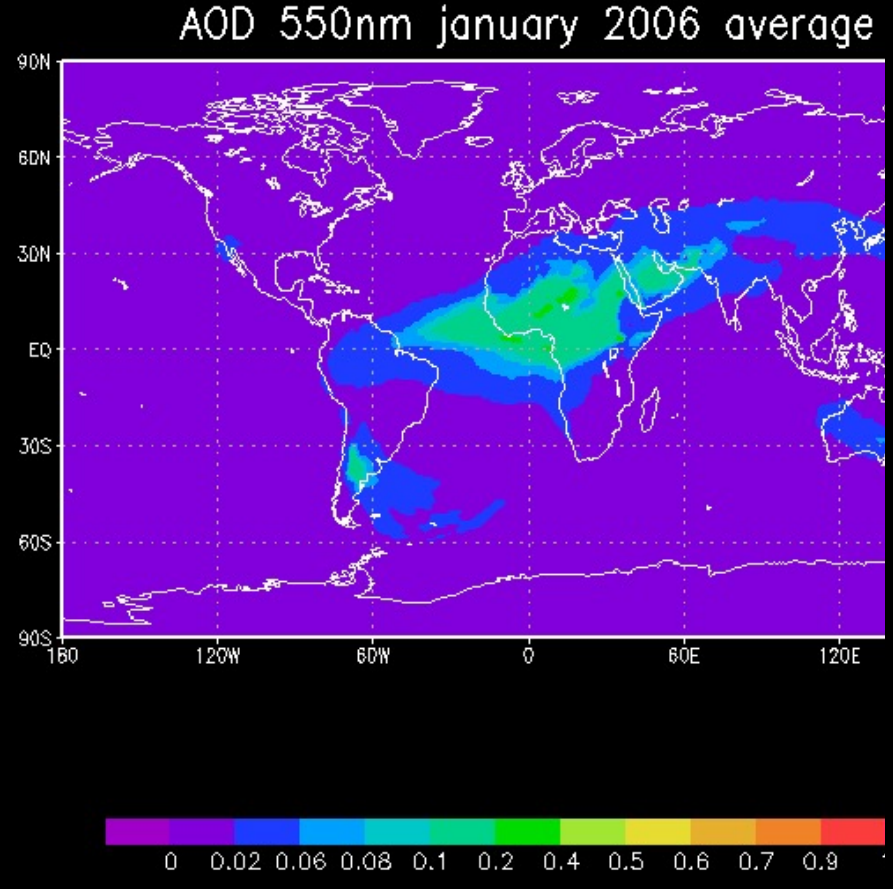
Full year 2006 simulation

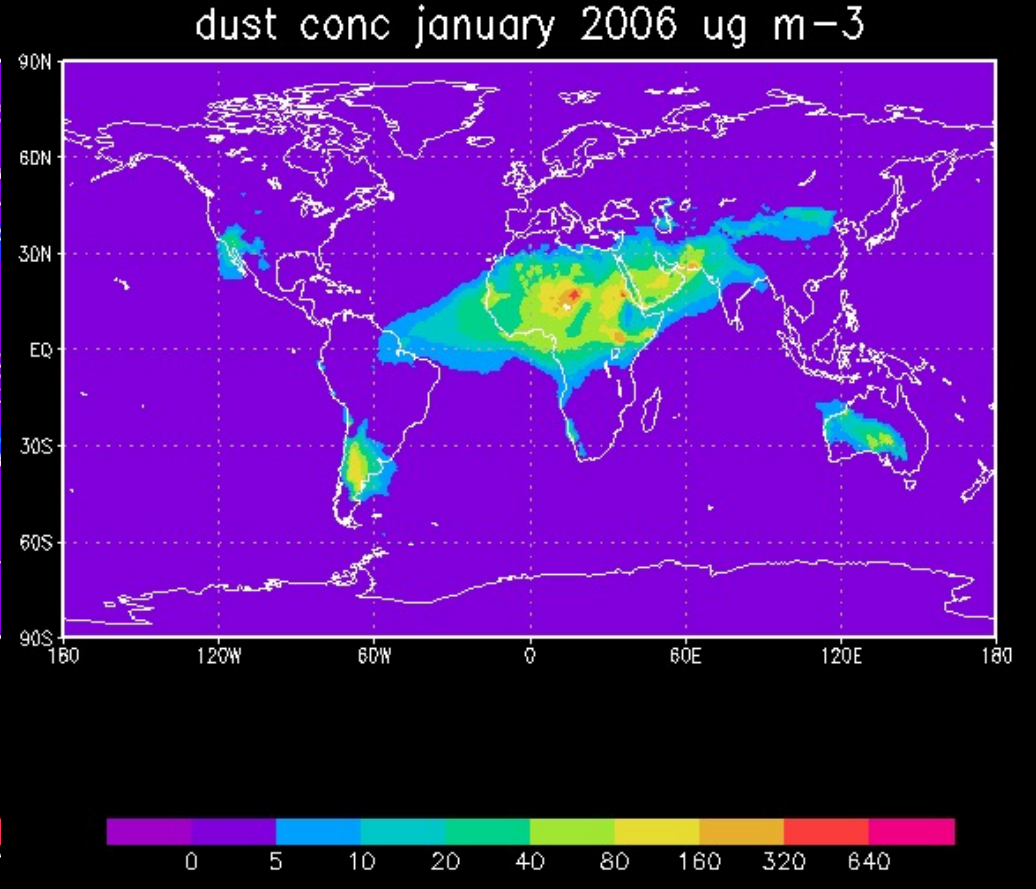
Simulation:

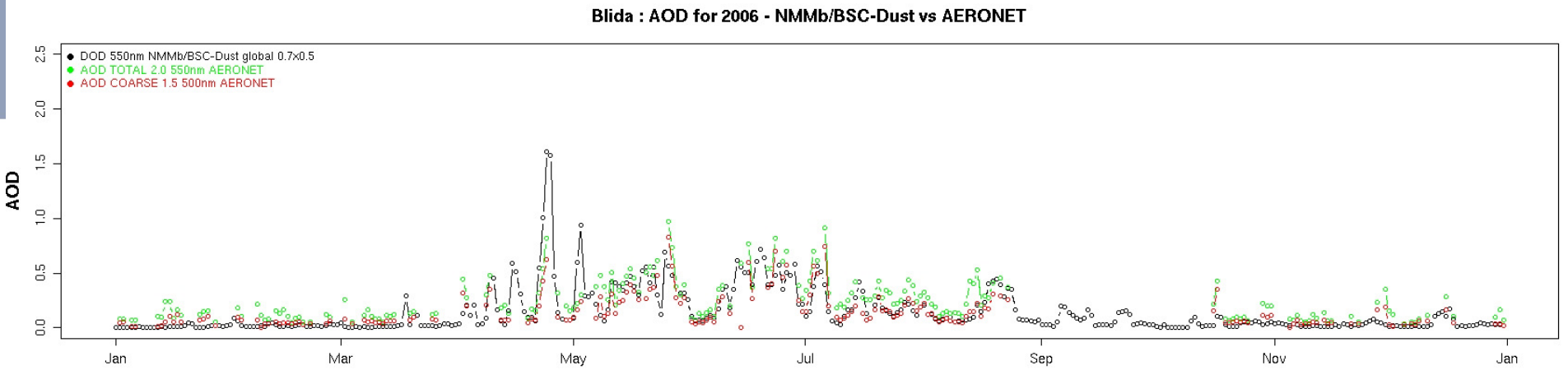
- Global simulation for year 2006
- 0.7º x 0.5º x 40 vertical levels
- Cold start without data assimilation
- Initial conditions from NCEP analysis 1x1º. Meteorological fields updated with NCEP every 24 hours.

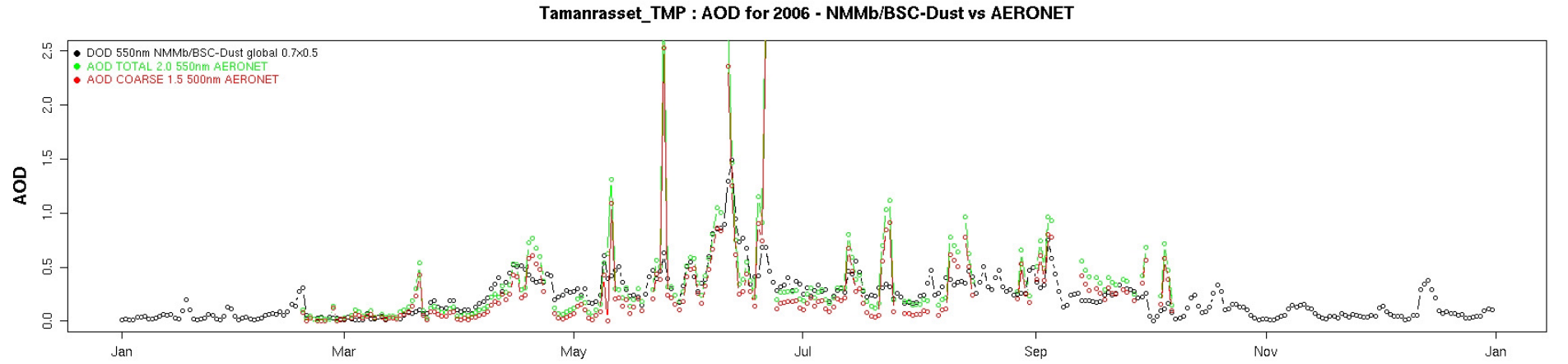
Aeronet validation:

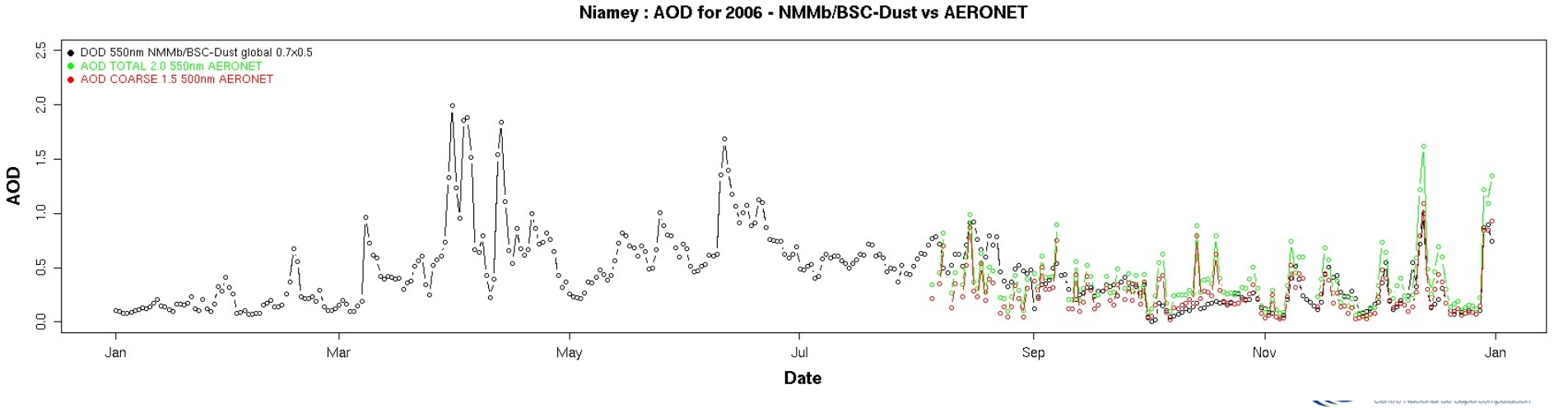
- Aeronet data here is Coarse AOD (mainly dust over dust affected stations)
- We validate daily averages


AOD 550nm january 2006 average
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
0
0.02
0.06
0.08
0.1
0.2
0.4
0.5
0.6
0.7
0.9


dust conc january 2006 ug m-3
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
0
5
10
20
40
80
160
320
640


Blida : AOD for 2006 - NMMb/BSC-Dust vs AERONET
DOD 550nm NMMb/BSC-Dust global 0.7x0.5
AOD TOTAL 2.0 550nm AERONET
AOD COARSE 1.5 500nm AERONET
AOD
0.0
0.5
1.0
1.5
2.0
2.5
Jan
Mar
May
Jul
Sep
Nov
Jan

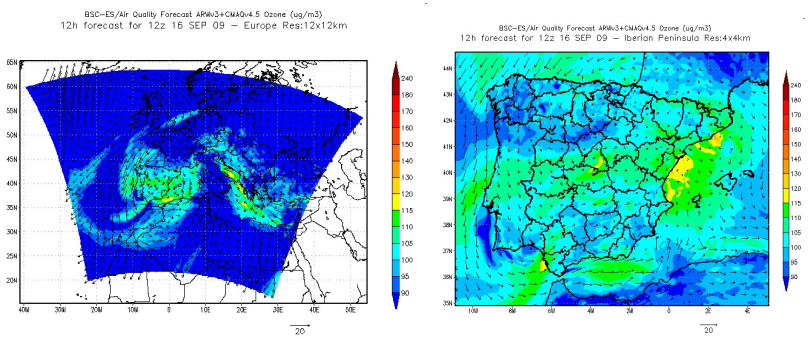

Tamanrasset_TMP : AOD for 2006 - NMMb/BSC-Dust vs AERONET
DOD 550nm NMMb/BSC-Dust global 0.7x0.5
AOD TOTAL 2.0 550nm AERONET
AOD COARSE 1.5 500nm AERONET
AOD
0.0
0.5
1.0
1.5
2.0
2.5
Jan
Mar
May
Jul
Sep
Nov
Jan

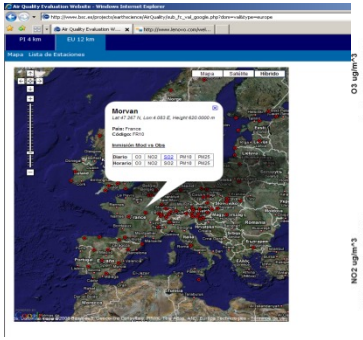

Niamey : AOD for 2006 - NMMb/BSC-Dust vs AERONET
DOD 550nm NMMb/BSC-Dust global 0.7x0.5
AOD TOTAL 2.0 550nm AERONET
AOD COARSE 1.5 500nm AERONET
AOD
0.0
0.5
1.0
1.5
2.0
2.5
Jan
Mar
May
Jul
Sep
Nov
Jan
Date

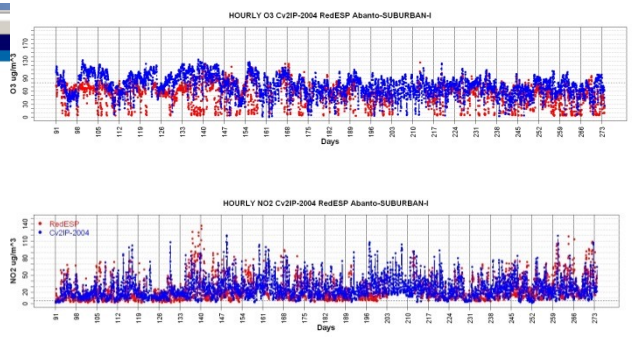
BSC air quality modelling activites

- CALIOPE daily experimental forecast and verification

✓ Daily experimental forecasts for meteorology and air quality (12 km for Europe and 4 km for the Iberian Peninsula) (http://www.bsc.es/caliope).

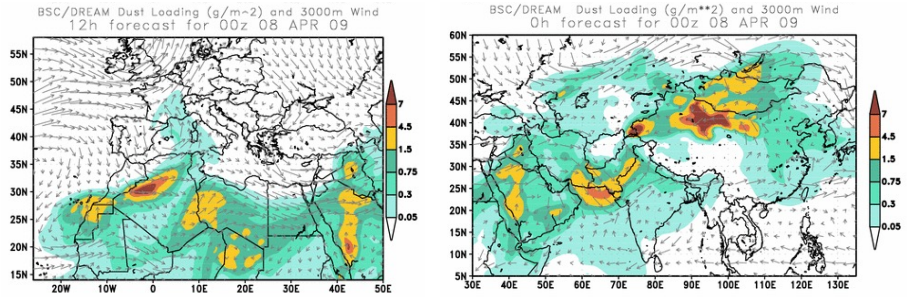


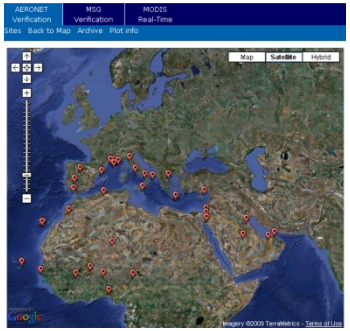


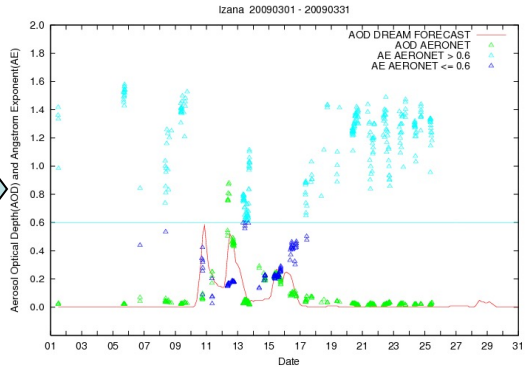


- BSC-DREAM8b daily forecast and verification

North Africa/Mediterranean - 1/3 x 1/3 degree resolution
Asia domain - 1/2 x 1/2 degree resolution







→ http://www.bsc.es/projects/earthscience/DREAM

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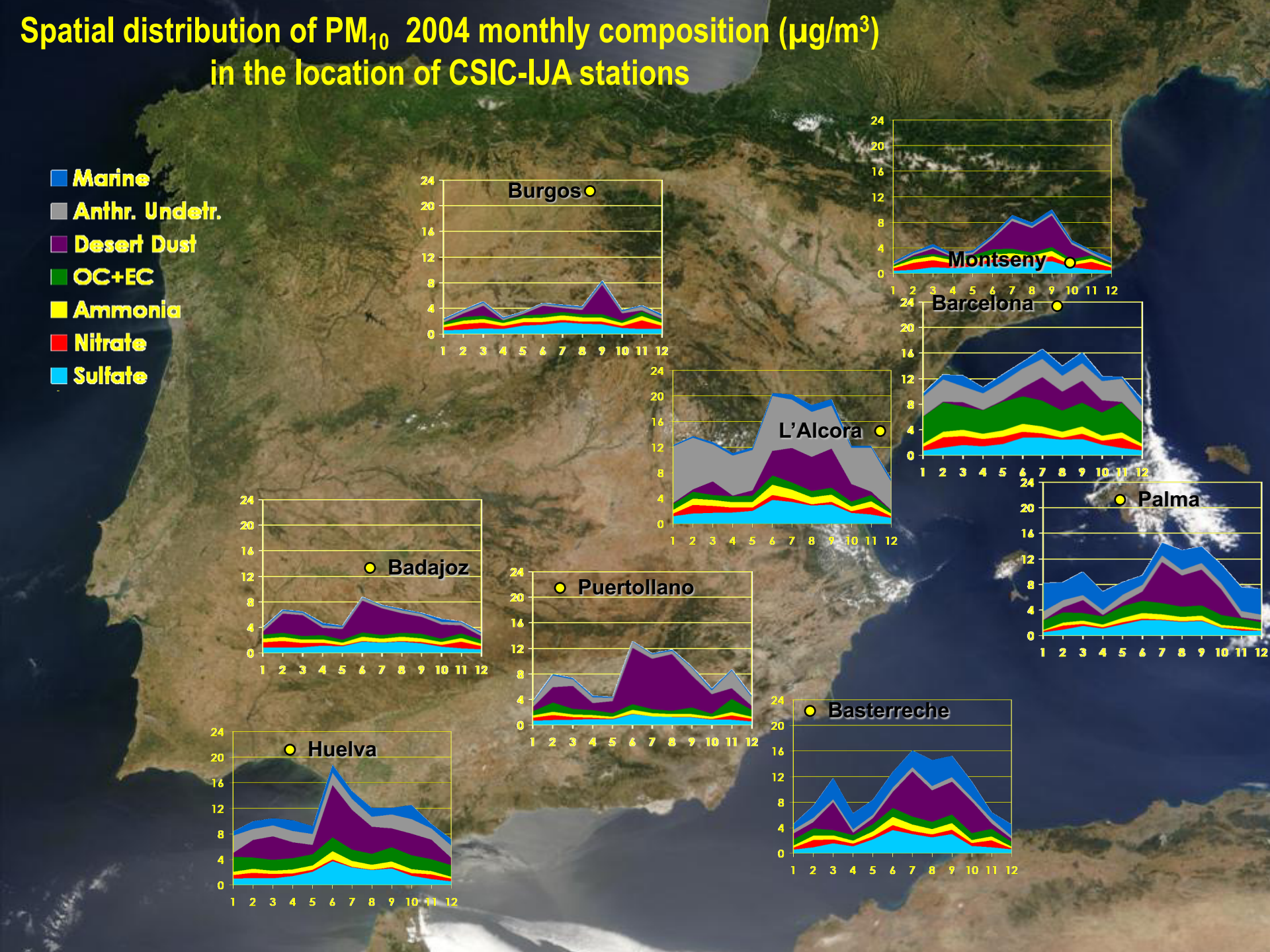
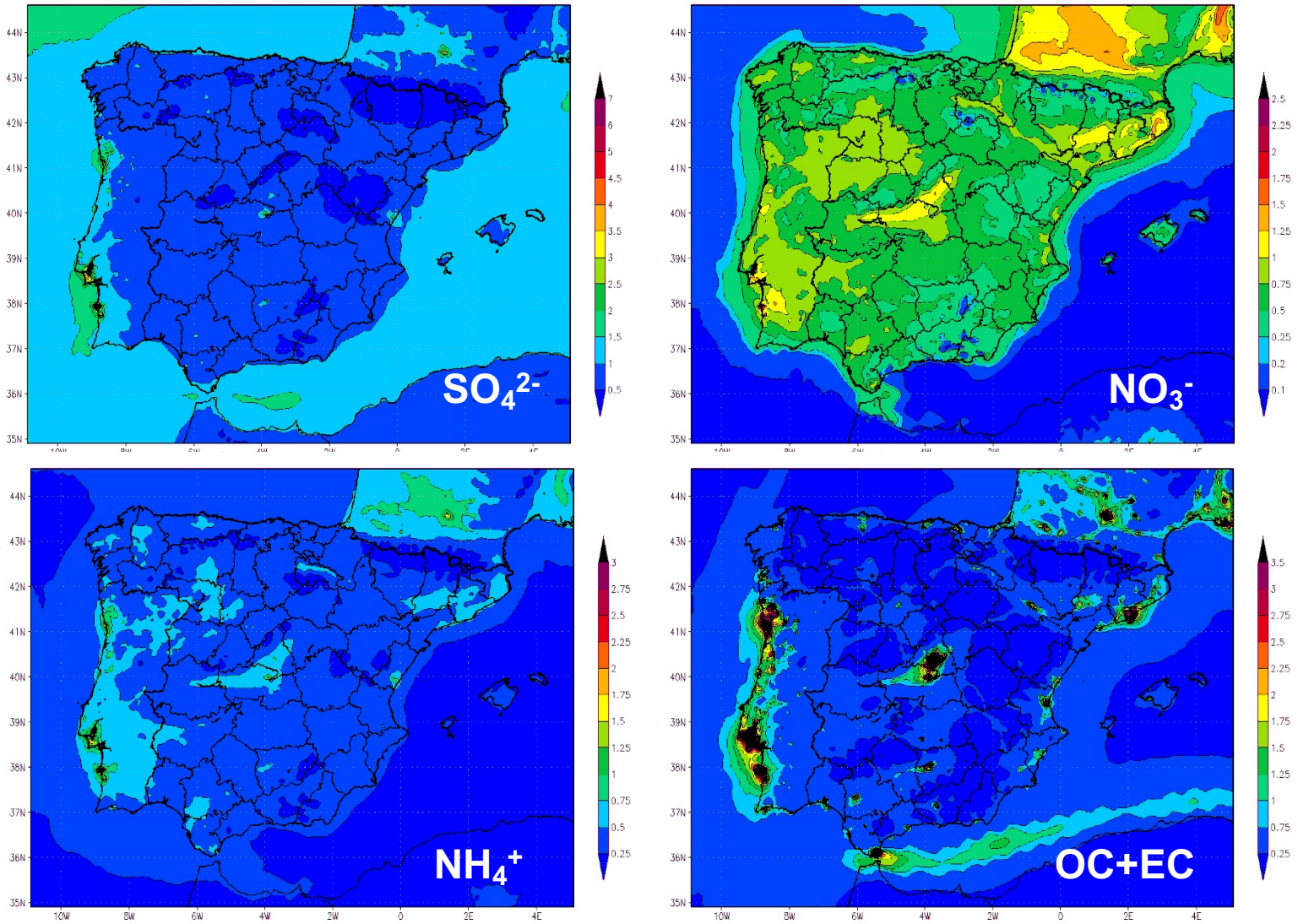
Spatial distribution of PM_{10} 2004 monthly composition ($\mu g/m^3$) in the location of CSIC-IJA stations



Spatial distribution in 2004 Winter (DJF)

BSC-ES/AQM ARW3.0+HERMES+CMAQv4.5 (µg/m^3) - Iberian Peninsula Res: 4 km x 4 km



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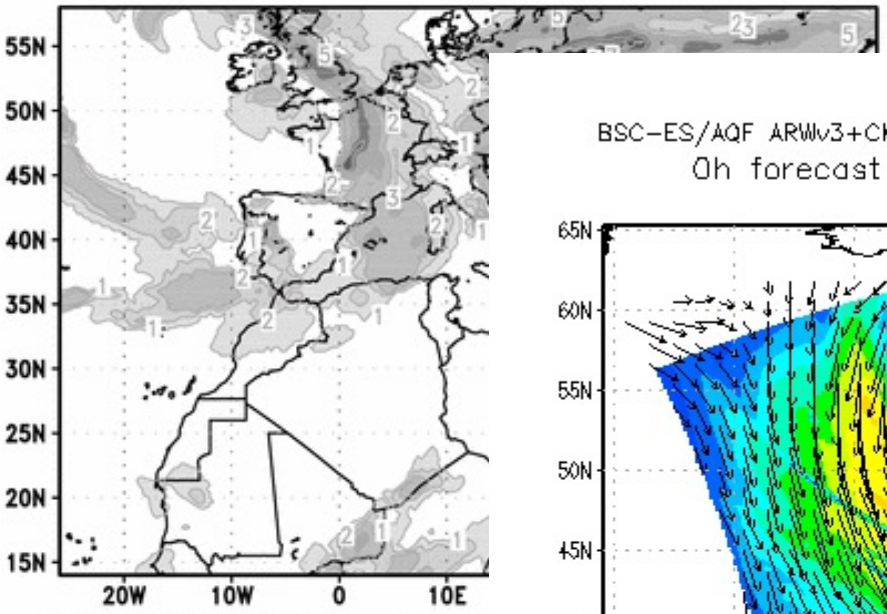
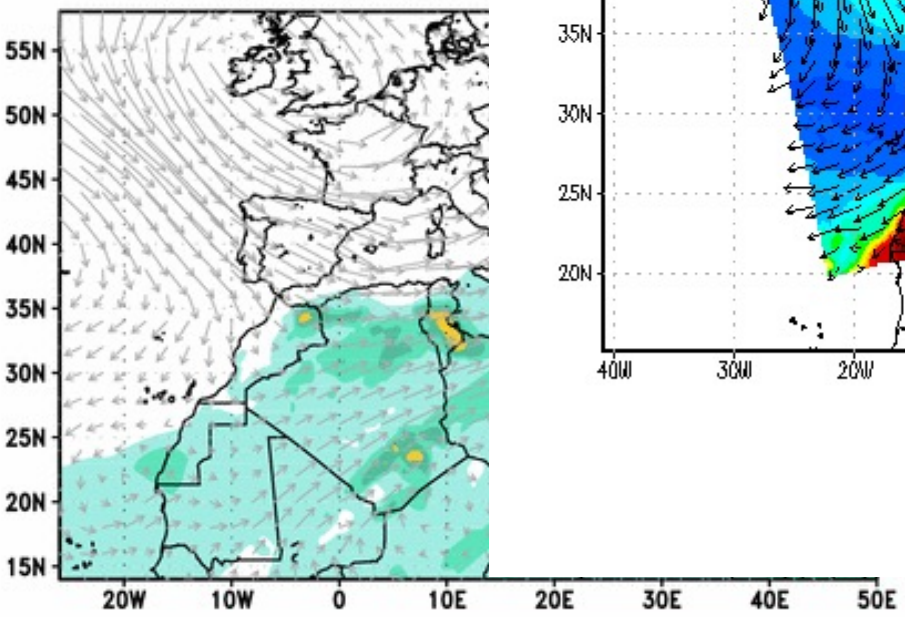
http://www.bsc.es/projects/earthscience/DREAM

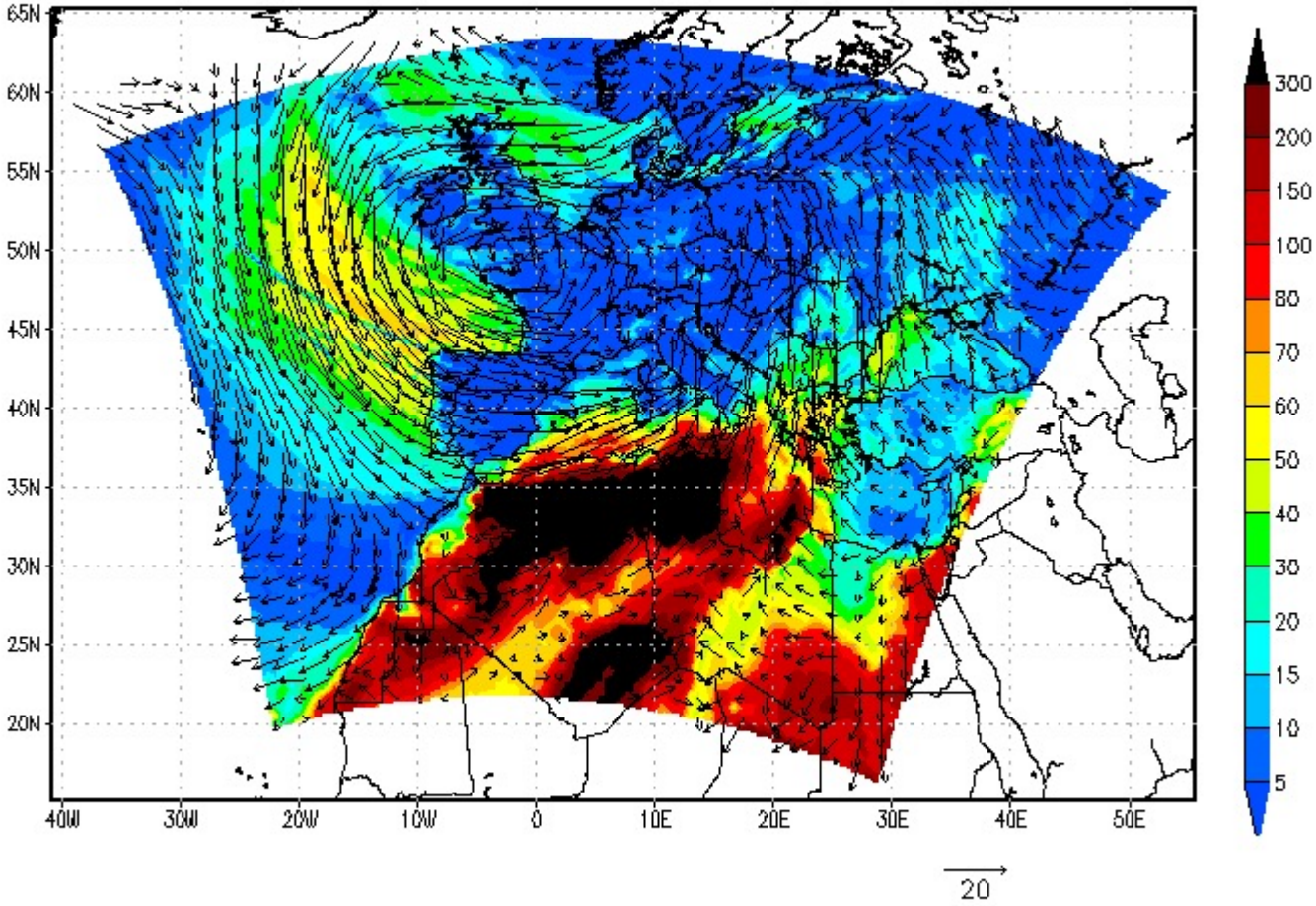
BSC-DREAM8b Total Cloud Cover
0h forecast for 12z 08 NOV 10



BSC-DREAM8b Dust Loading (
0h forecast for



BSC-ES/AQF ARWv3+CMAQv4.5+HERMES+BSC-DREAM8b Particulate Matter PM10 (ug/m3)
0h forecast for 00z 09 NOV 10 – Europe Res:12x12km



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THANK YOU FOR YOUR ATTENTION

jose.baldasano@bsc.es