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Dust prediction models

Sara Basart (sara.basart@bsc.es)

Training Workshop on Sand and Dust Storms in the Arab Region, Cairo, Egypt, 10-12 February 2018

Questions will be welcome!



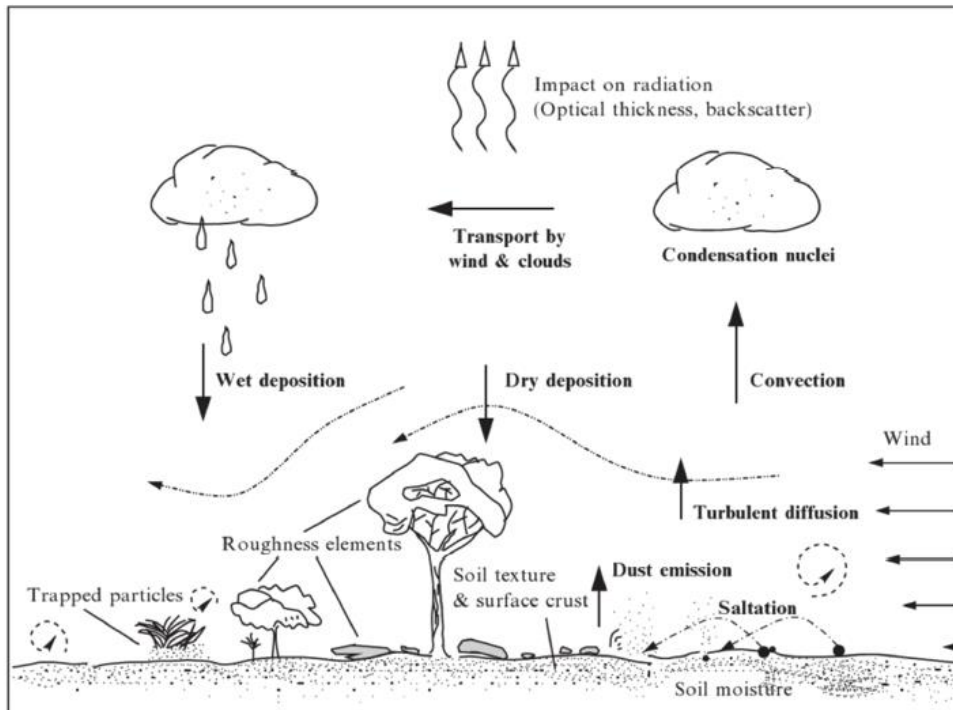
Introduction

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)

Dust forecasting models

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



Kathmandu, Nepal, March 2017

Outlook

1. Dust cycle and associated processes

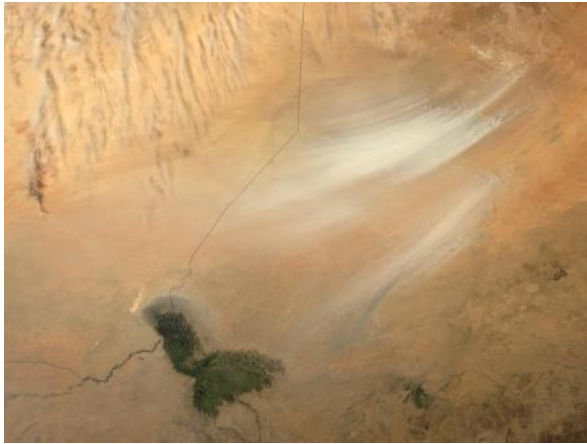
- *The atmospheric dust cycle*
- *Dust global climatology*
- *Types of dust storms and model forecasting skills*

2. Dust forecasting models

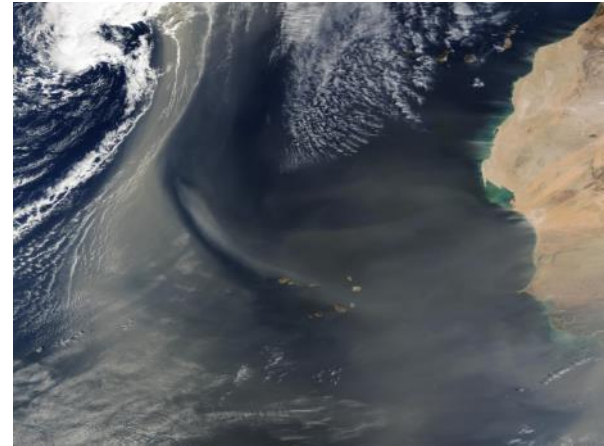
- *Dust emission schemes and dust sources*
- *Dust transport*
- *Dust deposition and sedimentation*

3. Modeling the dust cycle at BSC: From R&D to operational

Dust cycle and associated processes



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

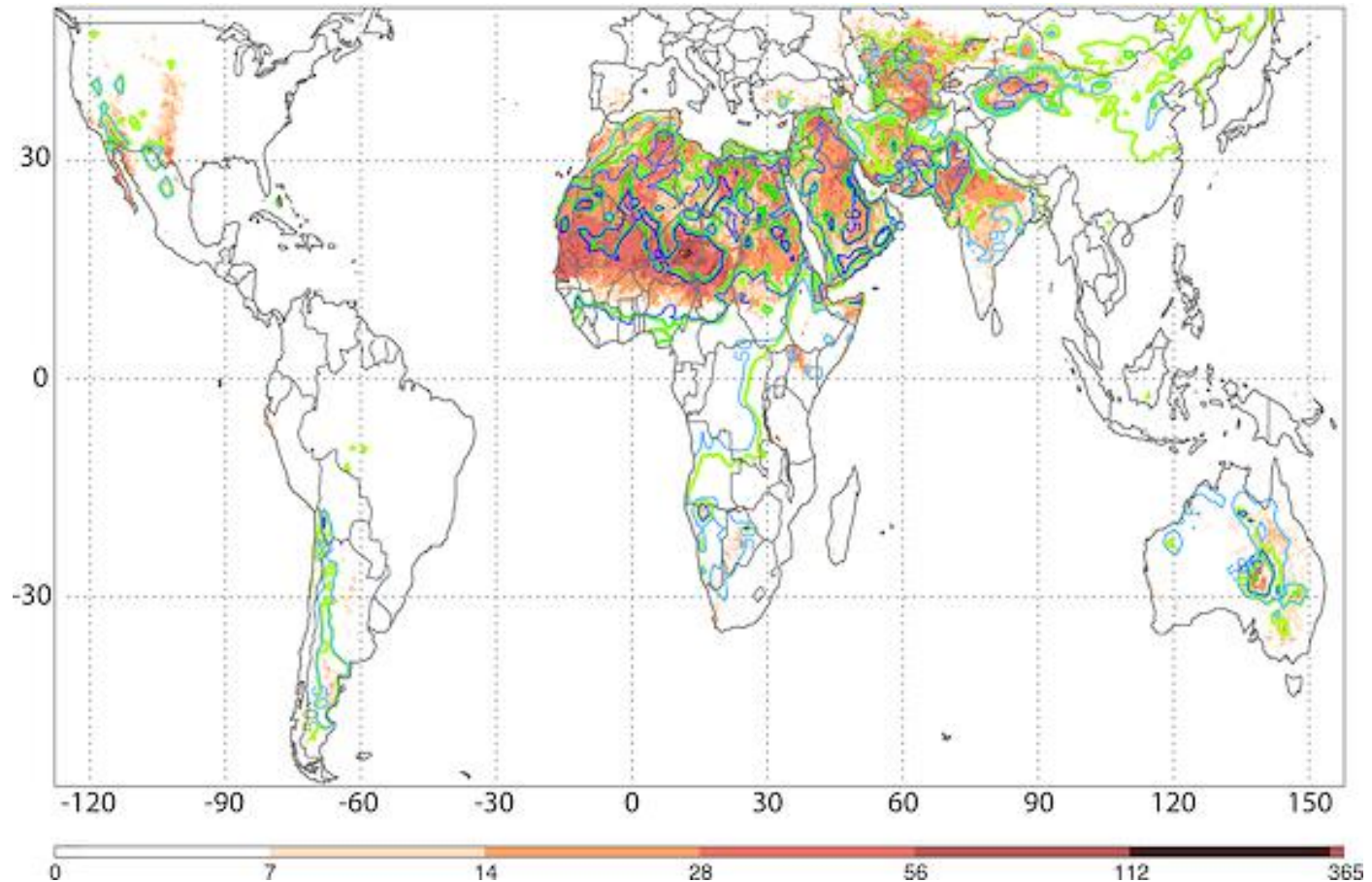


MODIS True color Western Africa – Atlantic Ocean

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 cycle and associated processes

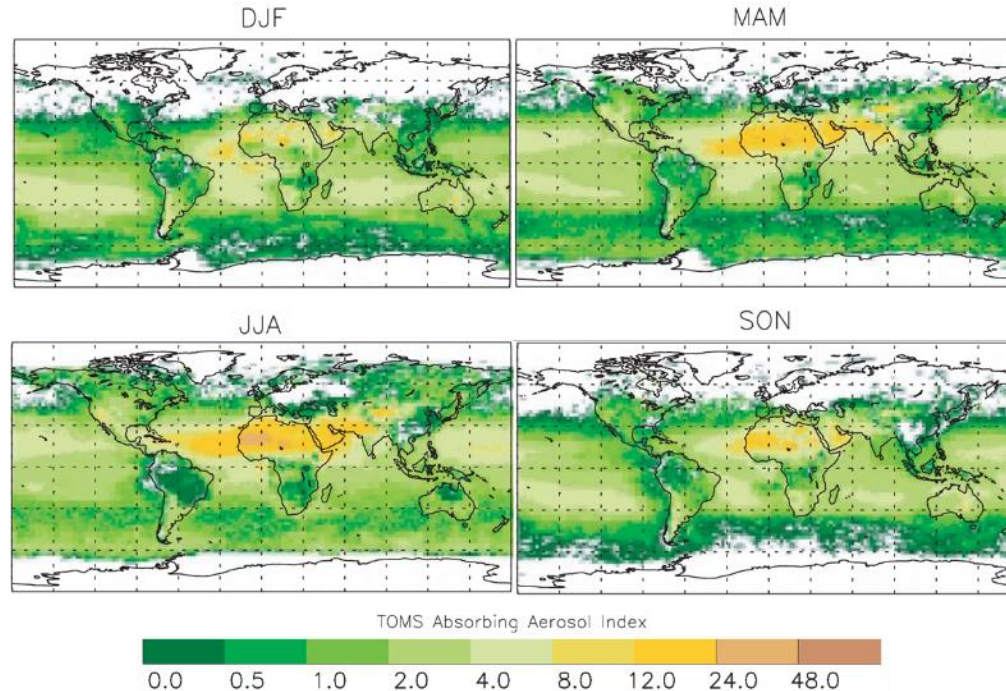
Dust global distribution



Global-scale attribution of anthropogenic and natural dust sources and their emission rates based on MODIS Deep Blue aerosol products by Ginoux et al. (2012)

Dust cycle and associated processes

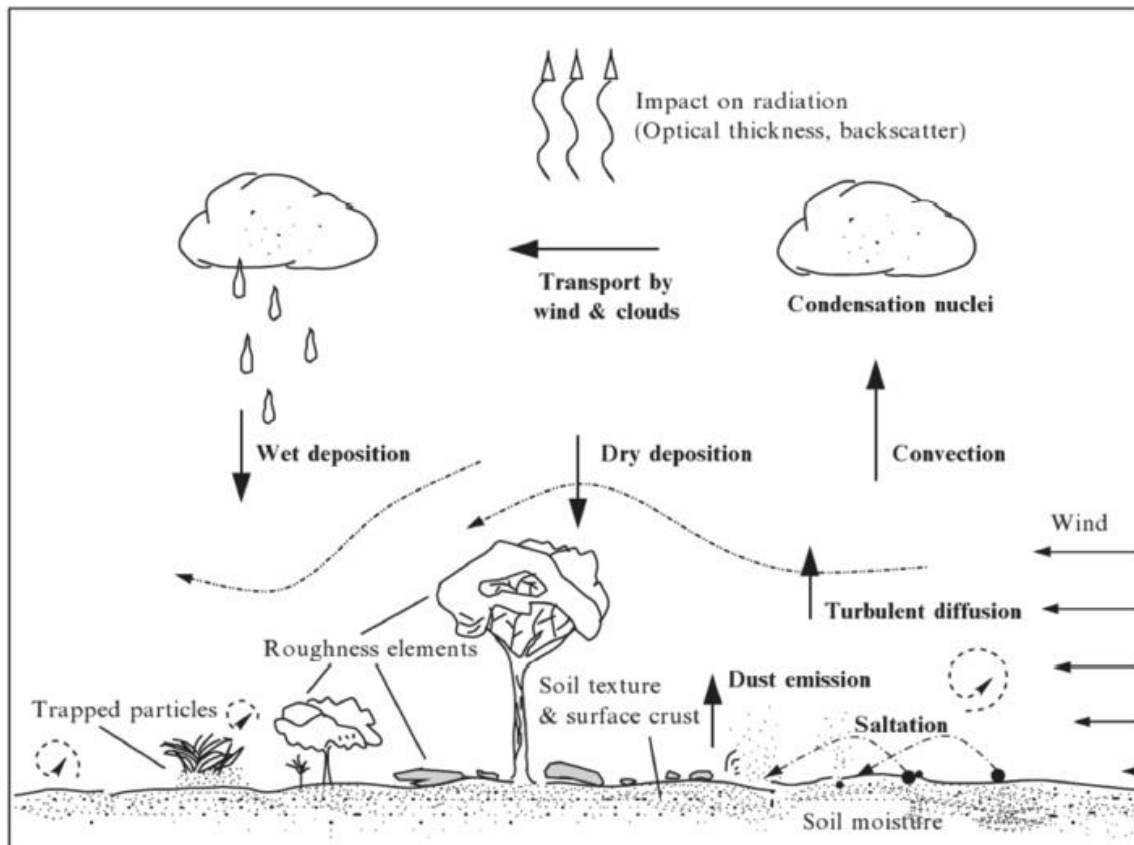
Temporal changes in the dust distribution: SEASONAL and DECADEAL CHANGES



- 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

Dust cycle and associated processes

The atmospheric dust cycle and involves a variety of processes:



Extracted from Shao (2008)

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

Dust cycle and associated processes

Dust Impacts

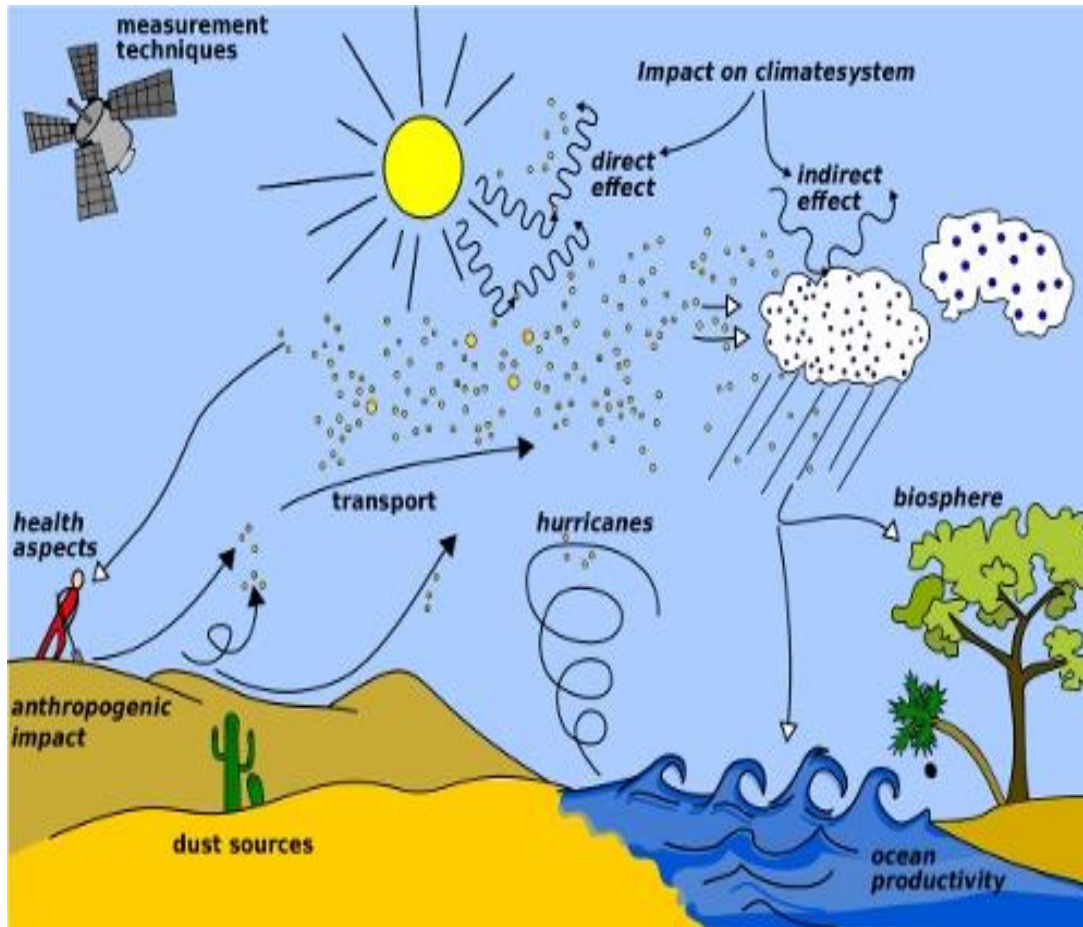


Image from WMO website
(<http://www.wmo.int/pages/prog/arep/wwrp/new/hurricanes.html>)

Ecosystems, meteorology and climate

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

Air Quality and Human Health

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

Aviation and Ground Transportation

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

Agriculture and fishing

Energy and industry

Dust cycle and associated processes

Types of dust storms:

Synoptic dust storms (large scale weather systems)

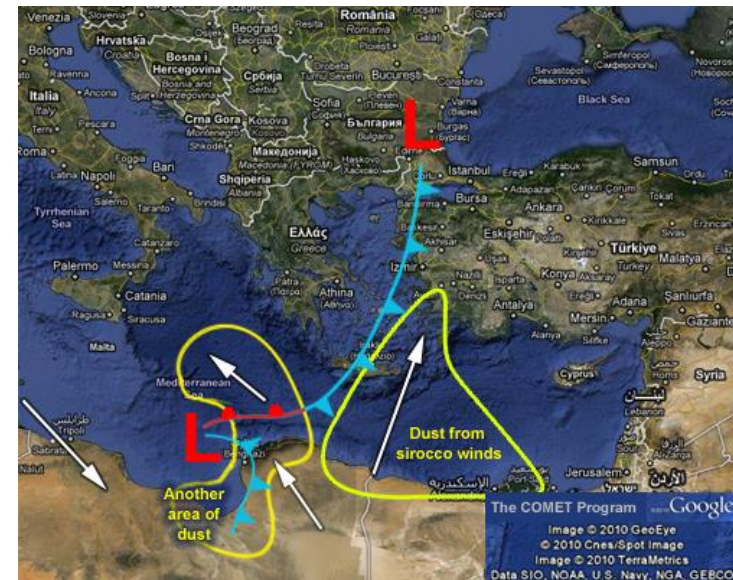
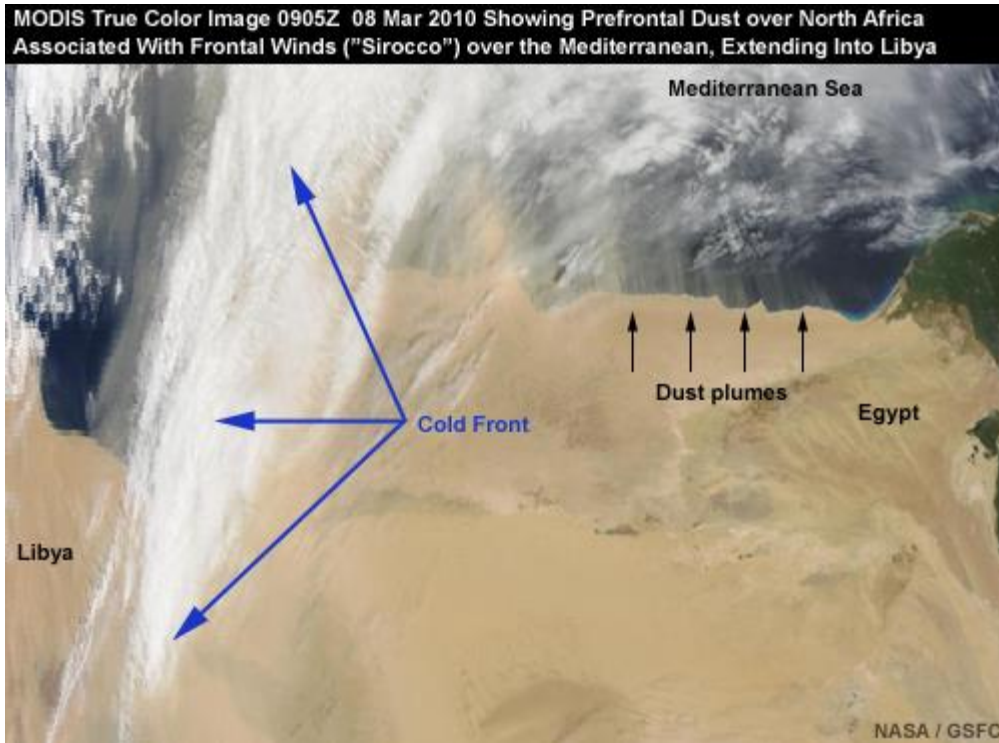
- Prefrontal winds
- Postfrontal winds
- Large-scale Trade winds
- ...

Mesoscale dust storms

- Downslope winds
- Gap flow
- Convection (dust devils and Haboobs)
- Inversion downburst storms
- ...

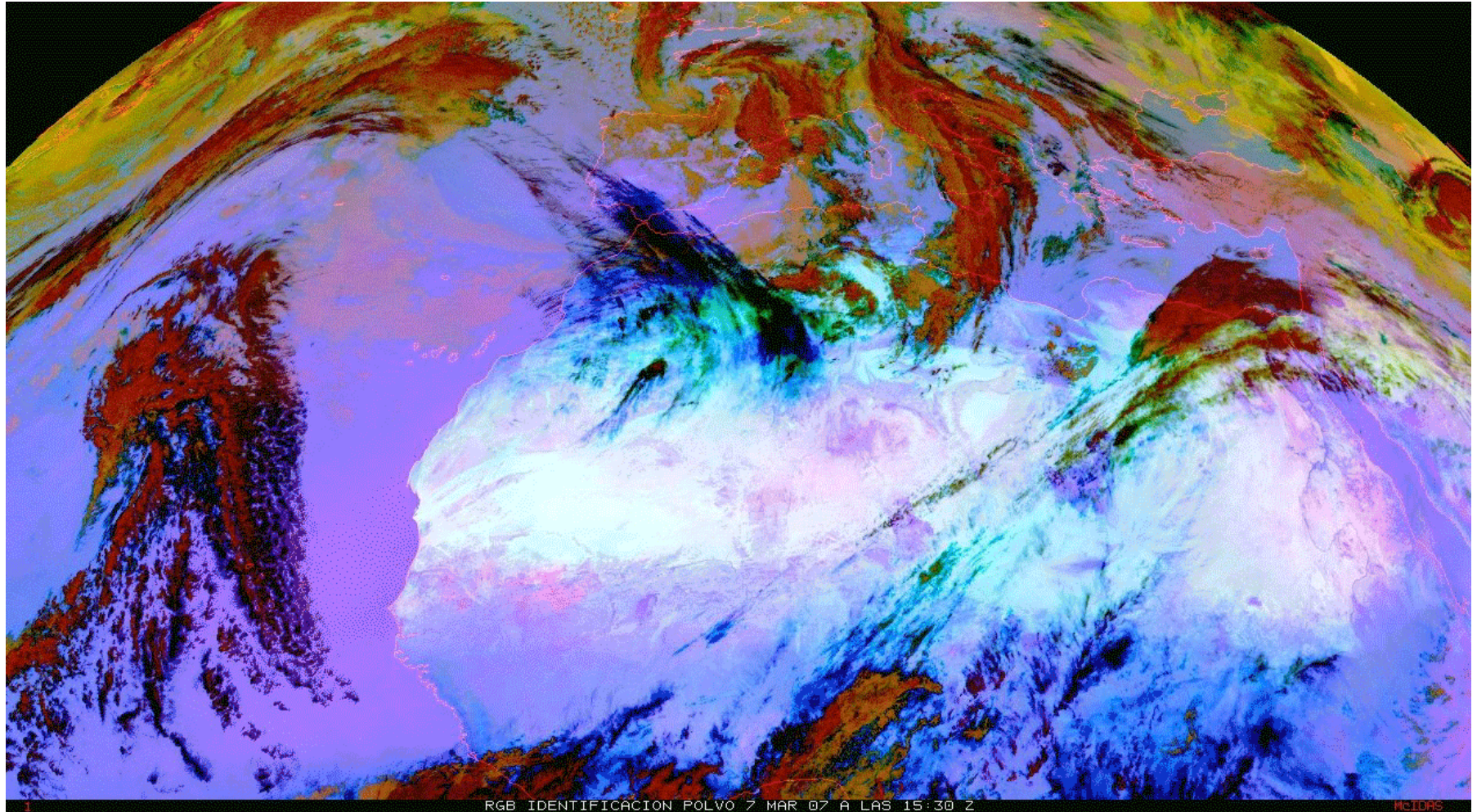
Dust cycle and associated processes

Synoptic dust storms: Pre-frontal



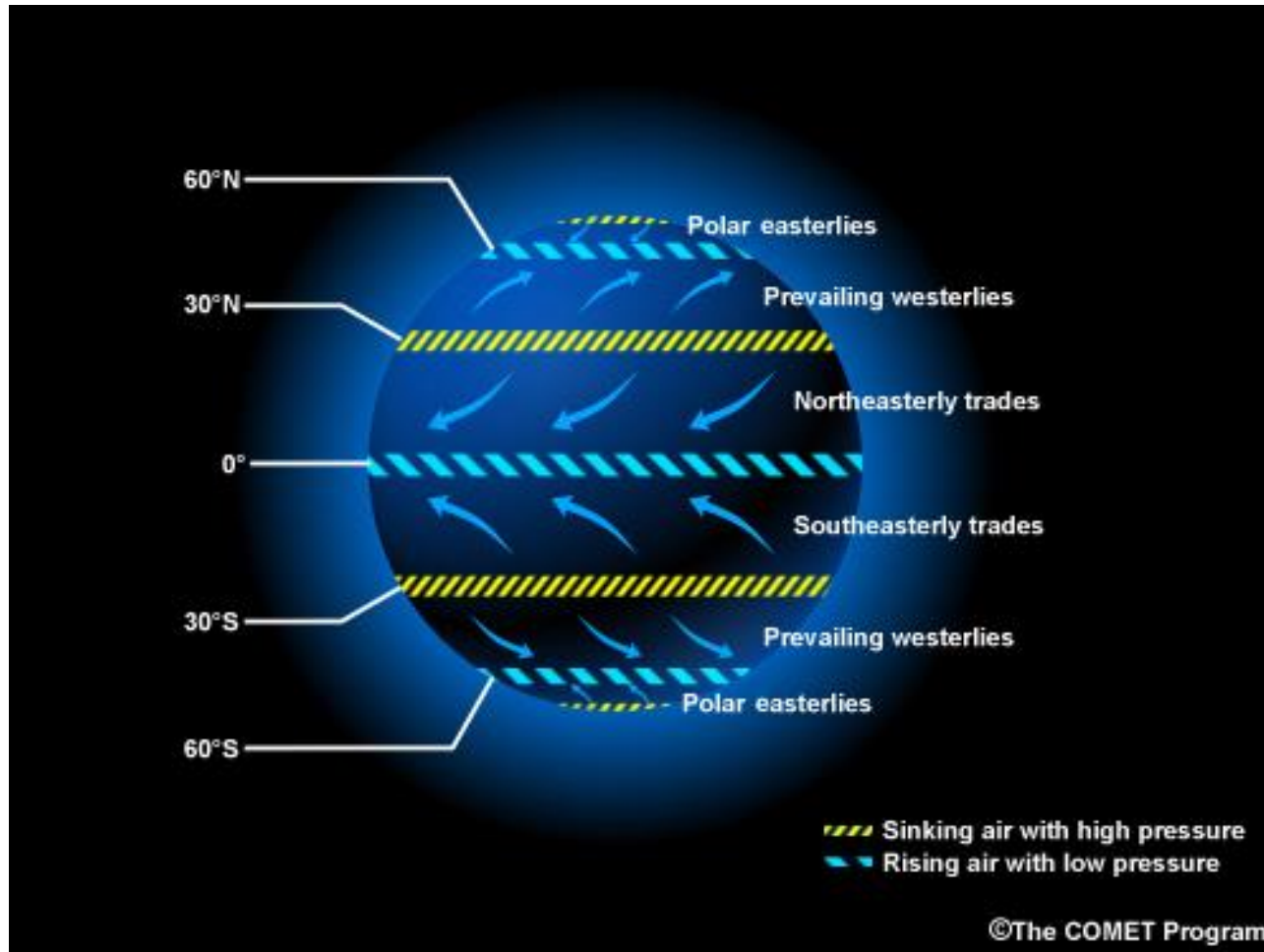
Dust cycle and associated processes

Synoptic dust storms: Post-frontal



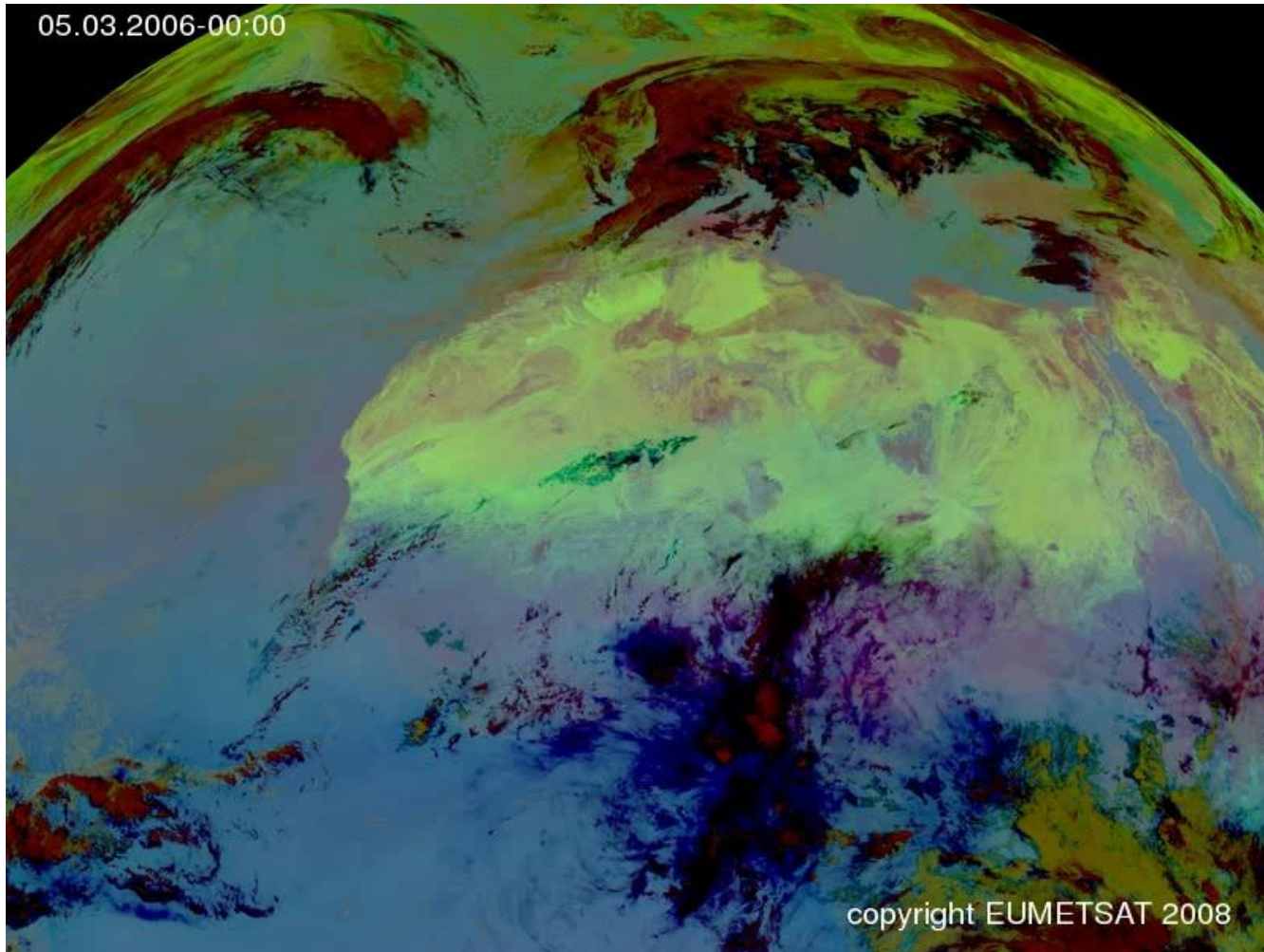
Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds



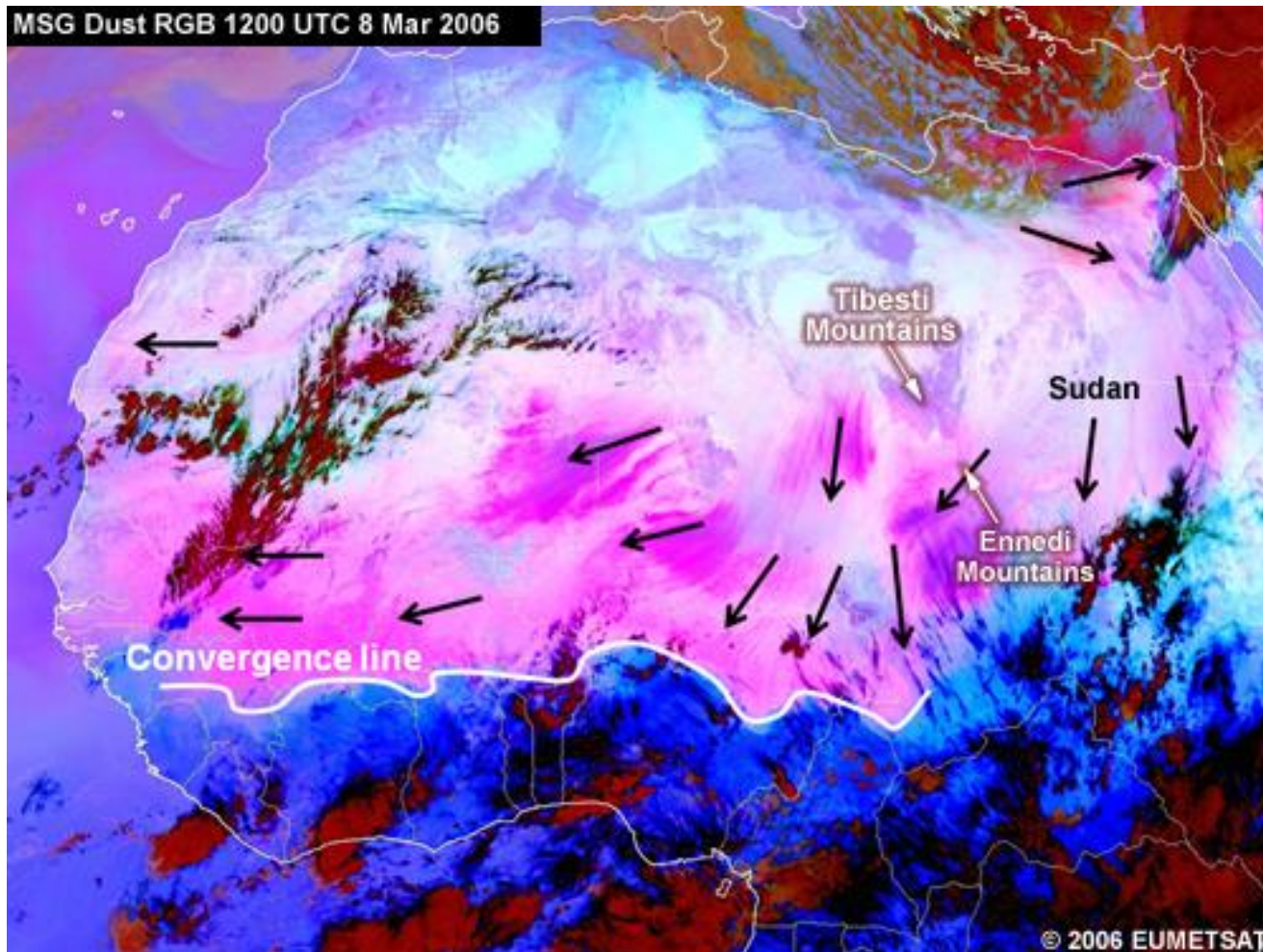
Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds



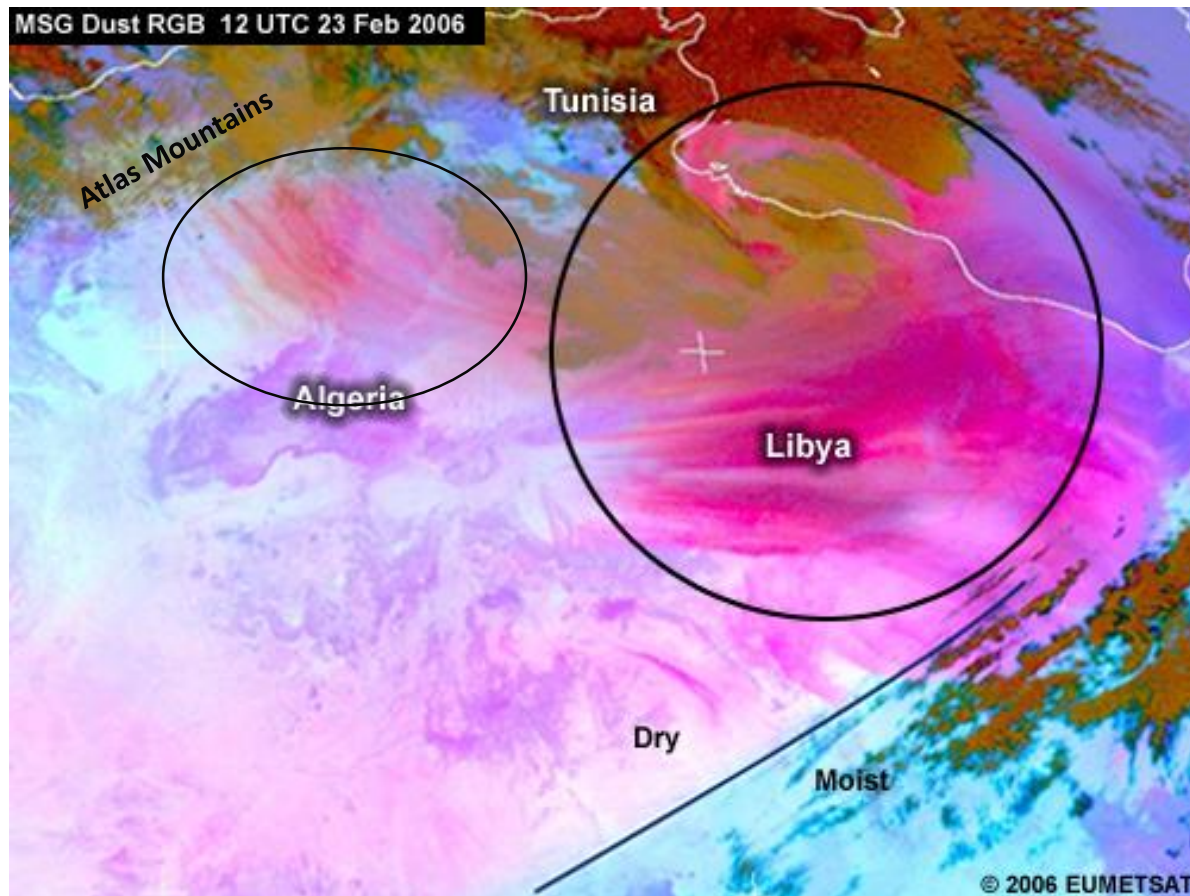
Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds



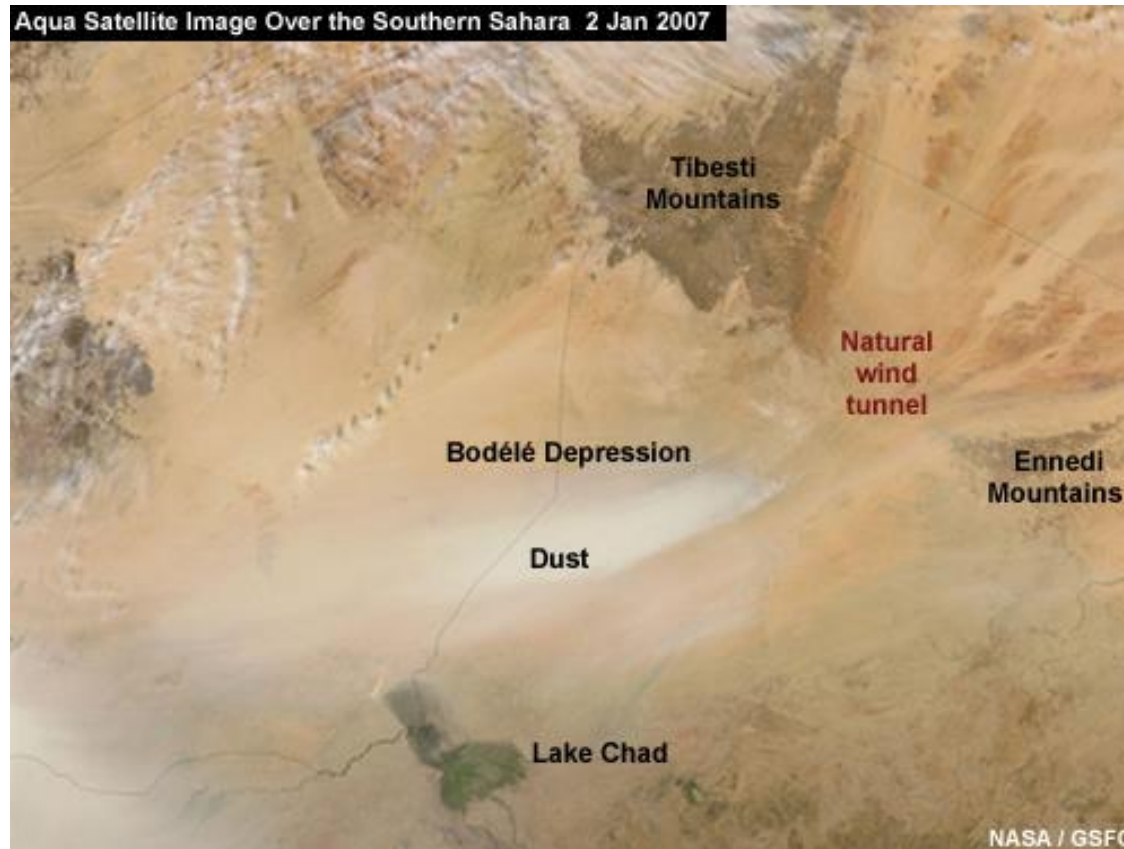
Dust cycle and associated processes

Mesoscale dust storms: Downslope winds



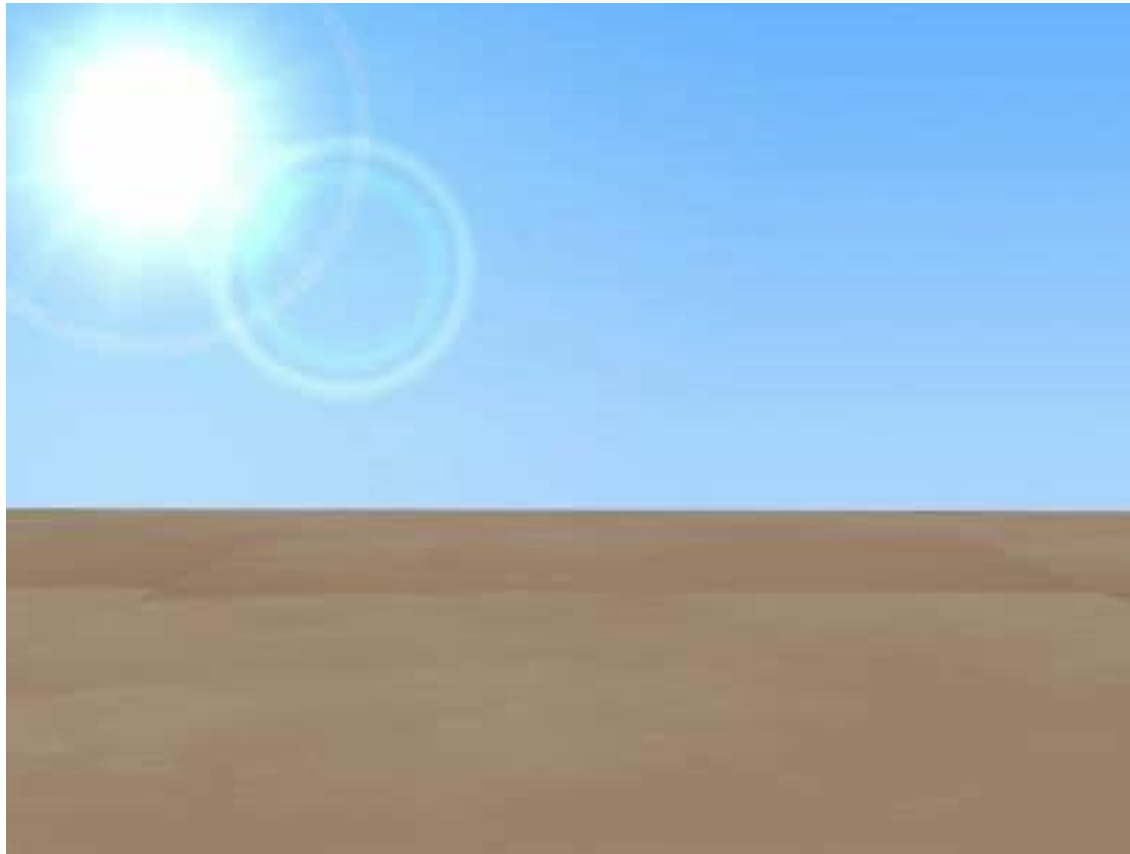
Dust cycle and associated processes

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

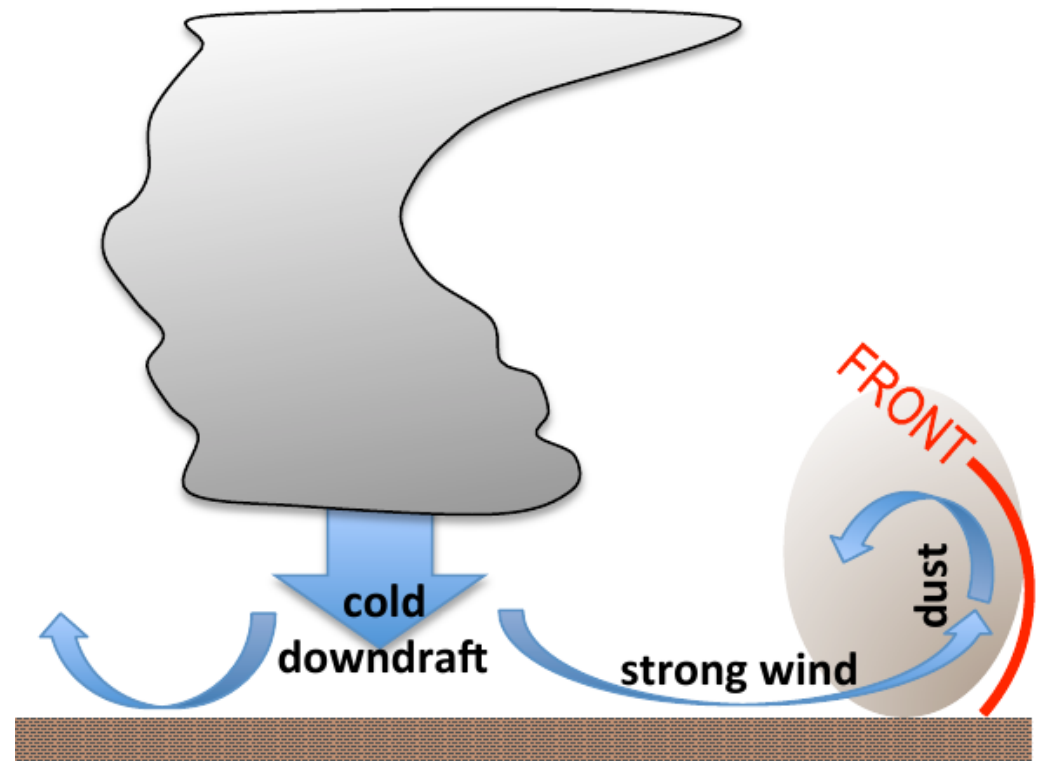


Movie from the COMET program at <http://meted.ucar.edu/> of the University Corporation for Atmospheric Research (UCAR)

Dust cycle and associated processes

Mesoscale dust storms: Haboobs

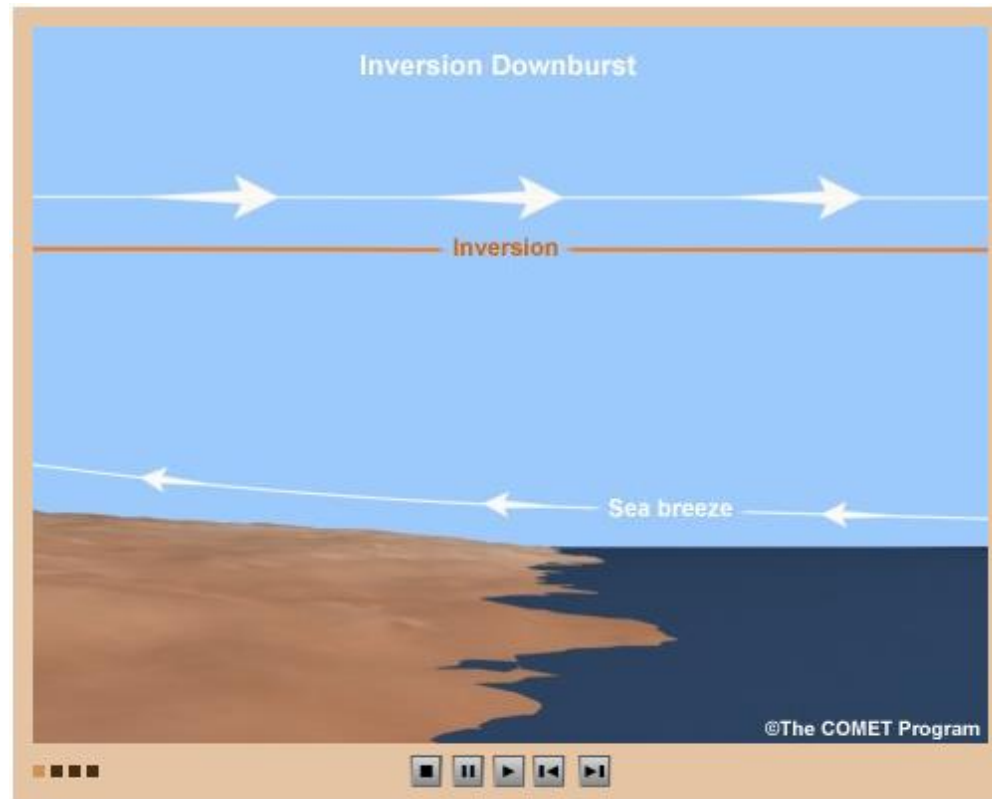
Intensive cold
downbursts from
convective cells
produced high velocity
surface wind, creating
cold front which was
lifting, mixing and
pushing dust



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

Dust cycle and associated processes

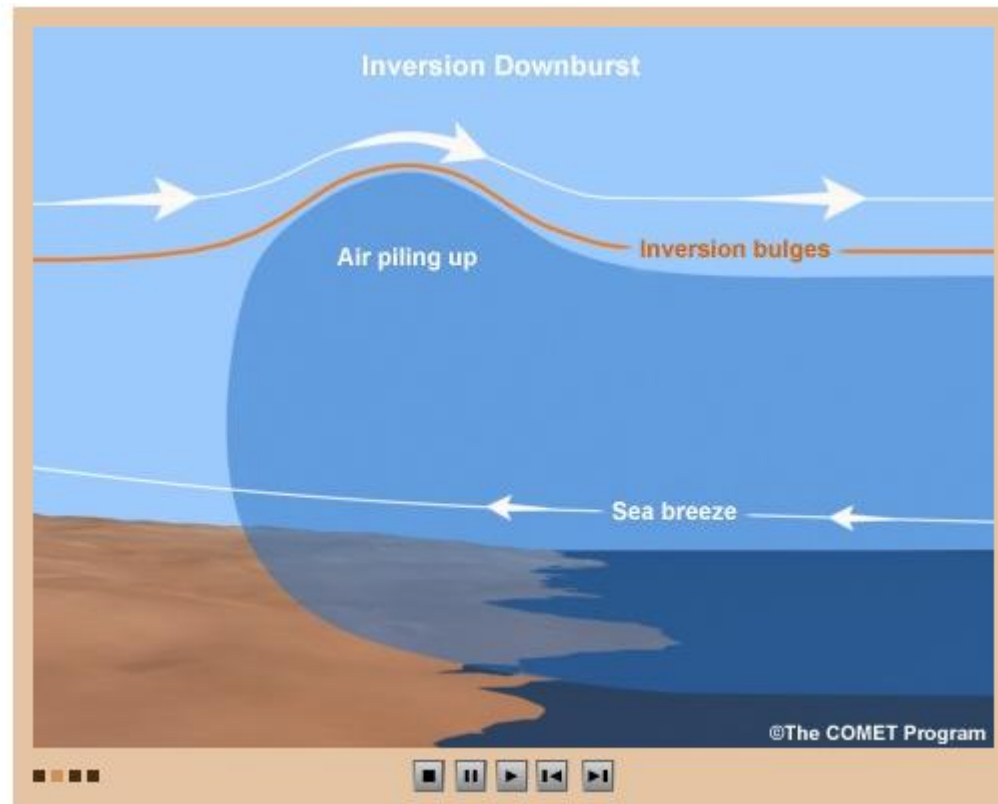
Mesoscale dust storms: Inversion downbursts



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

Dust cycle and associated processes

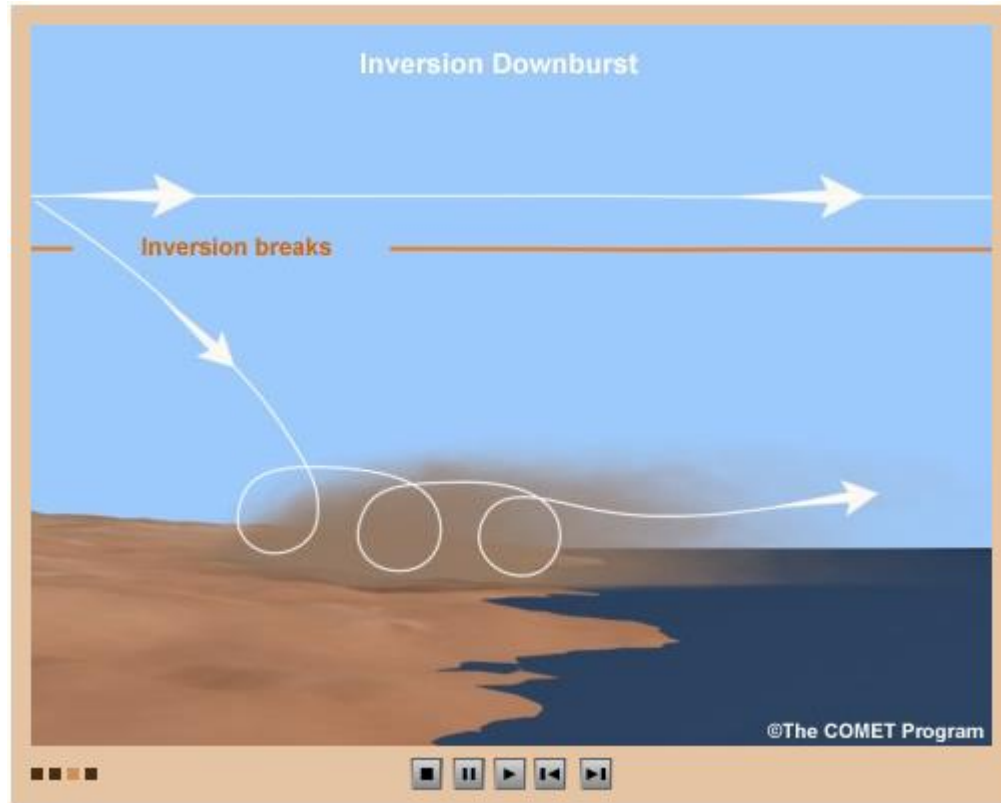
Mesoscale dust storms: Inversion downbursts



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

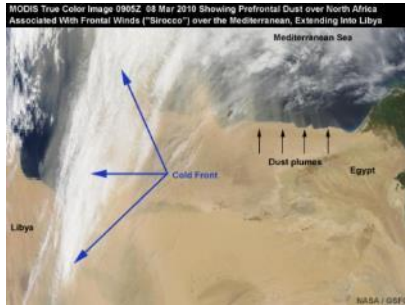
Mesoscale dust storms: Inversion downbursts



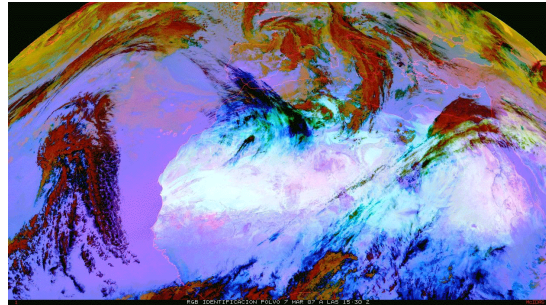
Movie from the COMET program at <http://meted.ucar.edu/> of the University Corporation for Atmospheric Research (UCAR)

Dust cycle and associated processes

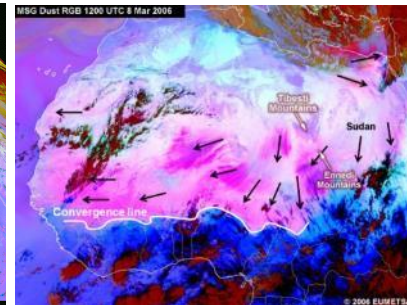
Synoptic dust storms (large scale weather systems) **Well captured by models.**



Pre-frontal winds

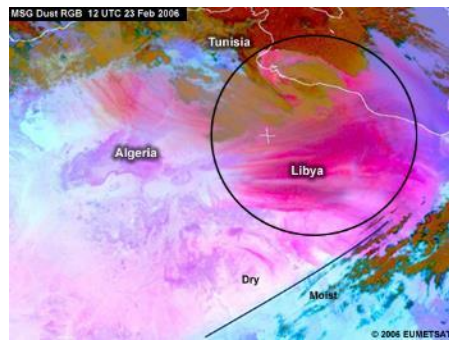


Post-frontal winds

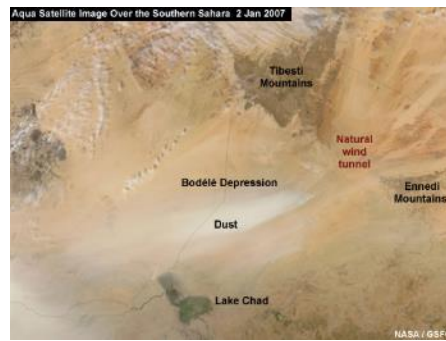


Large-scale trade winds

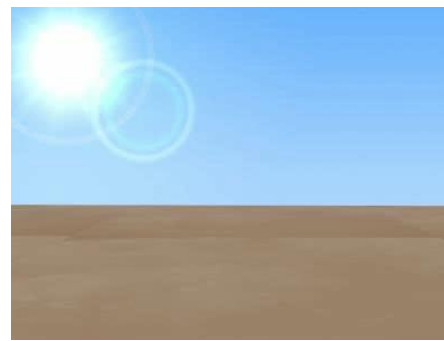
Mesoscale dust storms **Poorly captured by models.**
Some types improve in regional models.



Downslope winds



Gap flow



Dust devils



Haboobs

Dust forecasting models

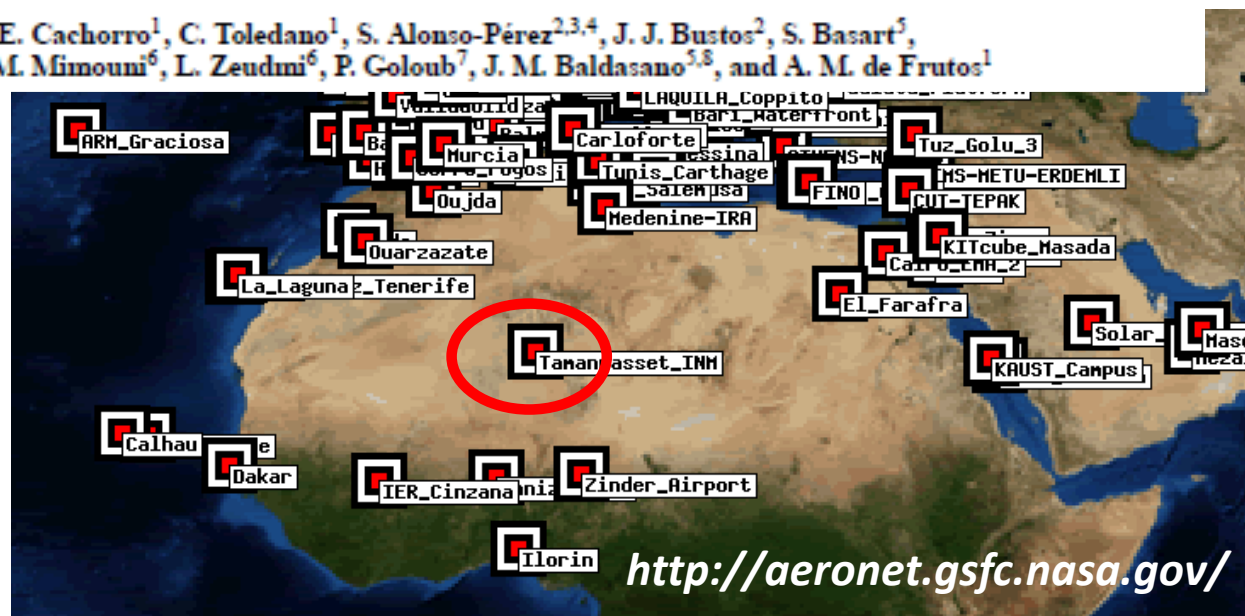
Atmos. Chem. Phys., 14, 11753–11773, 2014
www.atmos-chem-phys.net/14/11753/2014/
doi:10.5194/acp-14-11753-2014
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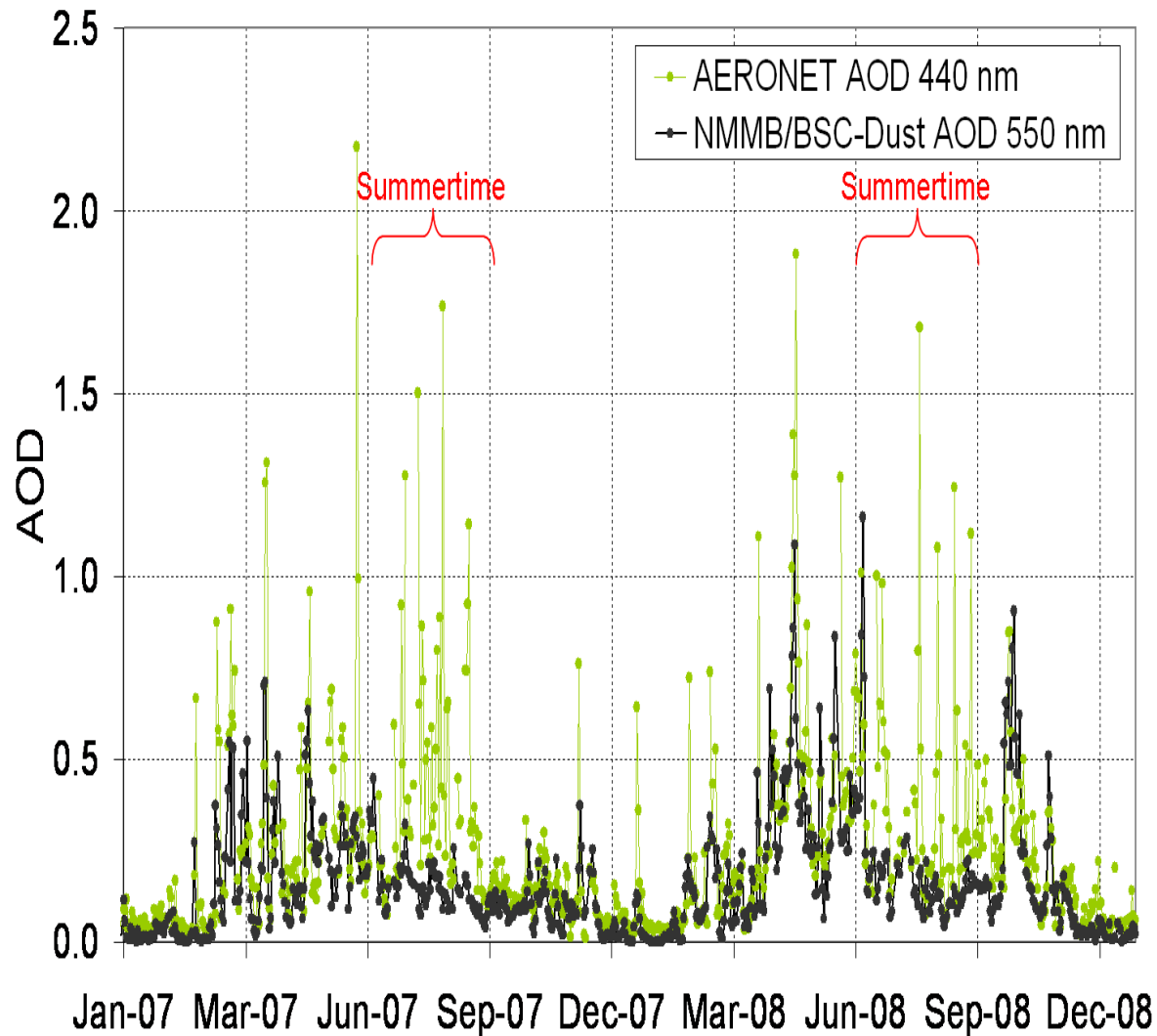


Aerosol characterization at the Saharan AERONET site Tamanrasset

C. Guirado^{1,2}, E. Cuevas², V. E. Cachorro¹, C. Toledano¹, S. Alonso-Pérez^{2,3,4}, J. J. Bustos², S. Basart⁵,
P. M. Romero², C. Camino², M. Mimoumi⁶, L. Zeudmi⁶, P. Goloub⁷, J. M. Baldasano^{5,8}, and A. M. de Frutos¹

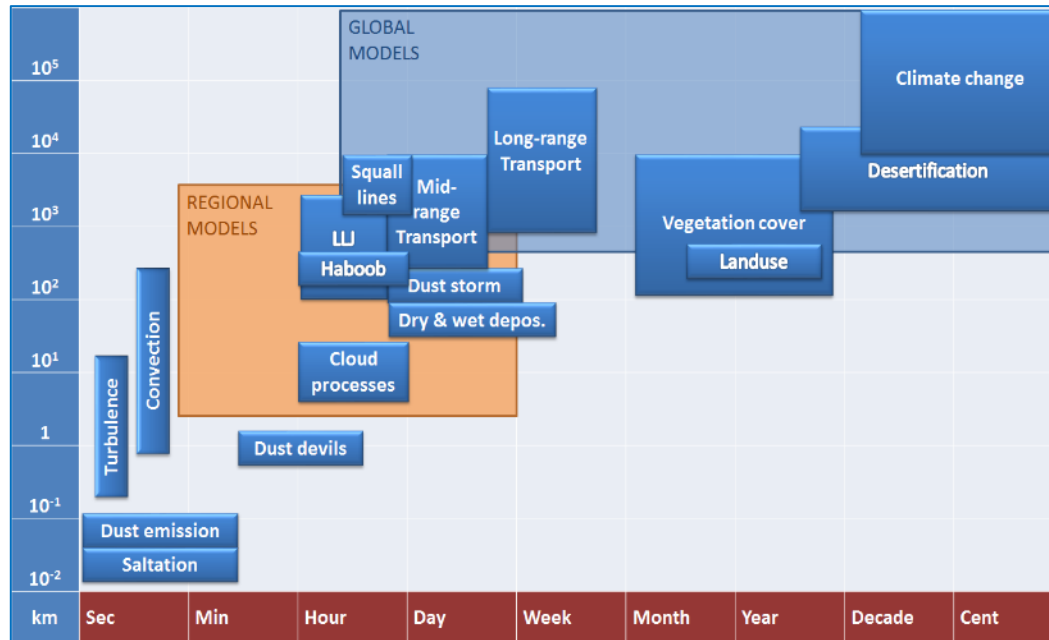


Dust forecasting models



Extracted from Guirado et al. (2014, ACP)

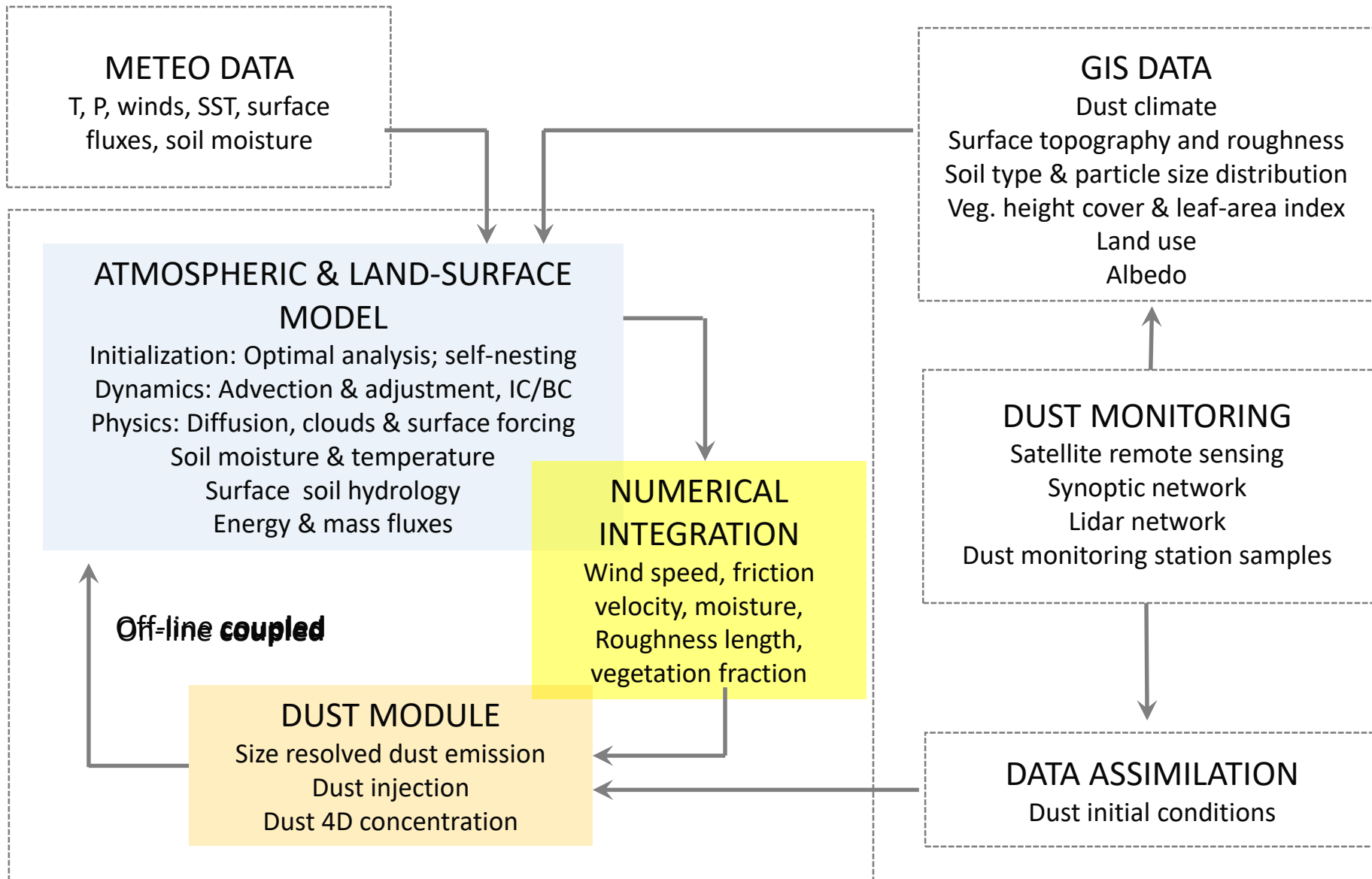
Dust forecasting models



- 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.

Dust forecasting models



Desert dust soil types

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



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

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

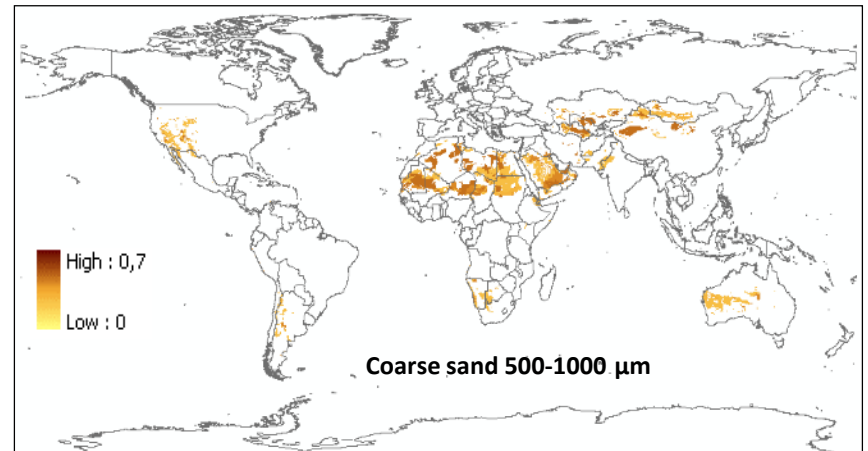
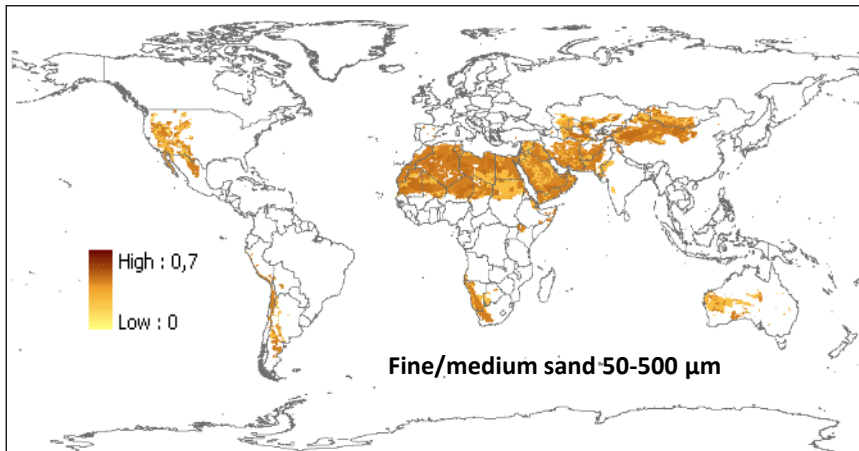
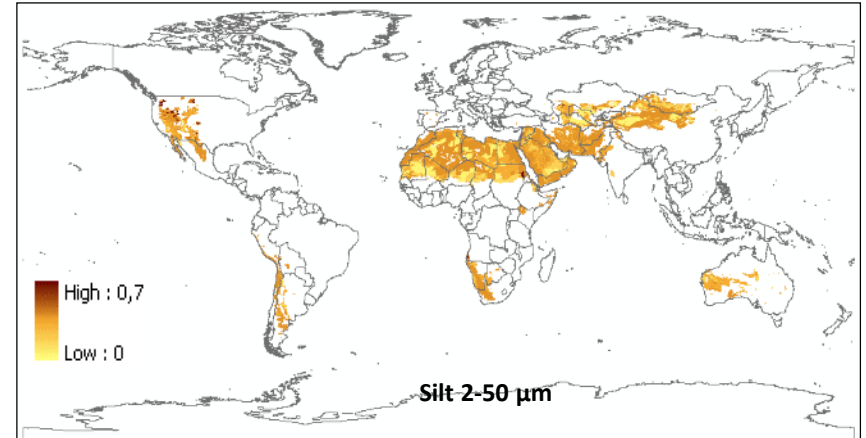
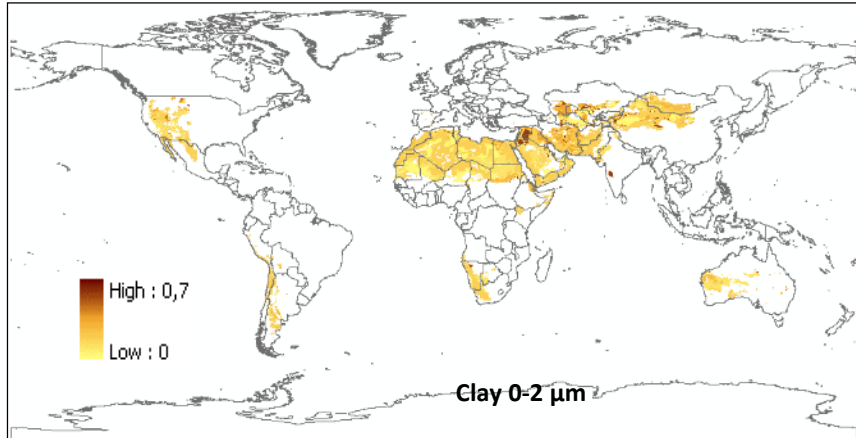
C) The Great Hamada south-west of El-Abiodh-Sidi-Cheikh;

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

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

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

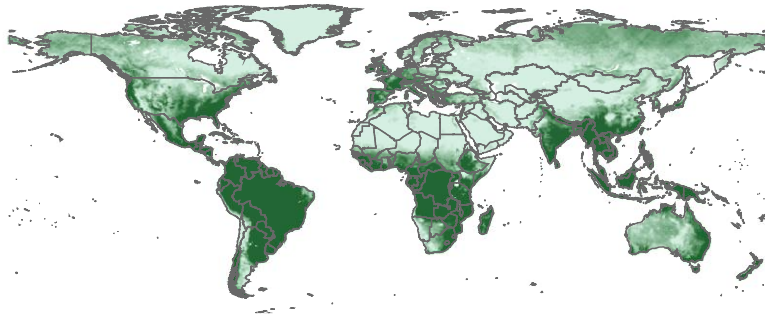
Soil size distribution derived from soil texture



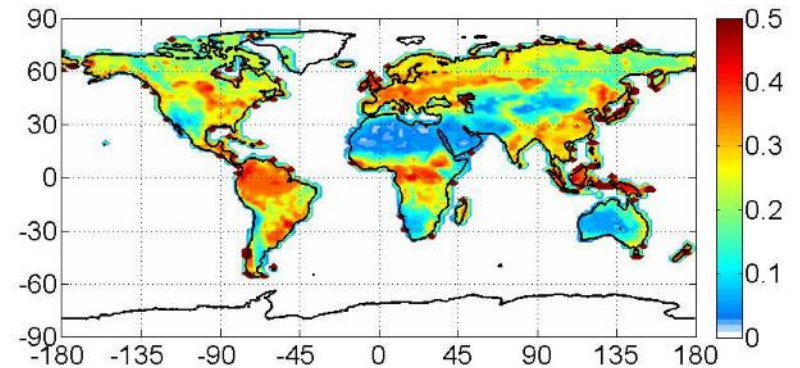
Four top soil texture classes according STASGO-FAO 1km database are converted to 4 parent soil size categories following Tegen et al. [2002].

Vegetation, roughness, soil moisture

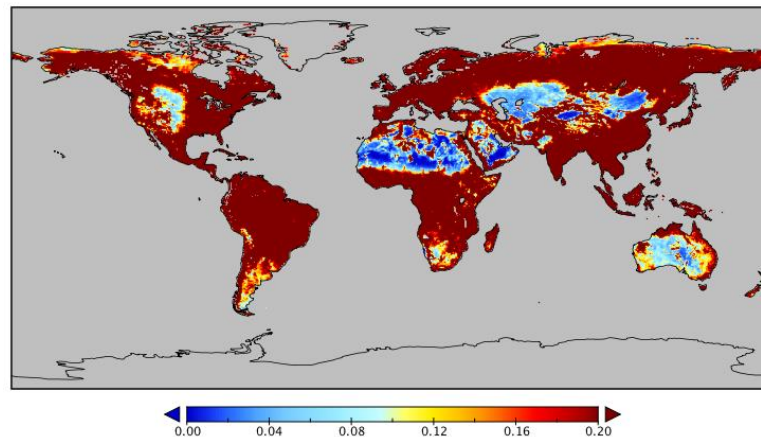
Vegetation fraction
(MODIS)



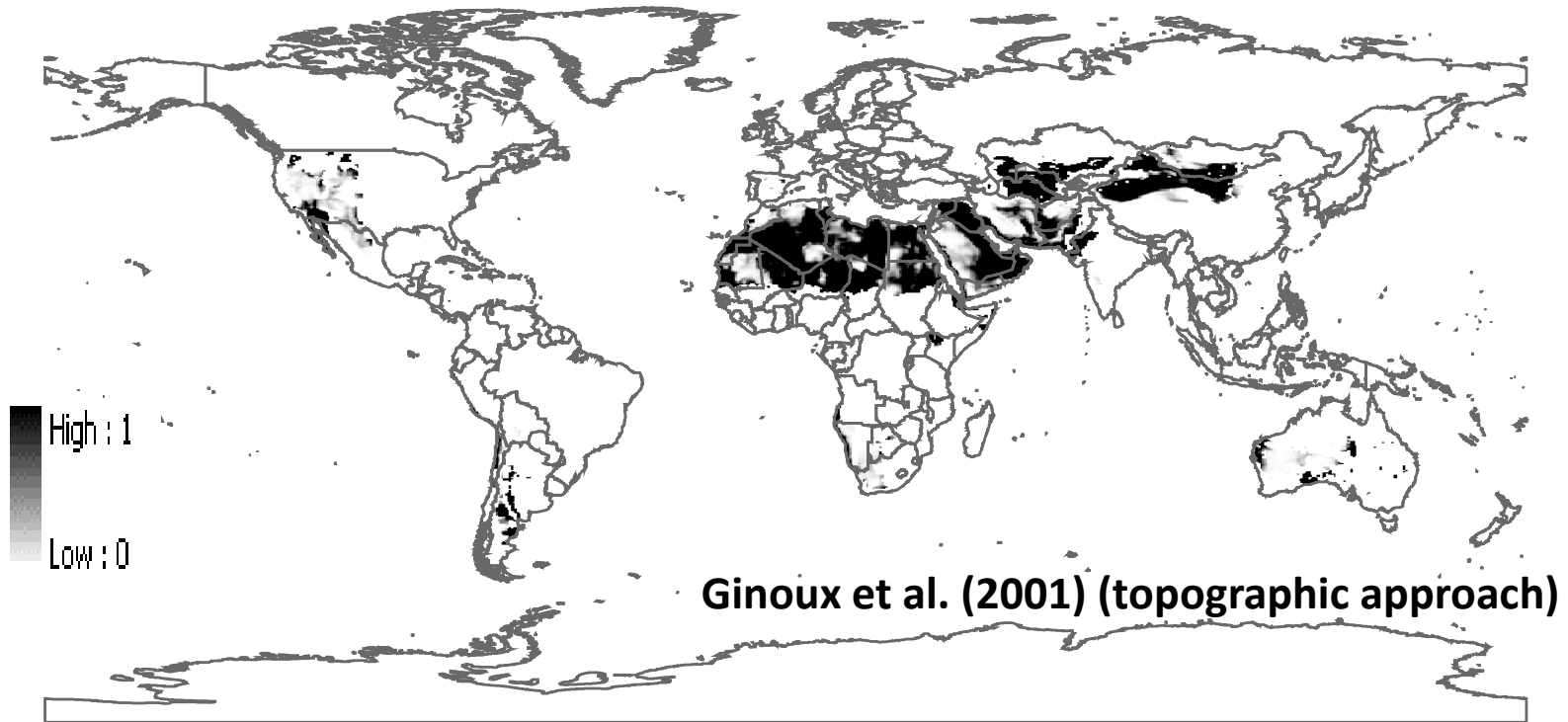
Soil moisture
(model based)



Roughness length
(ASCAT + PARASOL)



Source mapping: why?

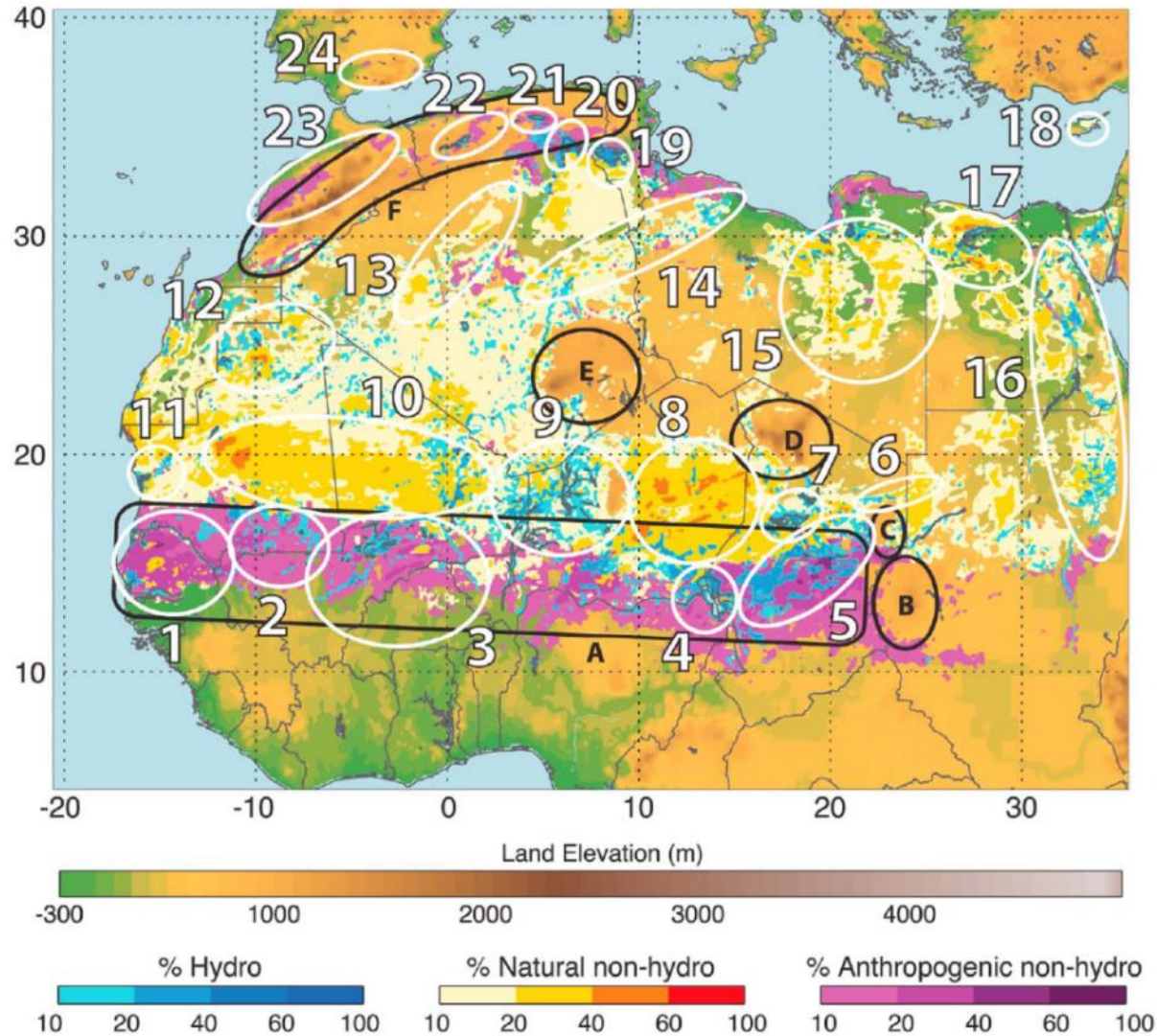


$$S = \left(\frac{z_{\max} - z_i}{z_{\max} - z_{\min}} \right)^5$$

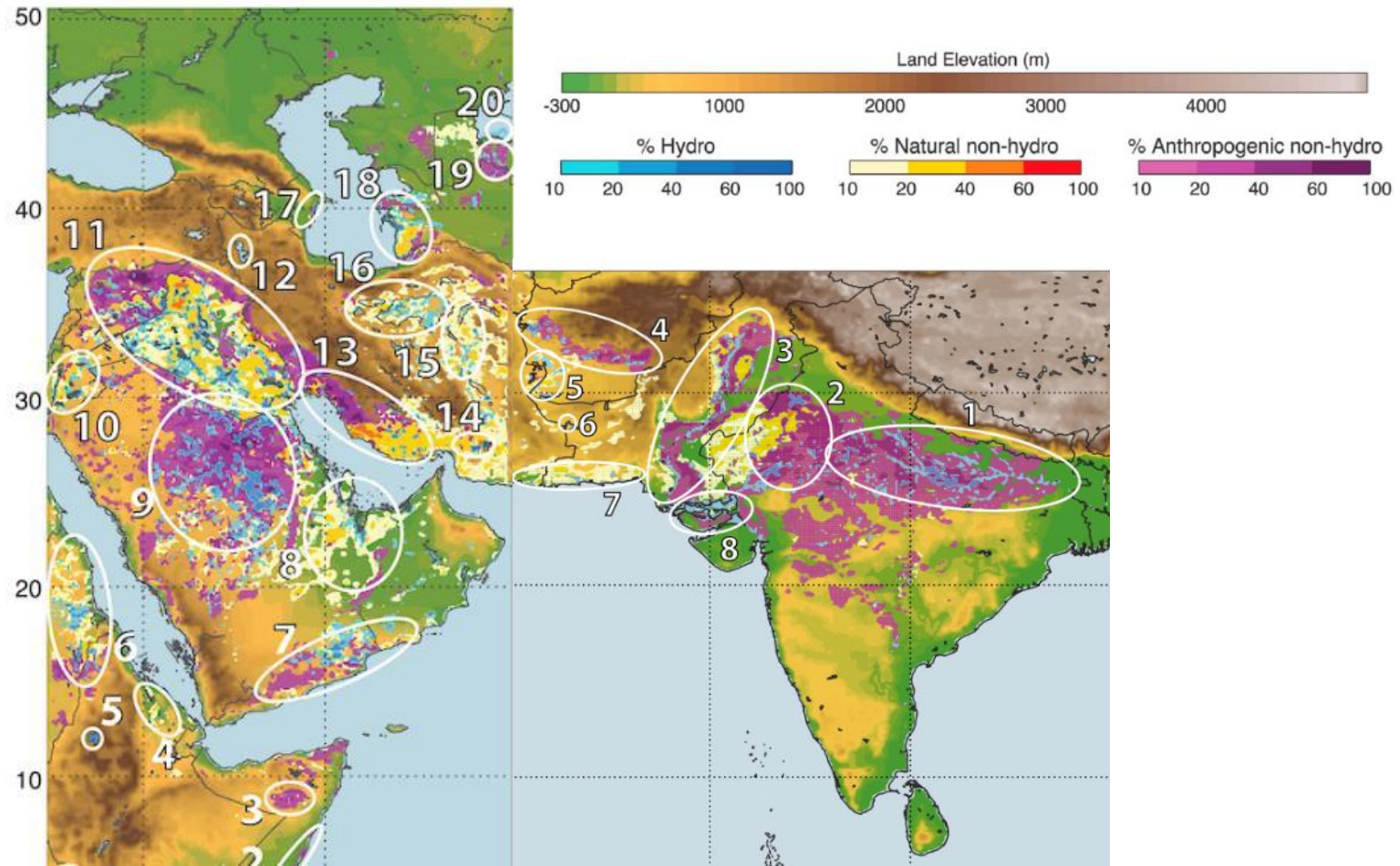
S: probability to have accumulated sediments in the grid cell i of altitude z_i

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

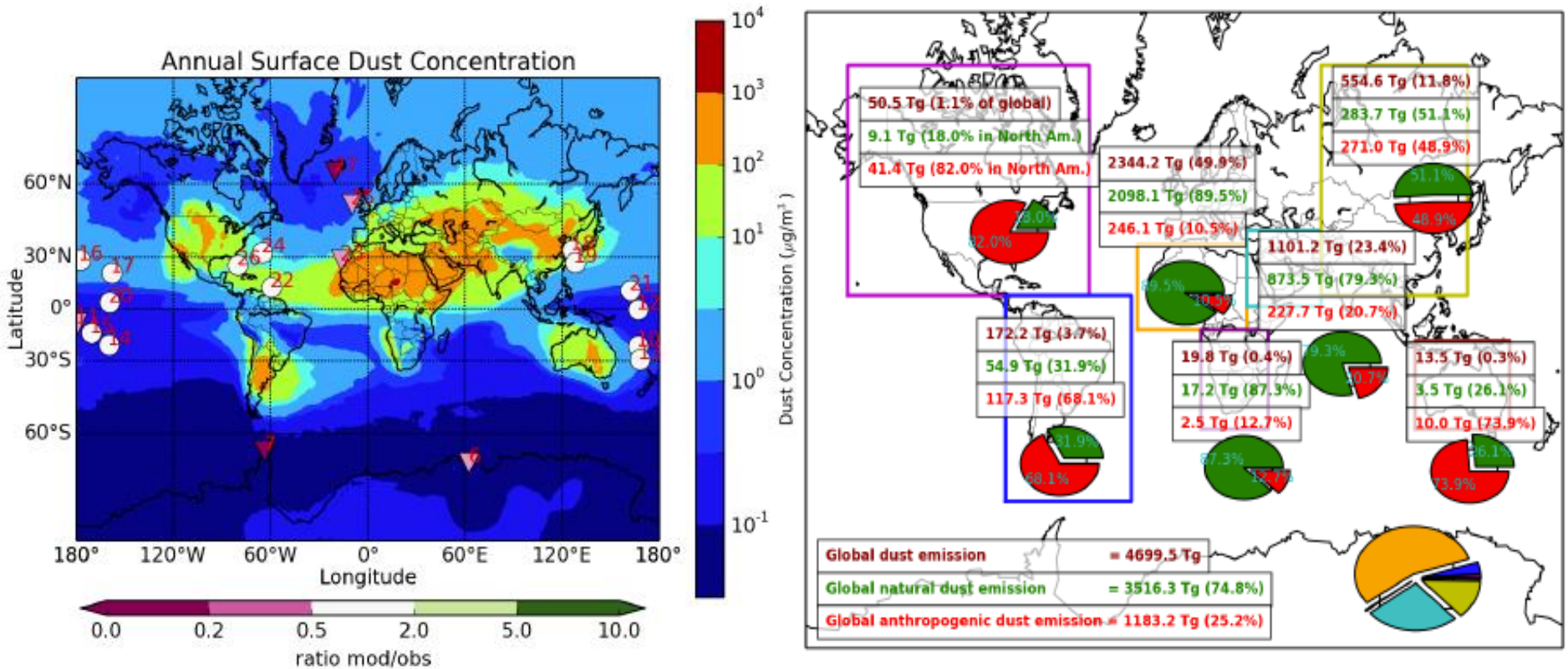
Natural and anthropogenic dust sources



Natural and anthropogenic dust sources



Current quantification natural vs. anthropogenic

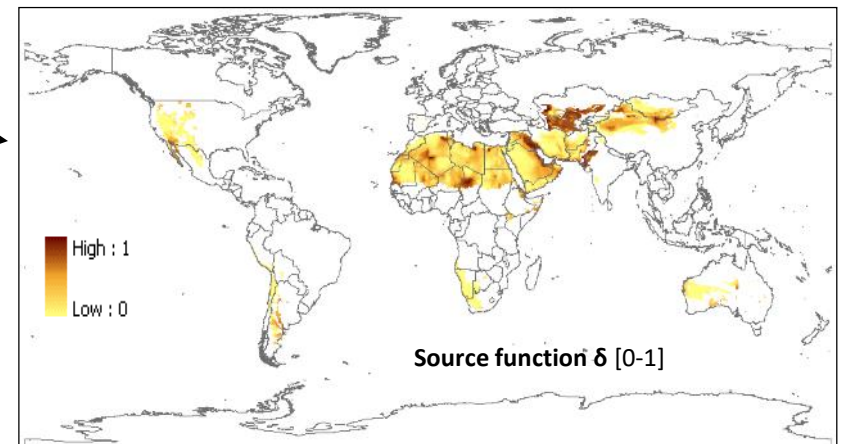
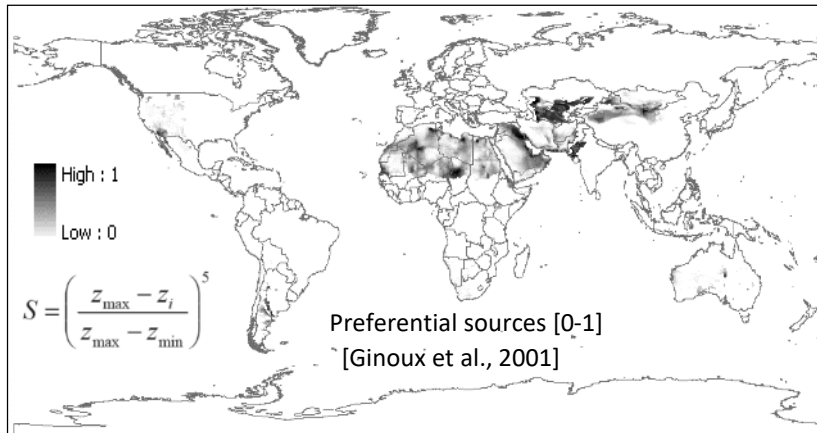
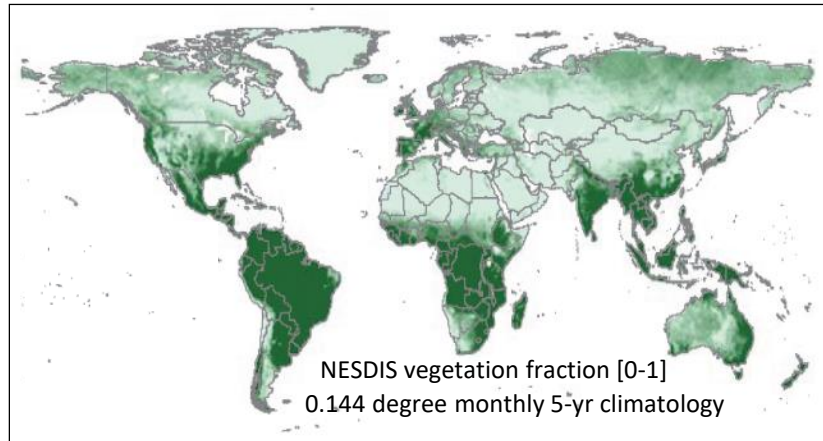
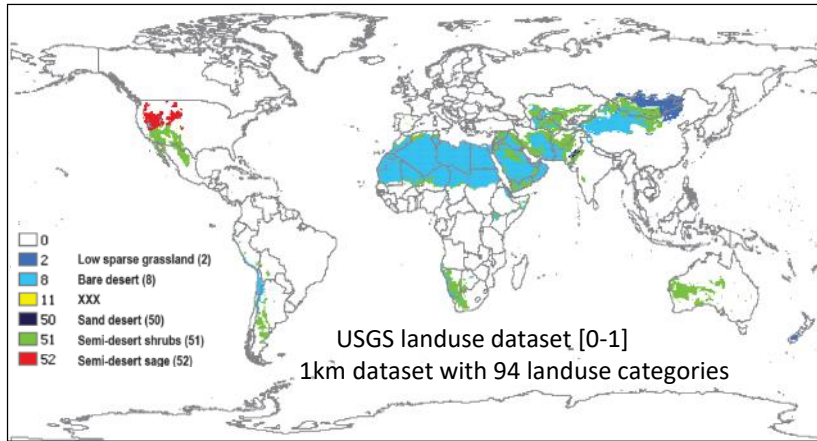


Major challenge for modeling



Dust sources functions

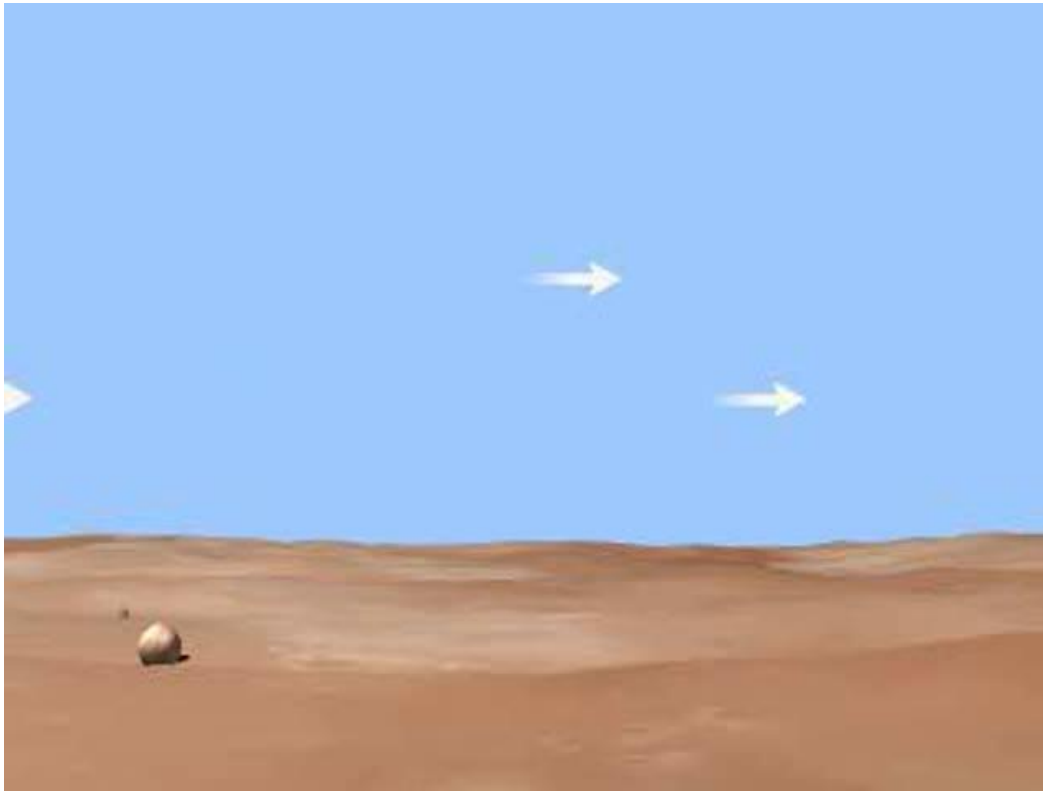
Dust source function: the NMMb/BSC-Dust model



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

Dust emission mechanisms

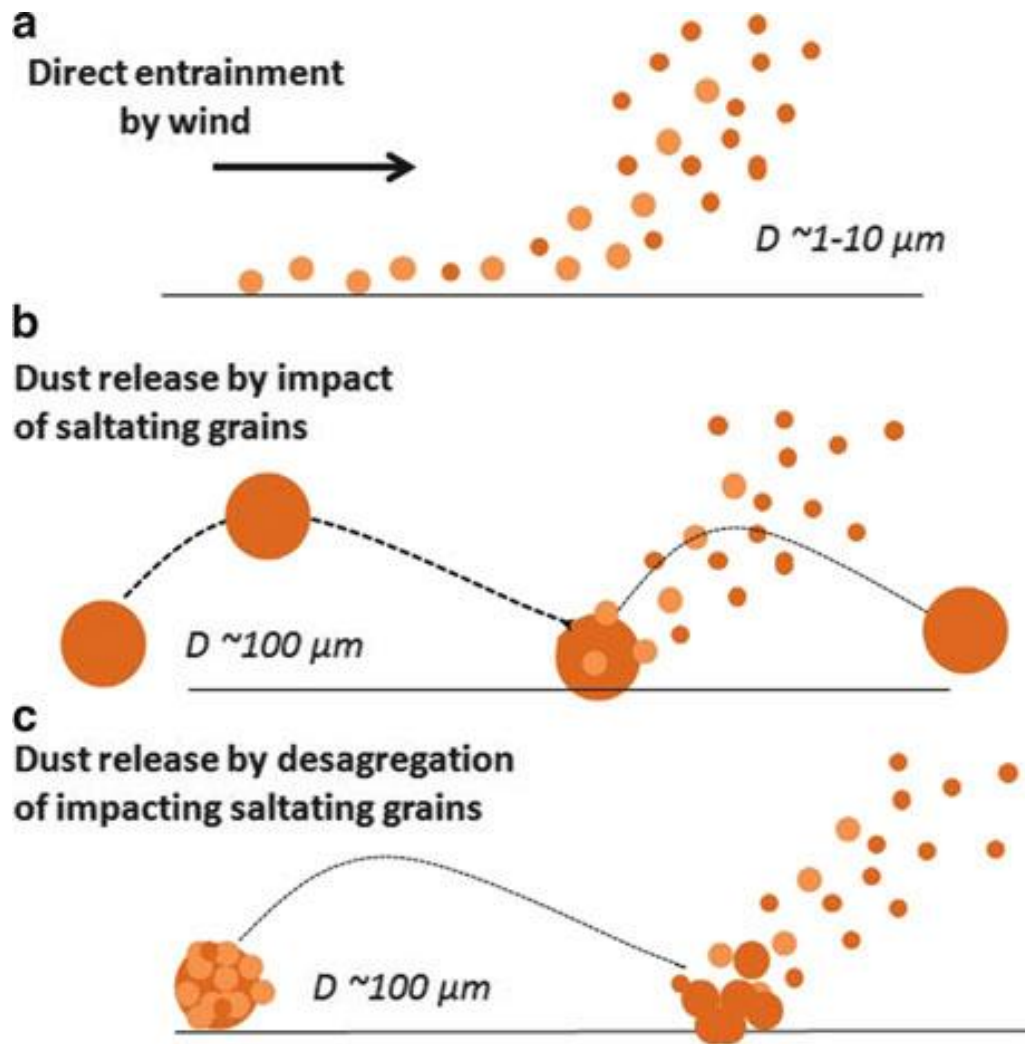
- Complex physical process involving entrainment of soil particles by the surface winds.



- Creep or rolling motion of the largest particles ($> 500 \text{ um}$)
- Saltation or horizontal motion of large soil grains (sand) ($50\text{-}500\text{um}$)
- Suspension of dust (after sandblasting or saltation bombardment) ($0.1\text{-}50 \text{ um}$)

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

Dust emission mechanisms



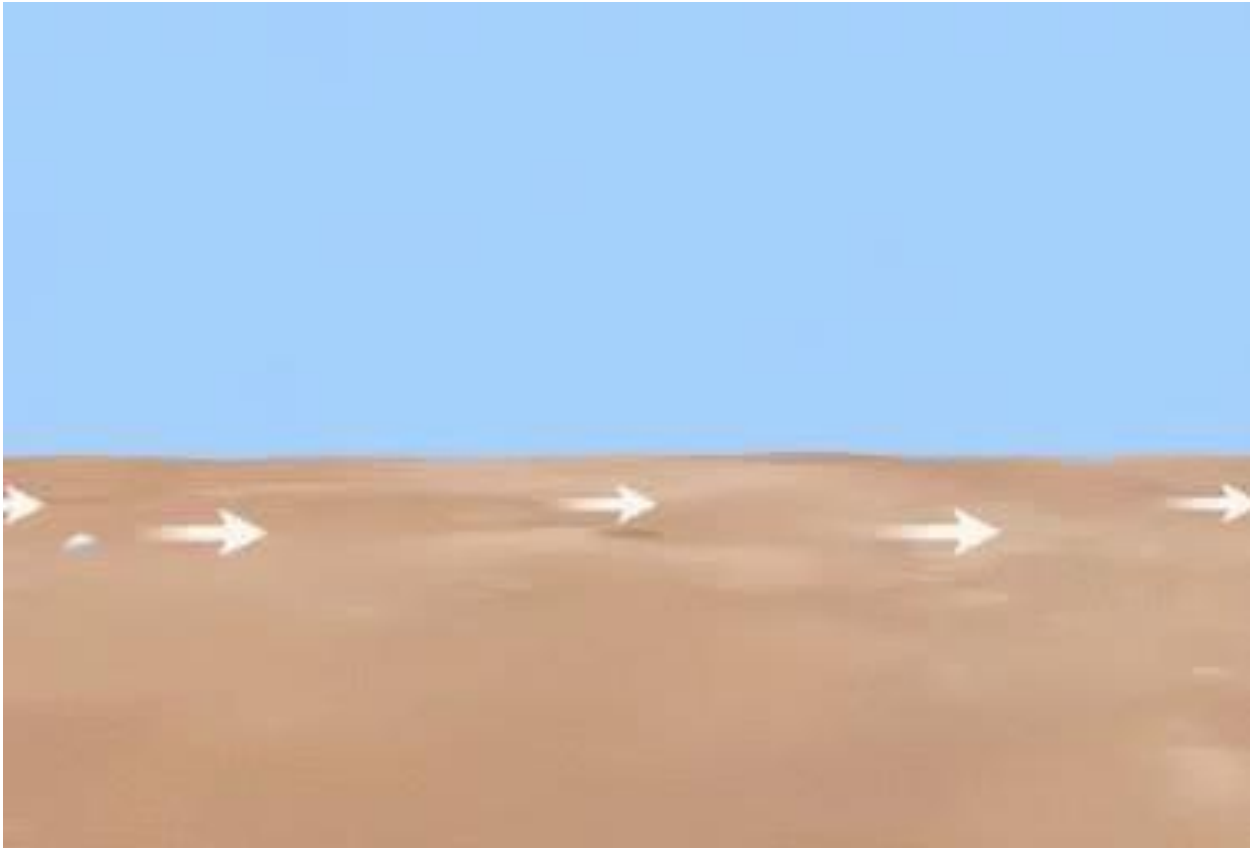
Emitted dust mass

&

Size distribution

Dust dry deposition

Sedimentation and dry deposition



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

Dust wet deposition

Wet scavenging

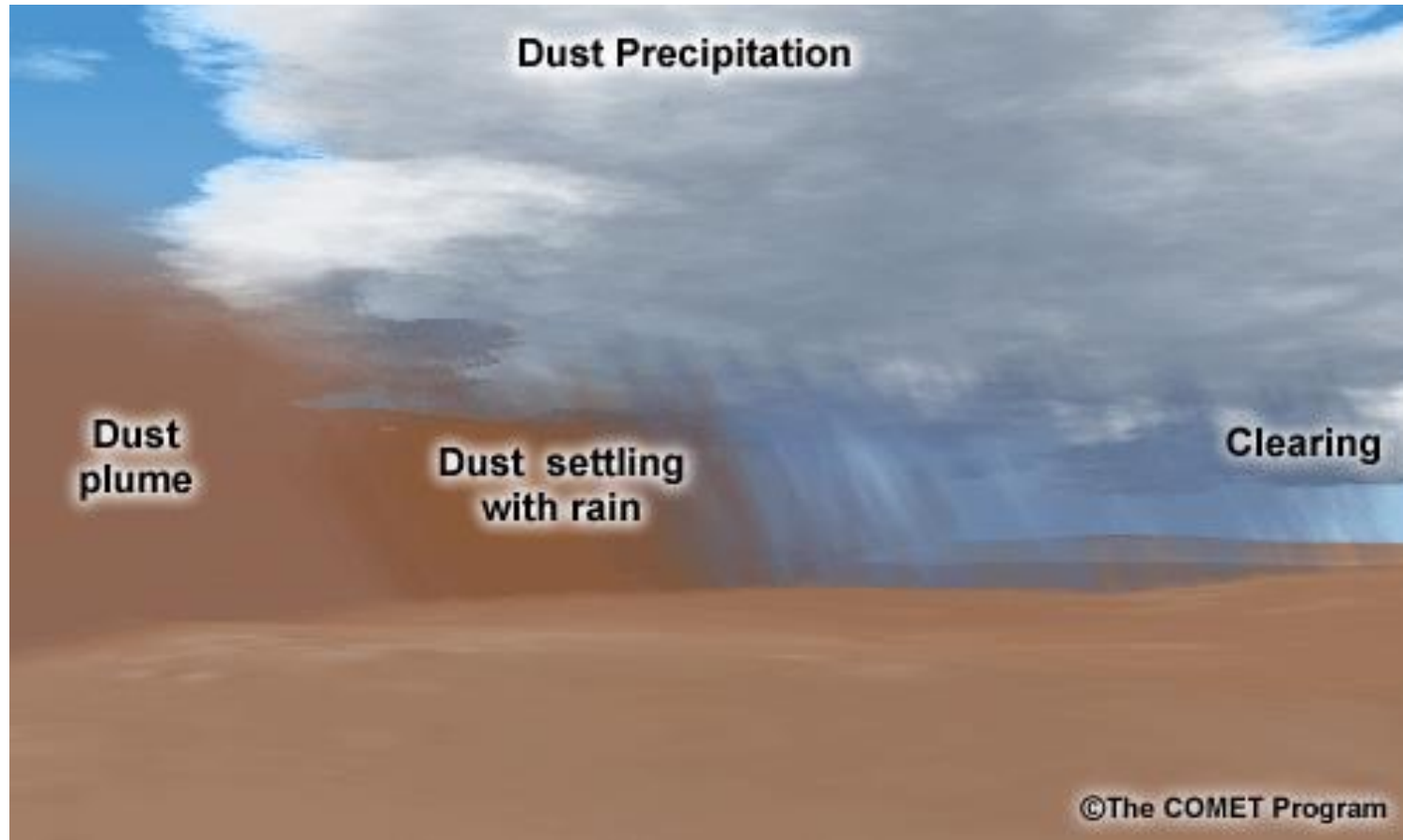
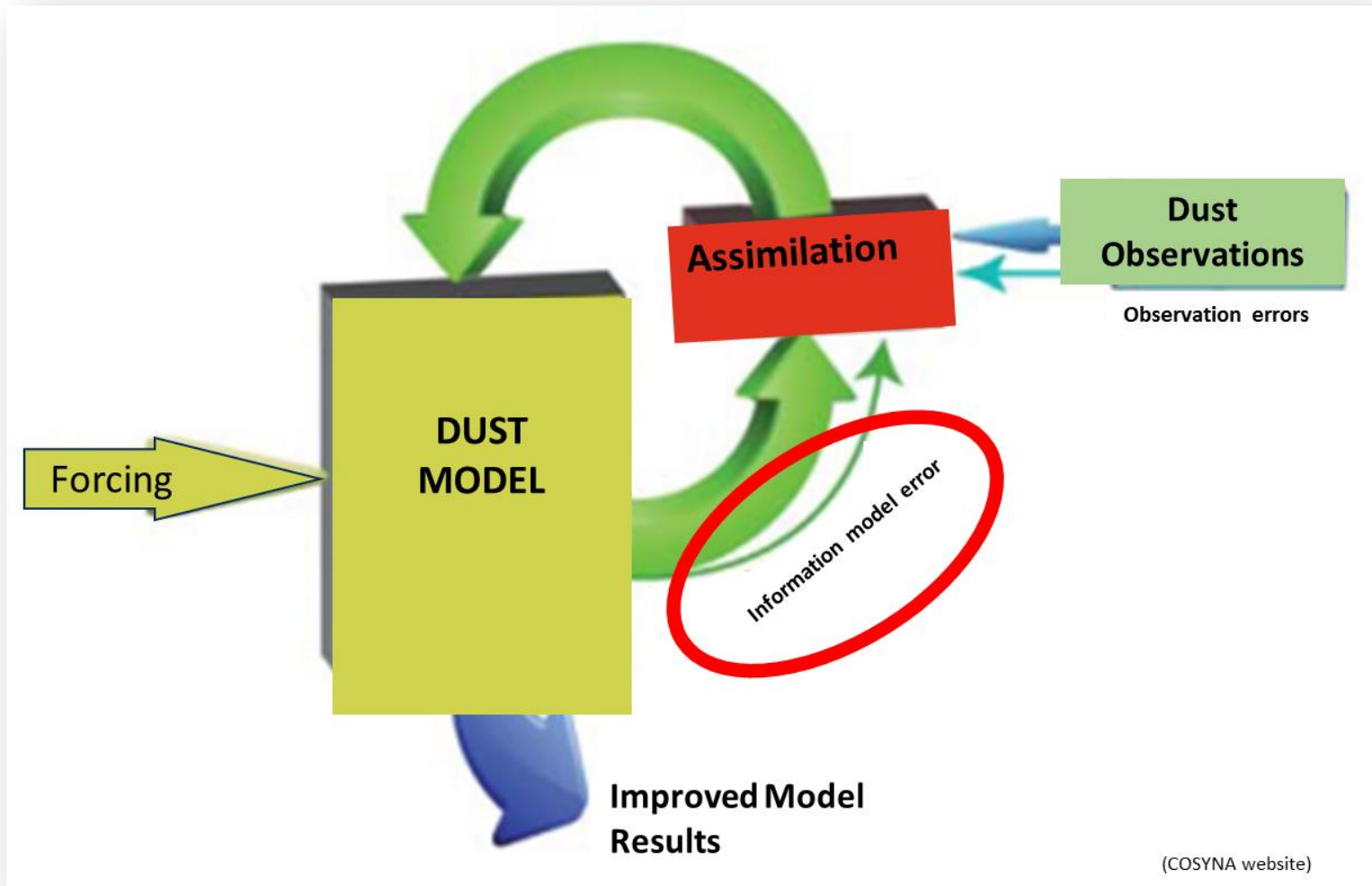


Image from the COMET program at <http://meted.ucar.edu/> of the University Corporation for Atmospheric Research (UCAR)

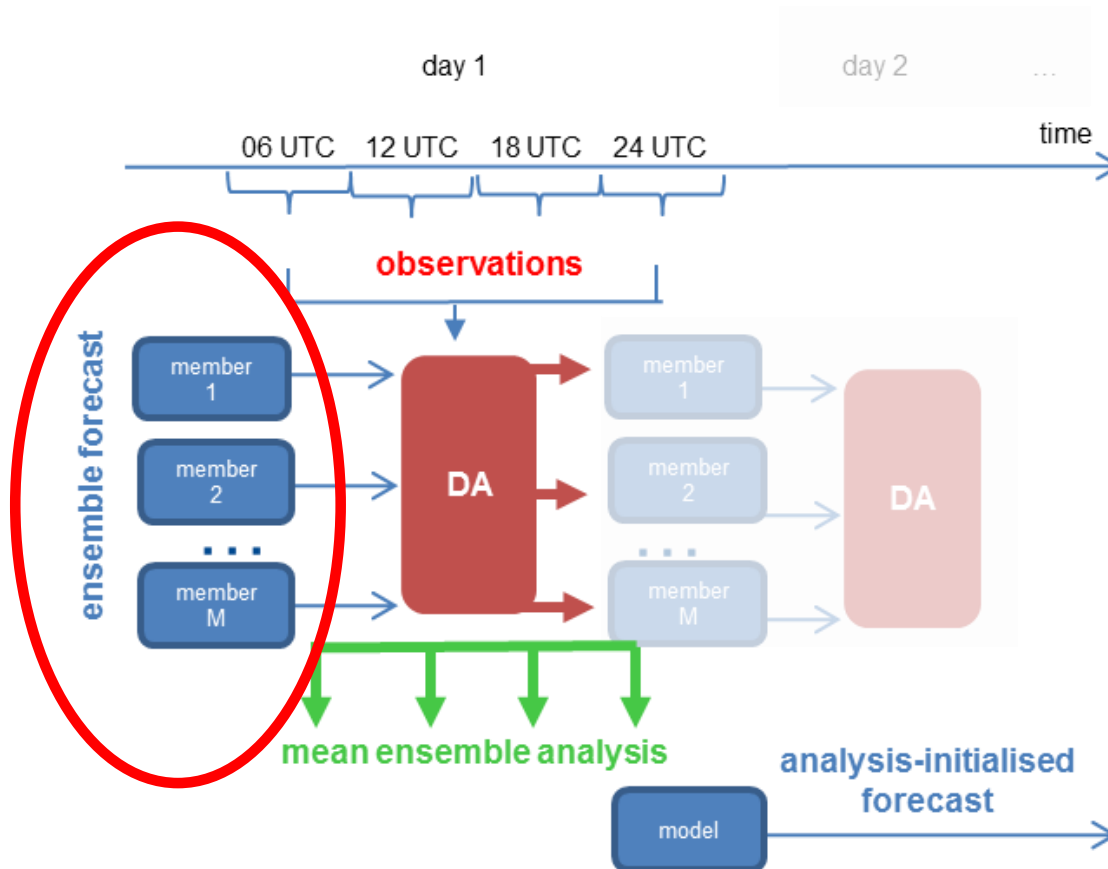
Data Assimilation



Obtaining the 'best' estimate of current atmospheric dust conditions (**analysis**)
Creating datasets describing the recent history of dust in the atmosphere (**reanalysis**)

Ensemble perturbations

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



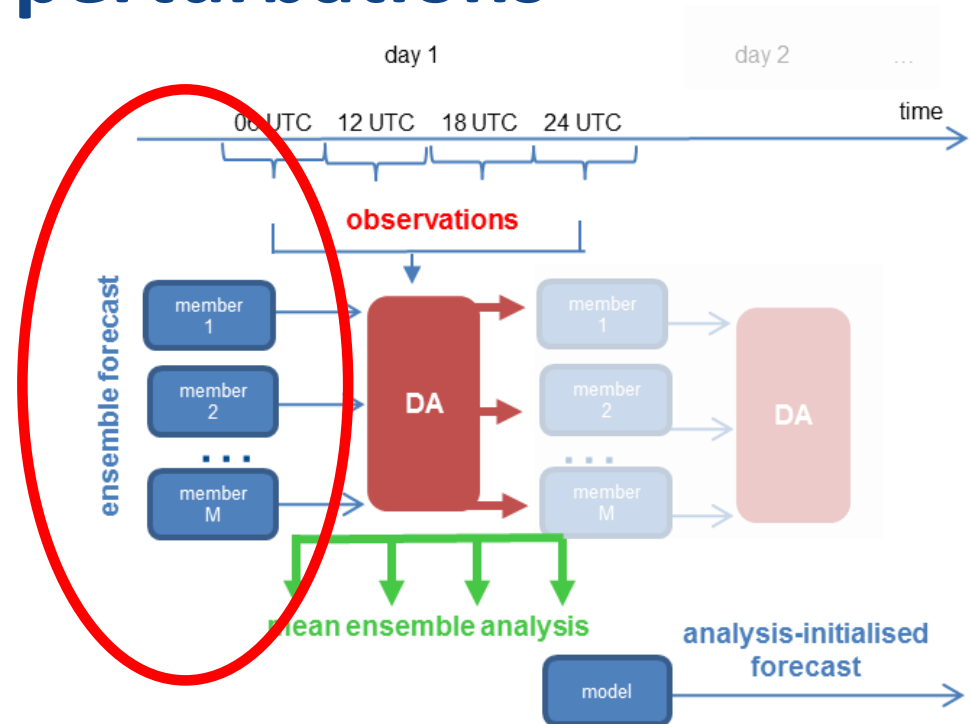
Ensemble perturbations

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

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

by perturbing:

- 1. the threshold friction velocity** which is soil moisture-dependent, and determines the velocity above which the soil particles begin to move in horizontal saltation flux;
- 2. the vertical flux of dust in each of the eight dust transport bins**



Dust forecasting models

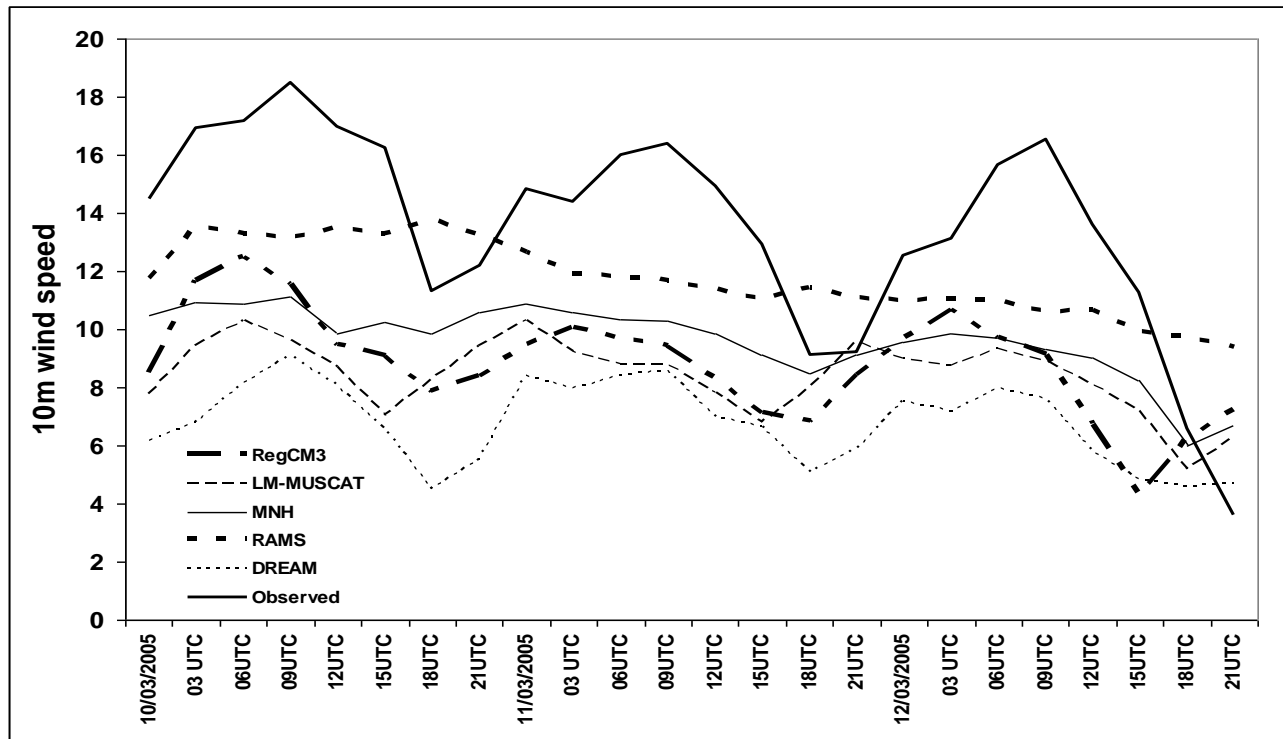
Main differences between dust models

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

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**



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AXA
Research Fund



**EXCELENCIA
SEVERO
OCHOA**

Thank you

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The source of some of the movies and information in this presentation is the COMET® Website at <http://meted.ucar.edu/> of the University Corporation for Atmospheric Research (UCAR), sponsored in part through cooperative agreement(s) with the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce (DOC) © 2007-2011 University Corporation for Atmospheric Research. All Rights Reserved.

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