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EXCELENCIA SEVERO OCHOA

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Dust prediction models

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Casablanca, 20th November 2014

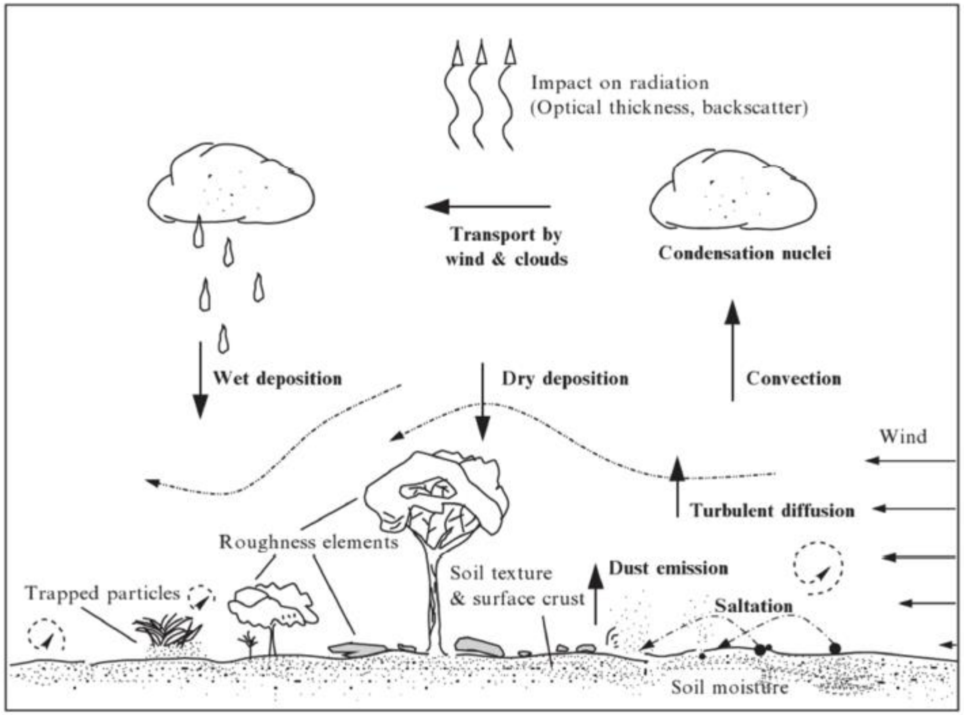
Questions will be welcome!

What do we need to forecast dust storms?

1. Satellites, surface observations, NWP models and dust models.
2. Good knowledge of the dust climatology in the region.
3. Good knowledge of observation limitations.
4. Good knowledge of the dust model limitations.

Dust forecasting models

Dust models are a mathematical representation of atmospheric dust cycle.



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)*

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Outlook

1. **Dust cycle and associated processes**

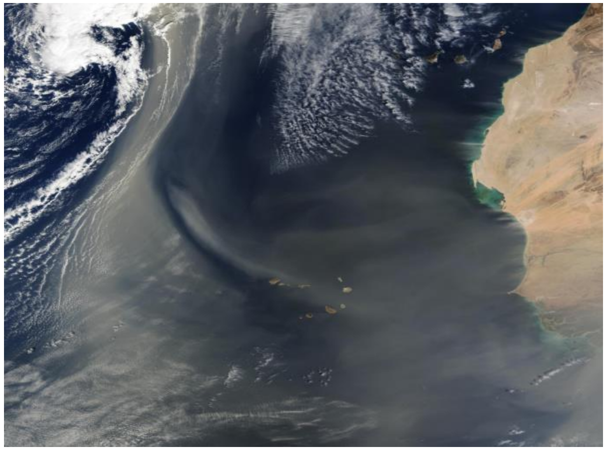
    - *The atmospheric dust cycle*
    - *Dust global climatology*
    - *Types of dust storms and model forecasting skills*

2. **Dust forecasting models**

    - *Dust emission schemes and dust sources*
    - *Dust transport*
    - *Dust deposition and sedimentation*
    - *Dust operatcional models at BSC*
    - *Model evaluation and model intercomparison:*
      The WMO SDS-WAS NAMEE RC

Dust cycle and associated processes

MODIS true colour composite image for March 2005 depicting a dust storm initiated at the Bodélé Depression (Chad Basin)

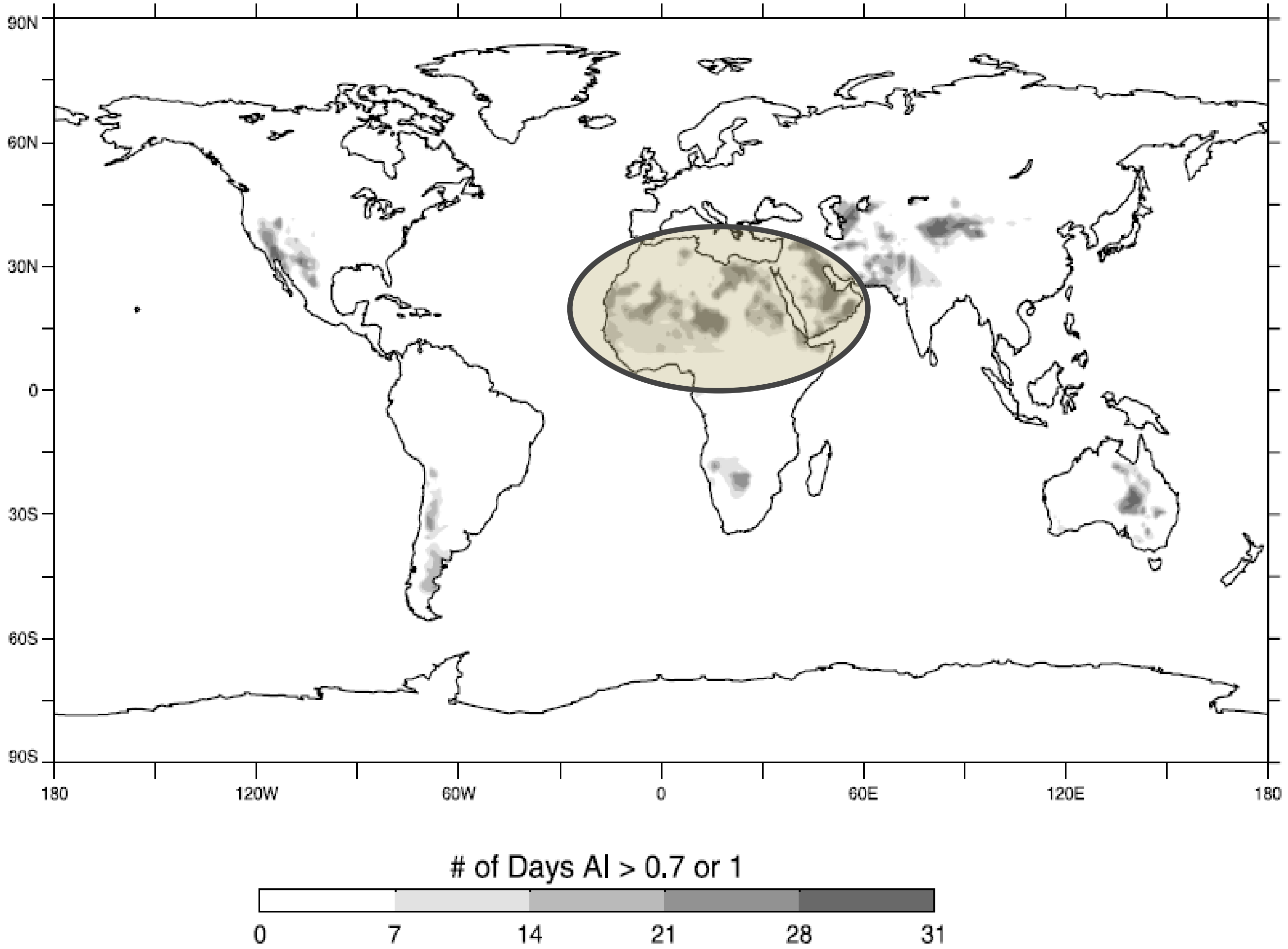


MODIS True color Western Africa – Altantic Ocean

People caught in a dust storm in Mali

Dust cycle and associated processes

Dust global distribution



The global distribution of **TOMS** dust sources.

Extracted from Prospero et al. (2002, Rev. Geophys.)

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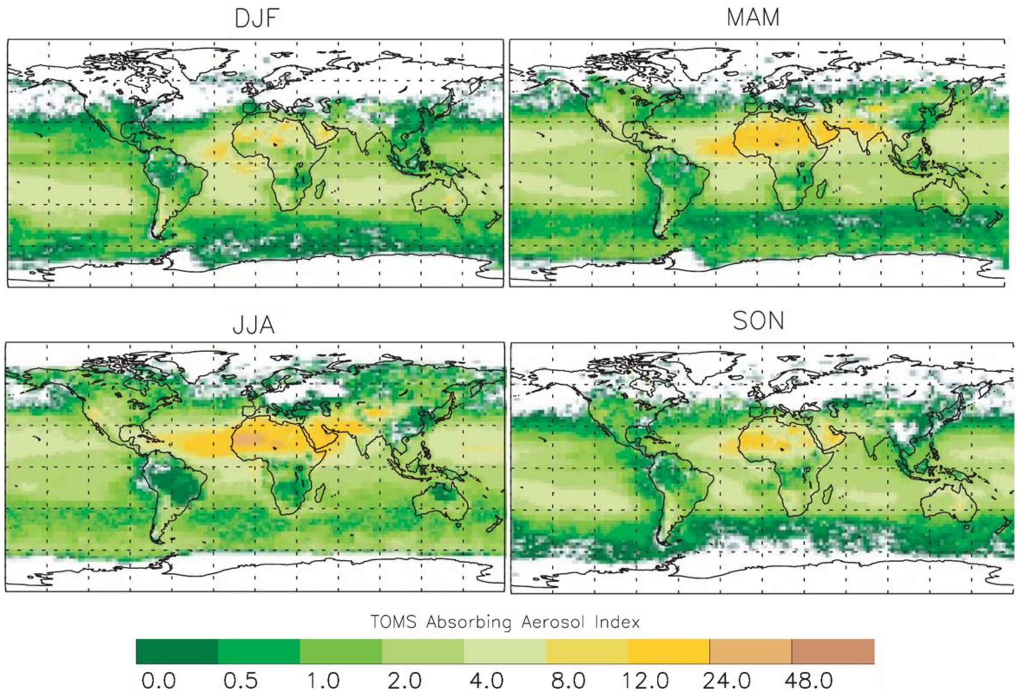
Dust cycle and associated processes

Temporal changes in the dust distribution: SEASONAL and DECADAL CHANGES



• Seasonal dust distribution changes well characterized. Follows seasonal changing weather regimes (mainly) and vegetation changes (in semi-arid areas)

• Interannual/decadal changes are controlled by climate and surface modification (land use, desertification). Decadal changes are not well captures by models

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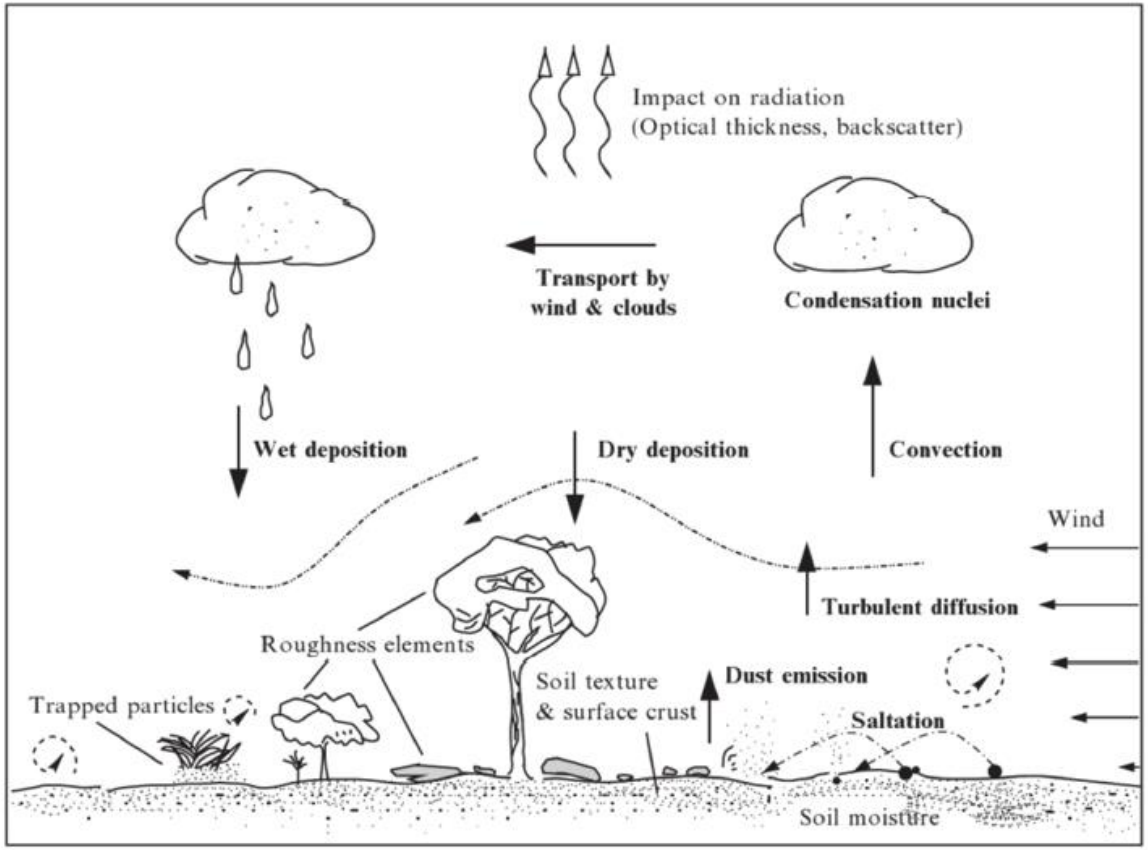
Dust cycle and associated processes

The atmospheric dust cycle and involves a variety of processes:



Extracted from Shao (2008)

- Dust emission from dry unvegetable surfaces (dust sources)
- Mid- and long-range transport
- Sedimentation, wet and dry deposition

Dust cycle and associated processes

Dust Impacts

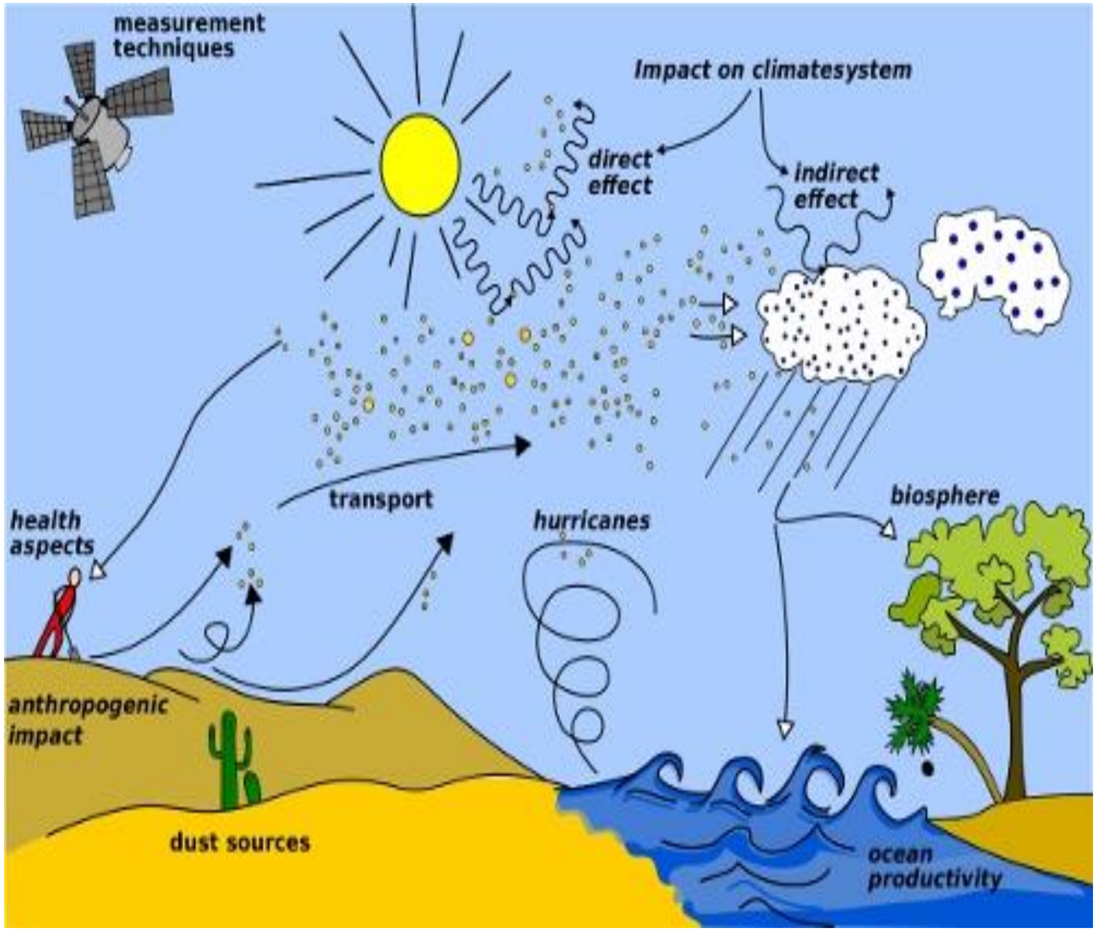


Image from WMO website (http://www.wmo.int/pages/prog/arep/wwrp/new/hurricanes.html)

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*

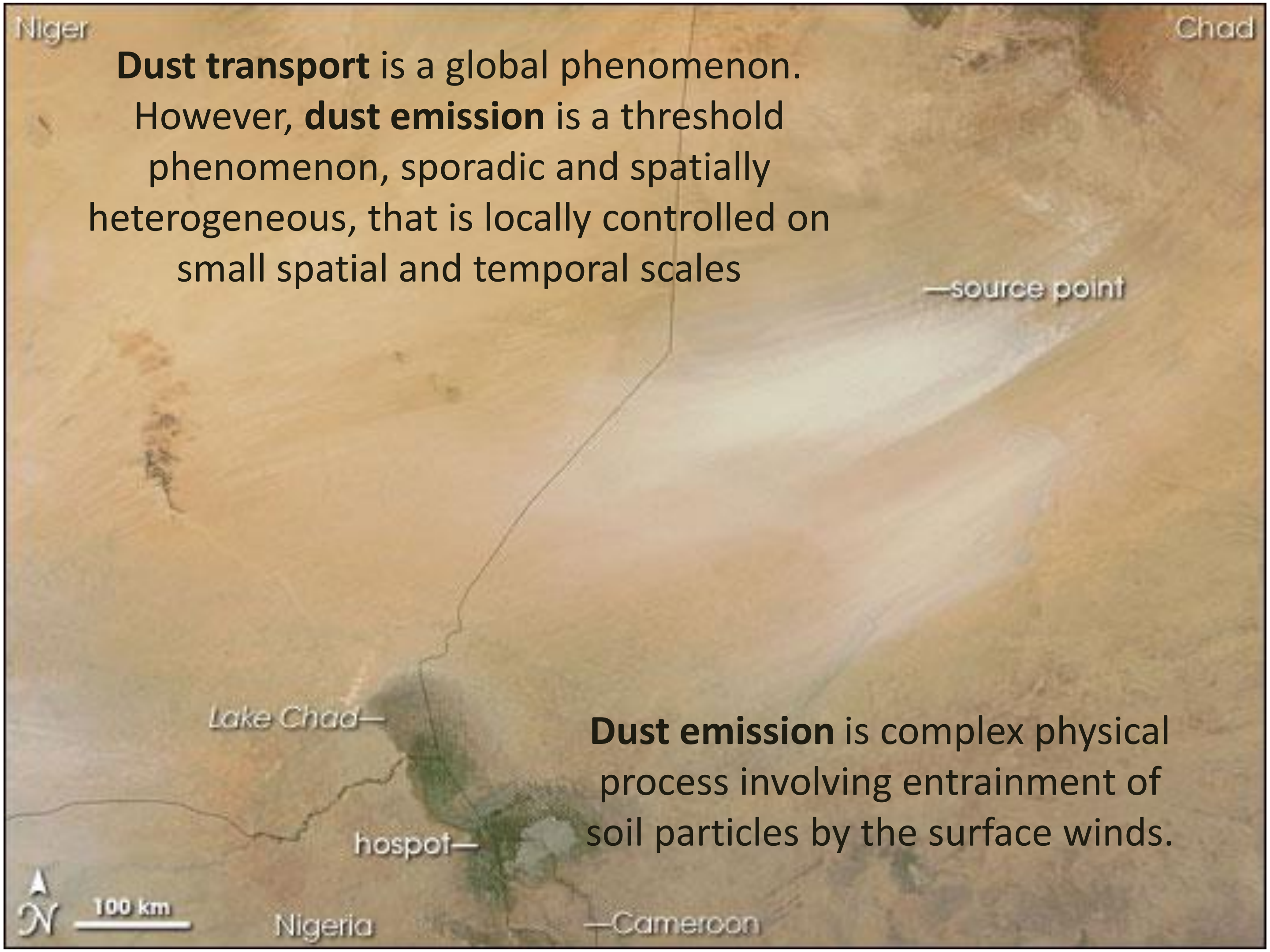
Aviation and Ground Transportation

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

Agriculture

Energy and industry

Dust cycle and associated processes



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 is complex physical process involving entrainment of soil particles by the surface winds.

Types of dust storms:

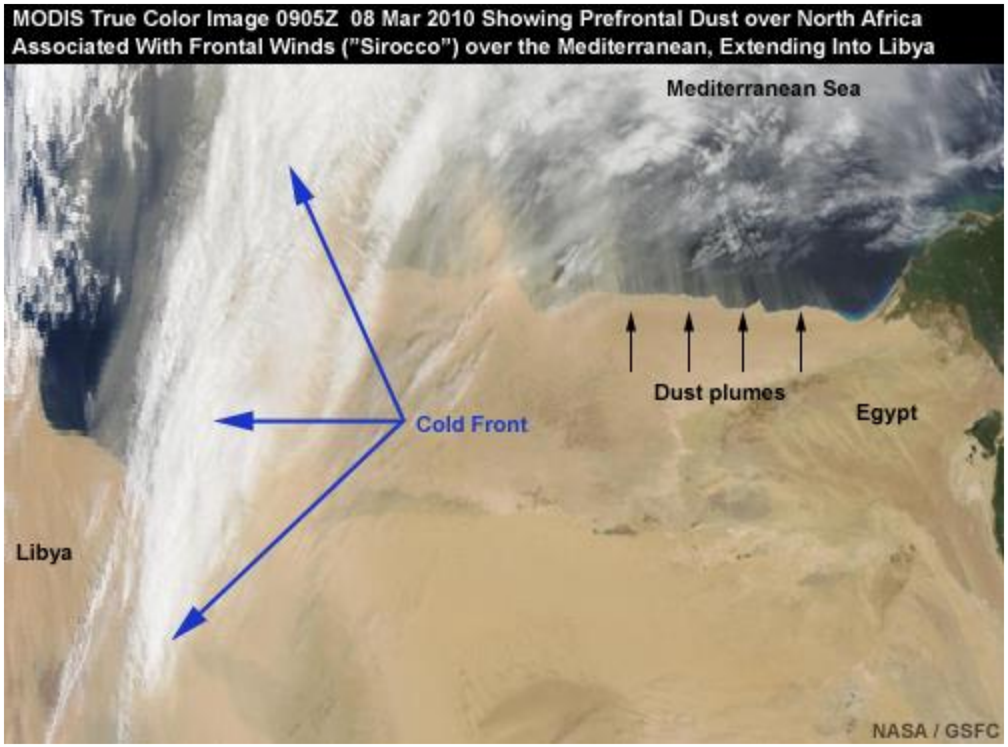
Synoptic dust storms (large scale weather systems)

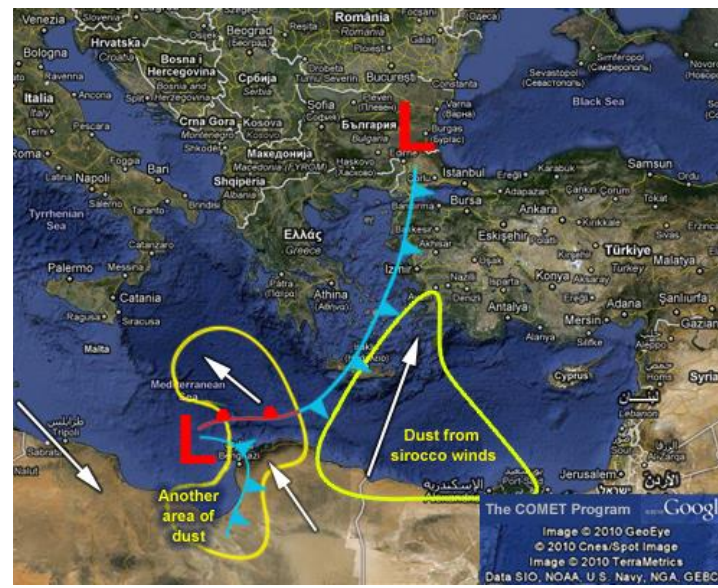
- Prefrontal winds
- Postprontal winds
- Large-scale Trade winds
- …

Mesoscale dust storms

- Downslope winds
- Gap flow
- Convection and Haboobs
- Inversion downburst storms
- …

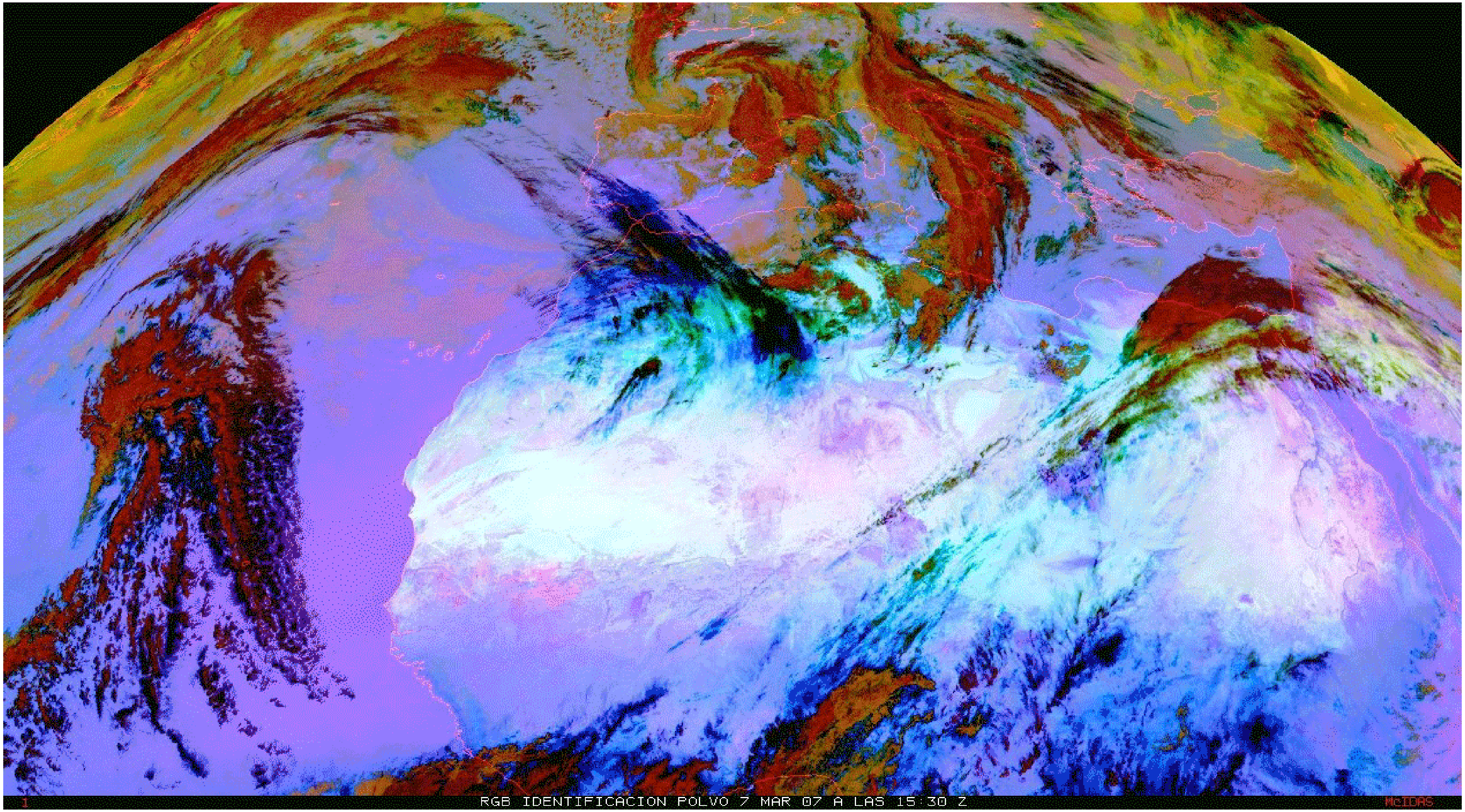
Synoptic dust storms: Pre-frontal





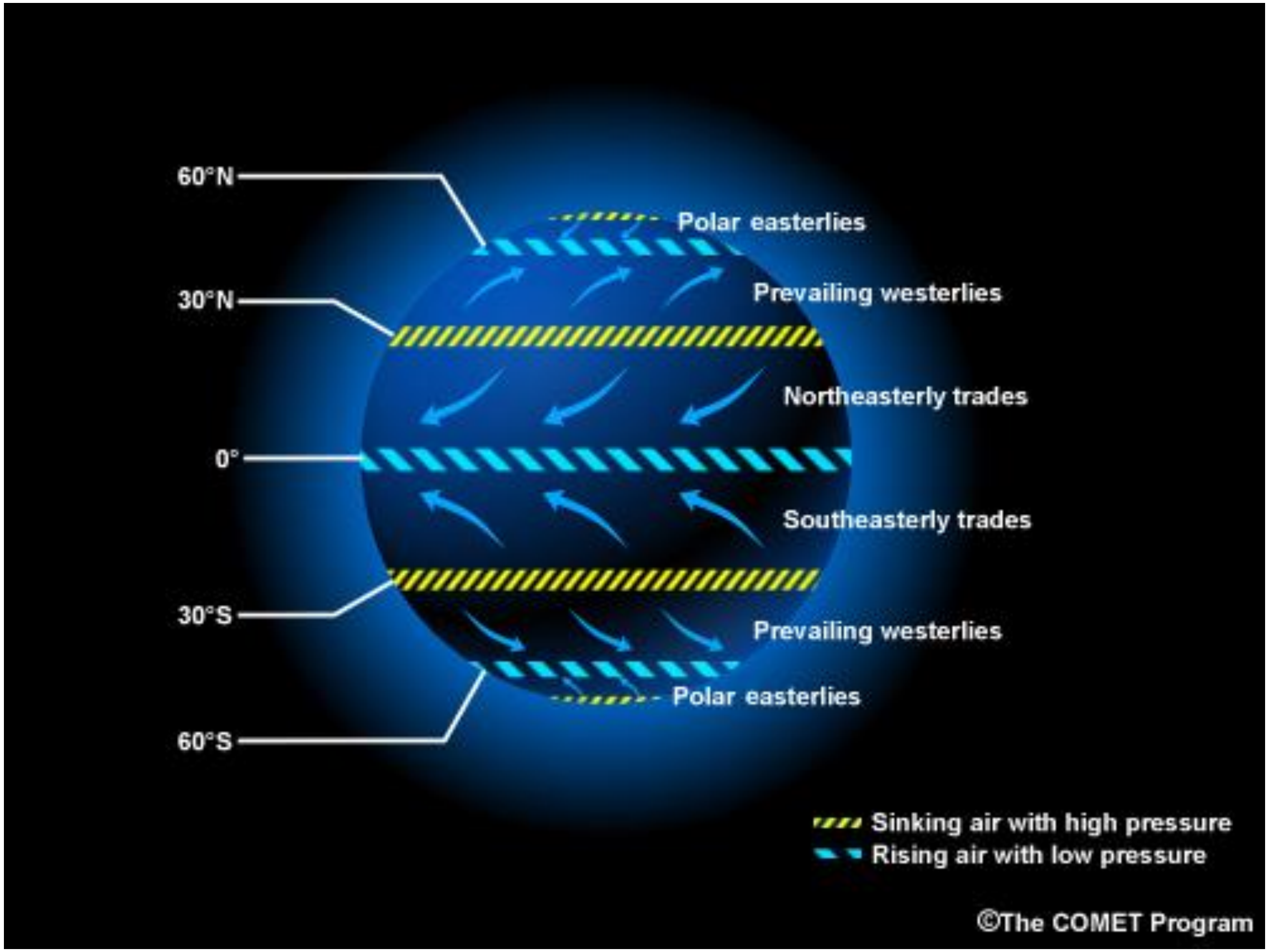
Dust cycle and associated processes

Synoptic dust storms: Post-frontal



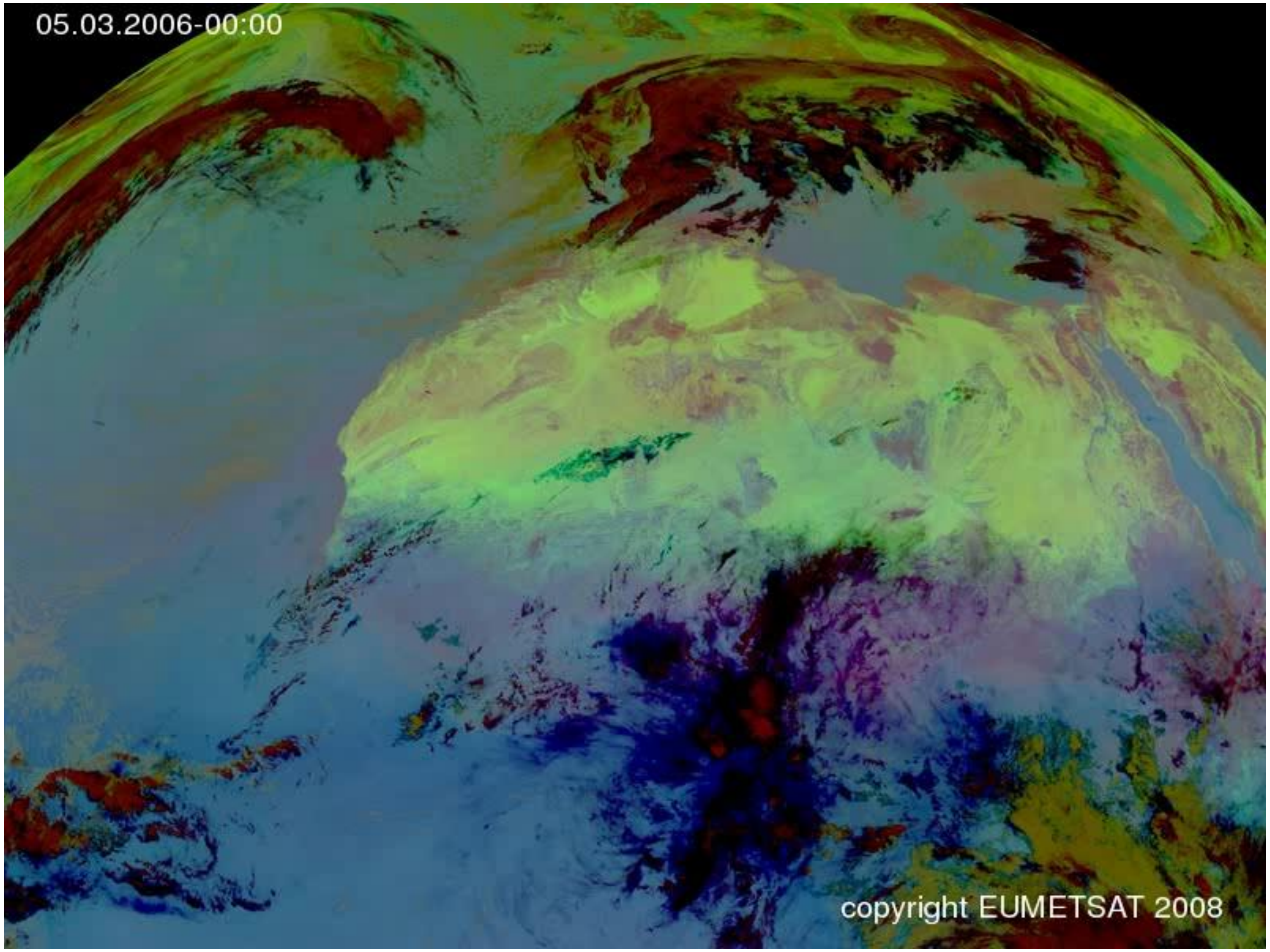
Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds



Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds



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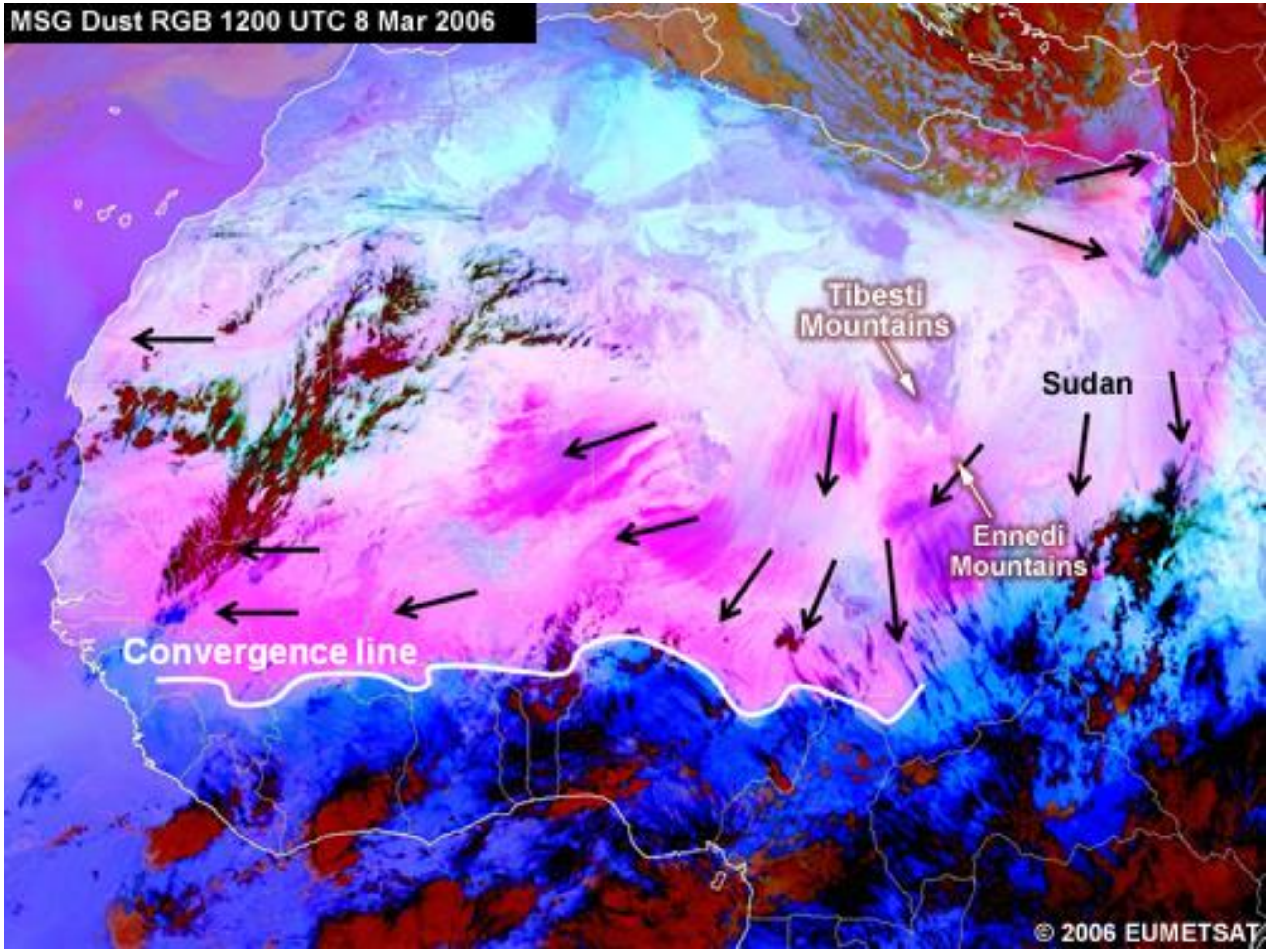
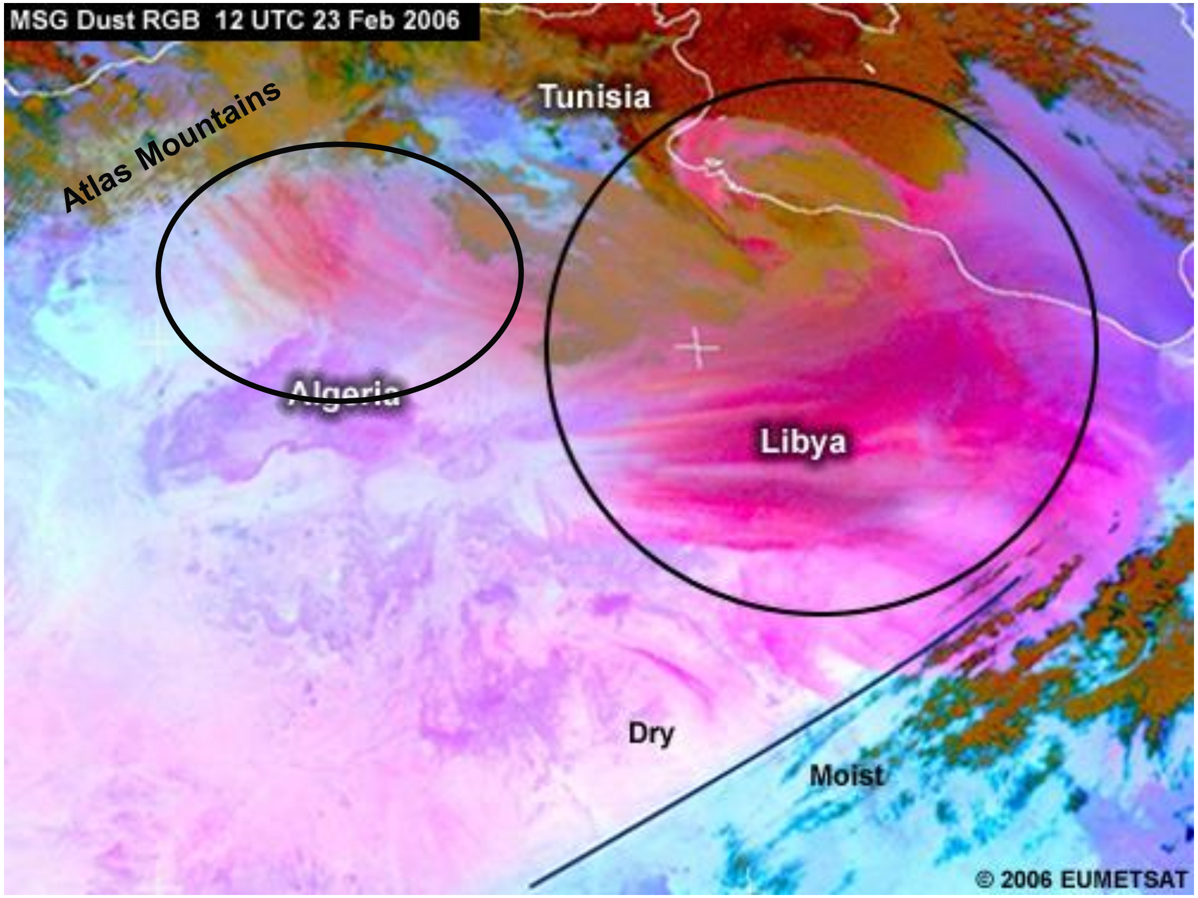
Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds

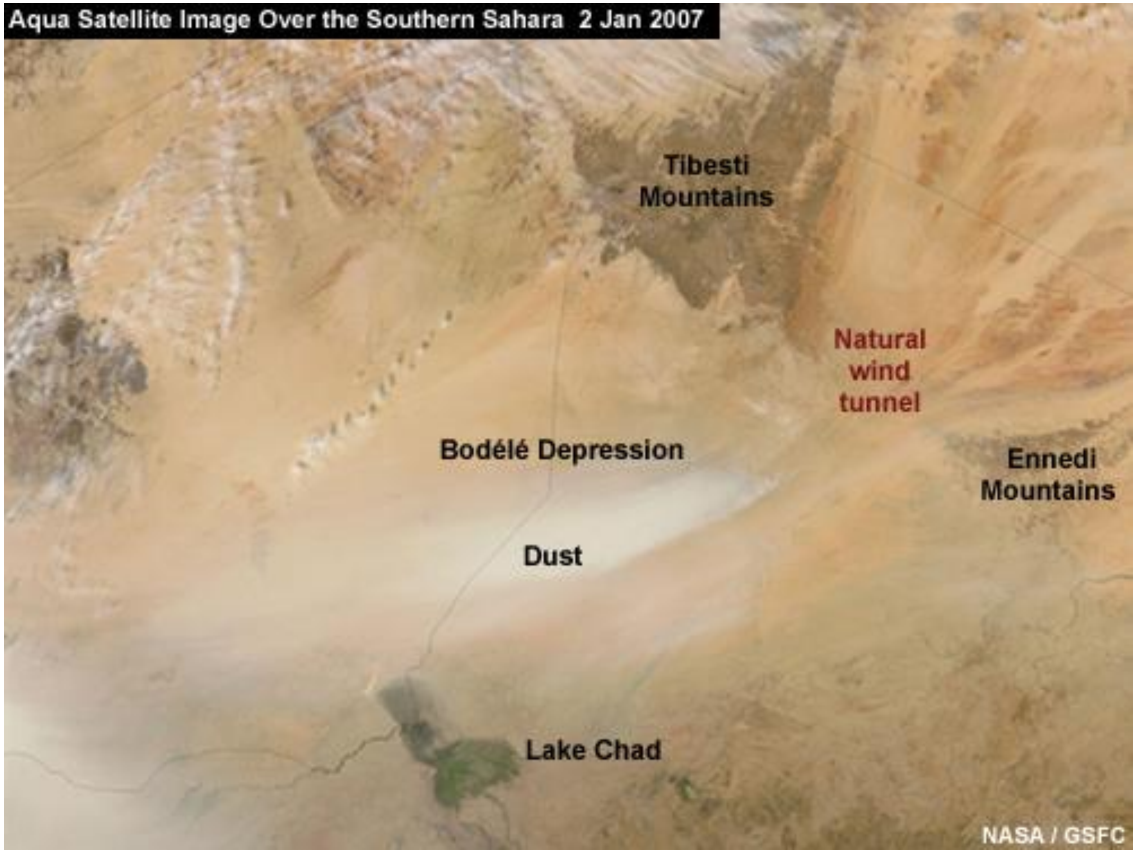


Mesoscale dust storms: Downslope winds



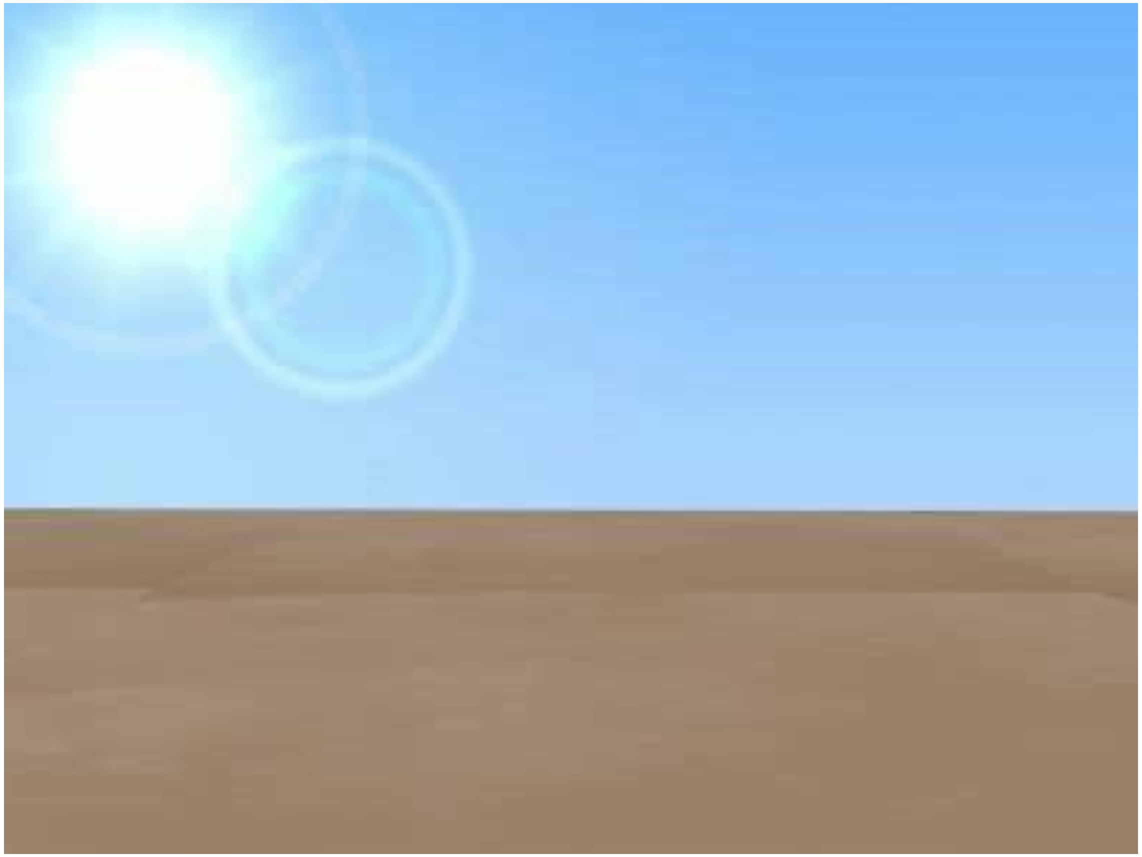
Dust cycle and associated processes

Mesoscale dust storms: Gap flow



Dust cycle and associated processes

Mesoscale dust storms: Dust devils (convection)



Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

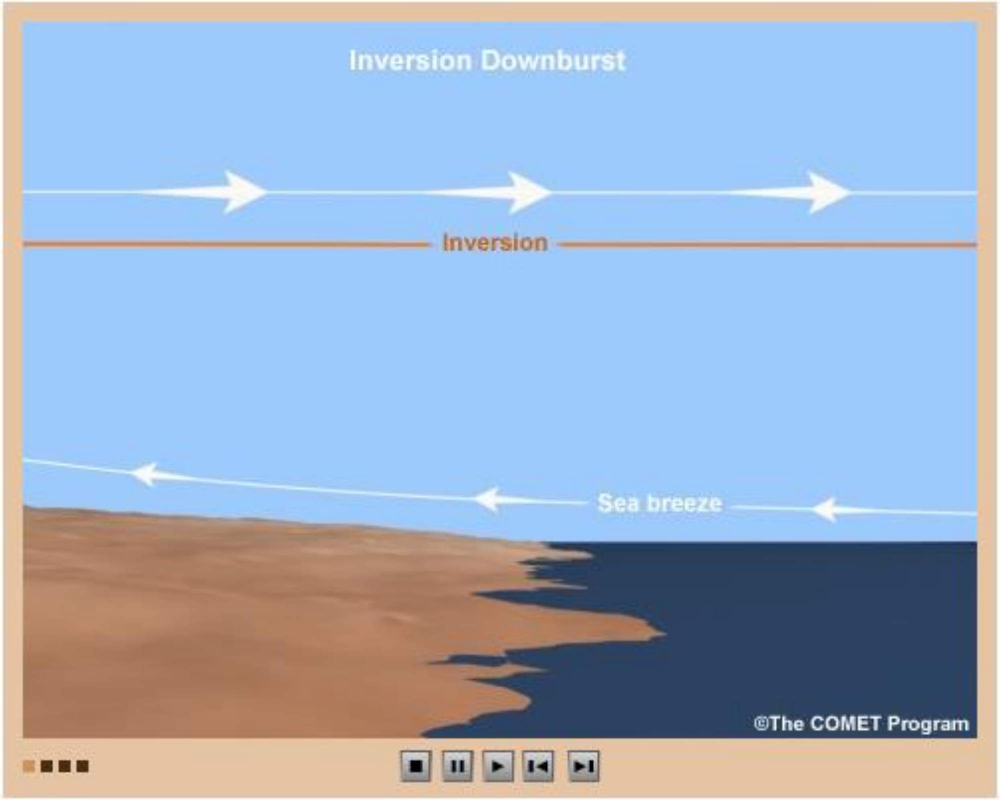
Dust cycle and associated processes

Mesoscale dust storms: Haboobs

Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust cycle and associated processes

Mesoscale dust storms: Inversion downbursts



Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

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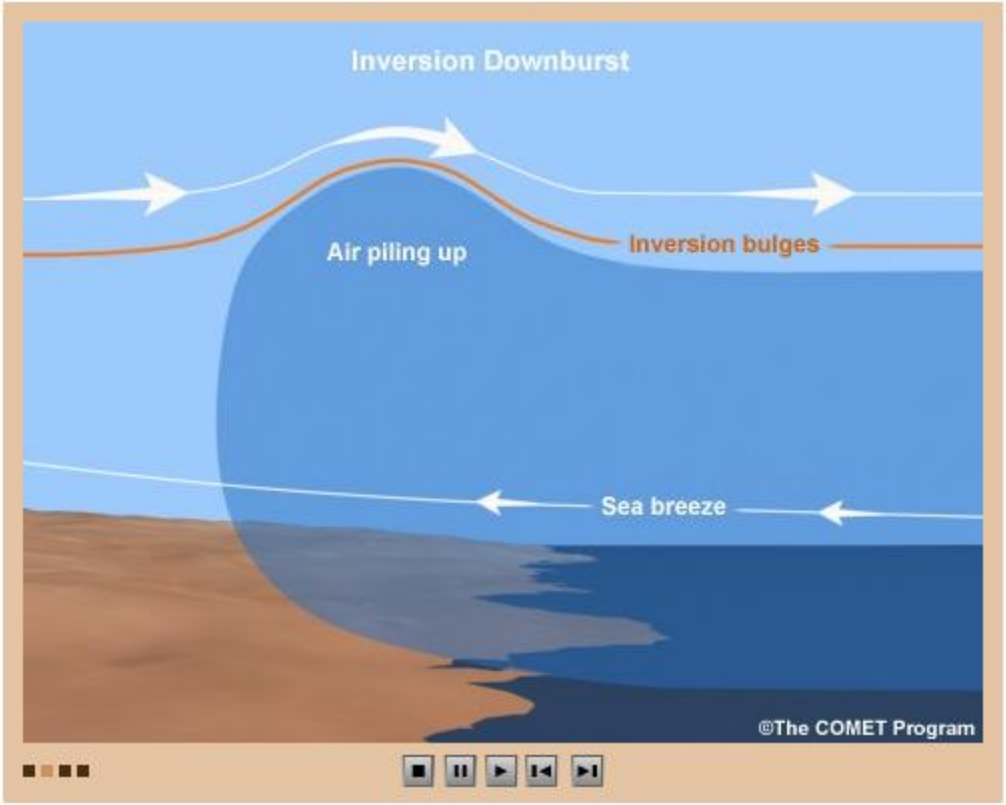
Mesoscale dust storms: Inversion downbursts



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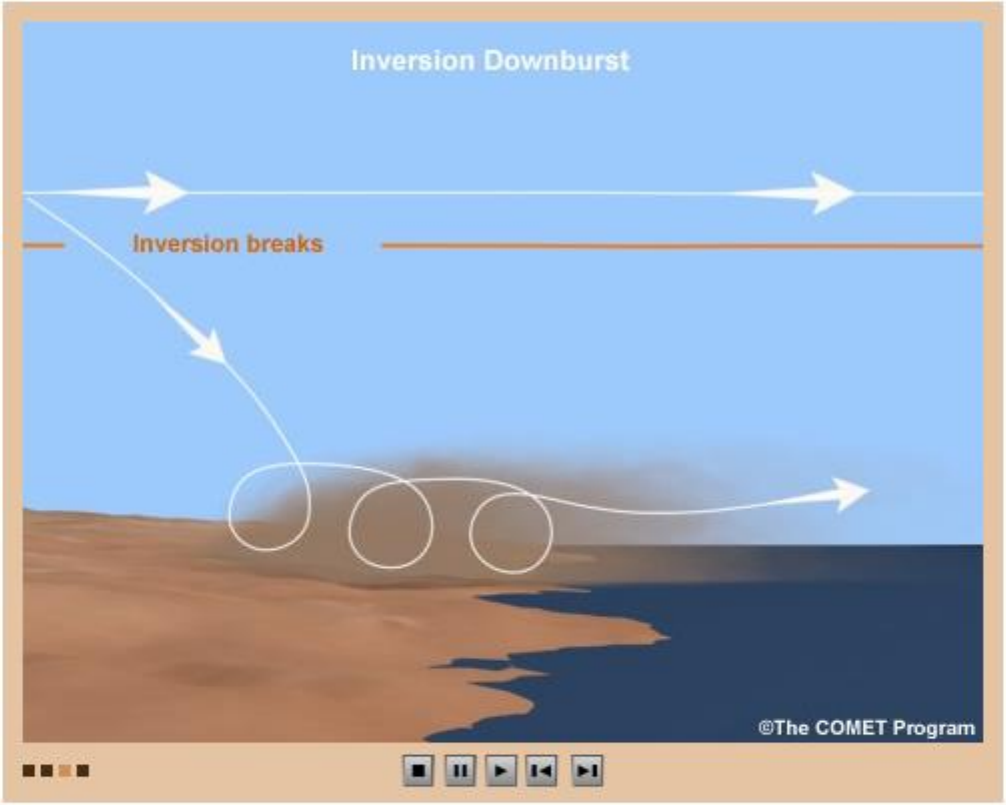
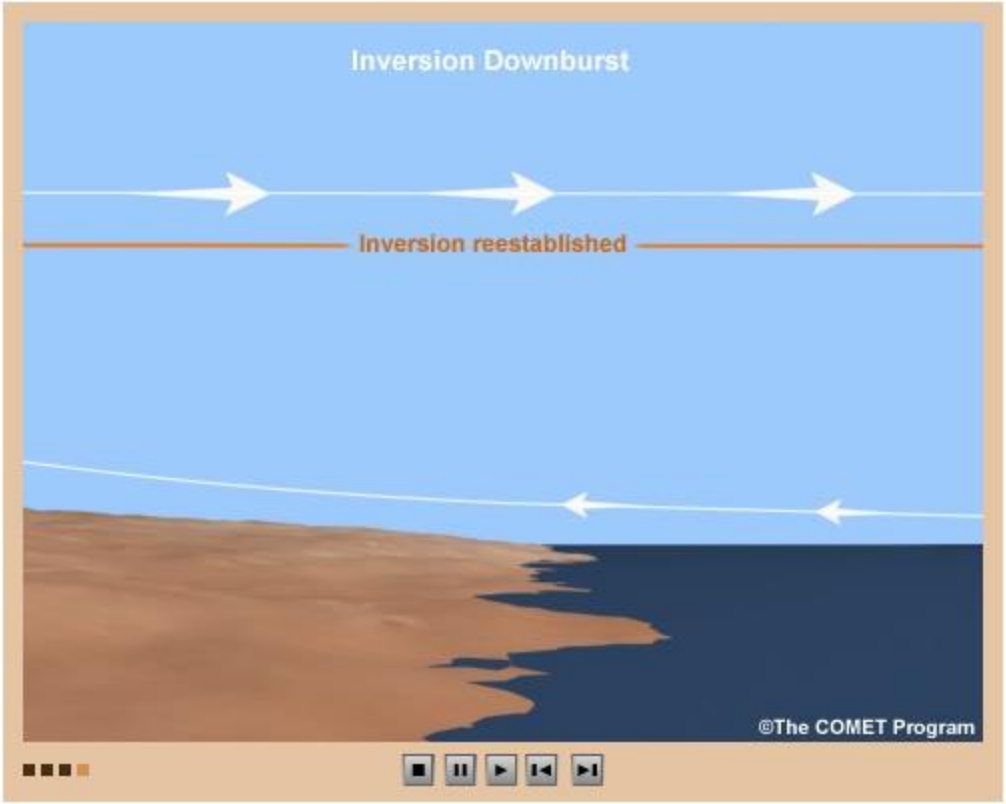
Mesoscale dust storms: Inversion downbursts



Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust cycle and associated processes

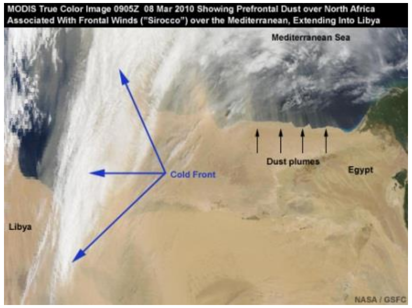
Mesoscale dust storms: Inversion downbursts



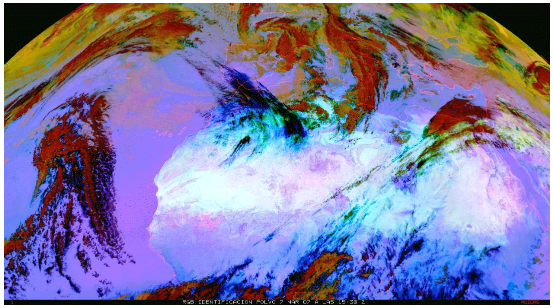
Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust cycle and associated processes: Types of dust storms

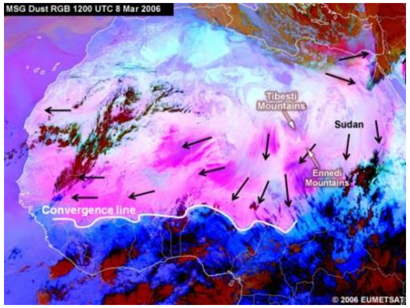
Synoptic dust storms (large scale weather systems) **Well captured by models.**



Pre-frontal winds

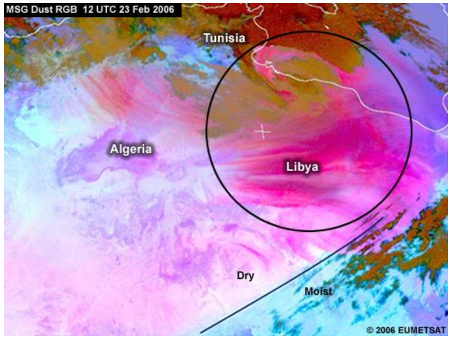


Post-frontal winds

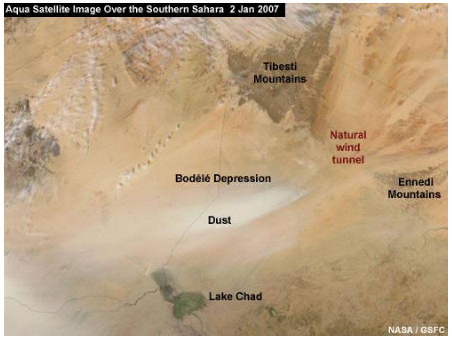


Large-scale trade winds

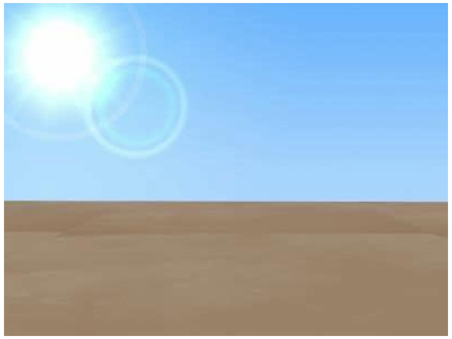
Mesoscale dust storms **Poorly captured by models.**
Some types improve in regional models.



Downslope winds



Gap flow



Convection

Haboobs

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Dust cycle and associated processes: Types of dust storms

Atmos. Chem. Phys., 14, 11753–11773, 2014
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Atmospheric Chemistry and Physics
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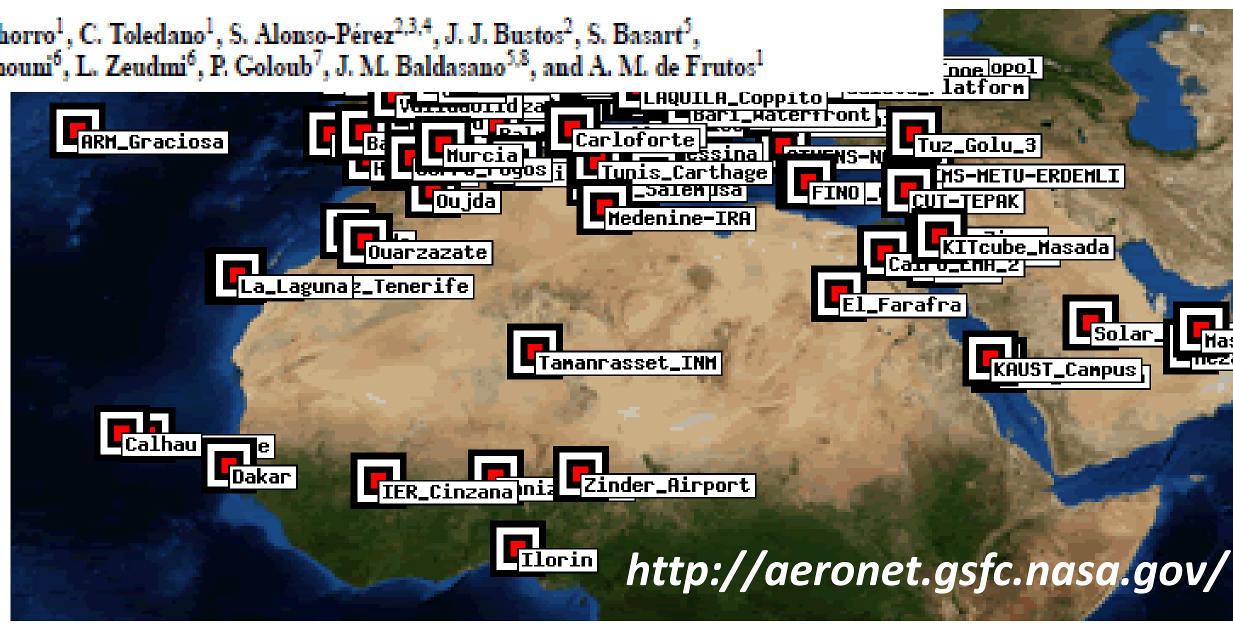
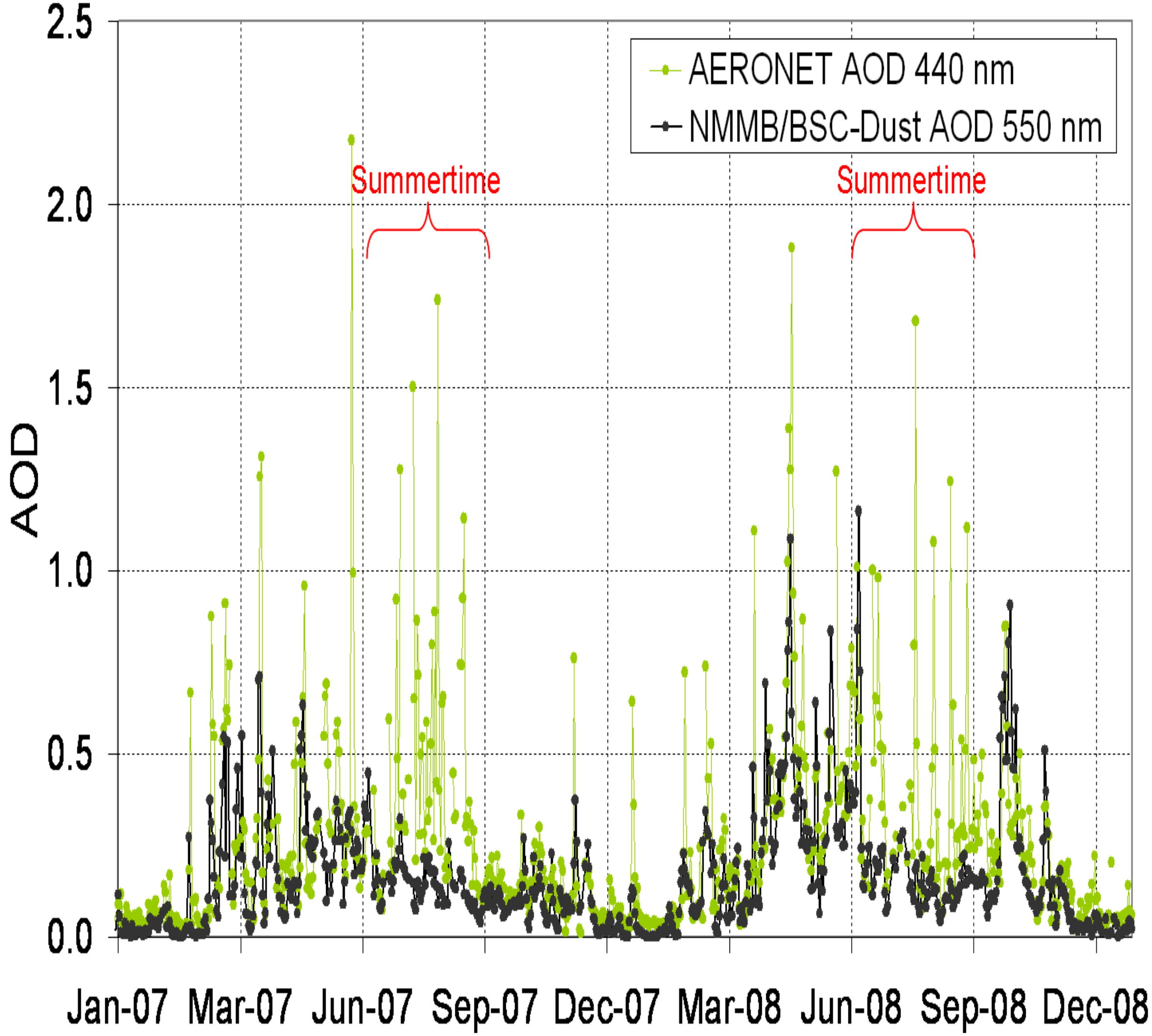
Aerosol characterization at the Saharan AERONET site Tamanrasset

C. Guirado[1,2], E. Cuevas[2], V. E. Cachorro[1], C. Toledano[1], S. Alonso-Pérez[2,3,4], J. J. Bustos[2], S. Basart[5], P. M. Romero[2], C. Camino[2], M. Mimouni[6], L. Zeudmi[6], P. Goloub[7], J. M. Baldasano[5,8], and A. M. de Frutos[1]

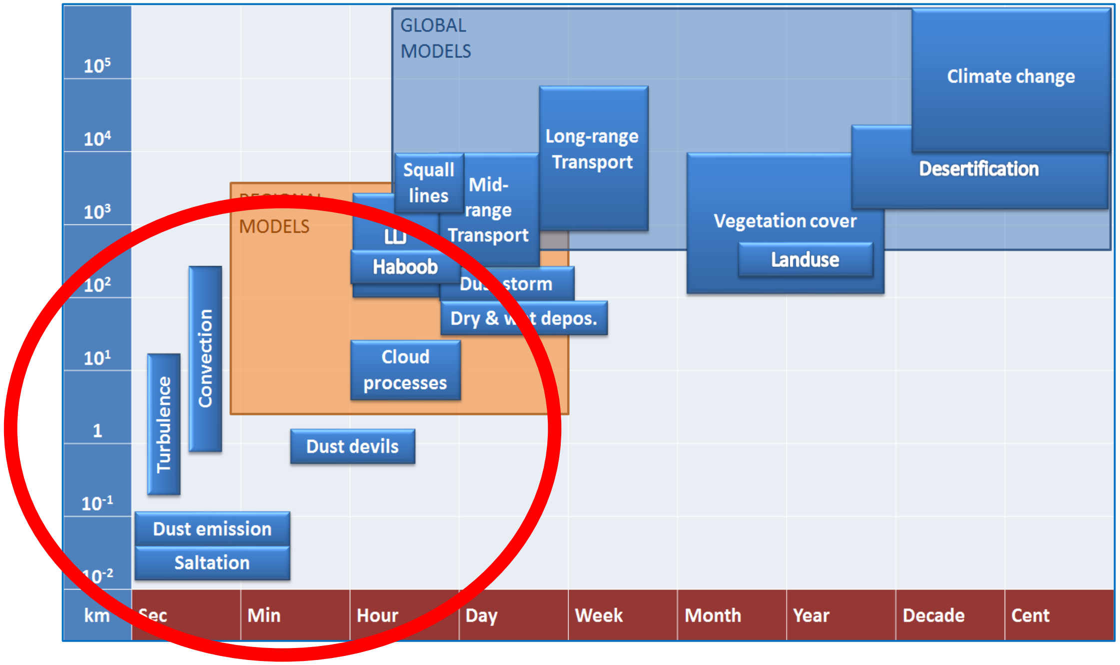


Dust cycle and associated processes: Types of dust storms



Extracted from Guirado et al. (2014, ACP)

Dust forecasting models



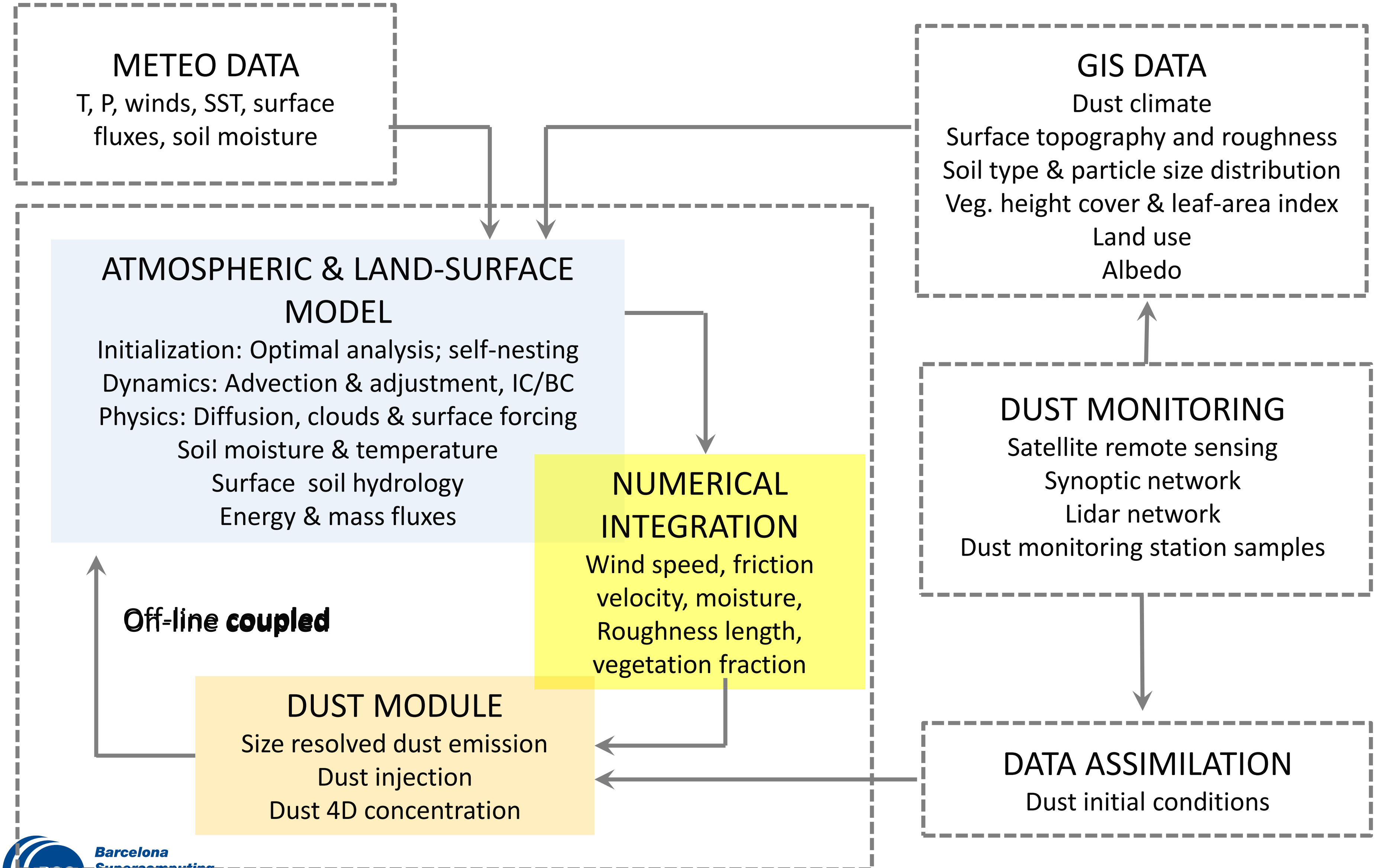
- Dust processes span over five orders of magnitude in space and time. **Dust transport** is a global phenomenon. However, **dust emission** is a threshold phenomenon, sporadic and spatially heterogeneous, that is locally controlled on small spatial and temporal scales.

- To correctly describe and quantify the dust cycle, one needs to understand equally well local-scale processes such as saltation and entrainment of individual dust particles as well as large-scale phenomena such as mid- and long-range transport.

Accurate representation of dust sources and sinks is critical for providing realistic magnitudes and patterns of atmospheric dust fields.

Image from L.Vendrell

Dust forecasting models



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Dust forecasting models: Global and regional models

Regional models offer a number of advantages in representation of dust compared to **Global models**.

- *Finer spatio-temporal resolution.*
- *Multiple physics parameterizations allow for more realistic representation of the topography, soil conditions and mesoscale circulations.*

Regional models are better suited for simulation of timing, duration and intensity of individual dust events.

Dust forecasting models

Dust models simulate the atmospheric dust cycle and involves a variety of processes:

$$\frac{\partial C_k}{\partial t} = -u\frac{\partial C_k}{\partial x} - v\frac{\partial C_k}{\partial y} - \left(w - v_{gk}\right)\frac{\partial C_k}{\partial z} - \nabla\left(K_H \nabla C_k\right) - \frac{\partial}{\partial z}\left(K_Z \frac{\partial C_k}{\partial z}\right) + \left(\frac{\partial C_k}{\partial t}\right)_{SOURCE} - \left(\frac{\partial C_k}{\partial t}\right)_{SINK}$$

Horizontal advection	Vertical advection & gravitational settling	Horizontal diffusion	Vertical diffusion	Dust emission	Wet and dry deposition

Dust forecasting models: Emission scheme

Dust source function

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;

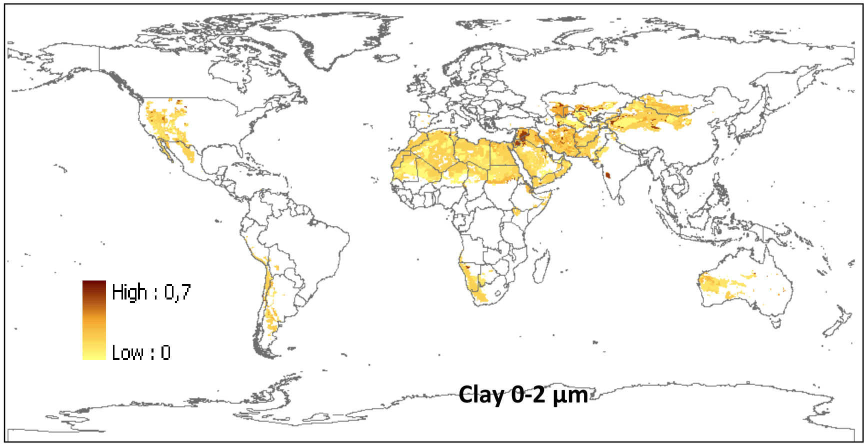
D) Daïa in the Mechfar, at Hassi Cheikh well;

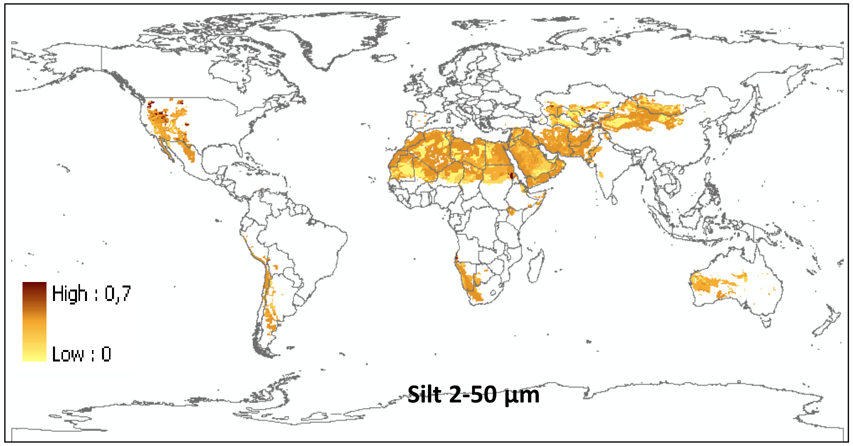
E) North-east of the Great Western Erg: coarse sand interdune corridor with deflation cauldron and palaeolake deposits;

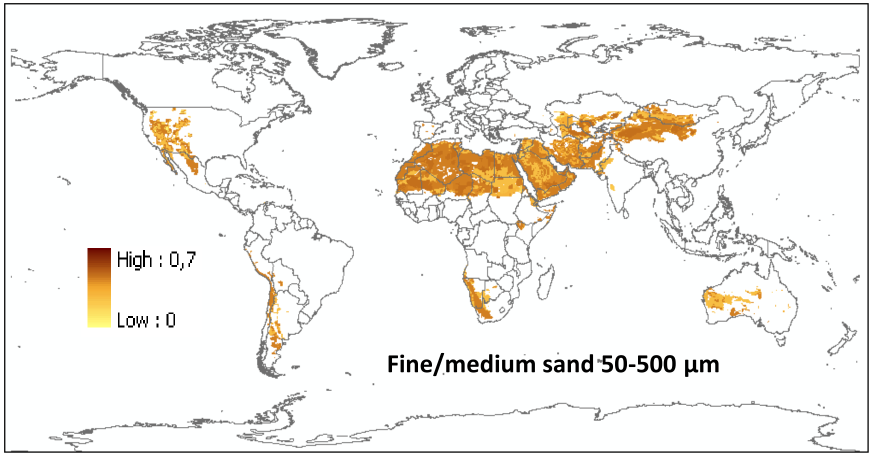
F) North-east of the Great Western Erg: great coarse sand dome dunes, covered by fine sand active dunes.

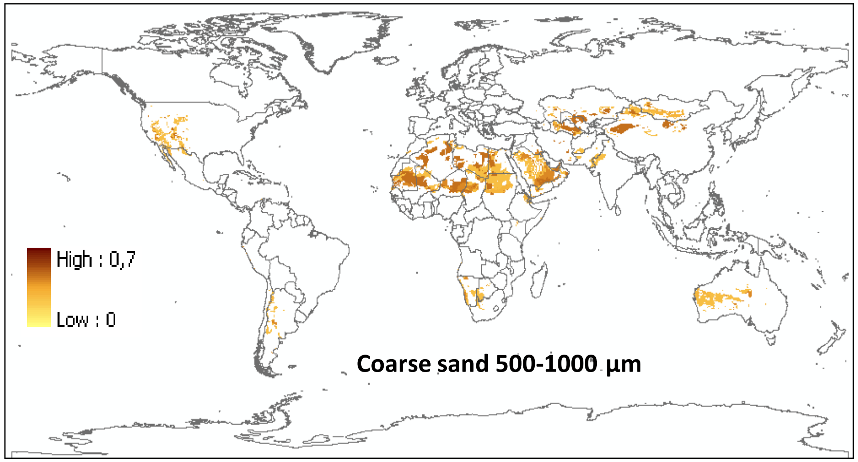
Dust forecasting models: Emission scheme

Parent soil size distribution





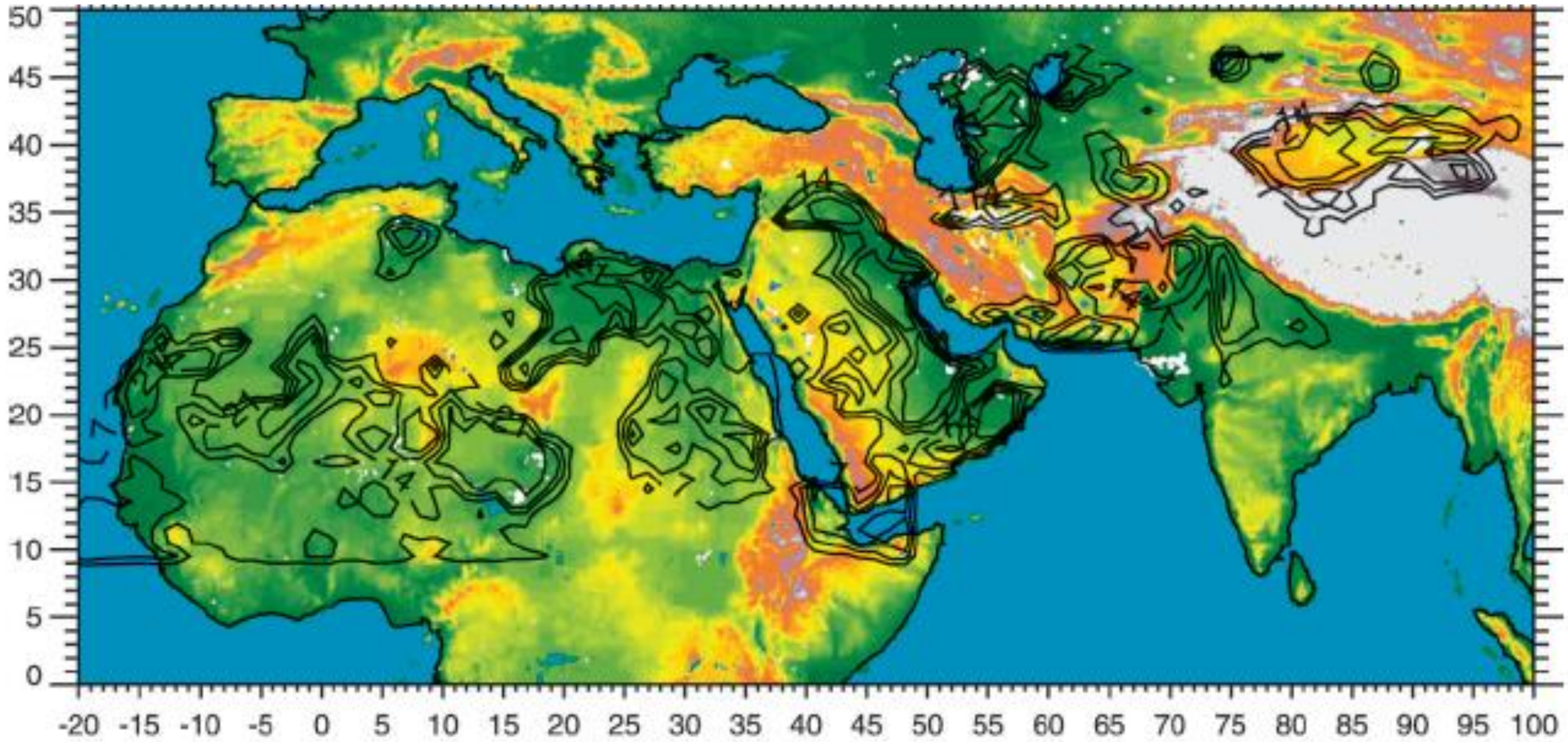




Four top soil texture classes according STASGO-FAO 1km database are converted to 4 parent soil size categories following Tegen et al. [2002]

Dust forecasting models: Emission scheme

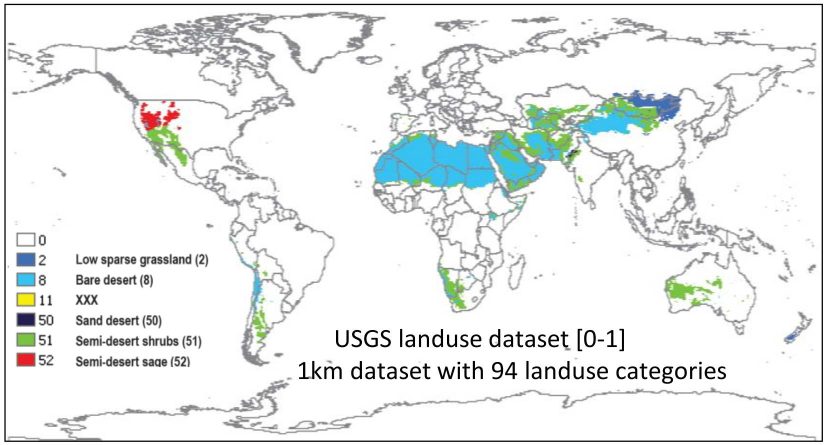
Dust source function

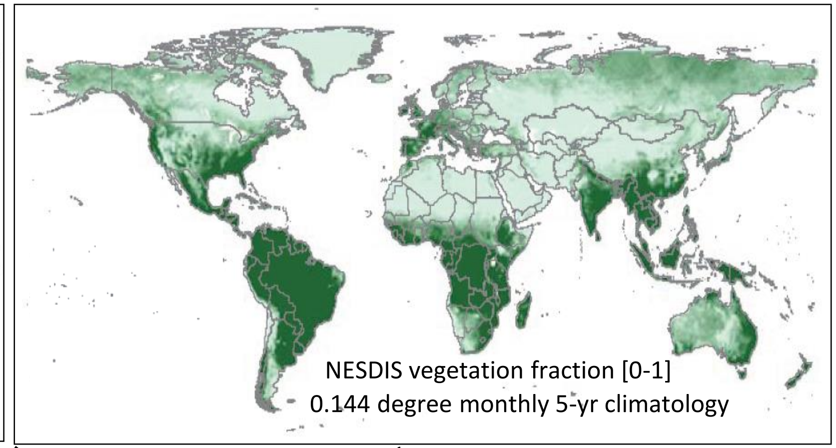


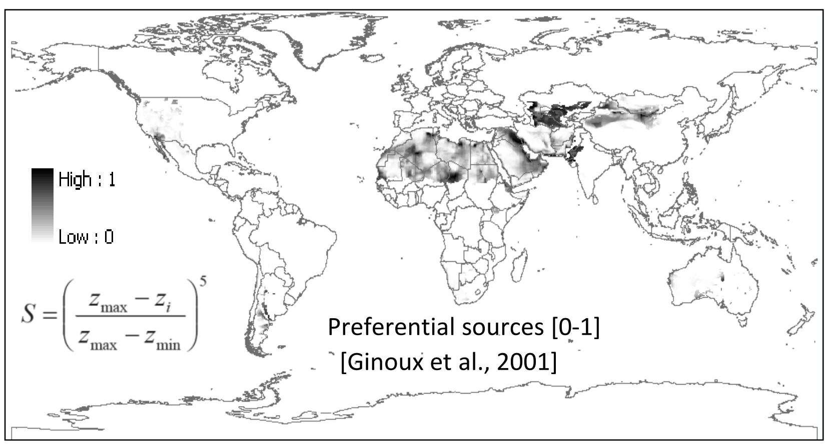
DUST HOT SPOTS ASSOCIATED WITH TOPOGRAPHIC DEPRESSIONS (Prospero et al., 2002)
Images show topography (color scale) and TOMS AI (contours)

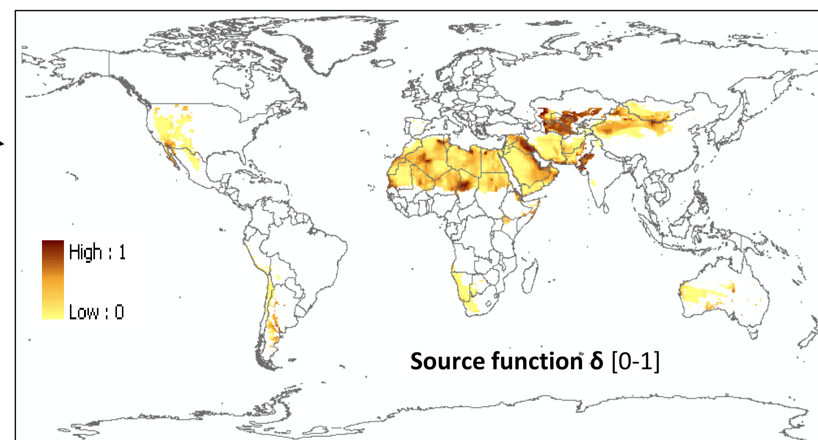
Dust forecasting models: Emission scheme

Dust source function: GOCART and NMMb/BSC-Dust models





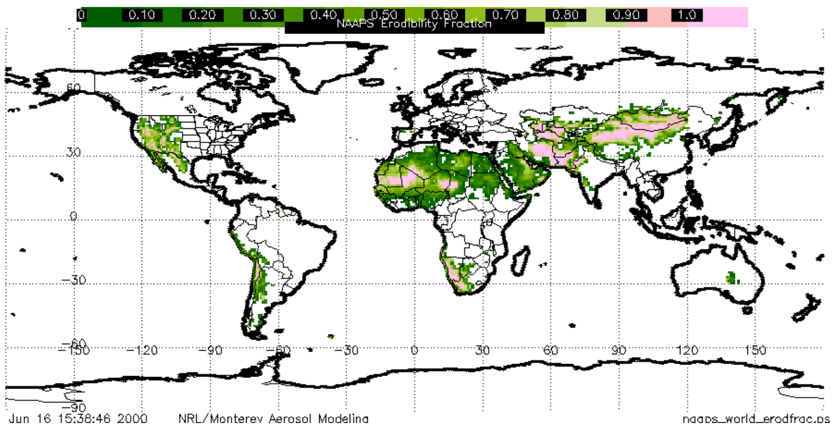




$$\delta = USGS \cdot PREF \cdot (1 - VEGFRAC) \cdot (1 - SnowCover)$$

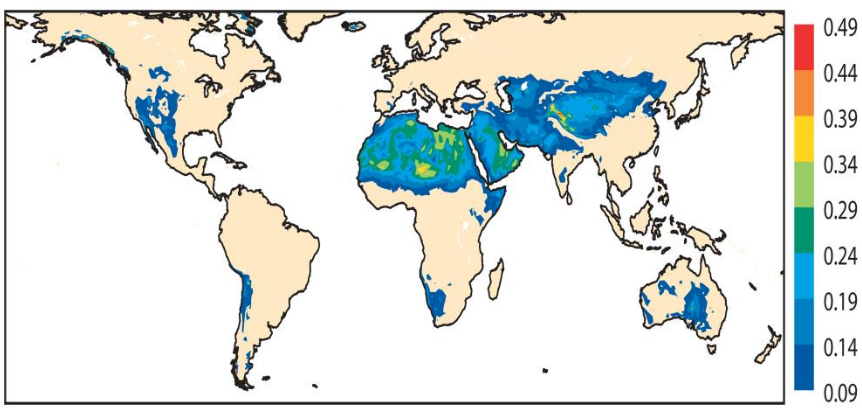
Dust forecasting models: Emission scheme

Dust source function: Other approaches



NAAPS model

Land use mask +
Erodibility map derived from TOMS
Satellite AI climatology



ECMWF-GEMS model

Background albedo in the ultraviolet-visible part of the shortwave spectrum. Only albedos with values between 0.09 and 0.54, assumed to be representative of light-colored soil and sparse vegetation are plotted.

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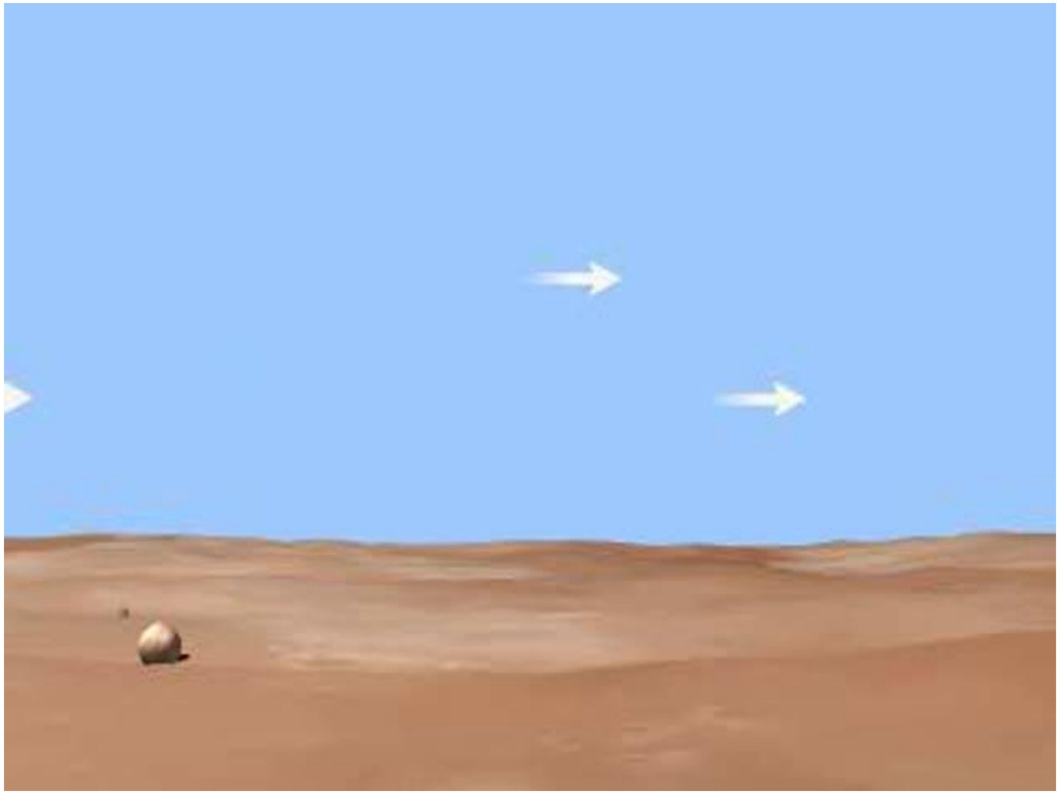
Dust forecasting models: Emission scheme

- Complex physical process involving entrainment of soil particles by the surface winds.



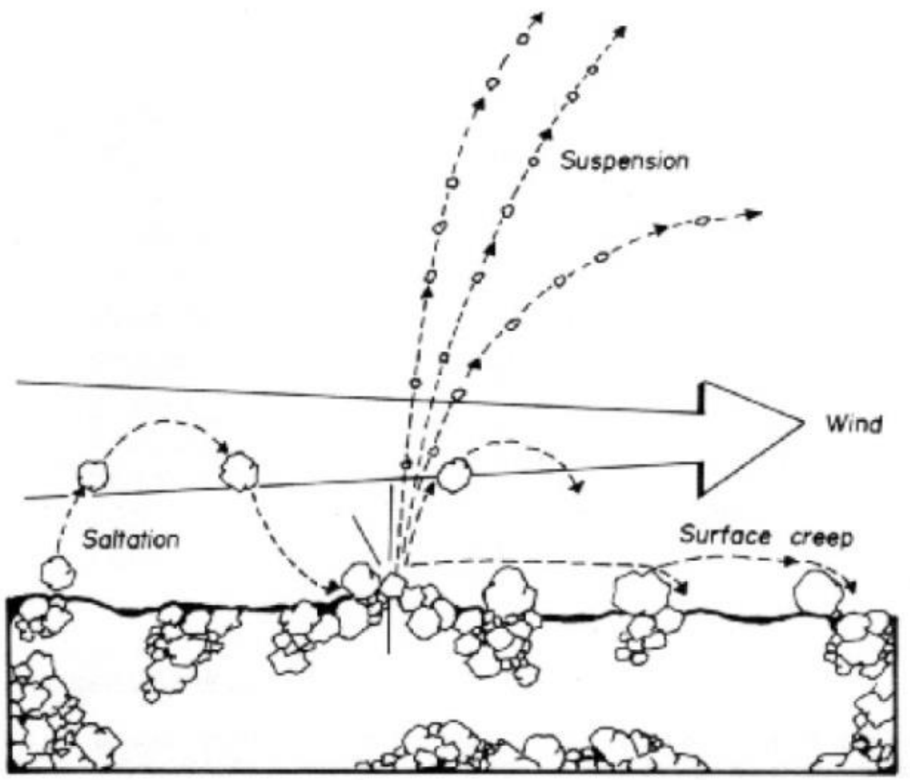
- Creep or rolling motion of the largest particles (> 500 um)

- Saltation or horizontal motion of large soil grains (sand) (50-500um)

- Suspension of dust (after sandblasting or saltation bombardment) (0.1-50 um)

Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust forecasting models: Emission scheme



Scheme of the major wind erosion processes with saltation, creeping and suspension (due to sandblasting) in dependency of wind speed.

Extracted www.extension.purdu.edu/extmedia/AY/AY-271.html

Dust forecasting models: Emission scheme

Simple schemes

Formulation of vertical dust flux (F)

$$F = c \cdot f \cdot P(u_*^n, u_{*th}) \quad \text{if} \quad u_* > u_{*t}$$

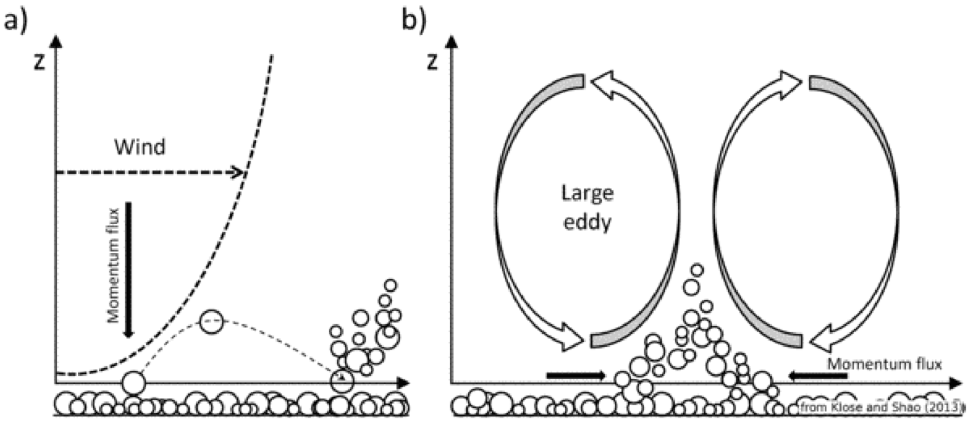
c: dimensional scale dependent constant proportinality
f: relative surface area of each soil particle fraction (which includes de source function, δ)
u_*: friction velocity
u_{*t}: threshold friction velocity
P: polinomial of degree n

Study	Scheme
Uno et al. (2001) CFORS	F= $cu_{10}{}^2(u_{10} - u_{10t})$
Liu and Westphal (2001) COAMPS	F= $fu_{10}{}^2(u_{10} - u_{10t})$
Liu and Westphal (2001) COAMPS	F= $fcu_*{}^4$

Dust forecasting models: Emission scheme

Dust storm generation requires:

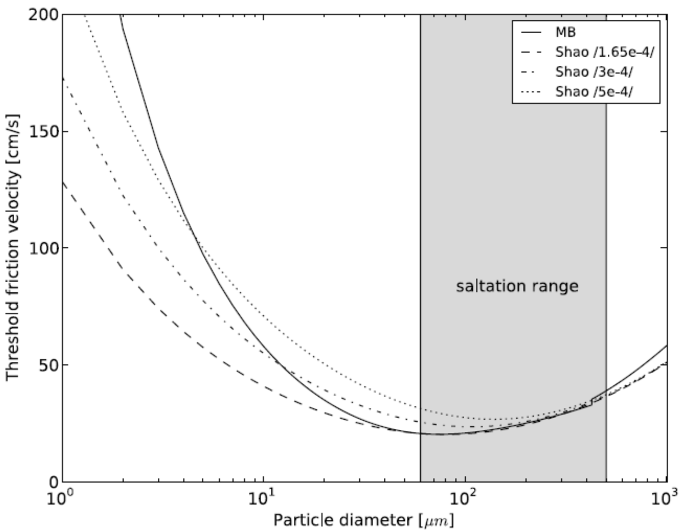
- High wind
- Wind shear and turbulence
- Unstable boundary layer



(a) Conventional view of dust emission via saltation bombardment; (b) Illustration of convective turbulent dust emission.
Extracted from Shao (2008)

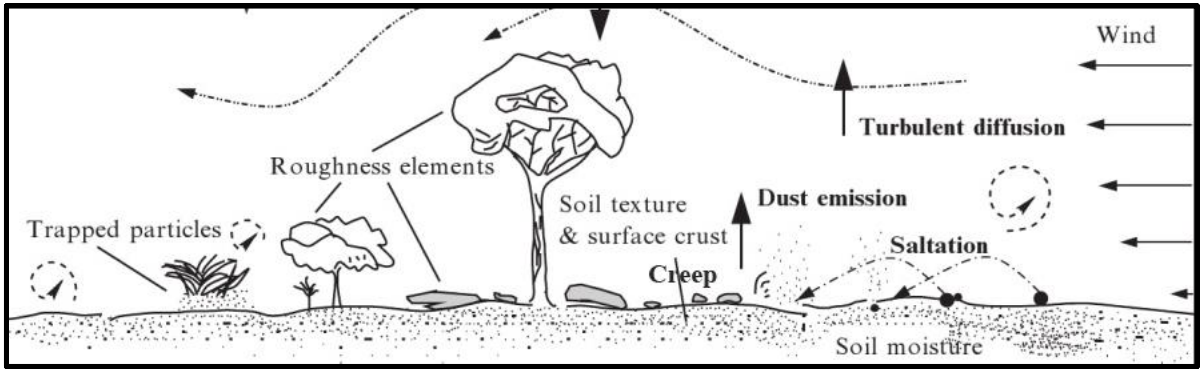
Friction velocity is the parameter used by dust models since it expresses wind speed, turbulence and stability

Threshold friction velocity vs particle radius →



Darmenova et al., 2009

Dust forecasting models: Emission scheme



Extracted from Shao (2008)

- **Threshold friction velocity u_{*thr}** is defined as the velocity above which soil particles begin to move in saltation flux
- Depends on **soil grain size, soil moisture and roughness** among others

$$u_{*thr}(D_p, z_0, w) = \frac{u_{*dry}(D_p)}{R(z_0, z_{0s})} \cdot H(w)$$

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Dust forecasting models: Emission scheme

Simple schemes

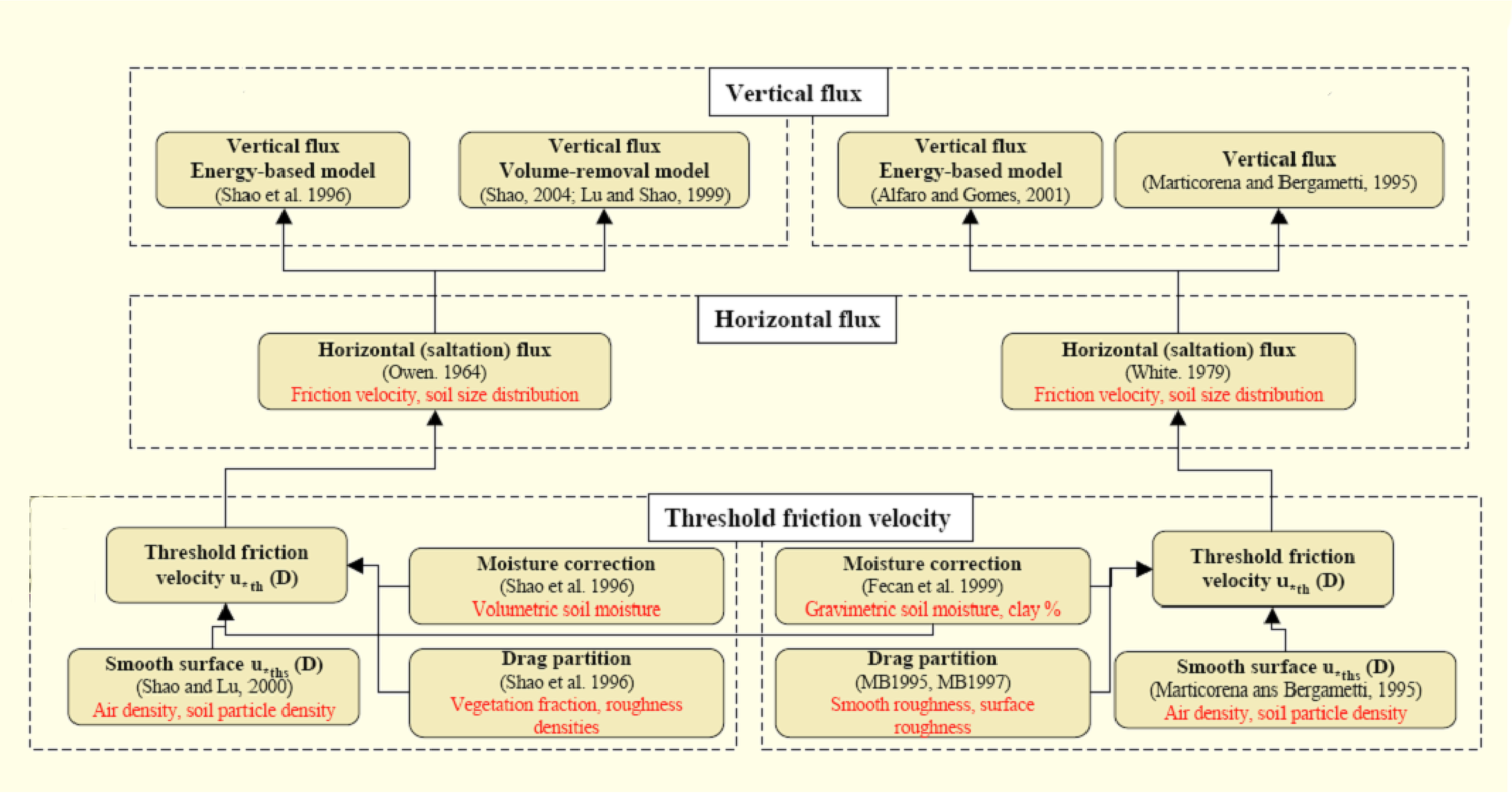
Limitations

- Oversimplified physical representation of dust emission.
- Normalization constant C is not known
- Erodible fraction is prescribed for predefined dust sources
- Threshold friction velocity is usually a fixed value (no dependence on the land surface properties)

- **Assuming constant threshold friction velocity will introduce bias in the modelling of the timing and intensity of dust events.**
- **The prescribed constant is model dependent and can result in large discrepancies in calculated dust loadings between different models.**

Dust forecasting models: Emission scheme

Physically based schemes



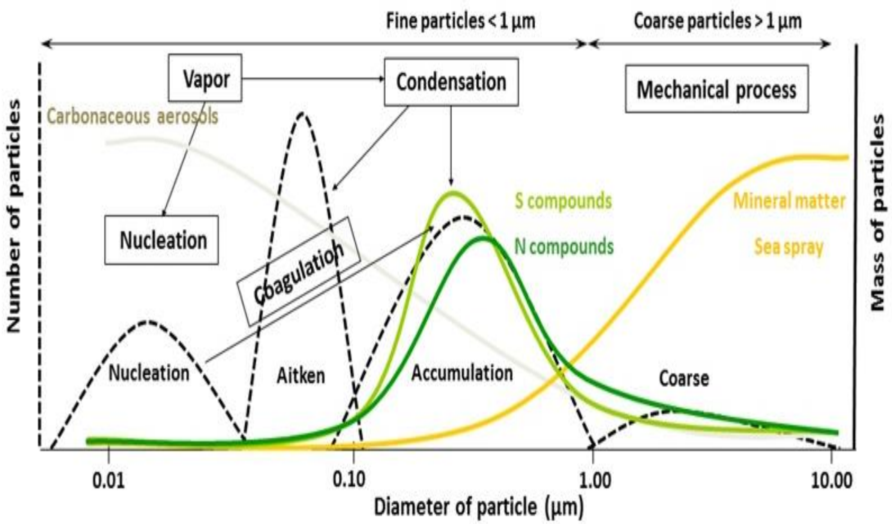
Physically-based **dust emission schemes** employ different parameterizations of the related physical processes, as well as require different input data.

Dust forecasting models: Emission scheme

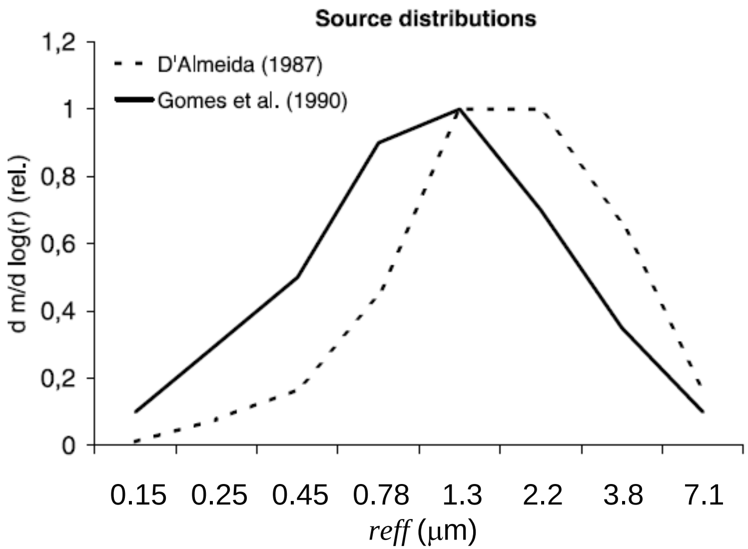
Parent soil size distribution are used to calculate **horizontal flux (H).**
Dust **horizontal concentration** is calculated distributing the **vertical flux (F)** of the **first two parent soil categories** (clay and silt) over the **model particle bins.**

Parameterizations of mass size distribution of the model at sources

Modal



Sectorial



8 bin size distribution from
Tegen and Lacis (1996)

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Dust forecasting models

Dust models simulate the atmospheric dust cycle and involves a variety of processes:

$$\frac{\partial C_k}{\partial t} = -u\frac{\partial C_k}{\partial x} - v\frac{\partial C_k}{\partial y} - (w - v_{gk})\frac{\partial C_k}{\partial z} - \nabla(K_H \nabla C_k) - \frac{\partial}{\partial z}\left(K_Z \frac{\partial C_k}{\partial z}\right) + \left(\frac{\partial C_k}{\partial t}\right)_{SOURCE} - \left(\frac{\partial C_k}{\partial t}\right)_{SINK}$$

Horizontal advection	Vertical advection & gravitational settling	Horizontal diffusion	Vertical diffusion	Dust emission	Wet and dry deposition

Dust forecasting models: Dispersion

Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

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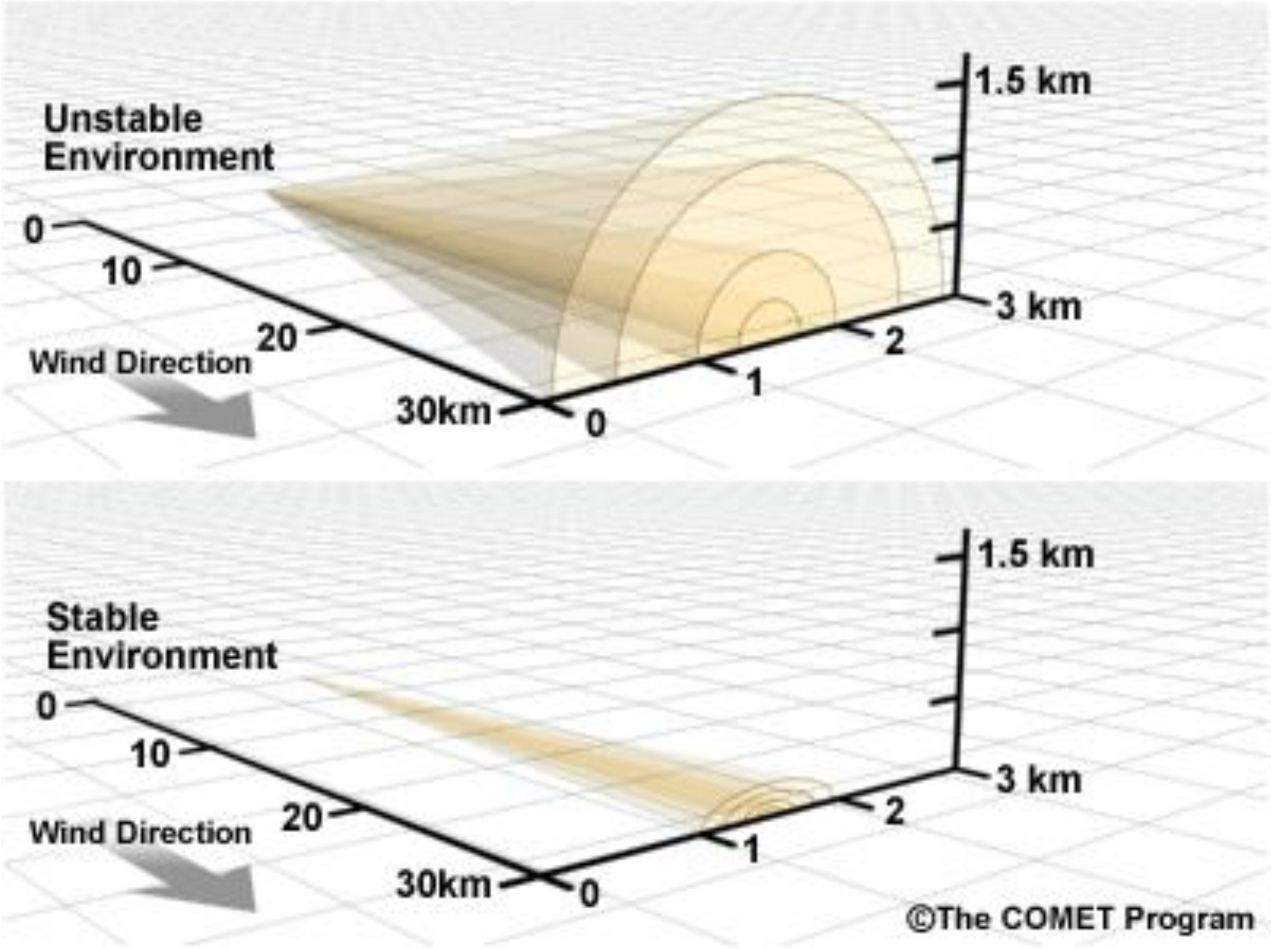
Dust forecasting models: Dispersion



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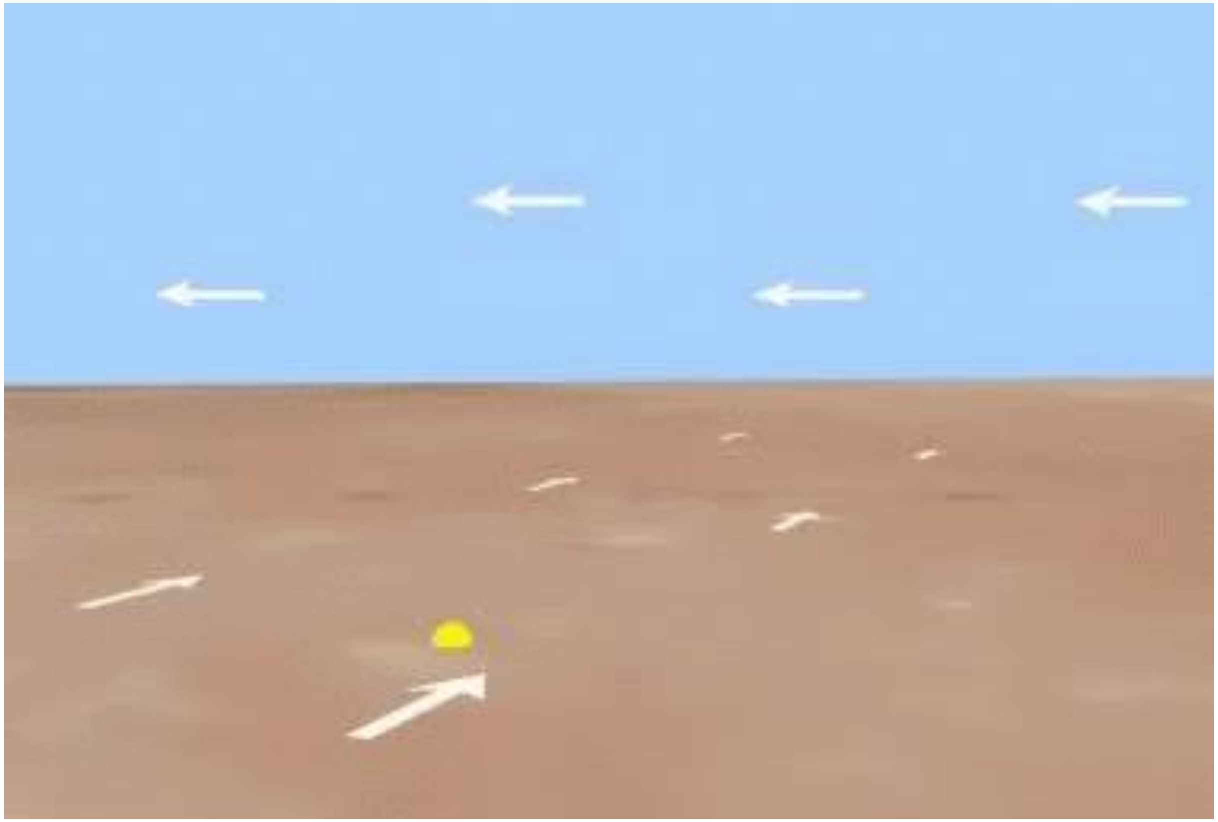
Dust forecasting models

Dust models simulate the atmospheric dust cycle and involves a variety of processes:

$$\frac{\partial C_k}{\partial t} = \underbrace{-u\frac{\partial C_k}{\partial x} - v\frac{\partial C_k}{\partial y}}_{\text{Horizontal advection}} \underbrace{-(w - v_{gk})\frac{\partial C_k}{\partial z}}_{\text{Vertical advection \& gravitational settling}} \underbrace{-\nabla(K_H \nabla C_k)}_{\text{Horizontal diffusion}} \underbrace{-\frac{\partial}{\partial z}\left(K_z \frac{\partial C_k}{\partial z}\right)}_{\text{Vertical diffusion}} + \underbrace{\left(\frac{\partial C_k}{\partial t}\right)_{SOURCE}}_{\text{Dust emission}} - \underbrace{\left(\frac{\partial C_k}{\partial t}\right)_{SINK}}_{\text{Wet and dry deposition}}$$

Horizontal advection | *Vertical advection & gravitational settling* | *Horizontal diffusion* | *Vertical diffusion* | *Dust emission* | *Wet and dry deposition*

Dust forecasting models: Advection and diffusion



Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust forecasting models

Dust models simulate the atmospheric dust cycle and involves a variety of processes:

$$\frac{\partial C_k}{\partial t} = -u\frac{\partial C_k}{\partial x} - v\frac{\partial C_k}{\partial y} - (w - v_{gk})\frac{\partial C_k}{\partial z} - \nabla(K_H \nabla C_k) - \frac{\partial}{\partial z}\left(K_Z \frac{\partial C_k}{\partial z}\right) + \left(\frac{\partial C_k}{\partial t}\right)_{SOURCE} - \left(\frac{\partial C_k}{\partial t}\right)_{SINK}$$

Horizontal advection	*Vertical advection & gravitational settling*	*Horizontal diffusion*	*Vertical diffusion*	*Dust emission*	*Wet and dry deposition*

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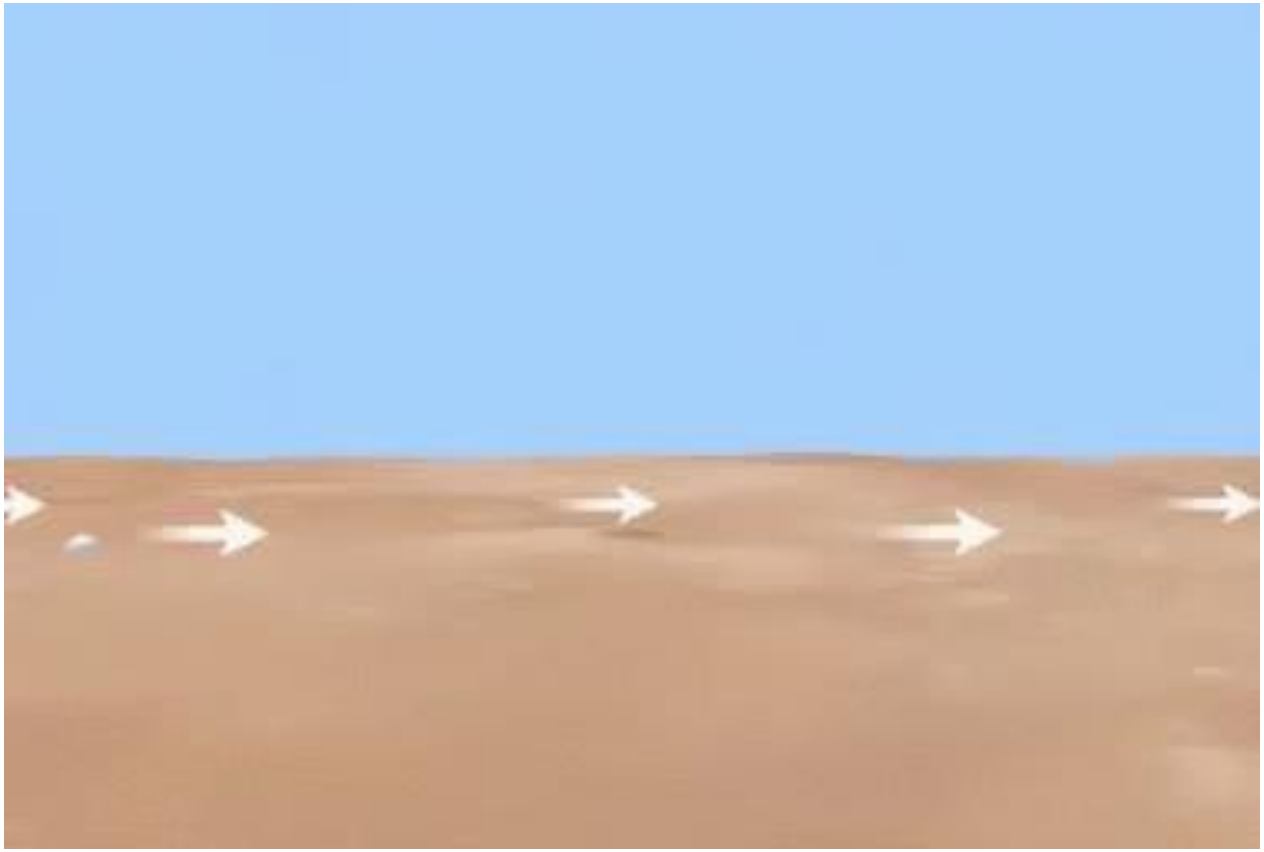
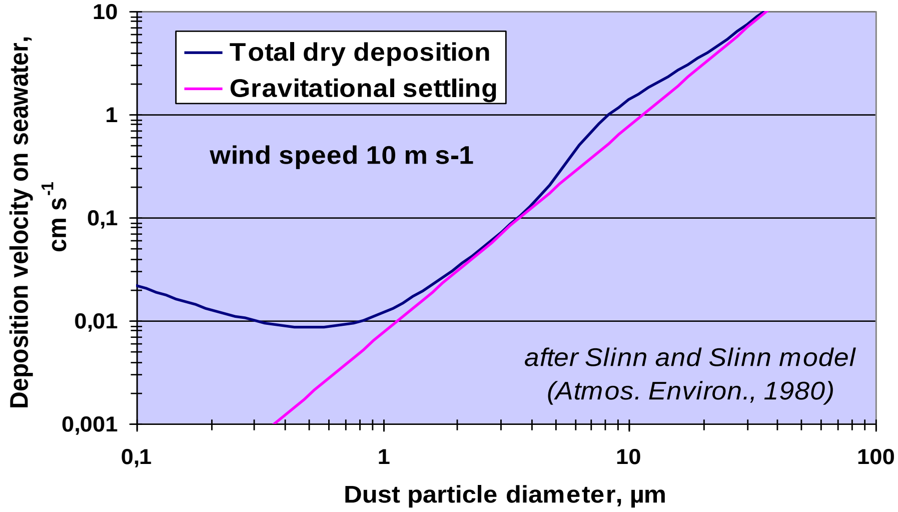
Sedimentation and dry deposition



Movie from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust forecasting models: Sedimentation and dry deposition scheme



- **Dry deposition** depends on the variety of factors such as meteorological conditions near the surface, physicochemical properties of mineral dust and the nature of the surface itself.

- **Sedimentation** (or gravitational settling) is the settling of particles fall down due to gravity → Very large particles will settle out quickly

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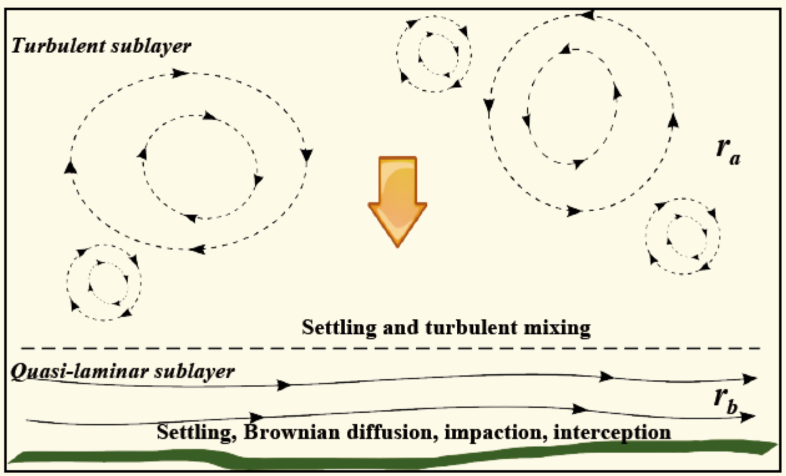
Dust forecasting models: Dry deposition scheme

Dry deposition velocity is represented as 3 resistances in series parallel to a second pathway - gravitational settling velocity:

$$v_d = \frac{1}{r_a + r_b + r_c} \longrightarrow F_d = -C \cdot v_d$$

- Aerodynamic resistance to transfer (r_a)
- Quasi-laminar surface layer resistance (r_b)
- Resistance to surface uptake (r_c)



Adopted after Shao, 2000

Dust forecasting models

Dust models simulate the atmospheric dust cycle and involves a variety of processes:

$$\frac{\partial C_k}{\partial t} = -u\frac{\partial C_k}{\partial x} - v\frac{\partial C_k}{\partial y} - (w - v_{gk})\frac{\partial C_k}{\partial z} - \nabla(K_H \nabla C_k) - \frac{\partial}{\partial z}\left(K_Z \frac{\partial C_k}{\partial z}\right) + \left(\frac{\partial C_k}{\partial t}\right)_{SOURCE} - \left(\frac{\partial C_k}{\partial t}\right)_{SINK}$$

Horizontal advection | *Vertical advection & gravitational settling* | *Horizontal diffusion* | *Vertical diffusion* | *Dust emission* | *Wet and dry deposition*

Dust forecasting models: Wet deposition scheme

Wet scavenging

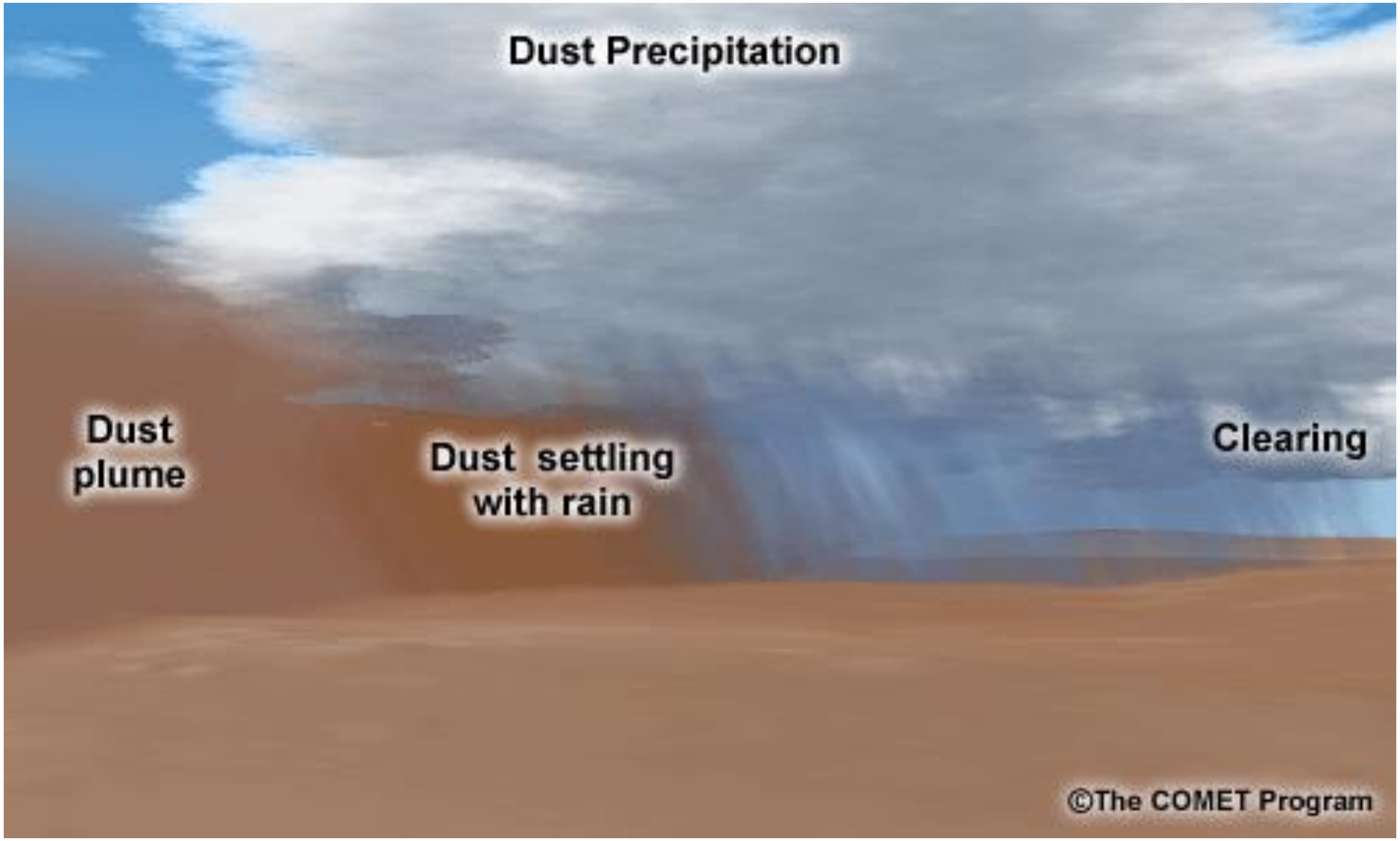
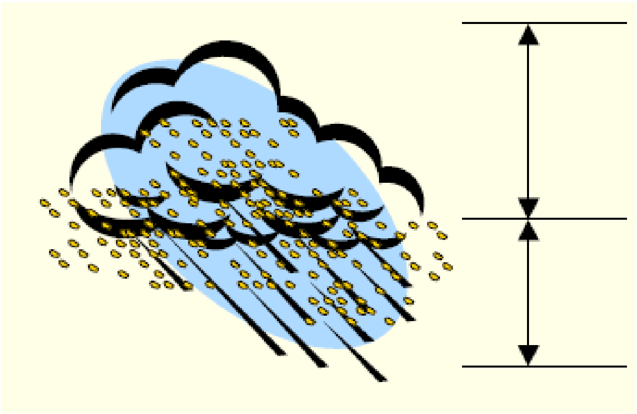


Image from the COMET program at http://meted.ucar.edu/ of the University Corporation for Atmospheric Research (UCAR)

Dust forecasting models: Wet deposition scheme



In-cloud scavenging:

- **nucleation scavenging** by activation and growth of particles to cloud droplets
- **collection** of a non-activated fraction of particles by coagulation with cloud and rain droplets

Below-cloud scavenging:

Collection by falling raindrops of particles under their collision.

Decrease rate of the aerosol concentration due to **wet scavenging** in a layer with uniform concentration can be described by a first-order equation:

$$\frac{\partial C}{\partial t} = -\lambda C$$

The **scavenging coefficient (C)** depends on:

- the particle size and solubility
- the collectors size distribution and fall speeds
- precipitation rate and phase (rain or snow).

Dust forecasting models: Wet deposition scheme

Existing problems

- **Rainout:** The soluble fraction of dust is not well known, so assigned scavenging efficiencies do not reflect regional specifics of dust properties and their dynamics (i.e., mineralogical composition, aging, etc.)
- **Washout:** Problems in modelling of clouds and precipitation remain a long-standing issue. Precipitation rates during violent convective rains are often underpredicted.
- **Dry versus wet deposition:** The relative importance of dry or wet deposition processes differs regionally and depends on the meteorological conditions and used parameterizations.

http://www.nrlmry.navy.mil/aerosol/icap.1087.php

http://www.nrlmry.navy.mil/aerosol/icap.1087.php

Dust forecasting models

Main differences between dust models

1. *Atmospheric driver*
2. *Meteorological input files IBC*
3. *Emission scheme*
4. *Geographic-information database*
5. *Land-surface scheme*
6. *Dry deposition scheme*
7. *Wet depositioon scheme*
8. *Spatio-temporal resolution*
9. *Data assimilation*
10. *….*

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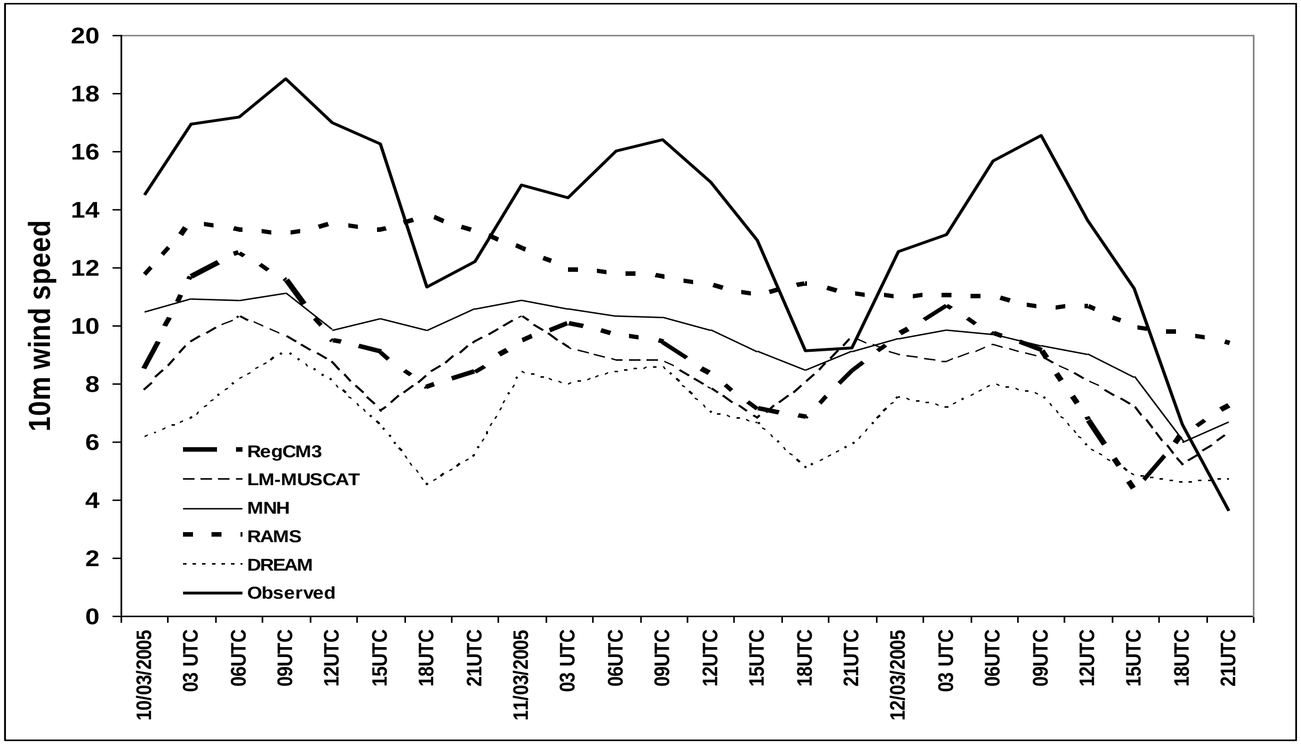
Dust forecasting models

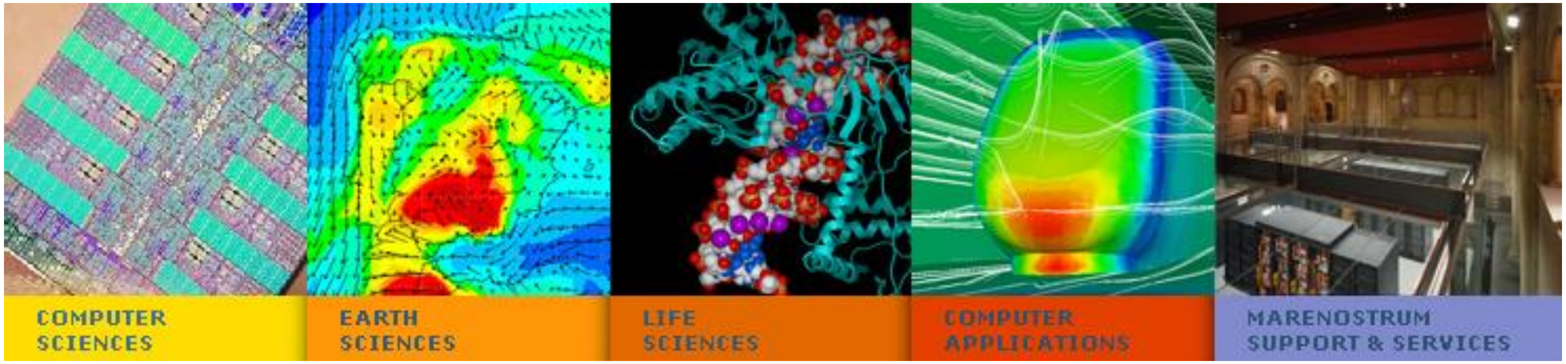
Experimental campaigns: BODEX 2005 (Todd et al. 2008, JGR)

First regional model intercomparison in the Bodélé hot spot



Strong differences between models!!!! → **Meteorology** and **emission scheme**

Earth Sciences Department: Mineral Dust Modelling



- Dust daily forecast:
  - **BSC-DREAM8b**

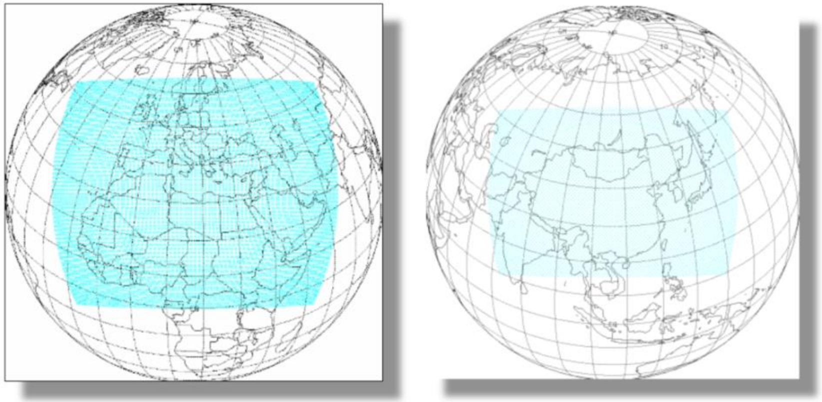
    http://www.bsc.es/projects/earthscience/BSC-DREAM/
  - **NMMB/BSC-Dust:**

    http://www.bsc.es/projects/earthscience/NMMB-BSC-DUST/
  - **Mineral dust database:** Files download

    http://www.bsc.es/earth-sciences/mineral-dust/catalogo-datos-dust/

Dust forecasting models: The BSC-DREAM8b v2.0

- Daily forecasts in 2 domains:
  - North Africa-Middle East-Europe (0.3º x 0.3º)
  - East Asia (0.5º x 0.5º)



- Main features
  - 8 particle size bin distribution (0.1 -10 μm)
  - Dust radiative feedbacks (Pérez et al., 2006)
- Latest developments (version 2.0; Basart et al. 2012a)
  - Updated dry deposition
  - Inclusion of a preferential source mask

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

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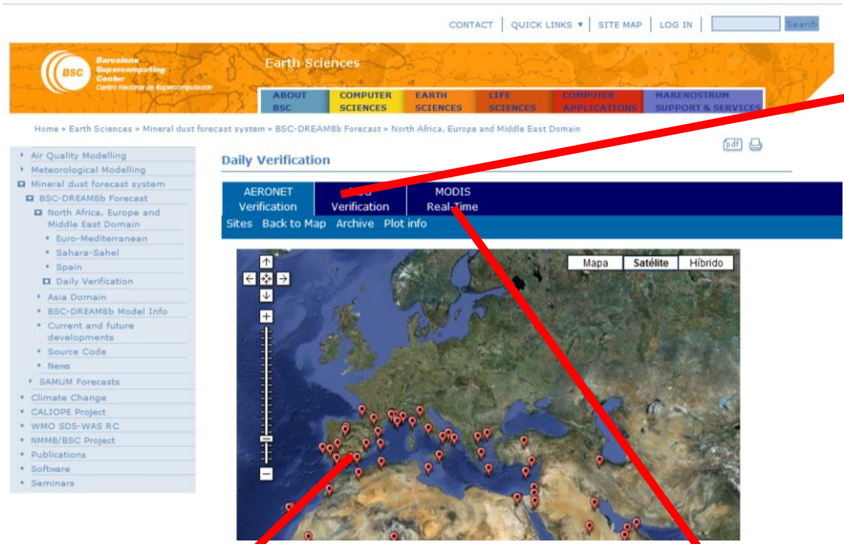
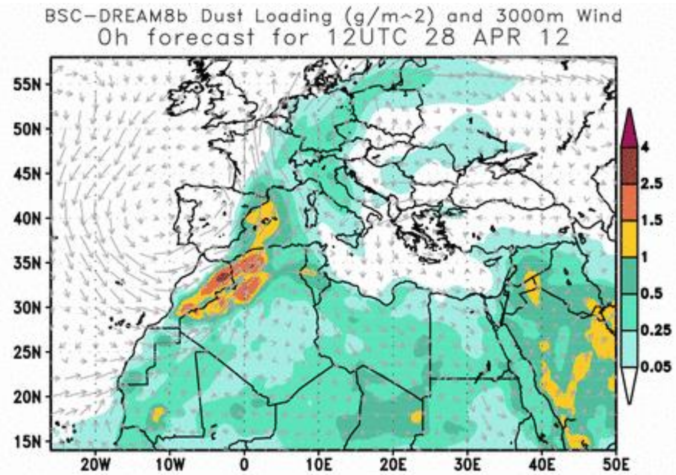
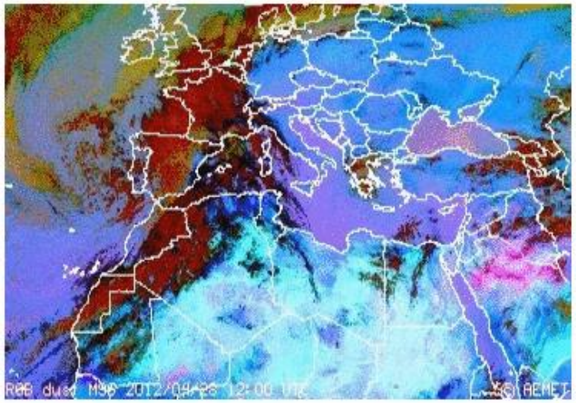
http://www.bsc.es/projects/earthscience/BSC-DREAM/

Dust forecasting models: The BSC-DREAM8b v2.0

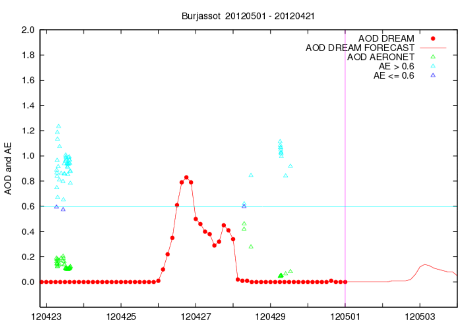


MSG/RGB

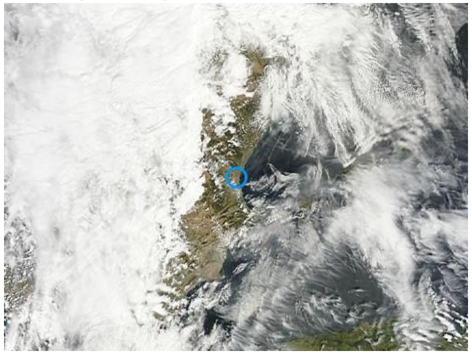




AERONET



MODIS



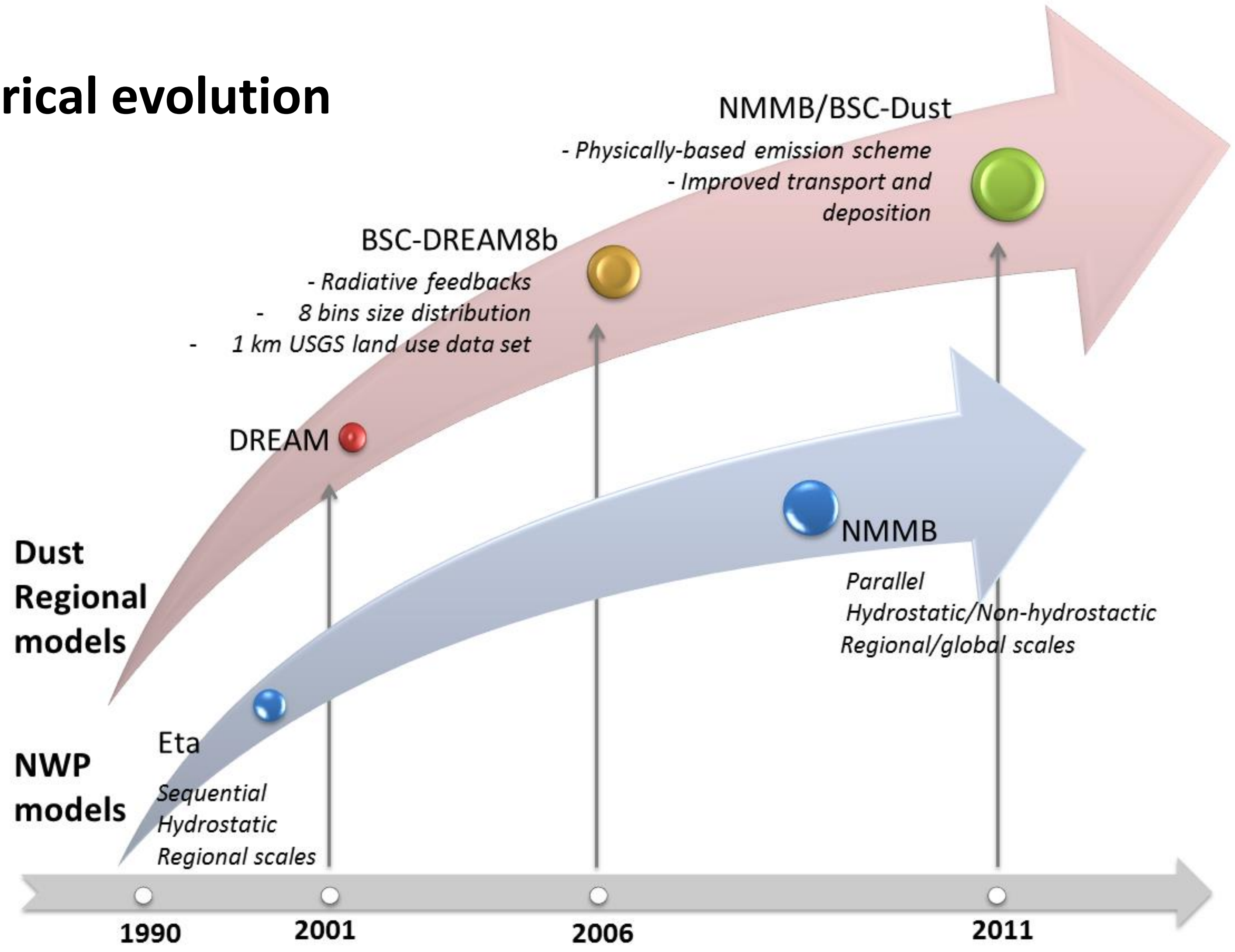
Inclusion of new satellite aerosol products: **OMI, CALIPSO** and **MISR**

Dust forecasting models: DREAM and BSC-DREAM8b

Study Region	Reference	Model version	Time period
North Africa-Middle East-Europe	Basart el al. (2009)	BSC-DREAM8b	Annual (2004)
	Basart et al. (2012b)	BSC-DREAM8b	Annual (2004)
Europe	Papayannis et al. (2008)	DREAM	Long-term (2000-2002)
	Pay et al. (2010)	BSC-DREAM8b	Annual (2004)
	Basart et al. (2012a)	BSC-DREAM8b	Annual (2004)
Western Mediterranean	Pérez et al. (2006a)	BSC-DREAM8b	Dust event (April 2002)
	Pérez et al. (2006b)	BSC-DREAM8b	Dust event (June 2002)
Spain	Jiménez-Guerrero et al. (2008)	DREAM	Dust event (June-July 2006)
	Pay et al. (2012)	BSC-DREAM8b	Annual (2004)
Portugal	Borrego et al. (2011)	BSC-DREAM8b	Annual (2010)
Italy	Kishcha et al. (2007)	DREAM	Long-term (2001-2003)
Eastern Mediterranean	Balis et al. (2006)	DREAM	Dust event (August-September 2003)
Greece	Papayannis et al. (2009)	DREAM	Long-term (2004-2006)
	Amiridis et al. (2009)	BSC-DREAM8b	Dust event (May 2008)
	Papanastasiou et al. (2010)	BSC-DREAM8b	Long-term (2001-2007)
Central Europe	Klein et al. (2010)	BSC-DREAM8b	Dust event (May-June 2008)
Georgia	Kokkalis et al. (2012)	BSC-DREAM8b	Dust event (May 2009)
Sub-Tropical Eastern North Atlantic	Alonso-Pérez et al. (2011)	DREAM	Long-term (1958-2006)
North-Central Africa	Todd et al. (2009)	BSC-DREAM8b	Dust event (BodEx, March 2005)
Morocco	Haustein et al. (2009)	BSC-DREAM8b	Dust event (SAMUM, May-June 2006)

Dust forecasting models: BSC dust forecasting models

Historical evolution



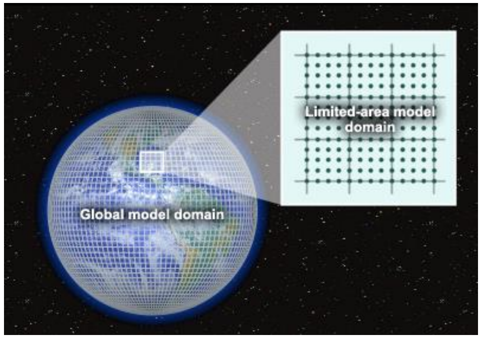
http://www.bsc.es/earth-sciences/mineral-dust/

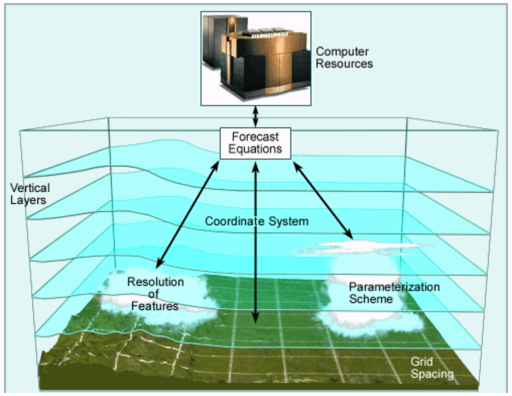
The NMMB/BSC-CTM Project

The **N**on-hydrostatic **M**ultiscale **M**odel (**NMMB**) :

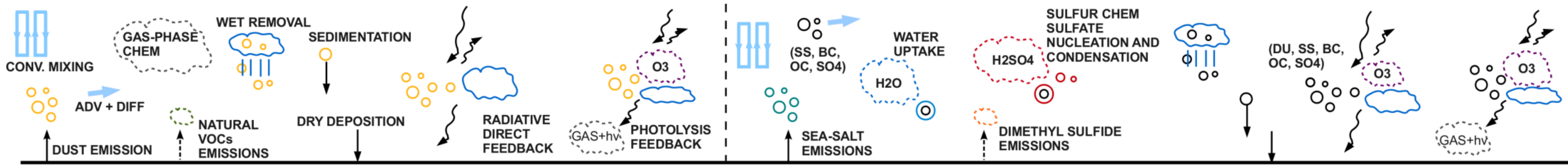
- Under development at NCEP (Janjic, 2005; Janjic and Black, 2007) as evolution of the WRF-NMM model
- Developed within the Earth System Modeling Framework (ESMF)
- Arakawa B grid and regular (global) or rotated (regional) lat/lon coordinate
- NMMB is the regional operational meteorological model in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

Multiscale (global to regional) and ***Nonhydrostatic*** (up to 1km^2 lat-lon resolution)

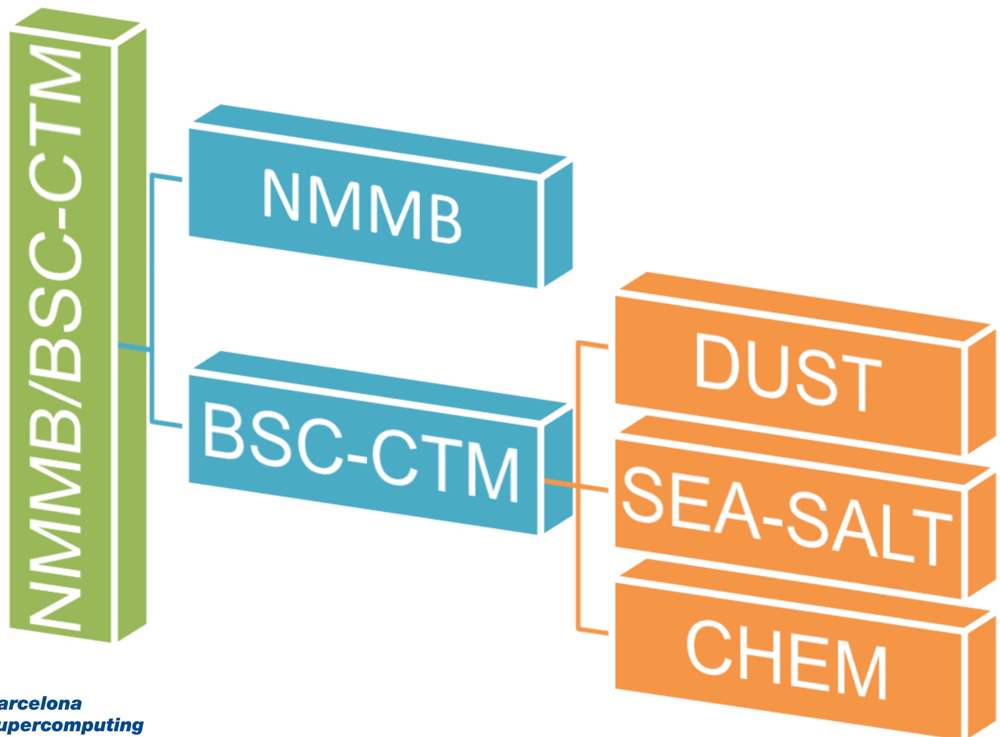


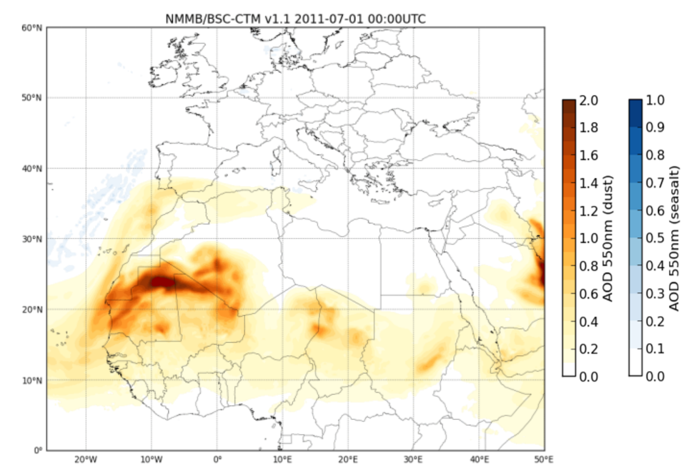


NMMB/BSC-Chemical Transport Model



- Fully ***on-line*** access coupling: feedback processes allowed
- ***Multiscale***: global to regional scales allowed

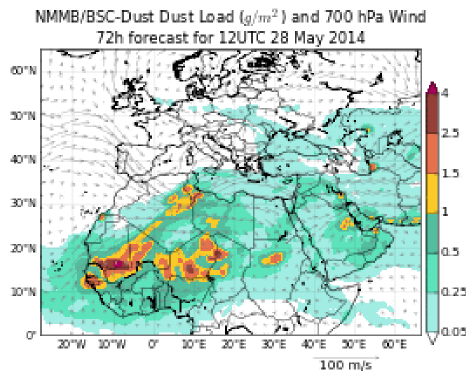


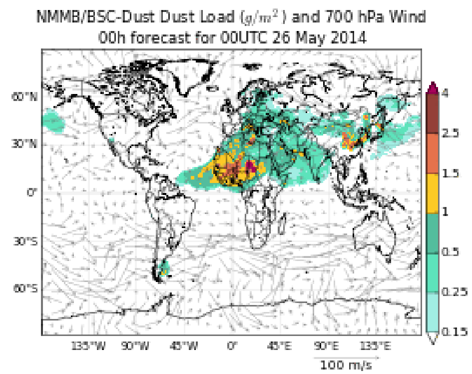


The NMMB/BSC-Dust model

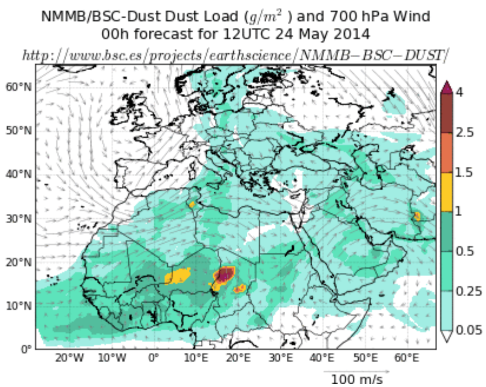
DAILY OPERATIONAL DUST FORECAST AT BSC

http://www.bsc.es/earth-sciences/NMMB-BSC-DUST/





NRT Evaluation



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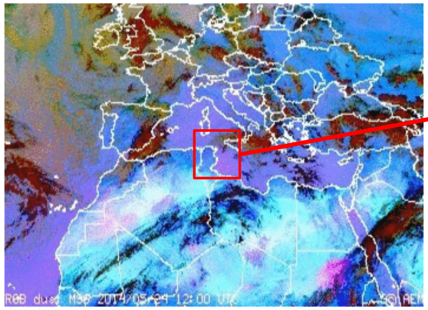
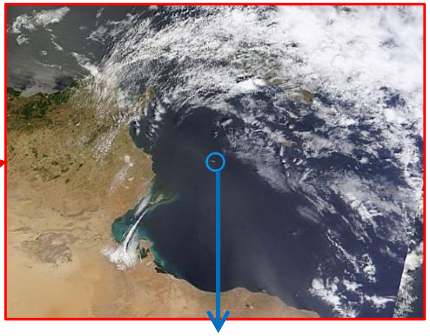
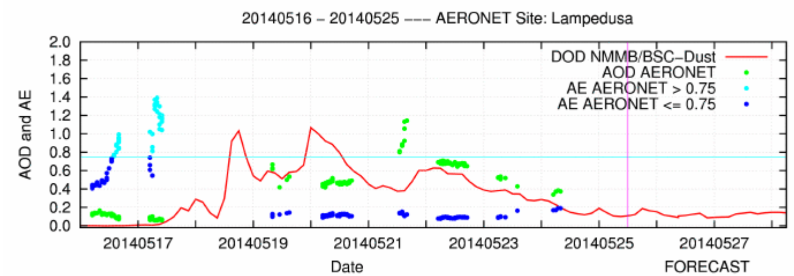


MODIS





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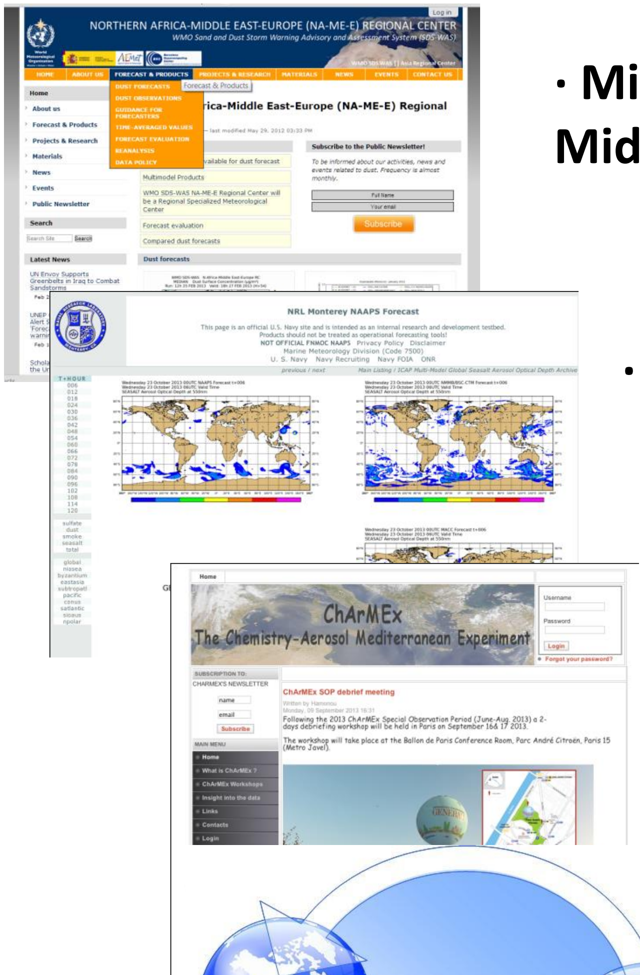
NMMB/BSC-CTM collaborations



- Mineral dust forecasts for SDS-WAS North Africa, Middle East and Europe Regional Center activies

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

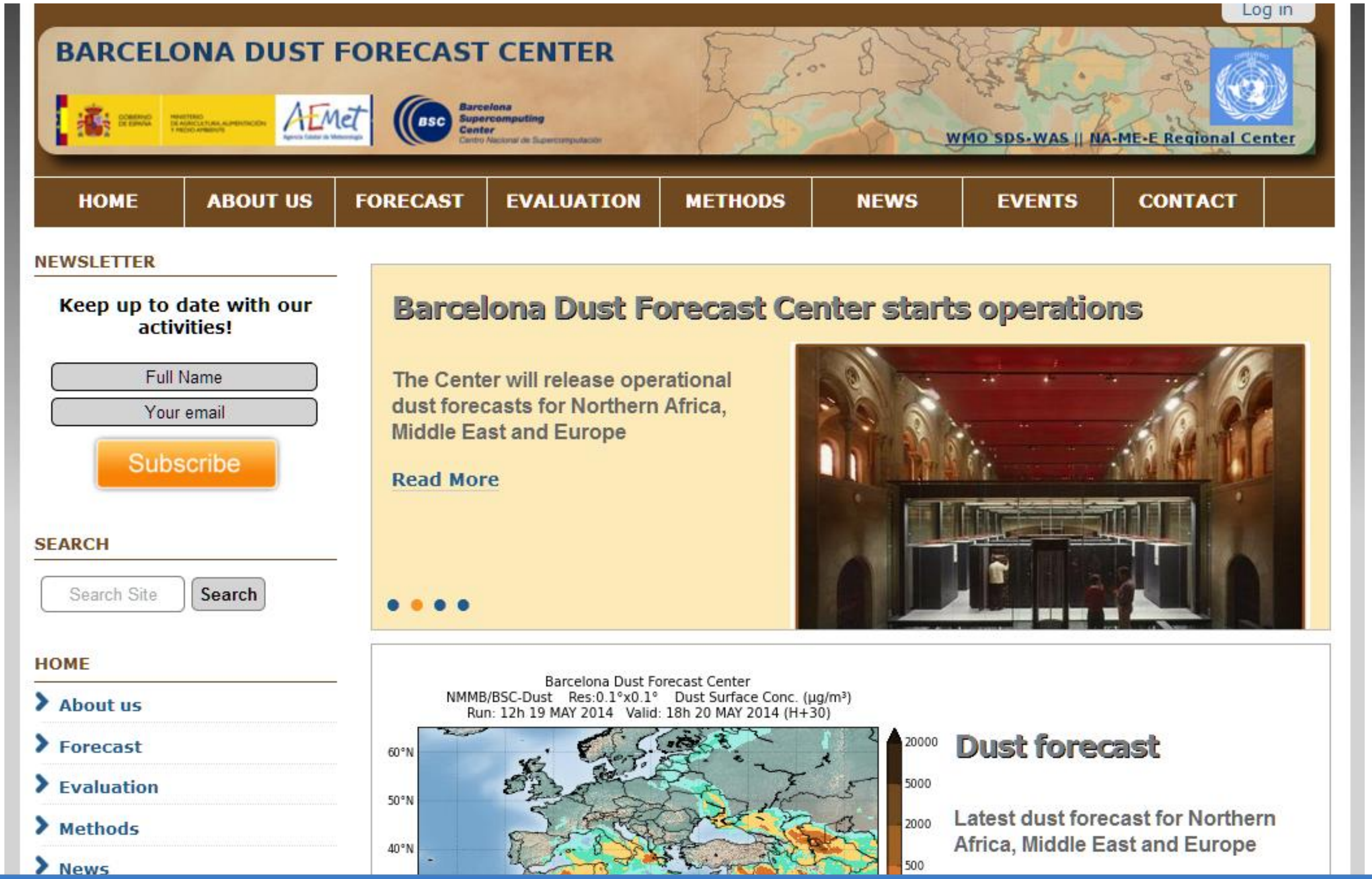
- The ICAP global-model intercomparison project

  http://www.nrlmry.navy.mil/aerosol/icap.1087.php

- The Charmex Chemistry-Aerosol Mediterranean experiment

- The AQMEII on-line Air Quality model intercomparison project

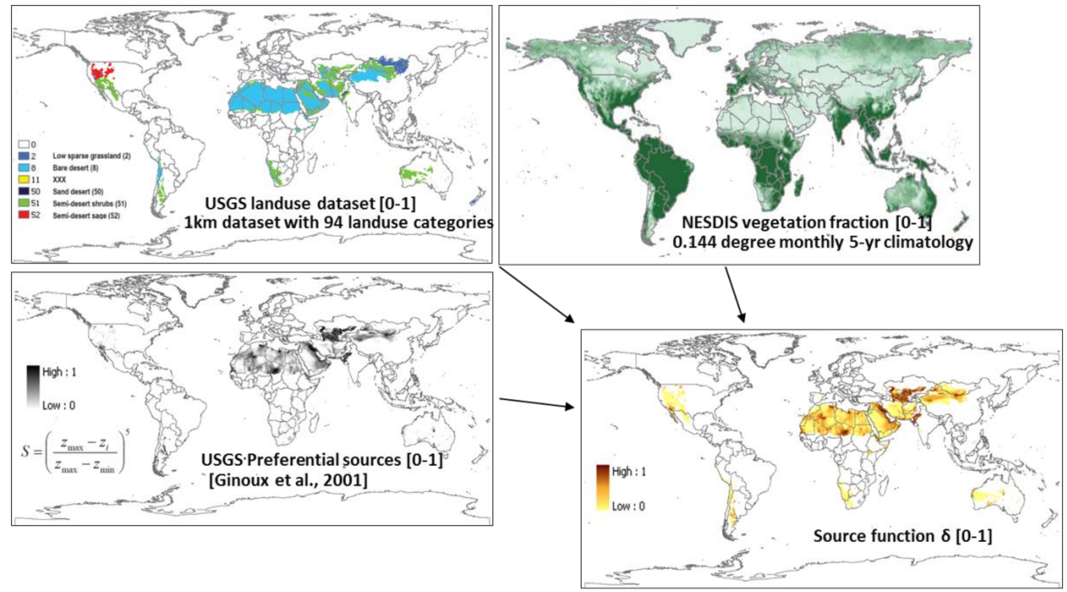
Barcelona Dust Forecasting Center (http://dust.aemet.es/)



First Specialized Center for Mineral Dust Prediction of WMO
NMMB/BSC-Dust *selected to provide operational forecasts at high resolution (10km) for NAMEE region*

EMISSION SCHEME

- Source function: includes update land databases (vegetation fraction, land textures, soil types and albedo) and a preferential "topographic" source mask



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

- Physically-based emission scheme which includes saltation and sandblasting

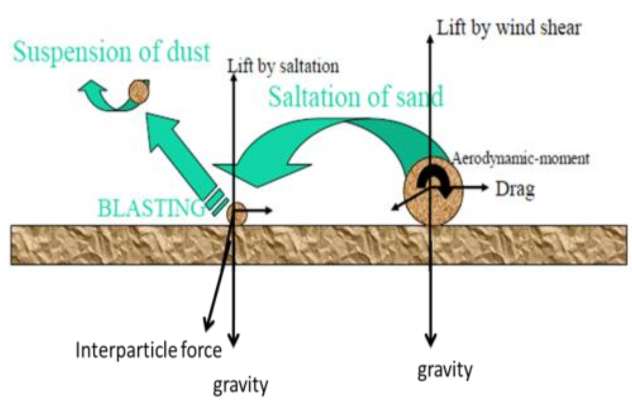


Image from Carlos Pérez

NMMB/BSC-Dust: Model configurations

NMMB/BSC-CTM v2.0

Full Year 2011

Cold start without data assimilation

Initial conditions from NCEP/FNL meteorological analysis (1ºx1º) at 0UTC and boundary conditions every 6 h

*The calibration factor of the emission flux applied is VFLUX=VFLUX*0.255 (from Pérez et al. 2011)*

Model outputs time resolution: 3-hourly

Experiment 0.10

NAMEE domain: 31ºW-71ºE and 0º-70ºN (*)

Vertical resolution: 40 σ-hybrid layers

Horizontal spatial resolution: ***0.10º x 0.10º***

*Grid points: 1021 * 701*

Fundamental time step: 25s

Execution time in MNv3:

24h simulation with 260 nodes (256 computation + 4 I/O): ***2.26 hours***

Experiment 0.25

NAMEE domain: 31ºW-71ºE and 0º-70ºN (*)

Vertical resolution: 40 σ-hybrid layers

Horizontal spatial resolution: **0.25º x 0.25º**

*Grid points: 409 * 281*

Fundamental time step: 40s

Execution time in MNv3:

24h simulation with 260 nodes (256 computation + 4 I/O): ***18 minutes***

Experiment Glob.

Global domain: 180ºW-180ºE and 90ºS-90ºN (*)

Vertical resolution: 40 σ-hybrid layers

Horizontal spatial resolution: **1.40625º x 1.0º**

*Grid points: 257*181*

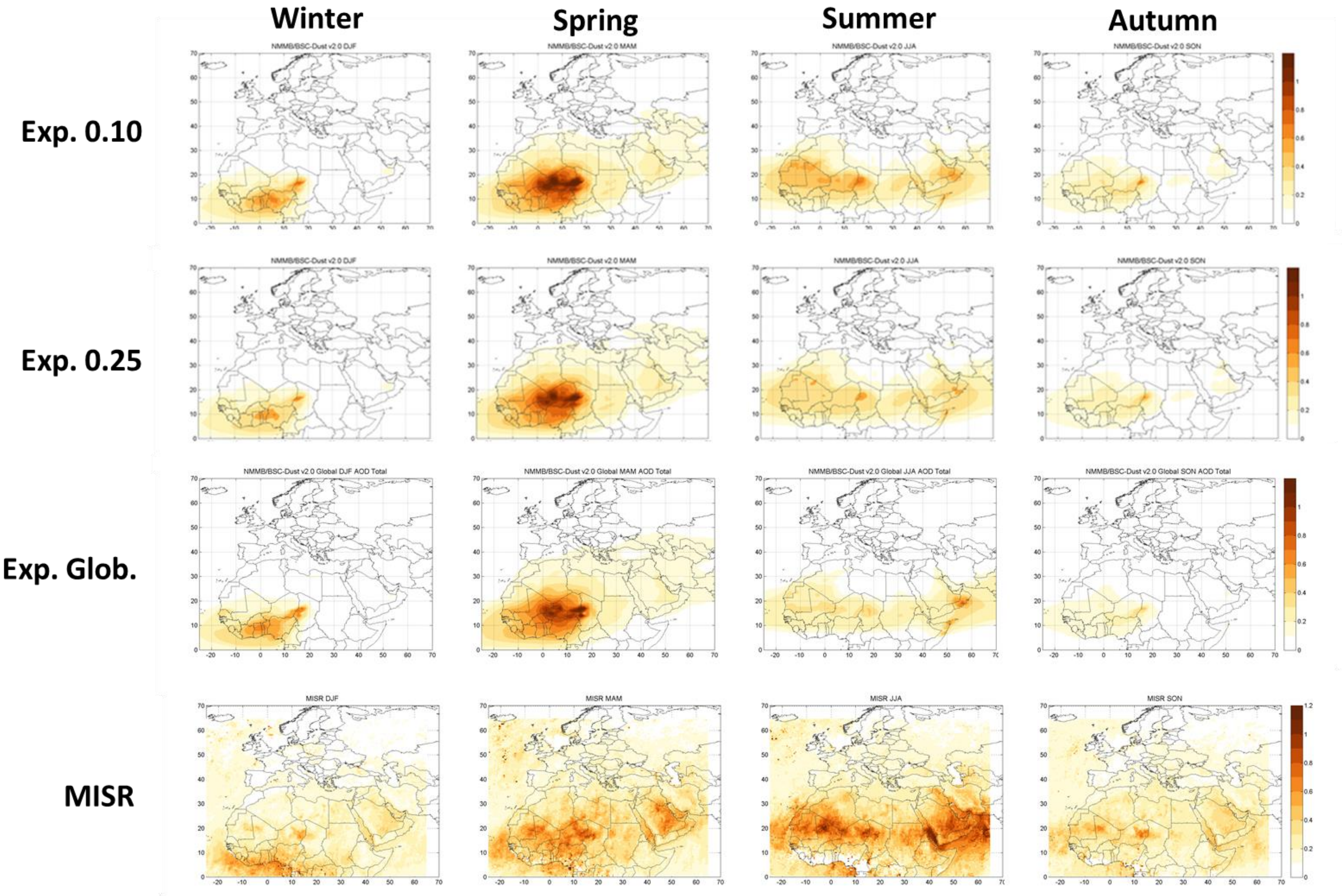
Fundamental time step: 180s

Execution time in MNv3:

24h simulation with 260 nodes (256 computation + 4 I/O): ***34 minutes***

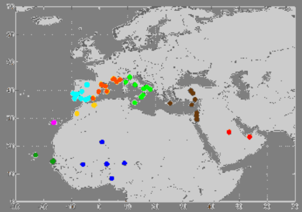
(*) NOTE: The coordinate grid box is defined taking into account the maximum and minimum latitude and longitude values with respect the center point of the domain.

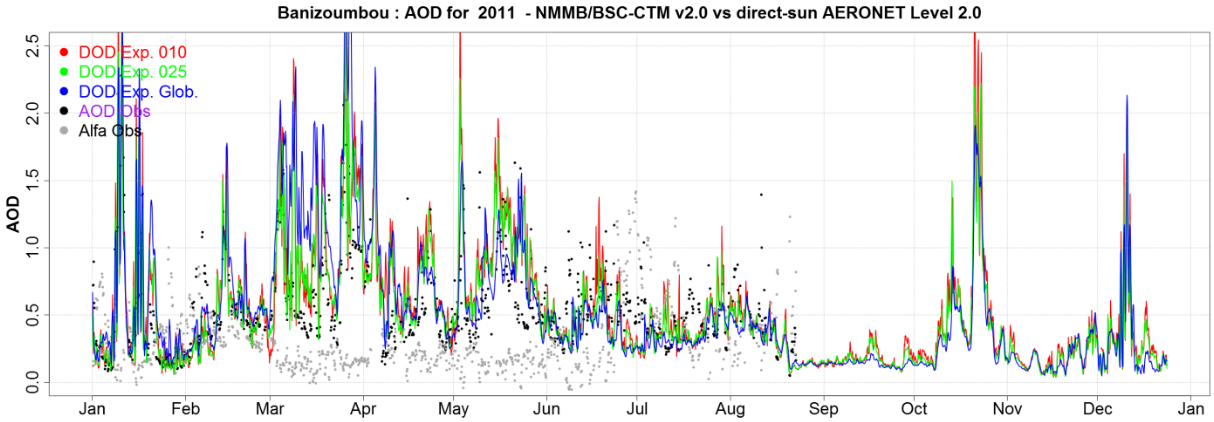
NMMB/BSC-Dust: AOD seasonal averages comparison

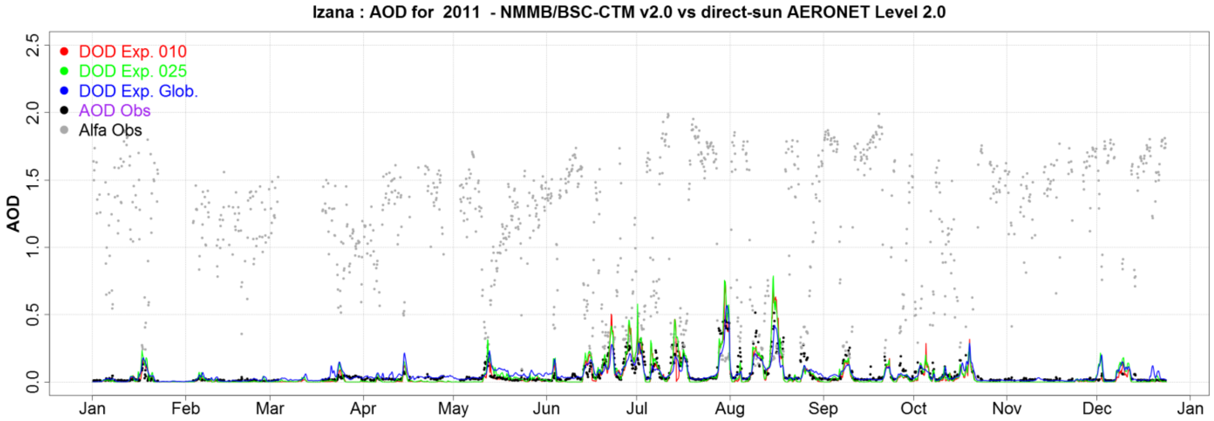


NMMB/BSC-Dust: AOD AERONET comparison

- AOD and AE (Level 2.0) of 50 stations distributed in 9 regions
- 3-hourly averages (± 90 min around the selected modelled hour)







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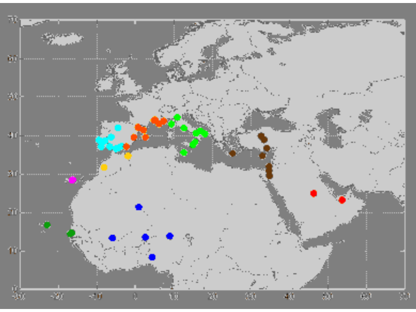
NMMB/BSC-Dust: AOD AERONET comparison

- AOD and AE (Level 2.0) of 50 stations distributed in 9 regions
- 3-hourly averages (± 90 min around the selected modelled hour)
- Filter applied to the AERONET observations
  - AE < 0.75 is considered in the calculations
  - AE >= 1.2 we assign AOD observe = 0

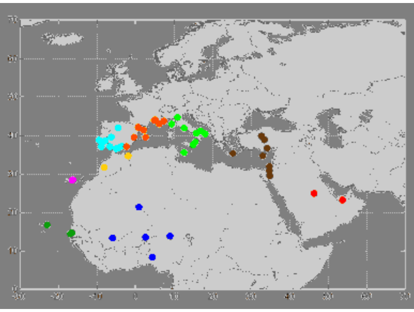


	Exp. 0.10				Exp. 0.25				Exp. Glob.			
Regions	*NDATA*	*r*	*RMSE*	*MB*	*NDATA*	*r*	*RMSE*	*MB*	*NDATA*	*r*	*RMSE*	*MB*
Sahara-Sahel	3266	0,54	0,38	-0,02	3337	0,56	0,36	-0,05	3337	0,52	0,41	-0,02
E.Trop.N.Atl	2177	0,68	0,27	-0,17	2218	0,70	0,26	-0,17	2218	0,47	0,30	-0,14
E.sub-Trop.N.Atl	1237	0,69	0,19	-0,12	1274	0,72	0,19	-0,12	1274	0,69	0,21	-0,13
NW. Africa	2209	0,77	0,10	-0,06	2254	0,76	0,10	-0,05	2254	0,72	0,11	-0,05
W.IP	4805	0,73	0,09	-0,03	4941	0,76	0,09	-0,03	4941	0,69	0,10	-0,02
E.IP-W.Med	4821	0,67	0,07	-0,01	4971	0,69	0,07	-0,01	4971	0,64	0,07	0,01
C. Med	5453	0,66	0,09	-0,01	5595	0,67	0,08	-0,01	5595	0,56	0,10	0,01
E. Med	4089	0,51	0,12	-0,01	4176	0,54	0,12	-0,01	4176	0,54	0,12	0,00
West Asia	1238	0,34	0,45	-0,30	1240	0,37	0,43	-0,30	1240	0,37	0,43	-0,31
NAMEE	***29295***	***0,73***	***0,20***	***-0,05***	***29446***	***0,75***	***0,19***	***-0,05***	***29446***	***0,70***	***0,20***	***-0,03***

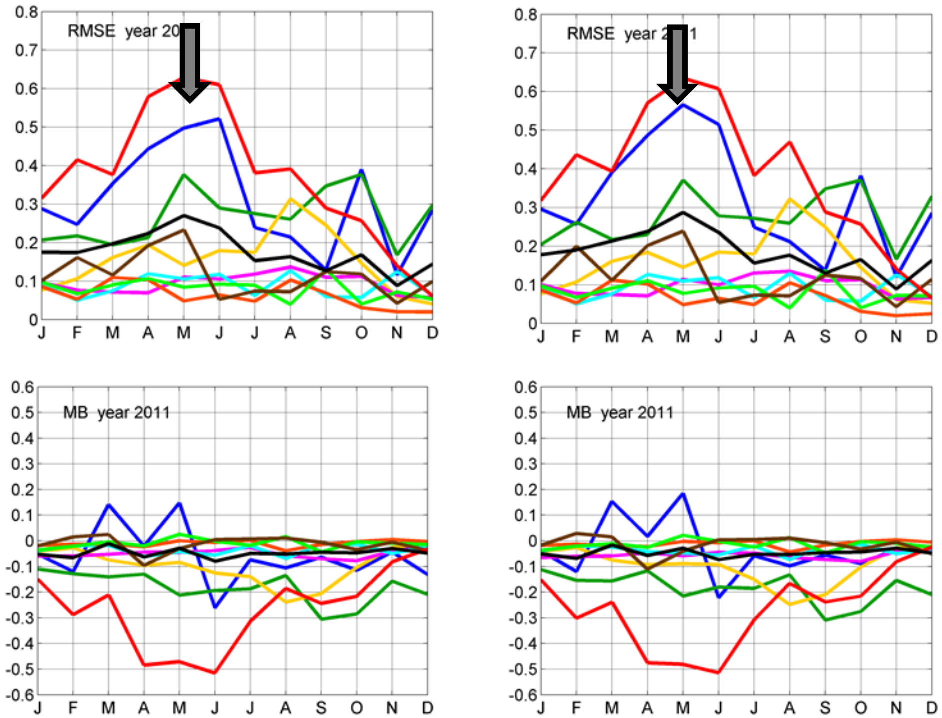
- In general, the skill scores obtained from the 3 model configurations (Exp. 0.10, Exp. 0.25 and Exp. Glob.) are in the same ranges.
  - *The different model configurations show the same seasonal/annual behaviour in all the regions*
  - *Slighlty decrease of the skill scores of Exp. 0.10 and Exp. Glob. respect Exp. 0.25 in all the study region (except in NW. Africa for Exp. 0.10)*

NMMB/BSC-Dust: AOD AERONET comparison

- AOD and AE (Level 2.0) of 50 stations distributed in 9 regions
- 3-hourly averages (± 90 min around the selected modelled hour)
- Filter applied to the AERONET observations
  - AE < 0.75 is considered in the calculations
  - AE >= 1.2 we assign AOD observe = 0



Exp. 0.10 **Exp. 0.25**



- Exp. 0.10 and Exp. 0.25 show similar results along the year

- Overestimations in Sahel during winter
  → *low-level instrusions*
- Underestimations in Sahara during summer
  → *Convective phenomena*
  → *Missing sources*
  → *Wet deposition scheme*
  → *Input meteorological data*
- Underestimations in West Asia during springtime
  → *under research*
- Exp. 0.10 shows a decrease of the RMSE and MB in May in Sahara-Sahel region.
  → *under research*

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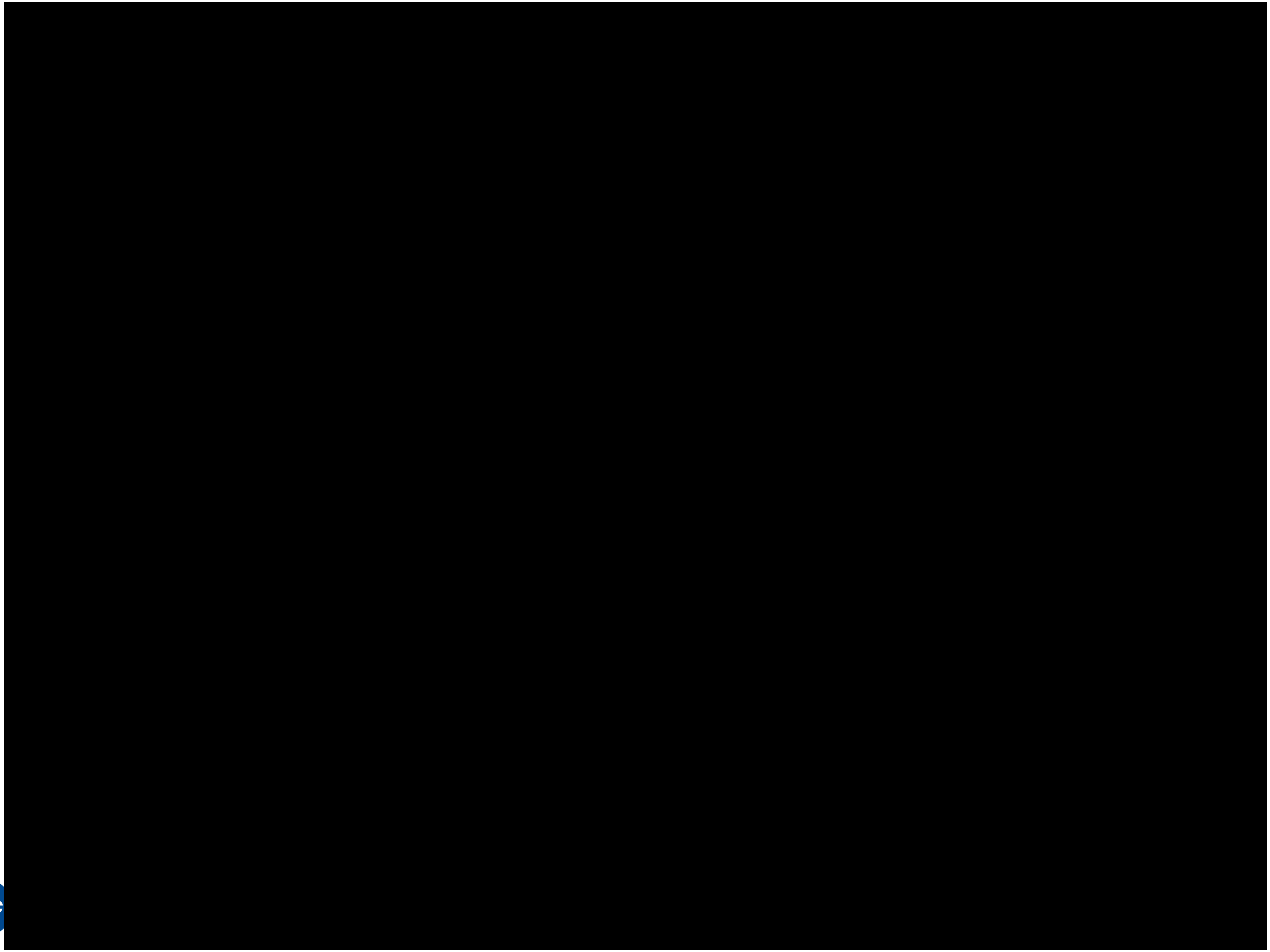
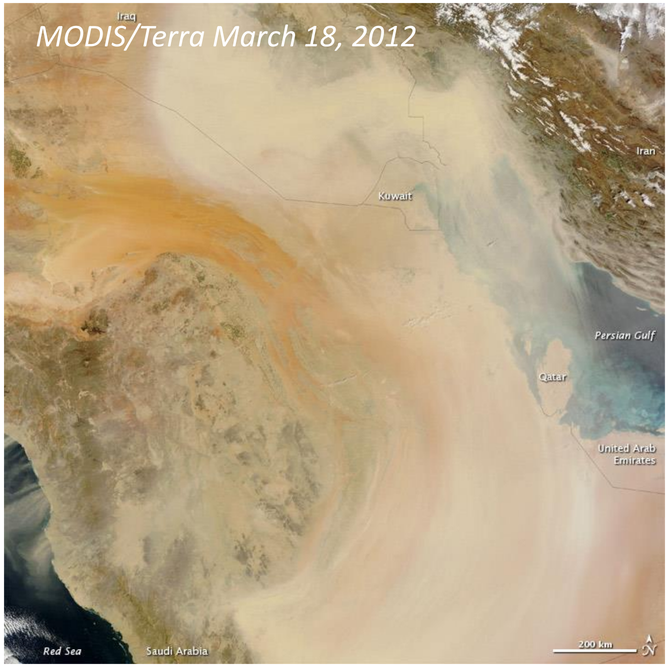
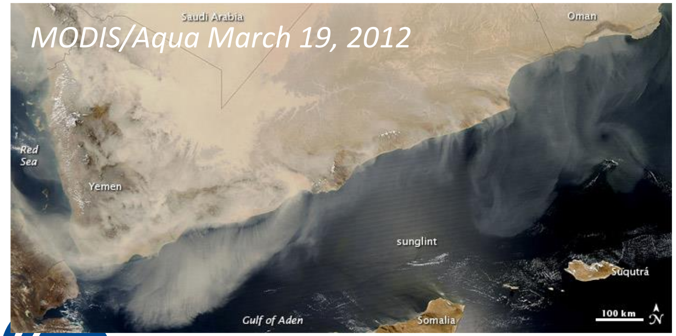
NMMB/BSC-Dust: Towards high-resolution simulations



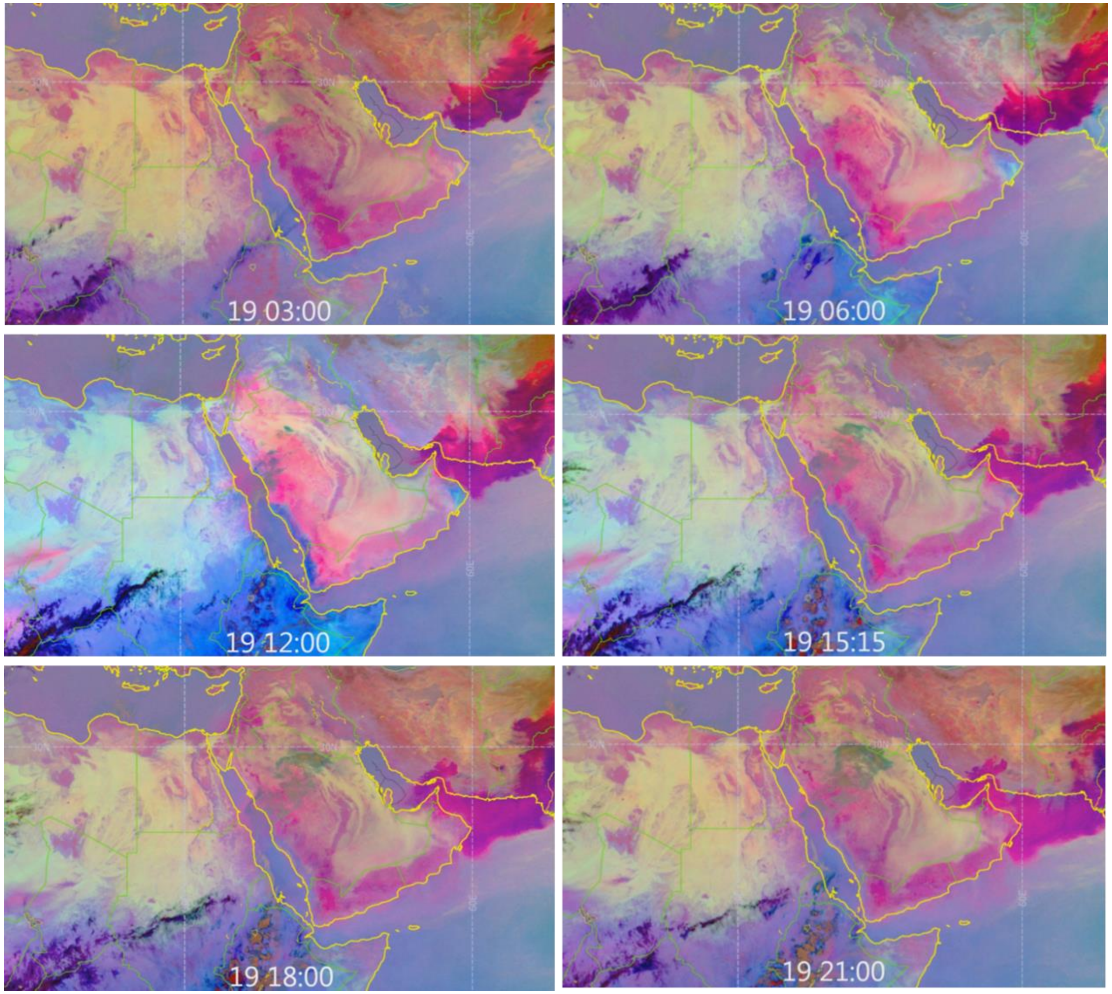
NMMB/BSC-Dust: Towards high-resolution simulations

Impact of the topography on dust transport





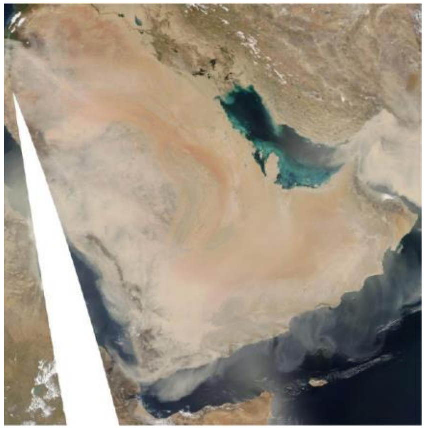
MSG/RGB March 19, 2012



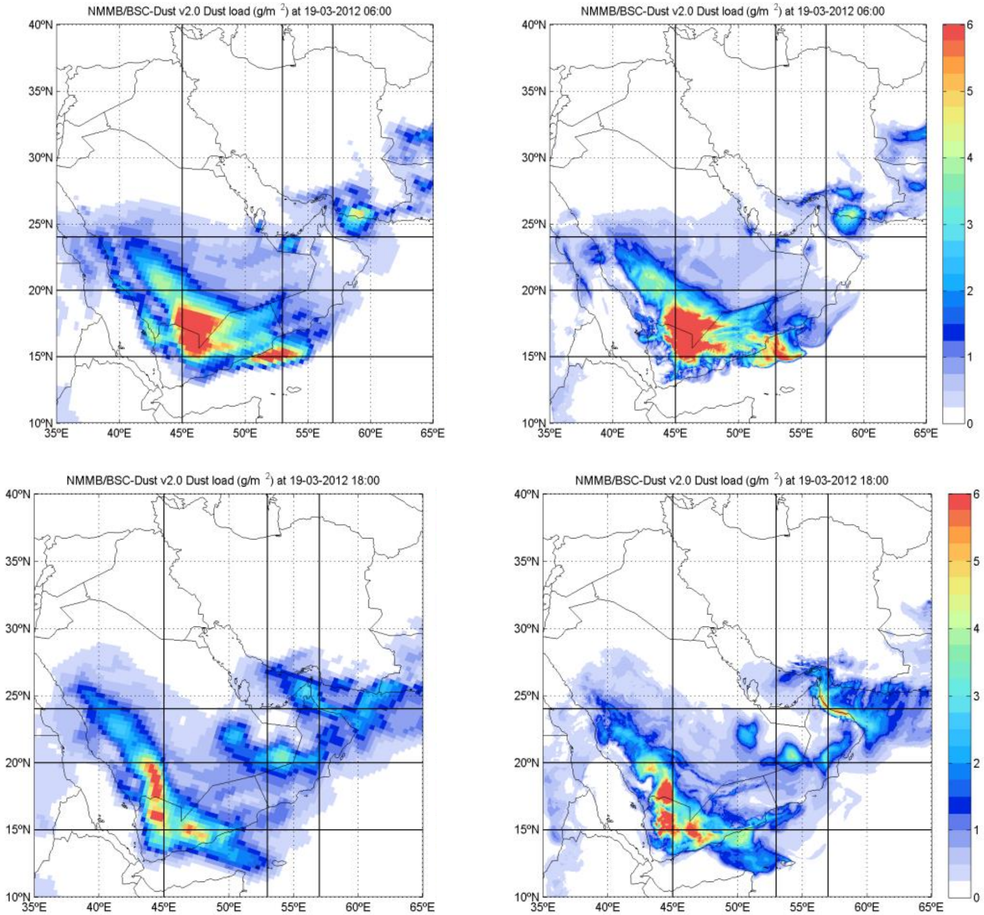
Basart and Baldasano, submitted to Aeolian Research

NMMB/BSC-Dust: Towards high-resolution simulations

The impact of model resolution in dust propagation in a complex terrain region such as West Asia: ***19th March 2012***

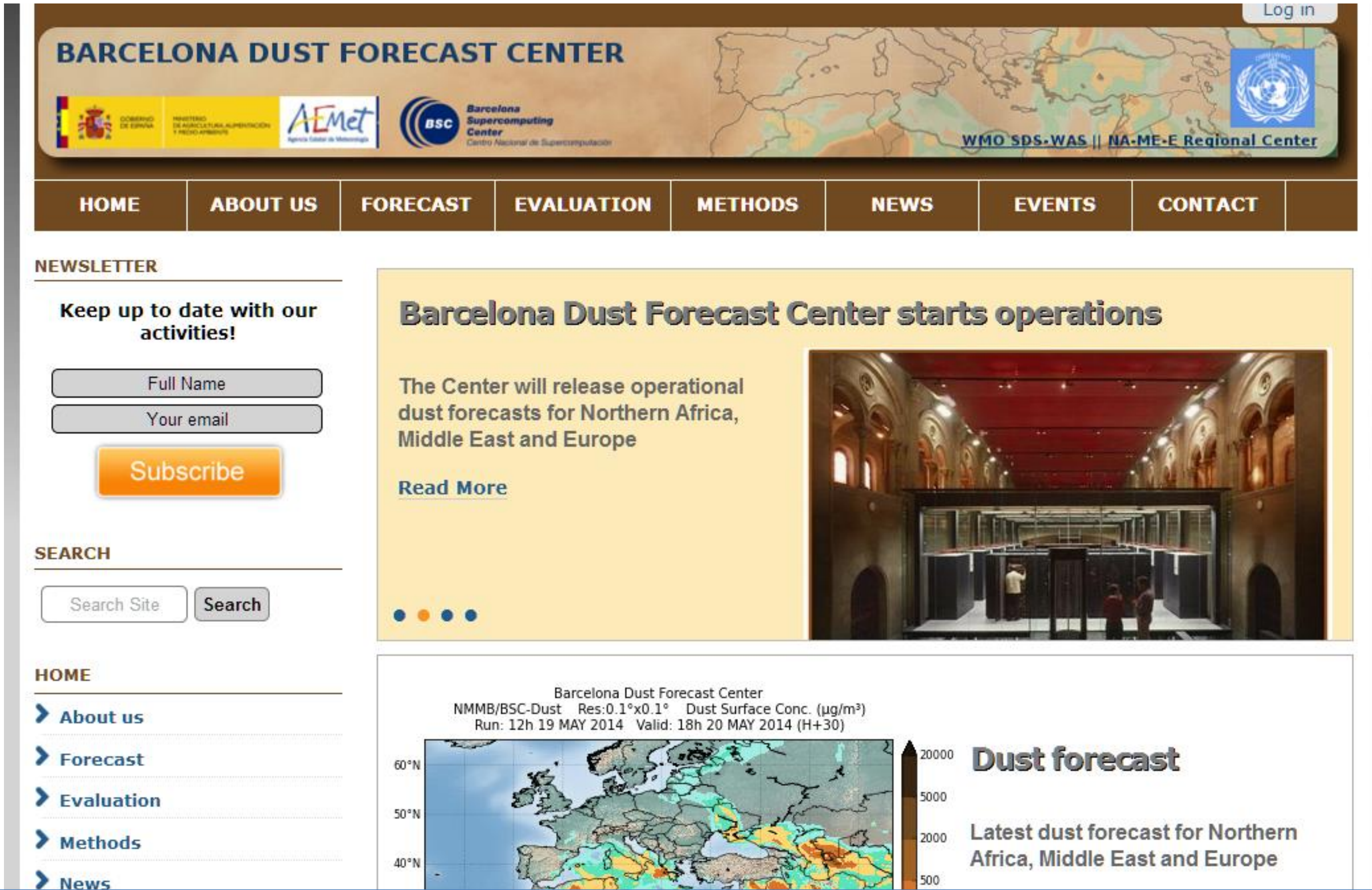


Exp. 0.33º x 0.33º ***Exp. 0.03º x 0.03º***



Basart and Baldasano, submitted to Aeolian Research

Barcelona Dust Forecasting Center (http://dust.aemet.es/)

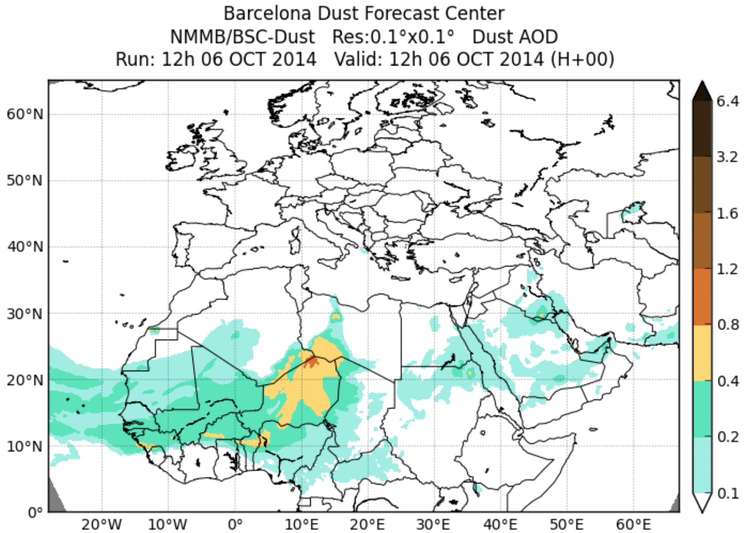


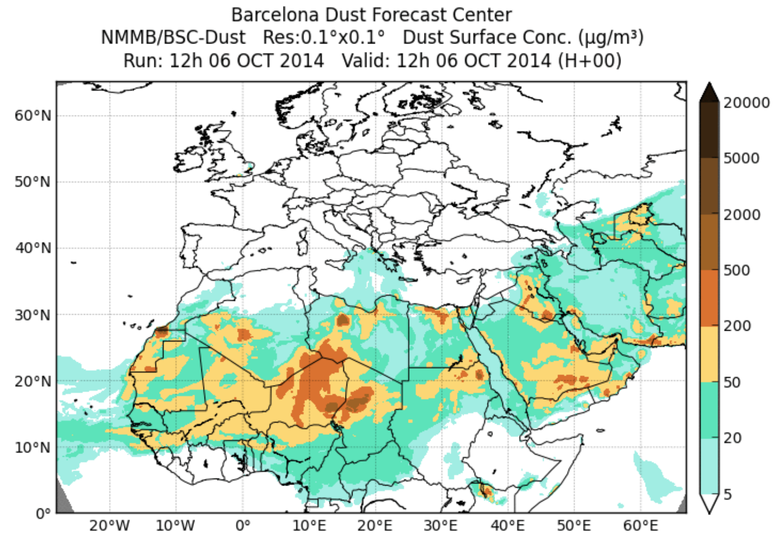
First Specialized Center for Mineral Dust Prediction of WMO

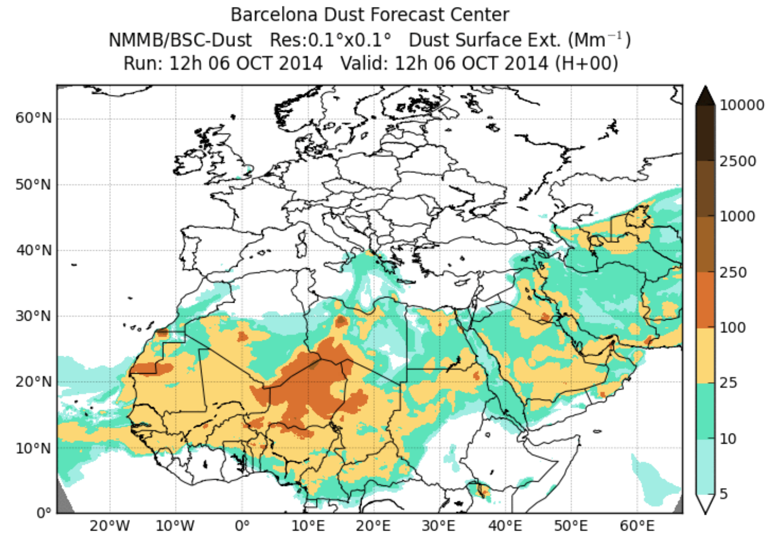
***NMMB/BSC-Dust** selected to provide operational forecasts at high resolution (10km) for NAMEE region*

BDFC (http://dust.aemet.es/)

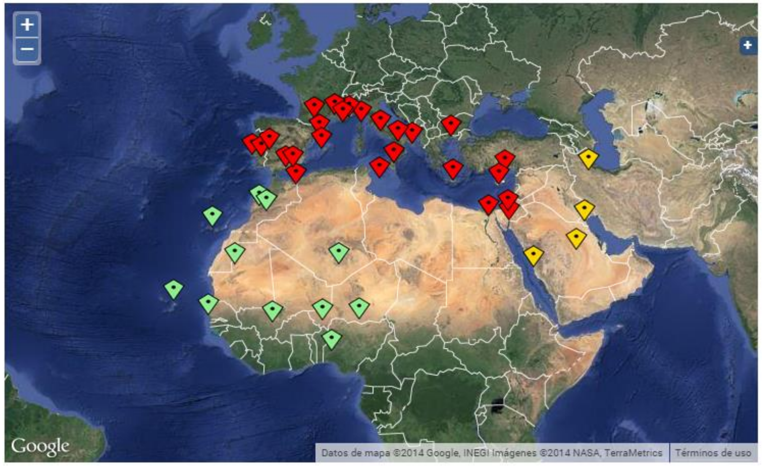
Dust Optical Depth at 550nm
Dust Dry Deposition
Dust Load
Dust Surface Concentration
Dust Surface Extinction at 550nm
Dust Wet Deposition







BDFC : NRT Evaluation using AERONET



Monthly scores

Date 2014-09

Methods: AERONET-based scores

Sep 2014. Dust Optical Depth.
Threshold Angstrom Exponent = 0.600

	BIAS	ROOT MEAN SQUARE ERROR	CORRELATION COEFFICIENT	FRACTIONAL GROSS ERROR	NUMBER OF CASES
Sahel/Sahara show stations	-0.23	0.35	0.39	1.00	550
Middle East show stations	-0.17	0.18	0.30	0.91	19
Mediterranean show stations	-0.26	0.33	0.27	1.50	414
TOTAL	-0.24	0.34	0.36	1.21	983

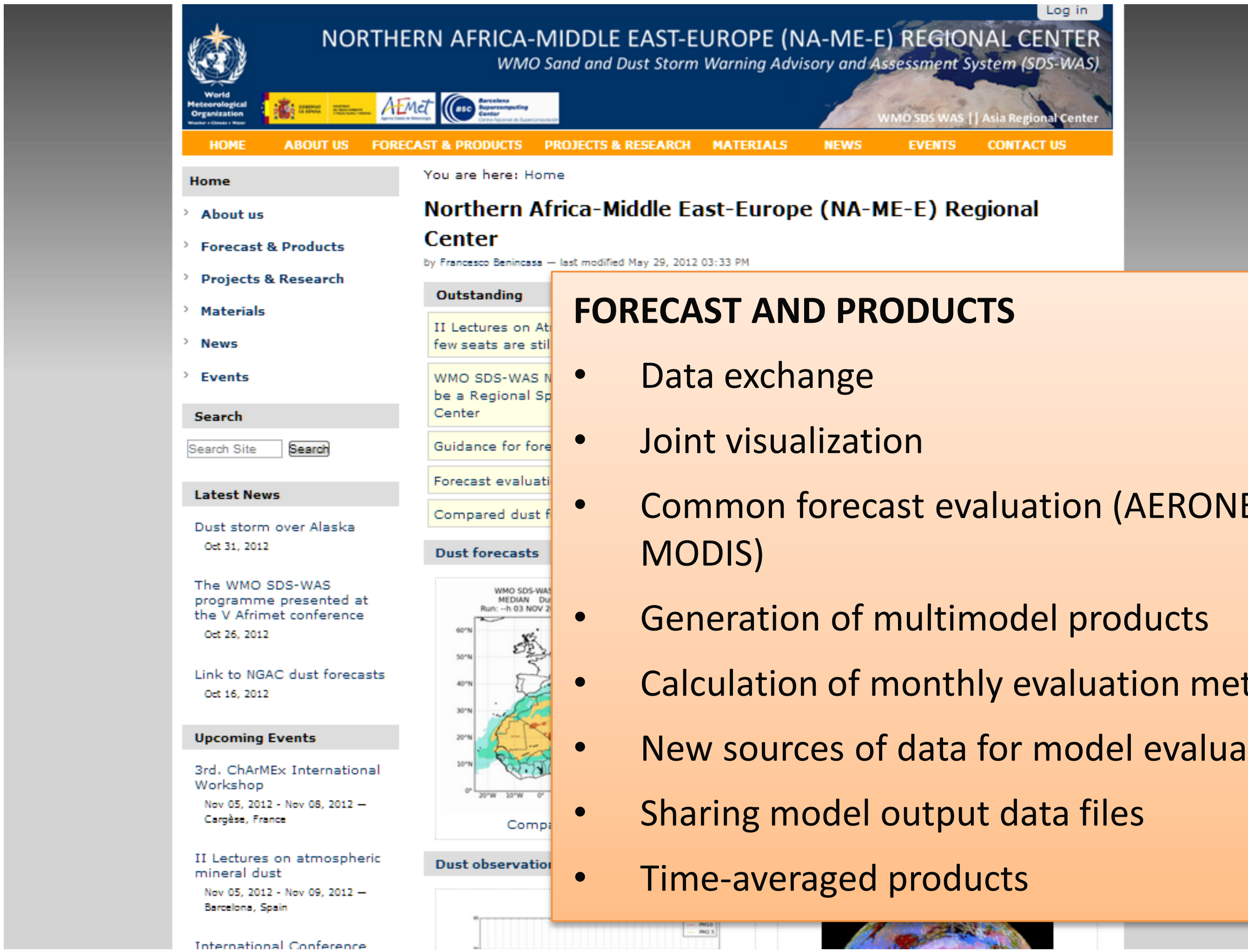
A set of evaluation metrics are selected:

- Bias
- RMSE
- correlation coefficient
- FGE

Calculations evaluation metrics are done for:

- monthly/seasonal/annual
- sites and regions

SDS-WAS NA-ME-E RC (http://sds-was.aemet.es/)



FORECAST AND PRODUCTS

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

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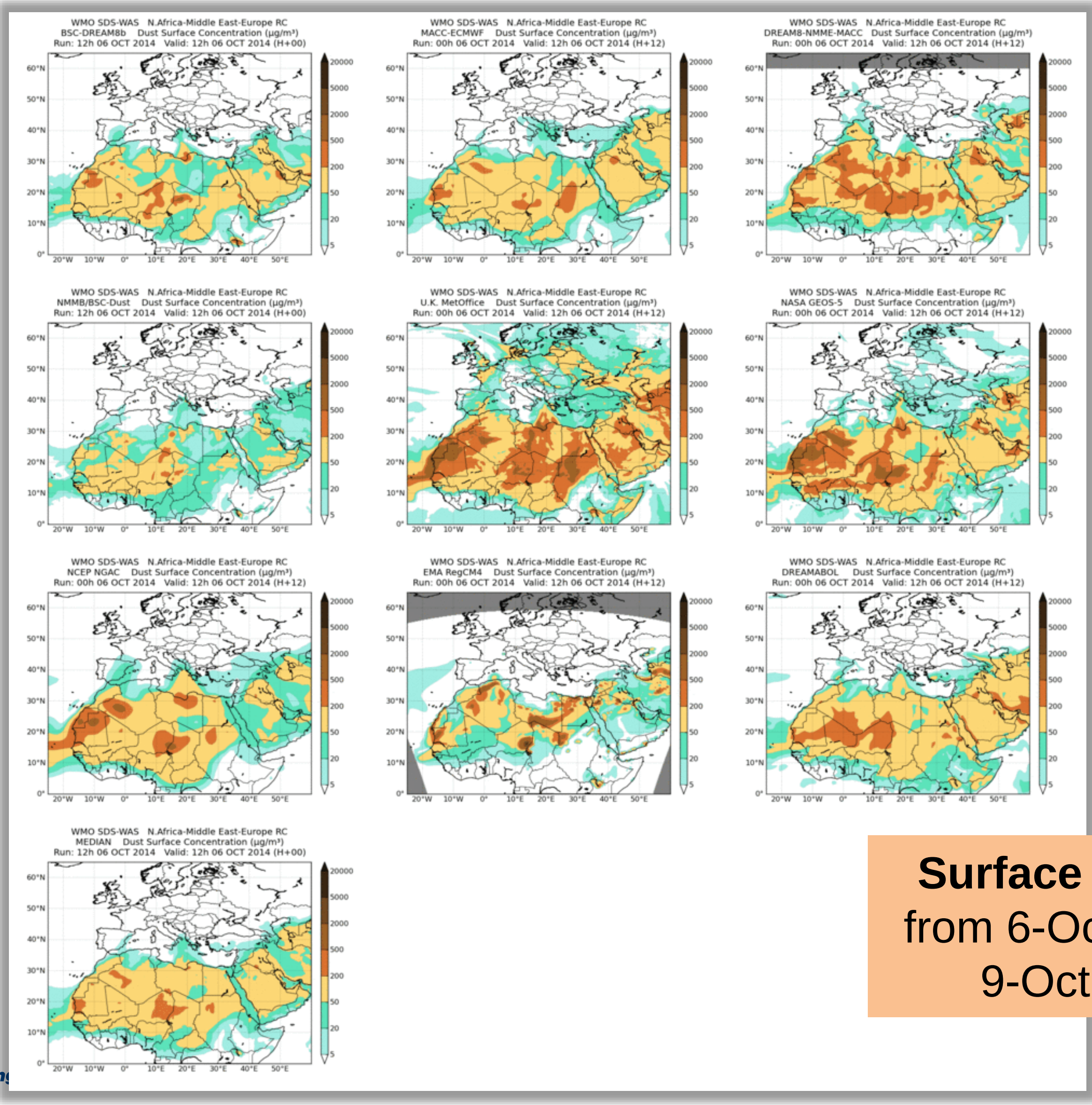
sdswas@aemet.es

SDS-WAS: Dust models

MODEL	RUN TIME	DOMAIN	DATA ASSIMILATION
BSC-DREAM8b	12	Regional	No
CHIMERE	00	Regional	No
LMDzT-INCA	00	Global	No
MACC	00	Global	MODIS AOD
DREAM-NMME-MACC	12	Regional	MACC analysis
NMMB/BSC-Dust	12	Regional	No
MetUM	00	Global	MODIS AOD
GEOS-5	00	Global	MODIS reflectances
NGAC	00	Global	No
EMA REG CM4	12	Regional	No
DREAMABOL	12	Regional	No

SDS-WAS: Surface concentration joint visualization



Surface concentration
from 6-Oct-2014 12:00 to
9-Oct-2014 00:00

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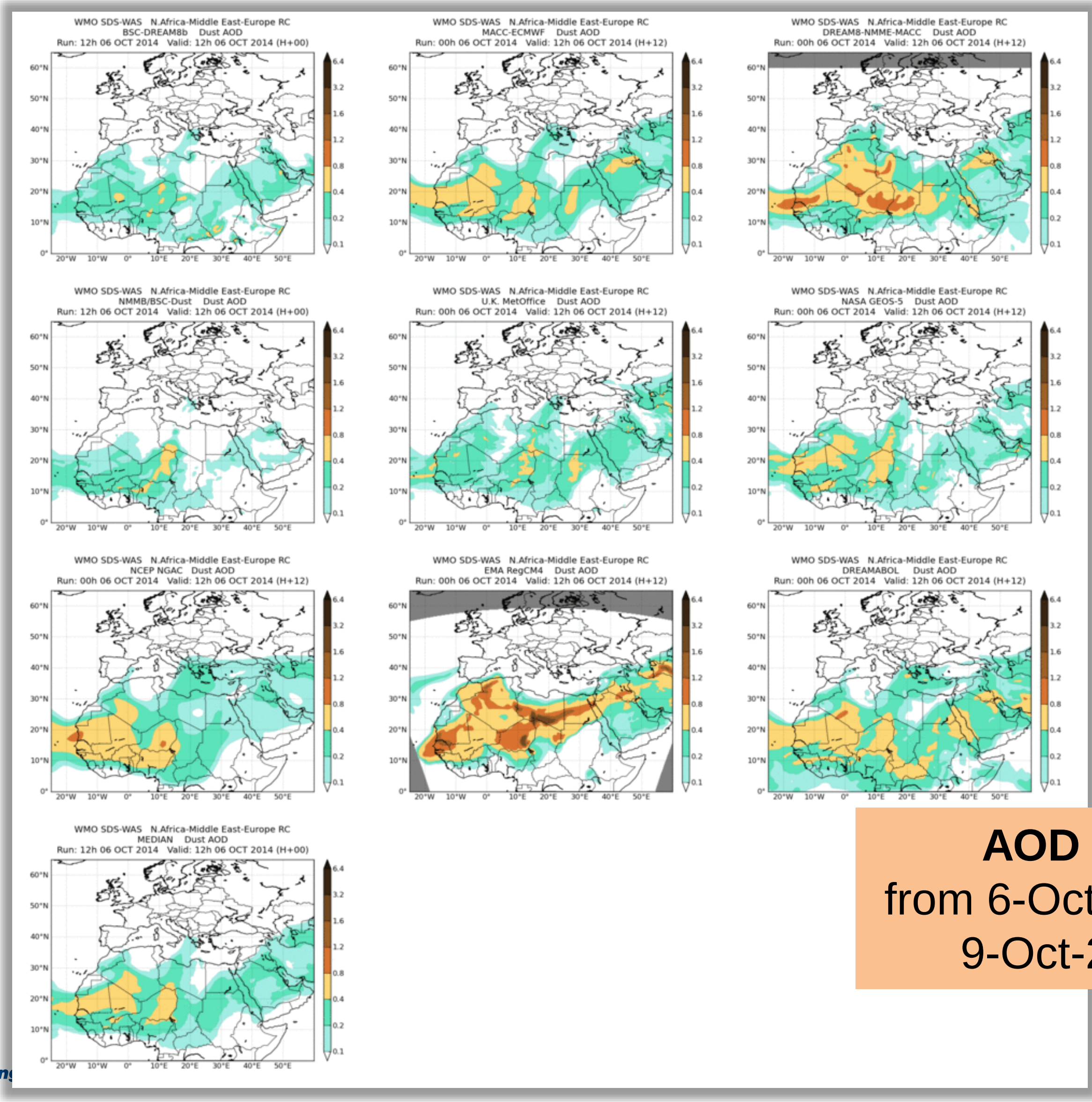
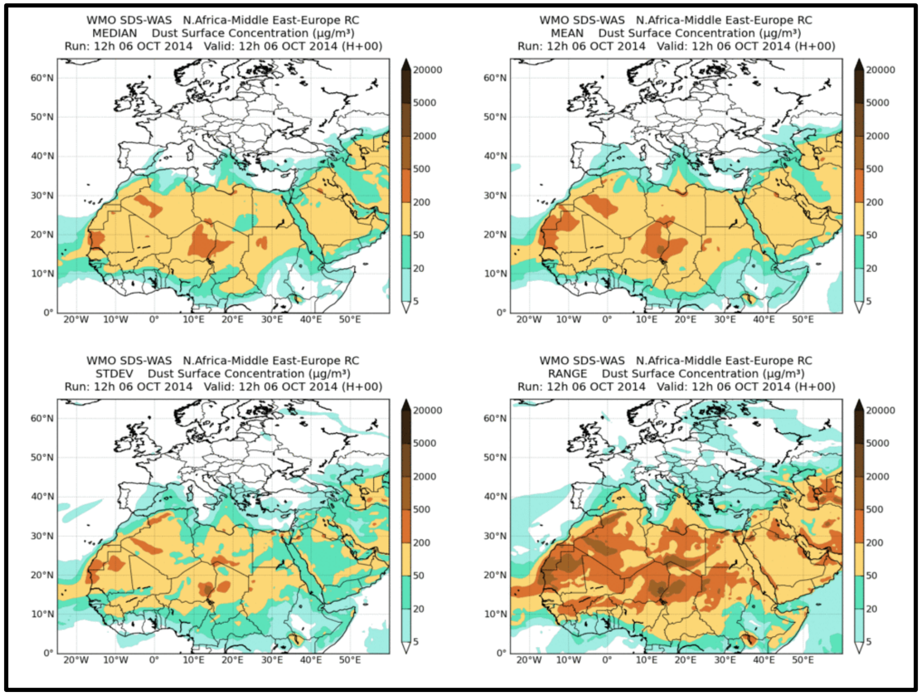
SDS-WAS: AOD joint visualization



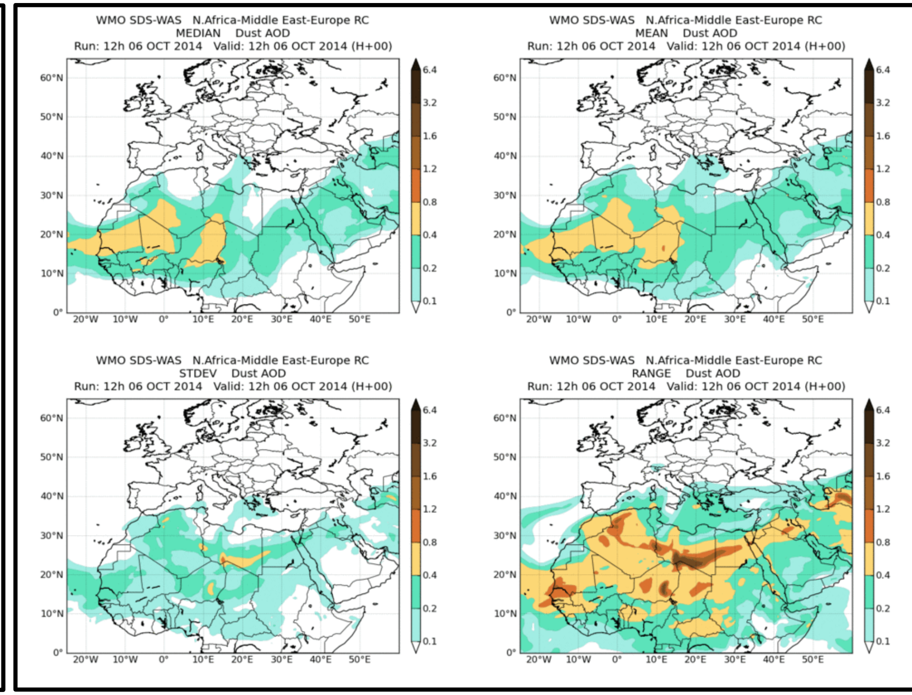
AOD at 550nm
from 6-Oct-2014 12:00 to
9-Oct-2014 00:00

SDS-WAS: Generation of multi-model products

Surface concentration



AOD at 550nm



from 6-Oct-2014 12:00 to 9-Oct-2014 00:00

Model outputs are bi-linearly interpolated to a common 0.5ºx0.5º grid mesh. Then, different multi-model products are generated:

CENTRALITY: median - mean

SPREAD: standard deviation – range of variation

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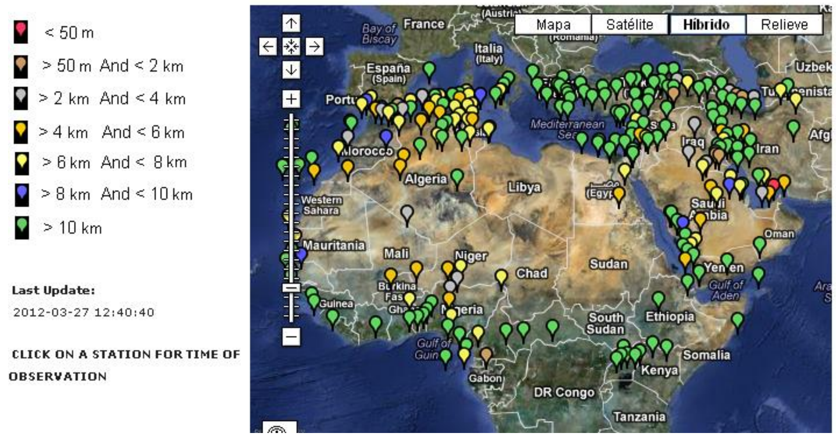
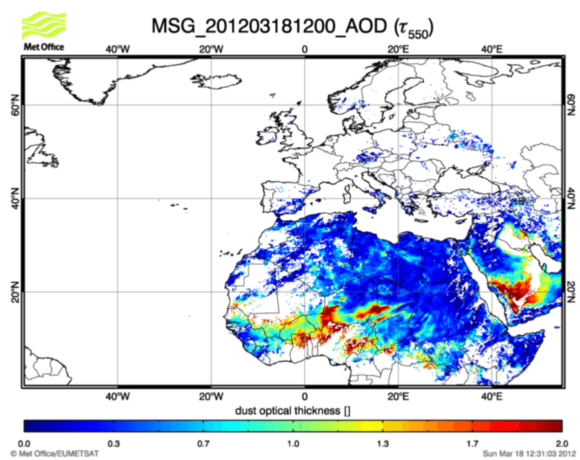
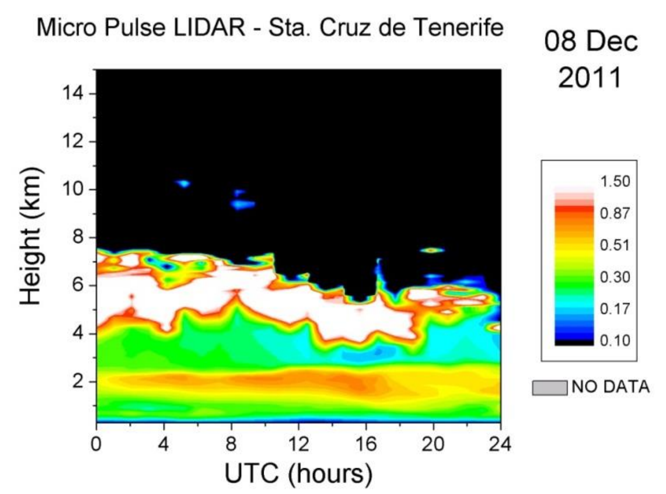
New sources of data for model evaluation

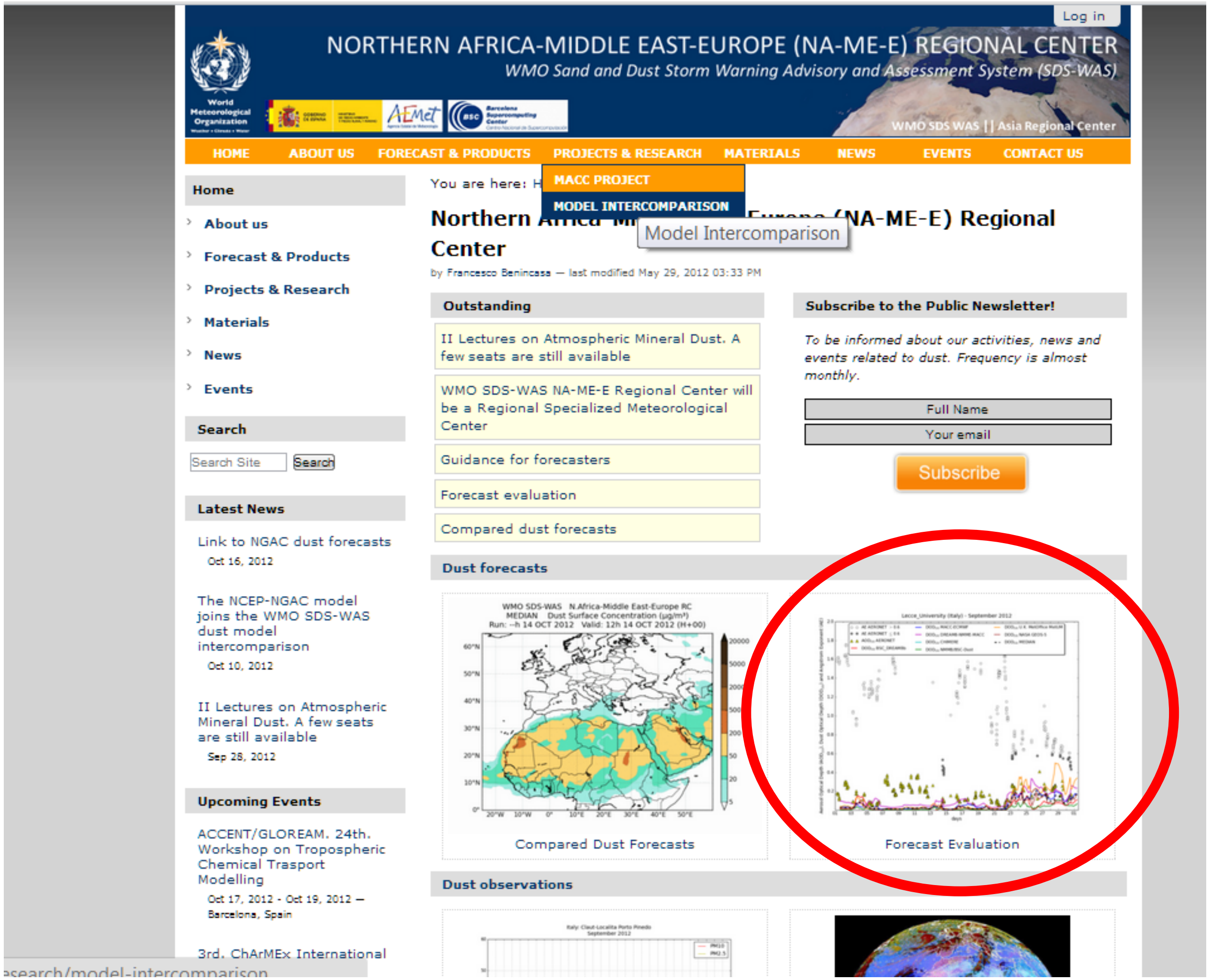
- Visibility
- MSG/SEVIRI
- MODIS
- OMI
- CALIPSO
- PARASOL
- MPLNET
- PM_{10}







SDS-WAS: Model intercomparison



http://sds-was.aemet.es

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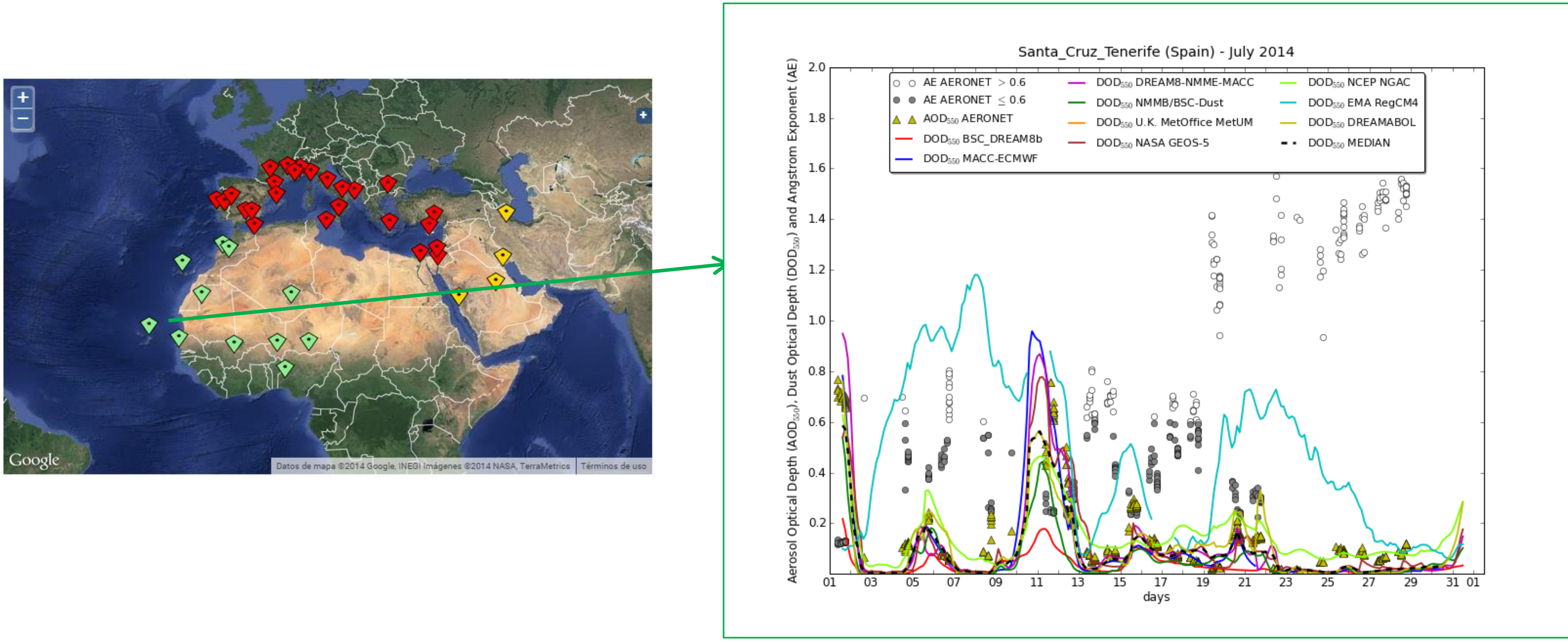
SDS-WAS: NRT Evaluation using AERONET



Model evaluation metrics (bias, correlation, RMSE and FGE) are calculated:

- By regions: NA-ME-E, Sahel/Sahara, Middle East and Mediterranean
- By time periods: monthly, seasonal and annual

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SDS-WAS: NRT Evaluation using AERONET

You are here: Home › Forecast & Products › Forecast evaluation › Model evaluation metrics. Annual scores

Model evaluation metrics. Annual scores

by Francesco Benincasa — last modified Jun 25, 2013 10:34 AM

Date: - Select Year -

Jan 2013 - Dec 2013. Dust Optical Depth.
Threshold Angstrom Exponent = 0.600

BIAS

	BSC_ DREAM8b	MACC- ECMWF	DREAM8- NMME-MACC	NMMB/ BSC-Dust	U.K. Met Office	NASA GEOS-5	NCEP NGAC	MEDIAN
Sahel/Sahara show stations	-0.19	-0.10	-0.04	-0.12	-0.06	-0.11	0.00	-0.10
Middle East show stations	-0.19	-0.11	0.00	-0.24	-0.06	-0.18	-0.16	-0.16
Mediterranean show stations	-0.15	-0.13	-0.08	-0.17	-0.09	-0.15	-0.07	-0.13
TOTAL	-0.18	-0.11	-0.05	-0.15	-0.07	-0.13	-0.04	-0.12

ROOT MEAN SQUARE ERROR

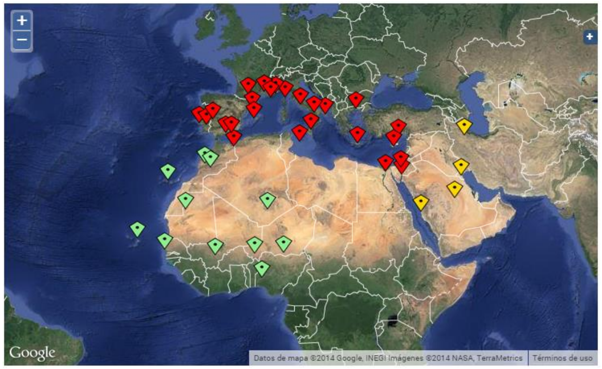
	BSC_ DREAM8b	MACC- ECMWF	DREAM8- NMME-MACC	NMMB/ BSC-Dust	U.K. Met Office	NASA GEOS-5	NCEP NGAC	MEDIAN
Sahel/Sahara show stations	0.38	0.34	0.34	0.35	0.33	0.33	0.31	0.32

A set of evaluation metrics are selected:

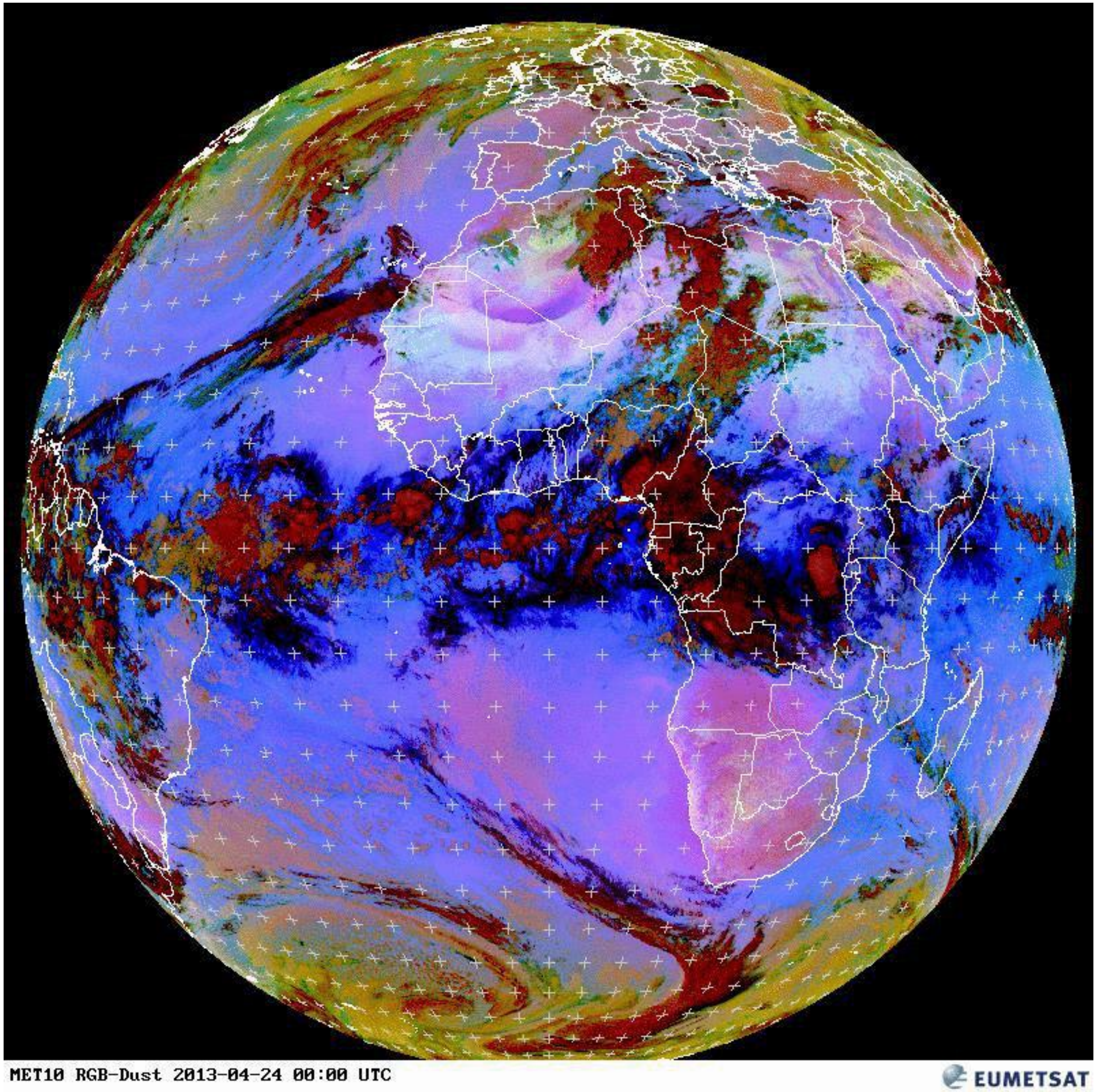
- Bias
- RMSE
- correlation coefficient
- FGE

Calculations evaluation metrics are done for:

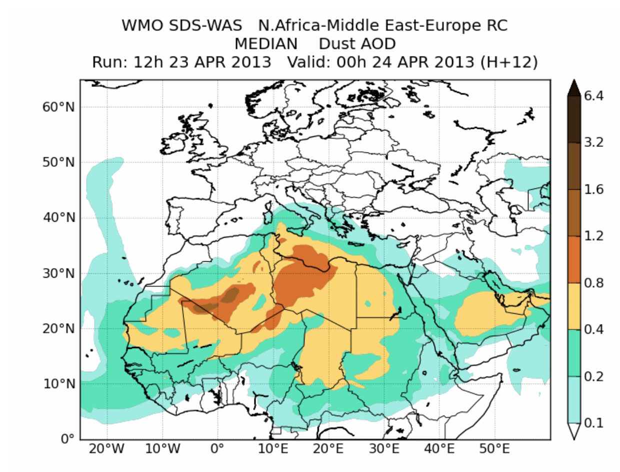
- monthly/seasonal/annual
- sites and regions



SDS-WAS: NRT Evaluation using satellite aerosol products

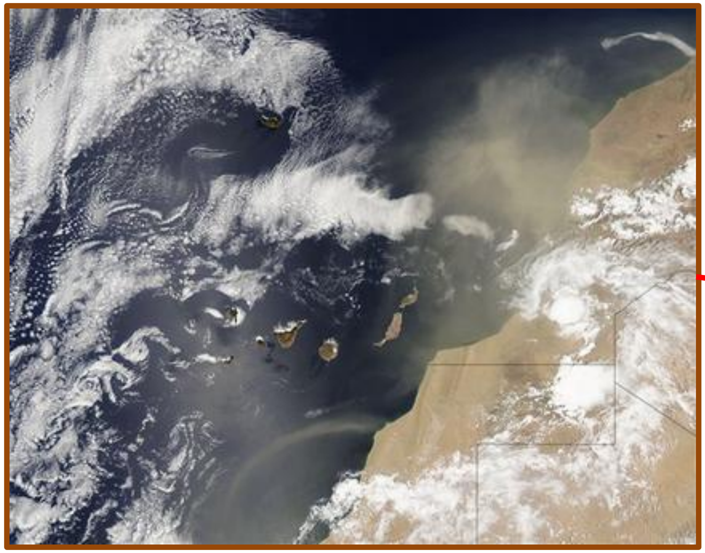


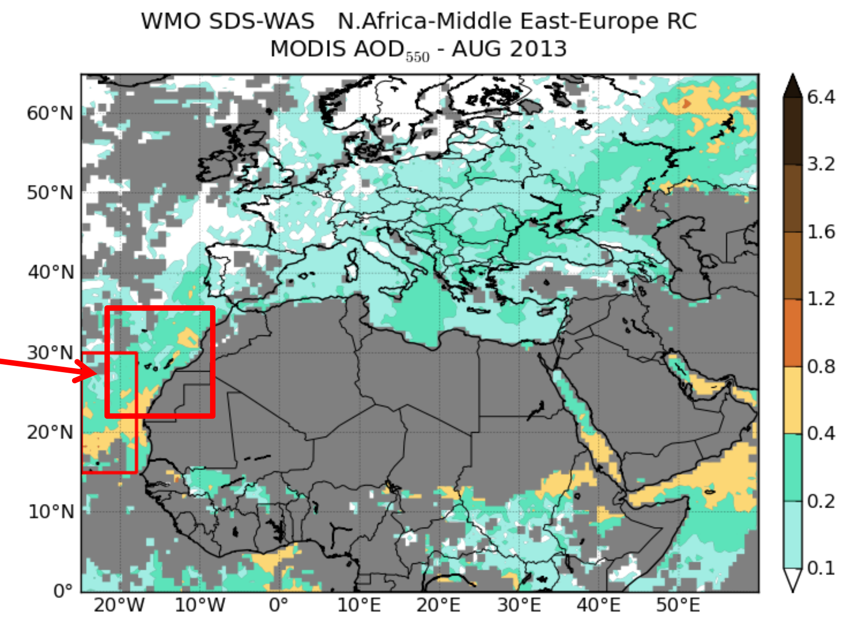
24 April 2013



SDS-WAS: NRT Evaluation using MODIS

19th August 2013

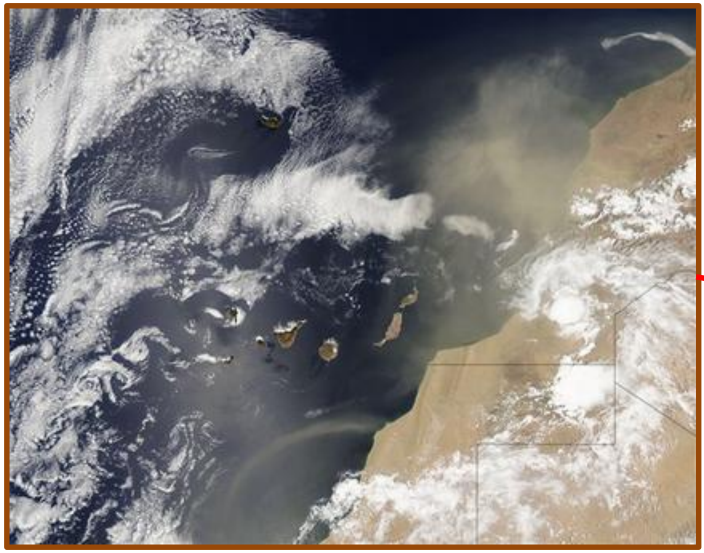


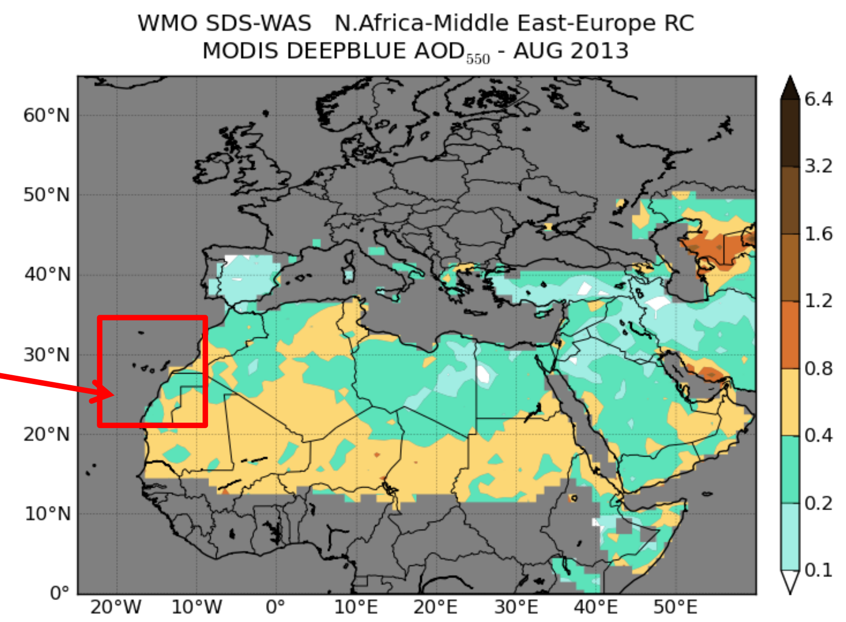


	BIAS	ROOT MEAN SQUARE ERROR	CORRELATION COEFFICIENT	FRACTIONAL GROSS ERROR	NUMBER OF CASES
BSC_ DREAM8b	-0.16	0.21	0.70	0.87	1220
NMMB/BSC-Dust	-0.13	0.20	0.68	0.81	1038
NCEP NGAC	0.14	0.21	0.78	0.41	1228

SDS-WAS: NRT Evaluation using MODIS Deep Blue

19th August 2013





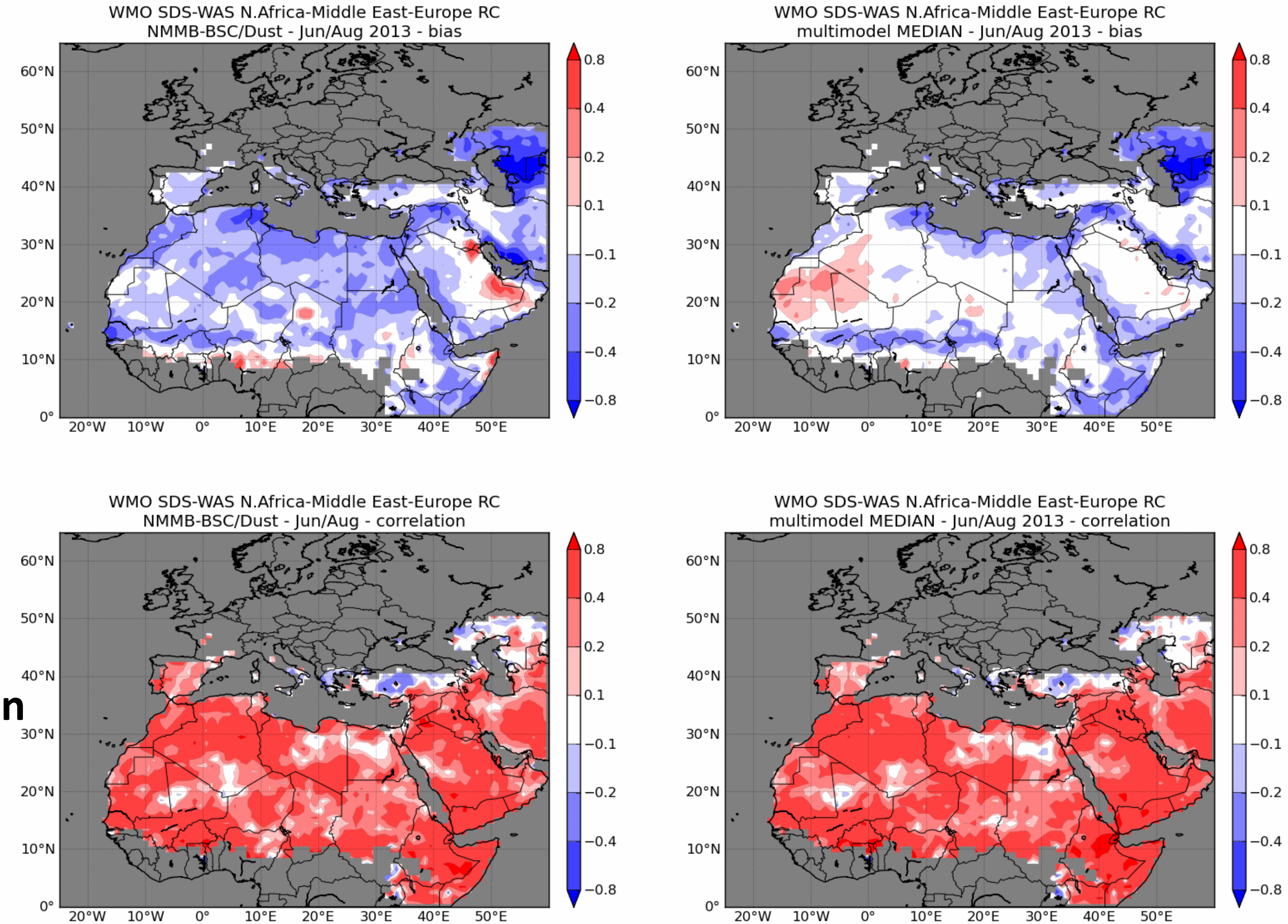
	BIAS	ROOT MEAN SQUARE ERROR	CORRELATION COEFFICIENT	FRACTIONAL GROSS ERROR	NUMBER OF CASES
BSC_ DREAM8b	-0.17	0.31	0.28	0.96	42618
NMMB/BSC-Dust	-0.20	0.33	0.29	1.05	41049
NCEP NGAC	-0.06	0.29	0.32	0.64	42664

SDS-WAS: NRT Evaluation using MODIS Deep Blue

NMMB-BSC/Dust | **Multimodel MEDIAN**

MB

Correlation



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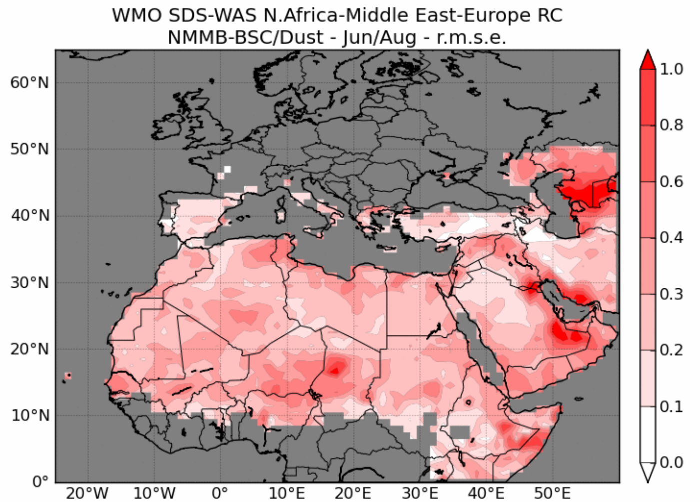
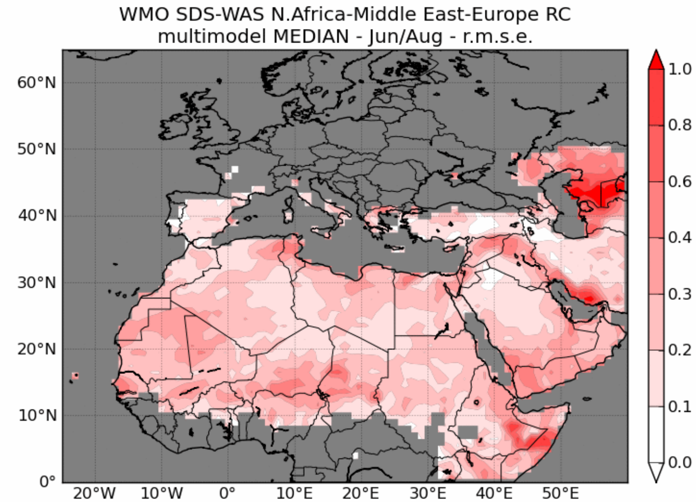
SDS-WAS: NRT Evaluation using MODIS Deep Blue

NMMB-BSC/Dust

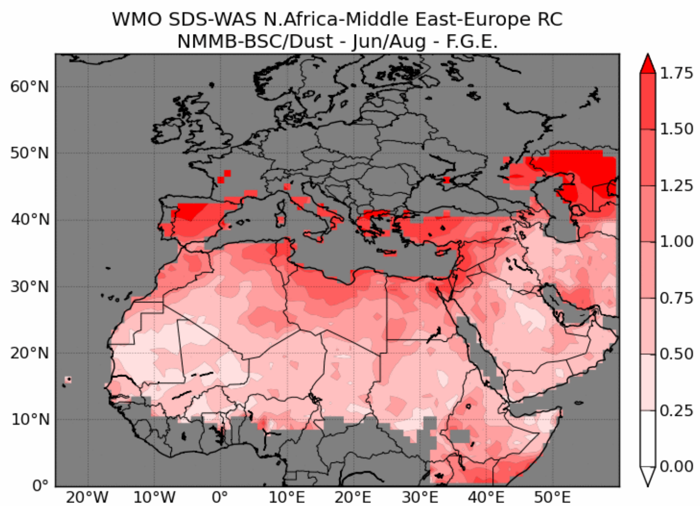
Multimodel MEDIAN

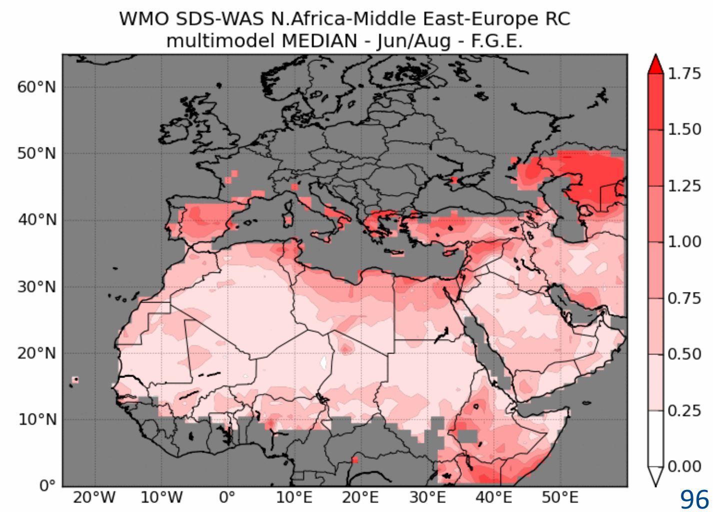
RMSE





FGE





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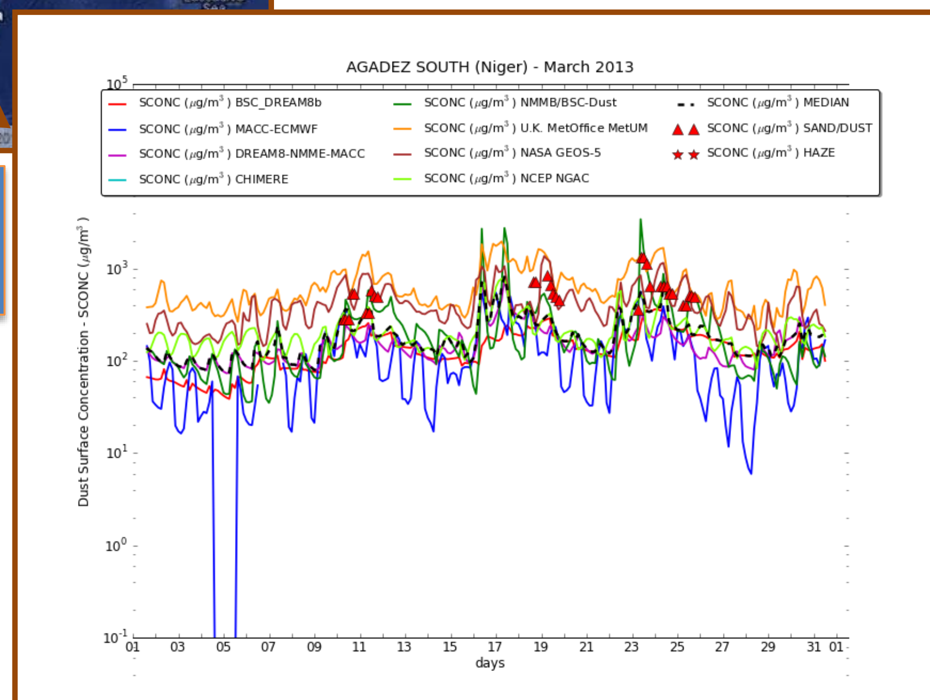
SDS-WAS: Evaluation using VISIBILITY data

AGADEZ SOUTH, Niger
March 2013



$PM10 = 1339.84\ V^{-0.67}$
Ben Mohamed et al. (1992)

$PM10 = 1772.24\ V^{-1.1}$
Camino et al. (2014, Aeolian Res.)

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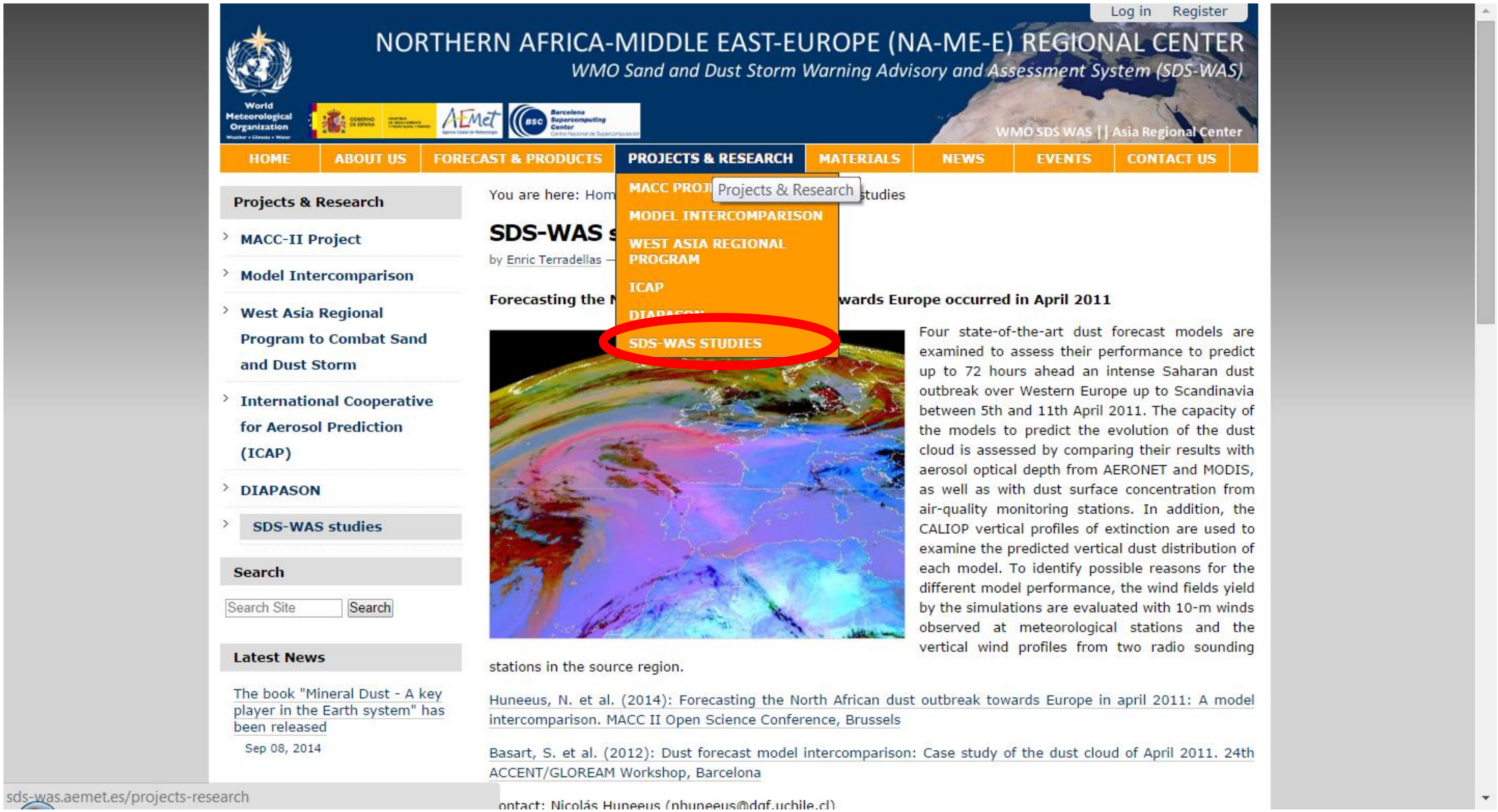
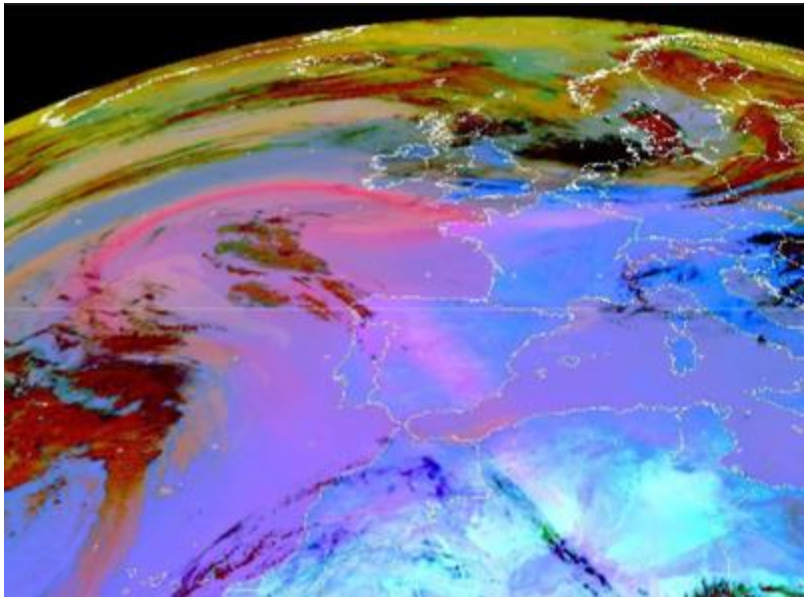
SDS-WAS: Model intercomparison



http://sds-was.aemet.es

SDS-WAS: Model intercomparison April 2011



MSG/SEVIRI RGB product 7 April
Courtesy of EUMETSAT

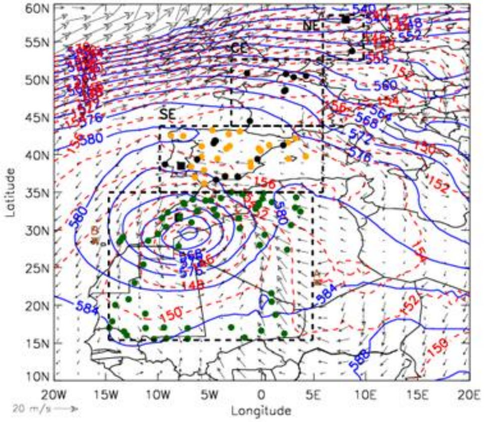
- The selected dust event corresponds to the one which occurred between the 5th and 11th of April of 2011.
- Participating models: BSC-DREAM8b, NMMB/BSC-Dust, ECMWF-MACC, UKMetOffice-UM and NMME-DREAM-MACC
- Comparison of each forecast (at 24, 48 and 72h) output to in-situ measurements of AOD (from AERONET), surface concentration (PM) and satellite retrieved AOD (MODIS, CALIPSO) and meteorology.

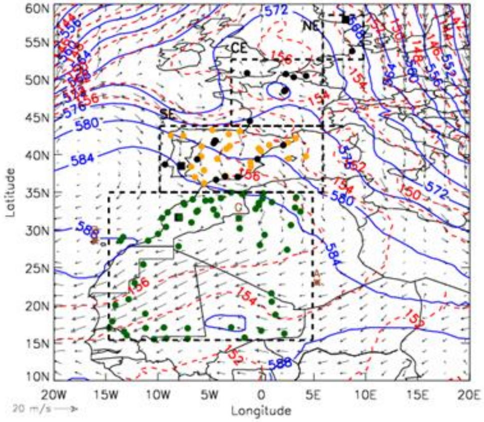
(Huneeus et al., *in preparation*)

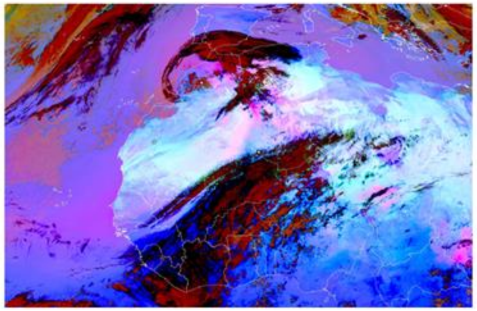
Contact: Nicolás Huneeus (nhuneeus@dgf.uchile.cl)

SDS-WAS NA-ME-E RC (http://sds-was.aemet.es/)

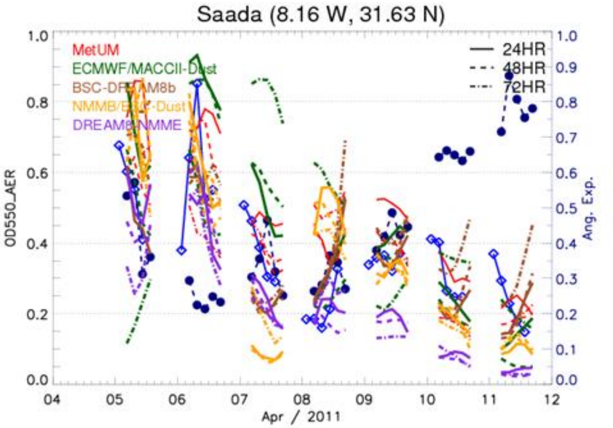
Forecasting the North African dust outbreaks towards Europe occurred in April 2011 (Hunneus et al., in preparation)

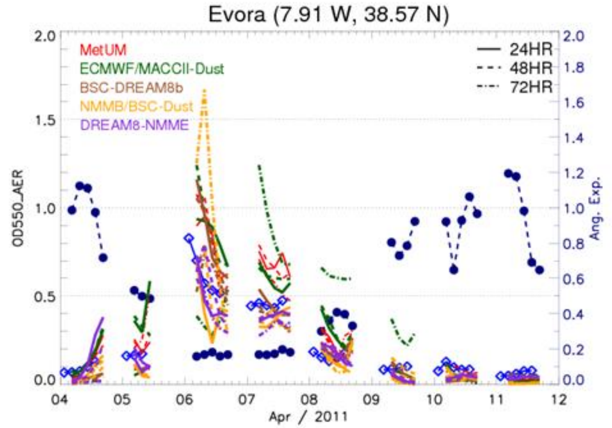


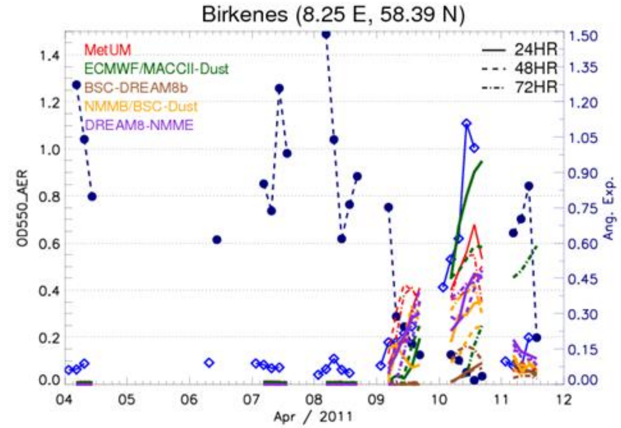




Model AOD at 550 μm against AERONET



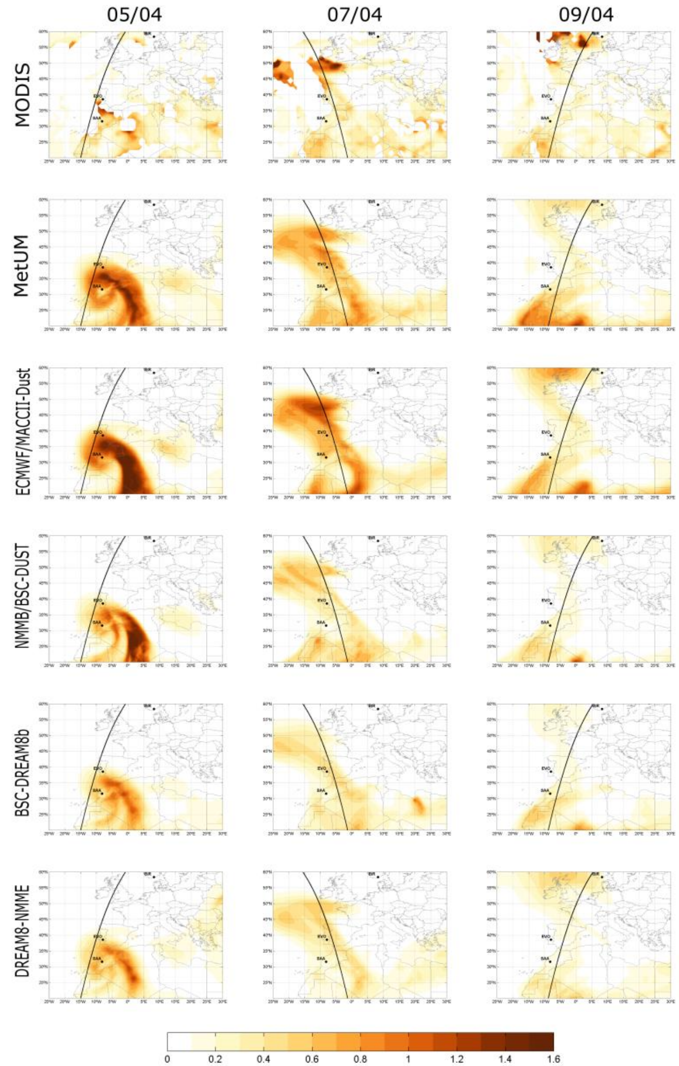




SDS-WAS NA-ME-E RC (http://sds-was.aemet.es/)

Forecasting the North African dust outbreaks towards Europe occurred in April 2011

(Hunneus et al., in preparation)



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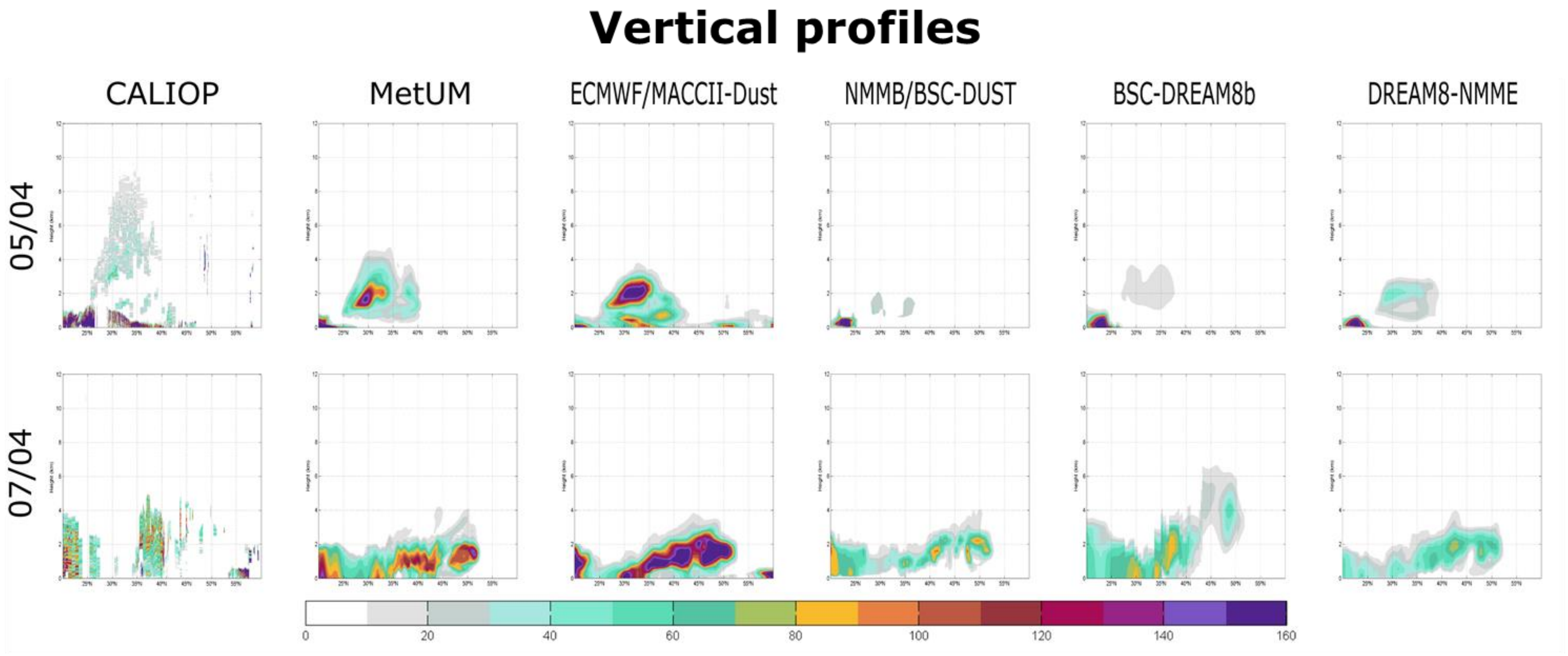
Forecasting the North African dust outbreaks towards Europe occurred in April 2011 (Hunneus et al., in preparation)



SDS-WAS: Lidar and models intercomparison

69 dust cases between Jan 2011 – Jun 2013

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BSC-DREAM8b v2
NMMB-BSC/Dust

SEEVCCC

DREAM8-NMME-MACC

Consiglio Nazionale delle Ricerche

BOLCHEM

Contact: Ioannis Binietoglou (ioannis@inoe.ro)

SDS-WAS: Study of a haboob in Iran

Case study of the small-scale extreme dust storm occurred in **Tehran** on **2nd June 2014**, at 5:30 PM local time, 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.

Contact: Slobodan Nickovic (nickovic@gmail.com)

SDS-WAS: Files download

BSC-DREAM8b v2.0	DOWNLOAD FILES	Model website
MACC-ECMWF	DOWNLOAD FILES	Model website
DREAM-NMME-MACC	DOWNLOAD FILES	Model website
NMMB/BSC-Dust	DOWNLOAD FILES	Model website
NASA-GEOS-5	DOWNLOAD FILES	Model website
NCEP-NGAC	DOWNLOAD FILES	Model website
Multimo		

Title	Size	Modified
latest - *(download all)*	4.0 kB	Apr 18, 2013 09:00 PM
2013 - *(download all)*	4.0 kB	Apr 01, 2013 09:00 PM
2012 - *(download all)*	4.0 kB	Apr 08, 2013 04:30 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.

Seminar by Francesco Benincasa

www.bsc.es

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غراسياس

Thank you

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