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Supercomputing  
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Centro Nacional de Supercomputación



# Dust prediction models

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*6<sup>th</sup> Dust Training, 25-27 October 2017, Istanbul*

**Questions will be welcome!**



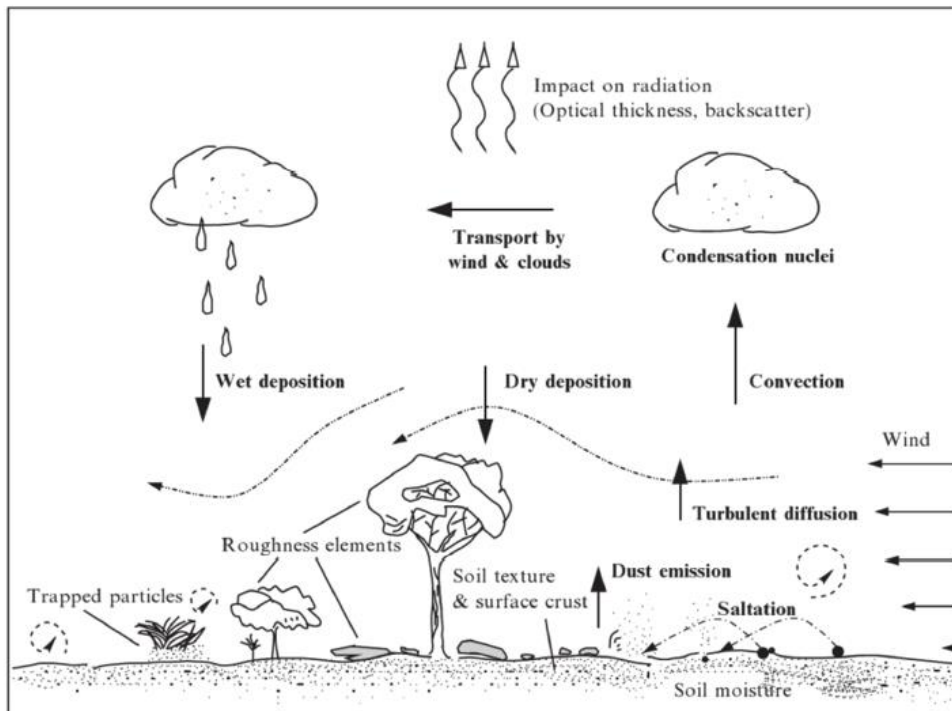
# Introduction

## 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)

# Outlook

## 1. Dust cycle and associated processes

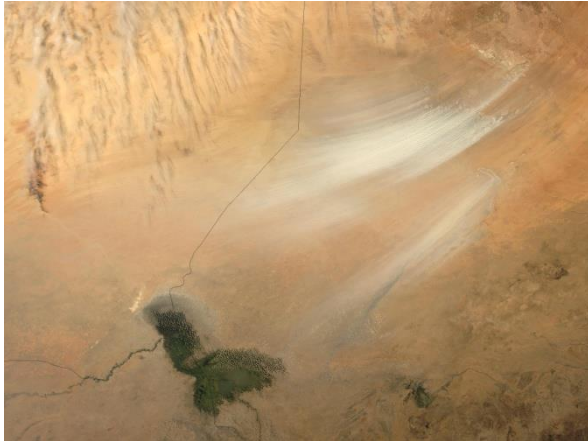
- *The atmospheric dust cycle*
- *Dust global climatology*
- *Types of dust storms and model forecasting skills*

## 2. Dust forecasting models

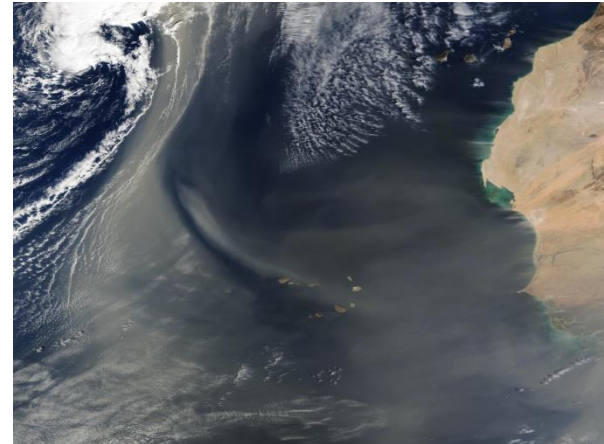
- *Dust emission schemes and dust sources*
- *Dust transport*
- *Dust deposition and sedimentation*

## 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)



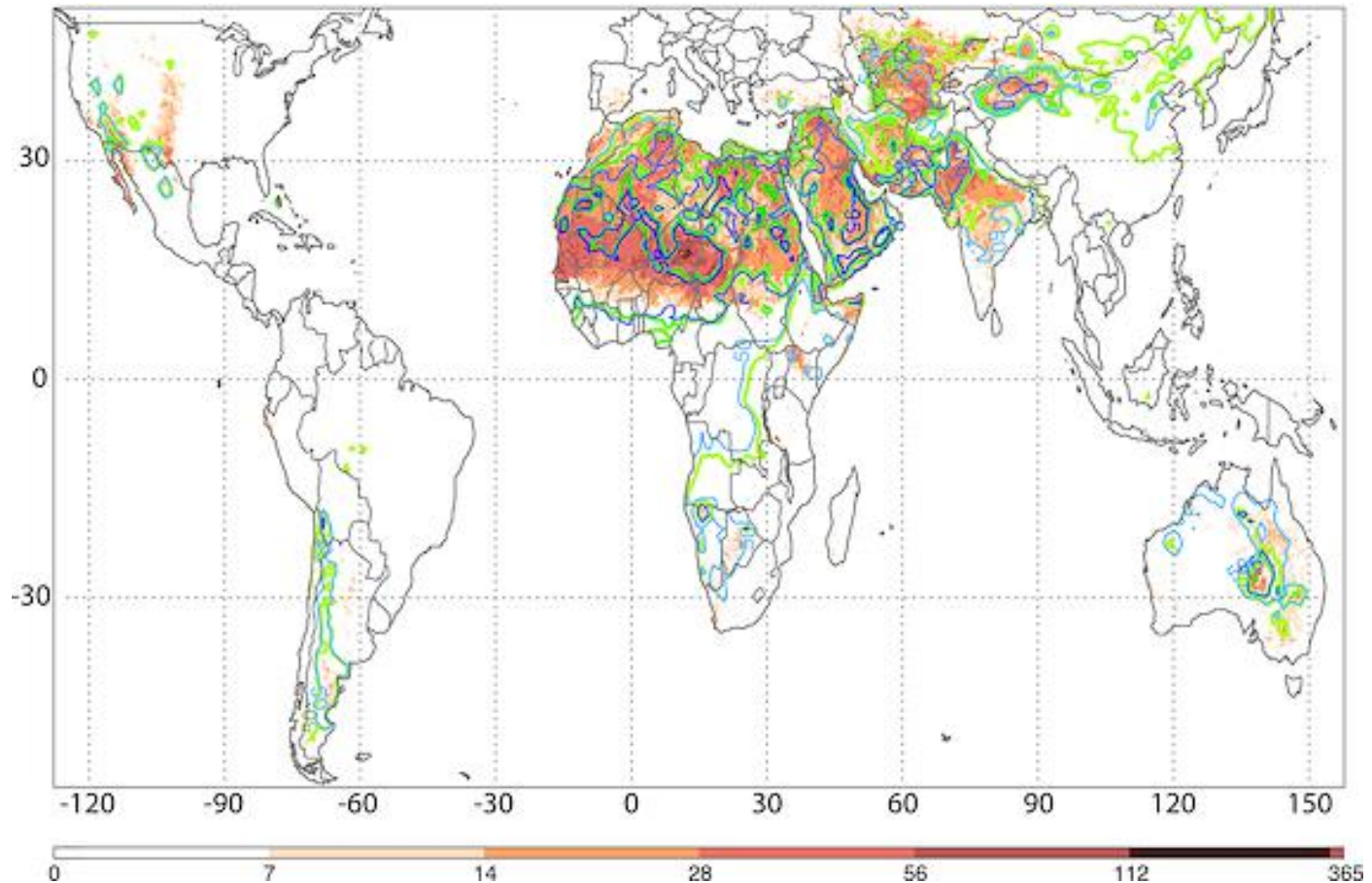
MODIS True color Western Africa – Atlantic Ocean



People caught in a dust storm in Mali

# Dust cycle and associated processes

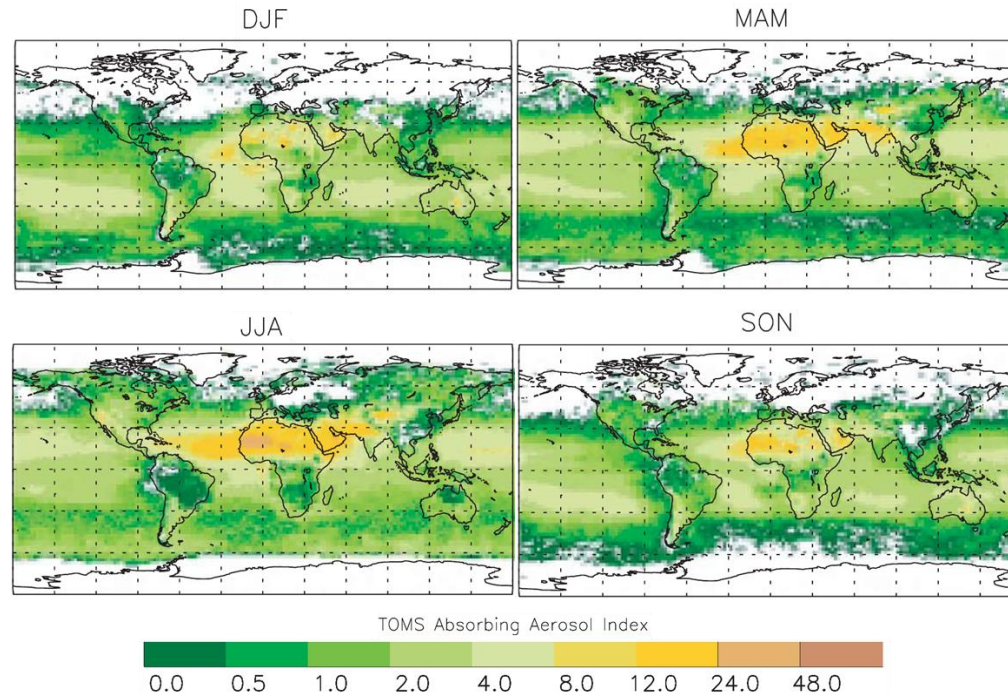
## Dust global distribution



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

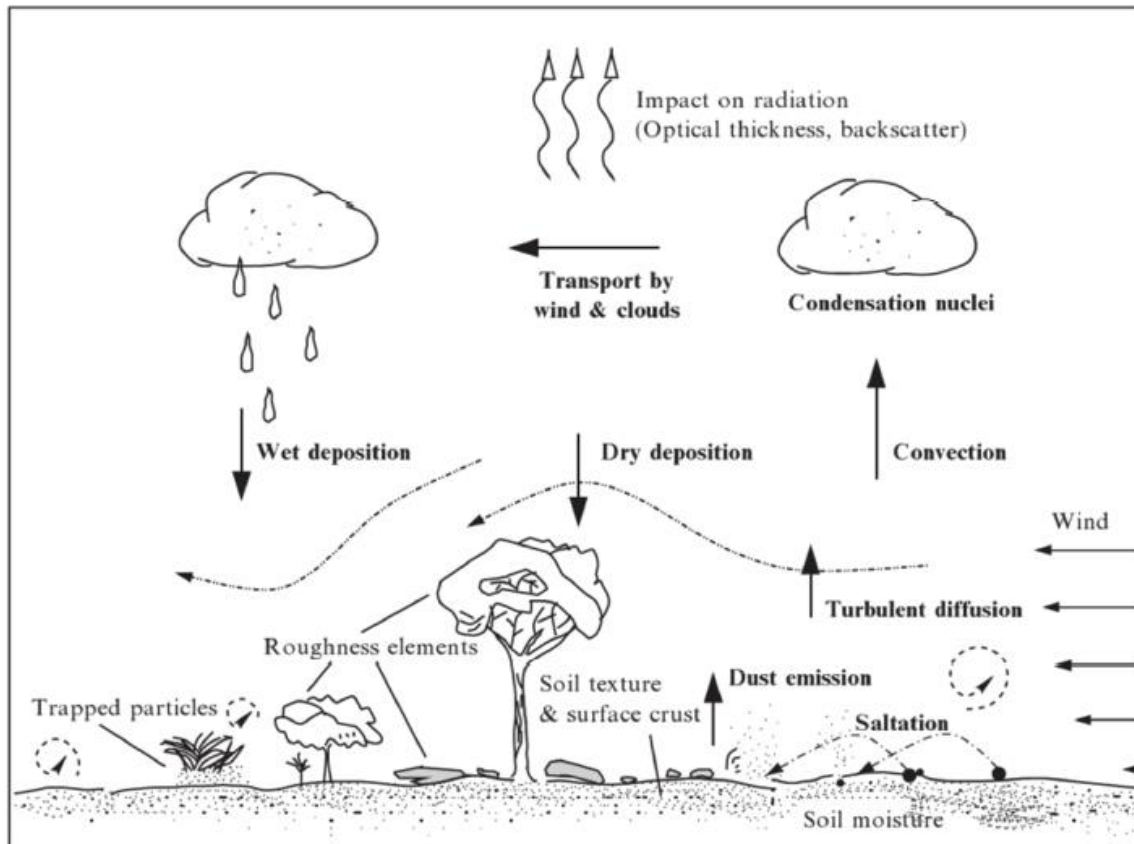


- Seasonal dust distribution changes well characterized. Follows seasonal changing weather regimes (mainly) and vegetation changes (in semi-arid areas)
- Interannual/decadal changes are controlled by climate and surface modification (land use, desertification). Decadal changes are not well captures by 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

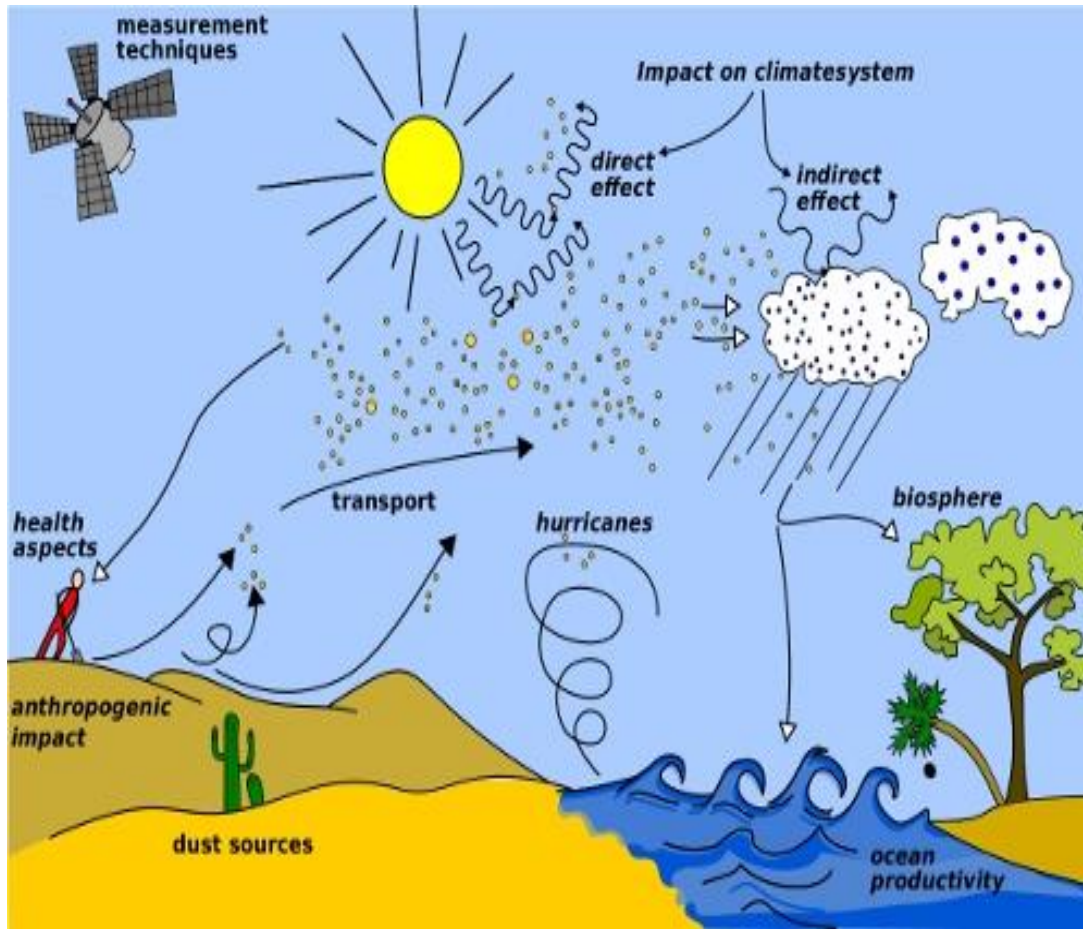


Image from WMO website  
(<http://www.wmo.int/pages/prog/arep/wwrp/new/hurricanes.html>)

## 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*

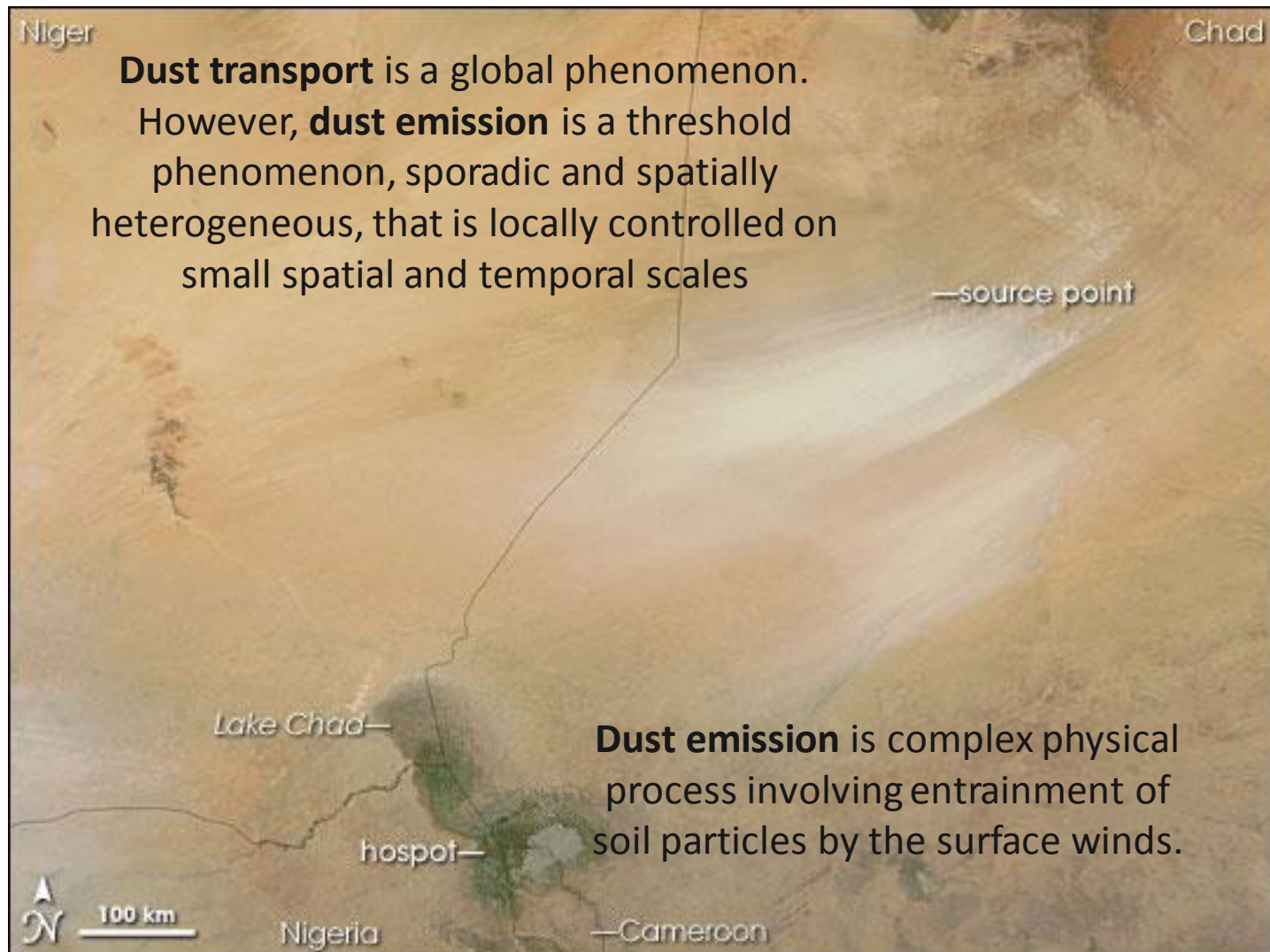
## Aviation and Ground Transportation

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

## Agriculture and fishing

## Energy and industry

# Dust cycle and associated processes



# Dust cycle and associated processes

## Types of dust storms:

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

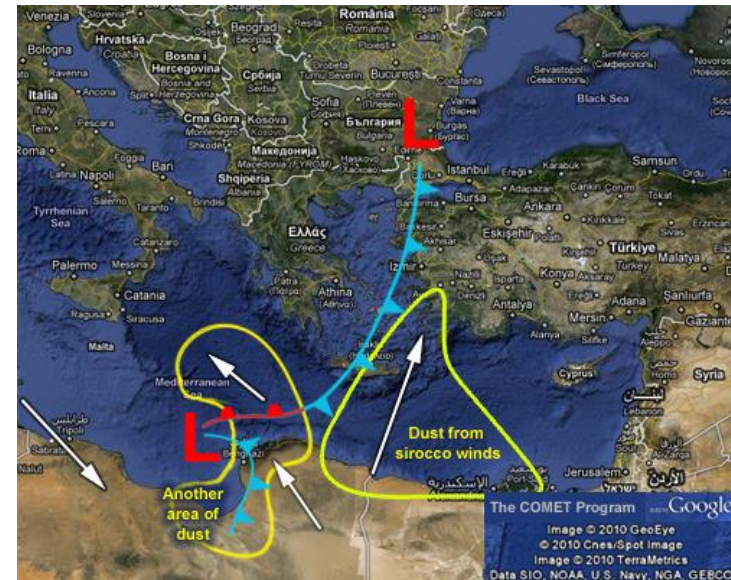
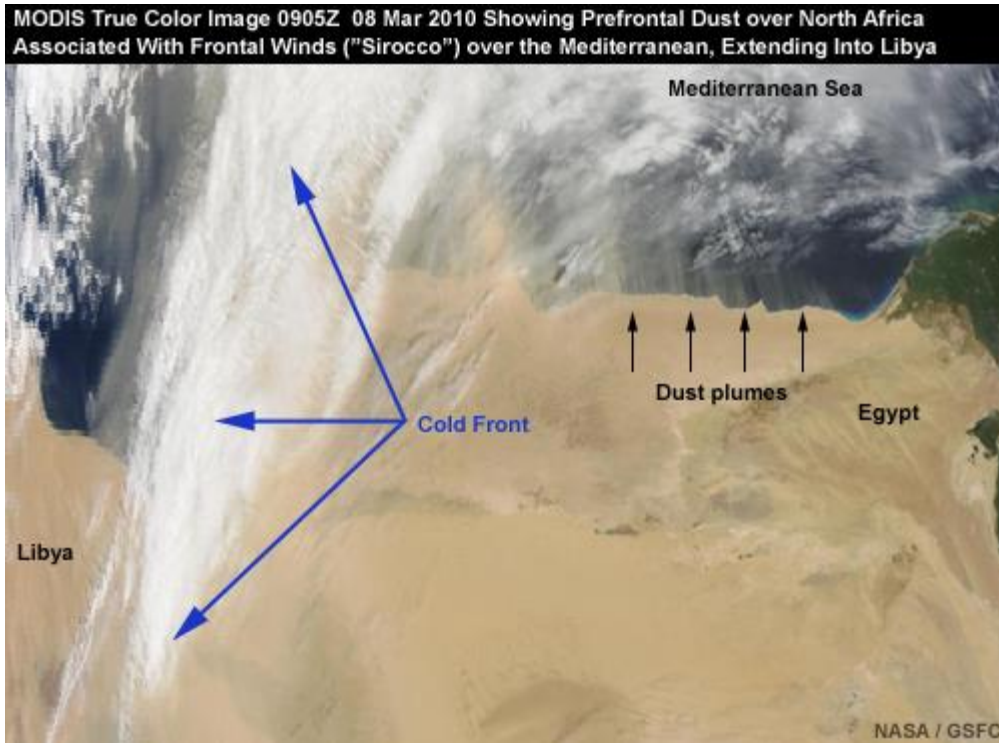
- Prefrontal winds
- Postfrontal winds
- Large-scale Trade winds
- ...

### **Mesoscale dust storms**

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

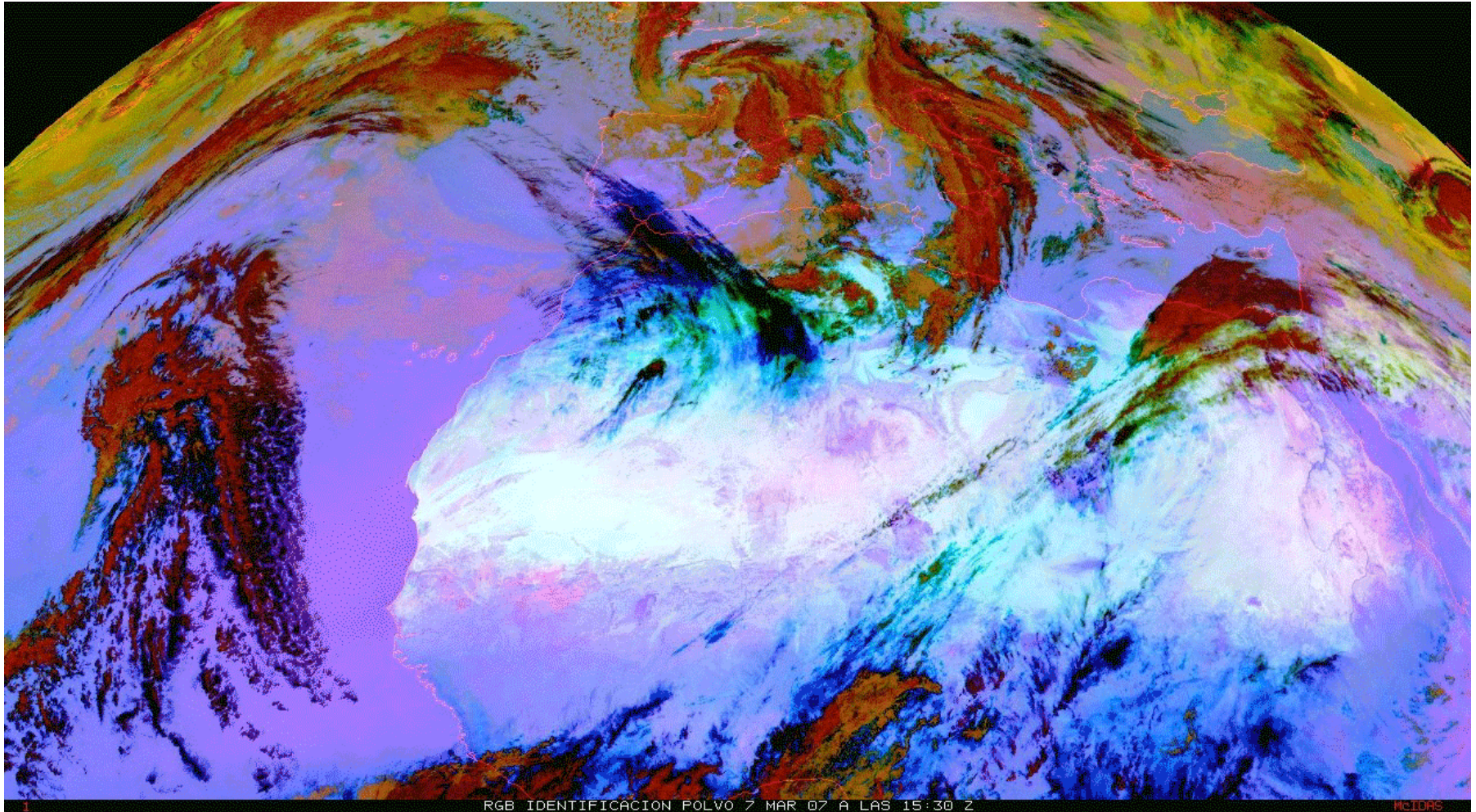
# Dust cycle and associated processes

## Synoptic dust storms: Pre-frontal



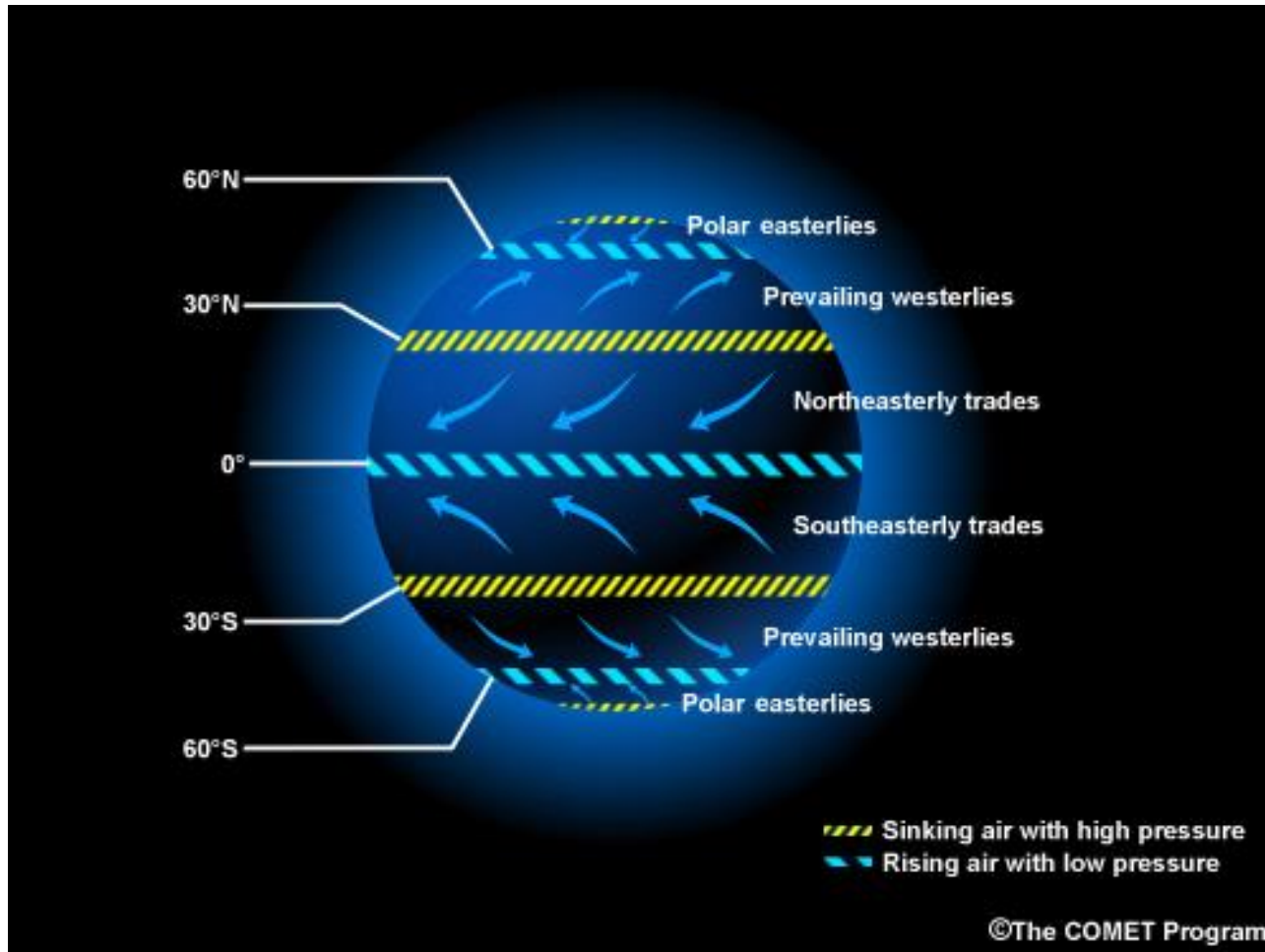
# Dust cycle and associated processes

Synoptic dust storms: Post-frontal



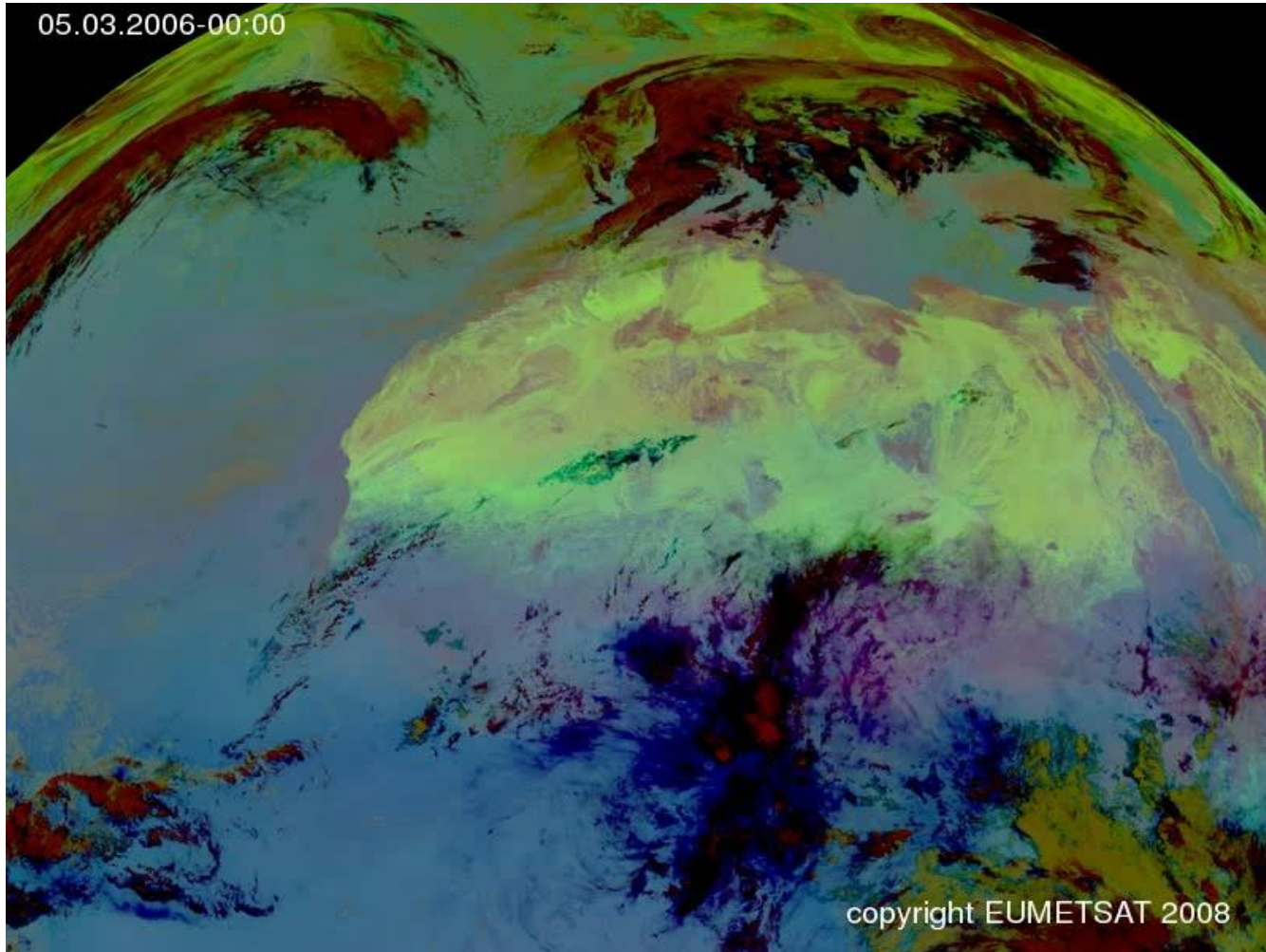
# Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds



# Dust cycle and associated processes

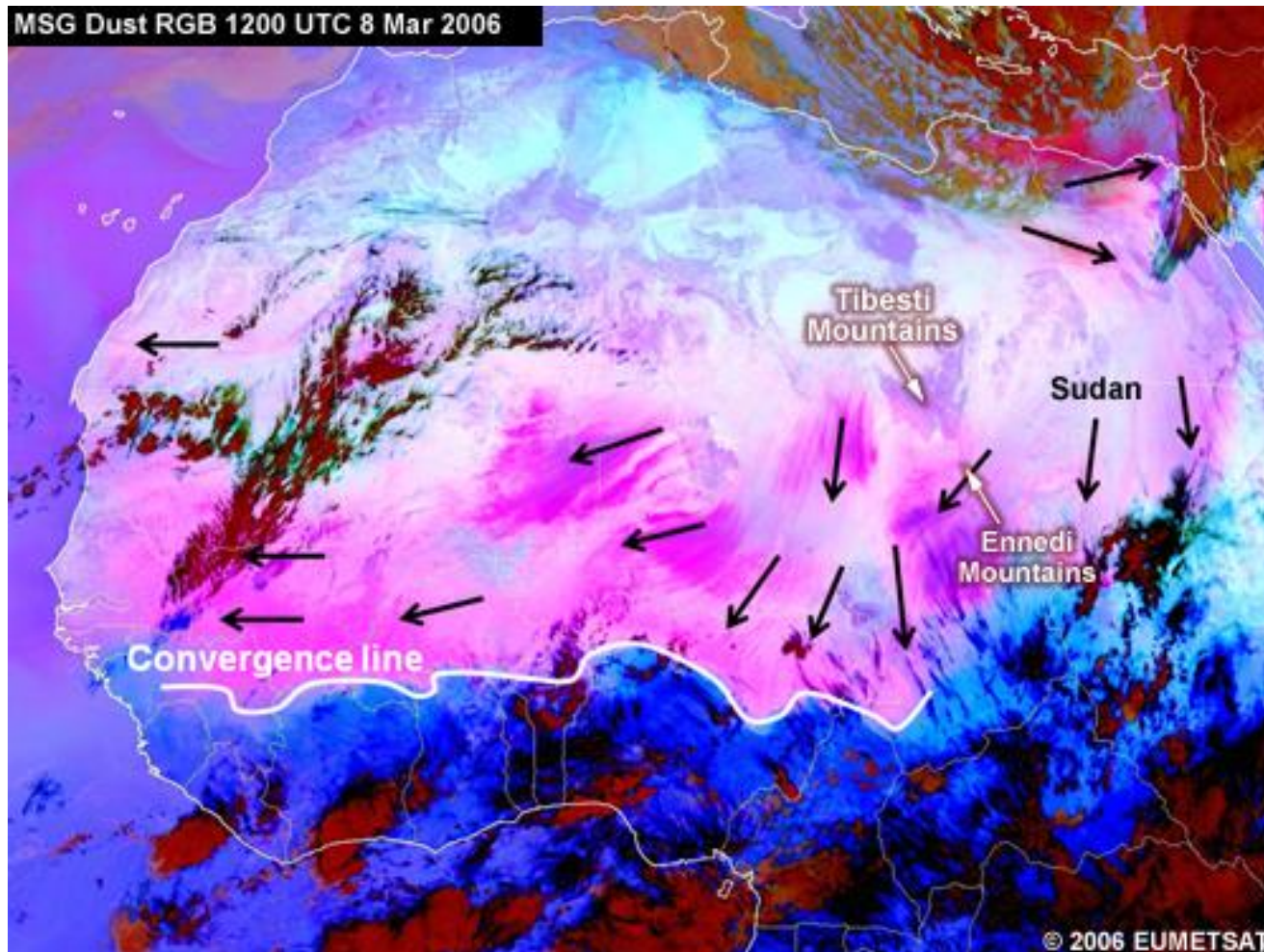
Synoptic dust storms: Large-scale trade winds





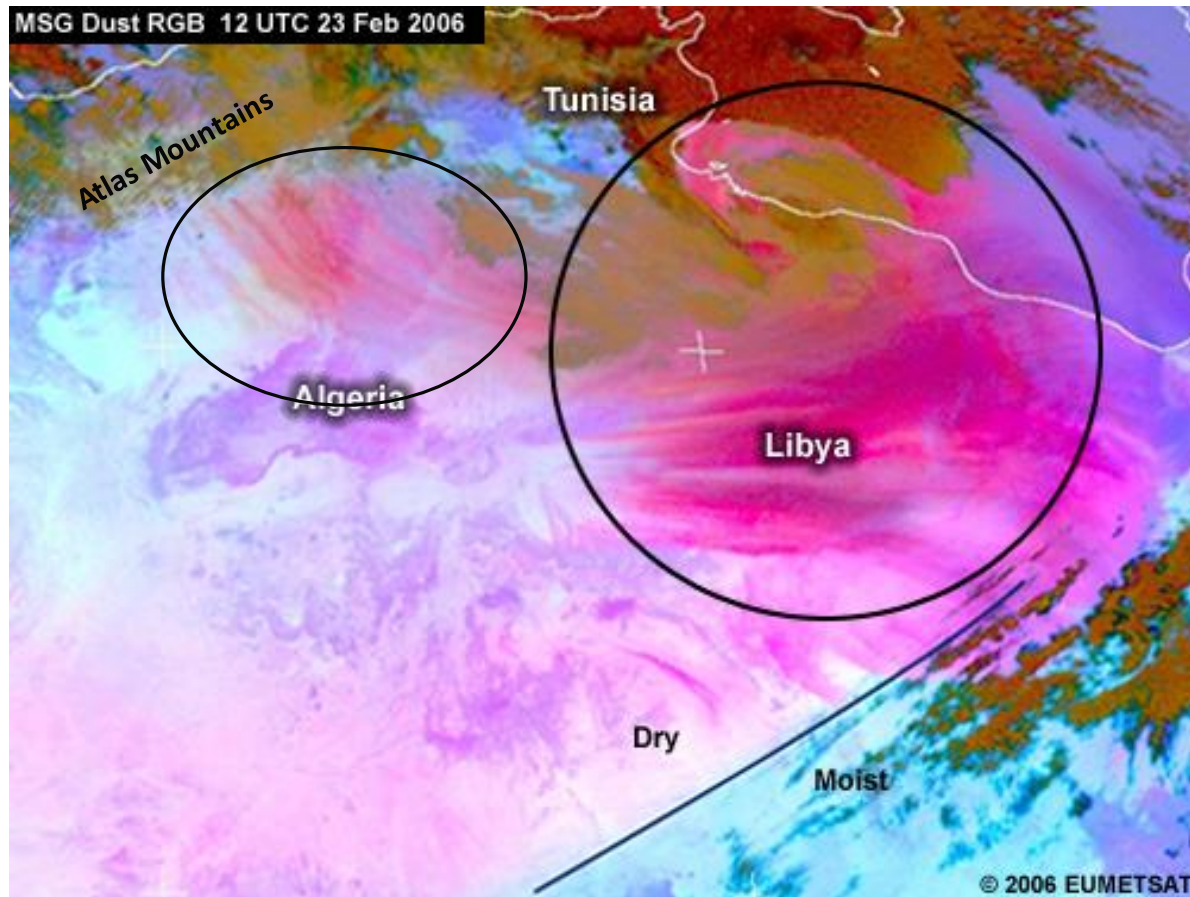
# Dust cycle and associated processes

Synoptic dust storms: Large-scale trade winds



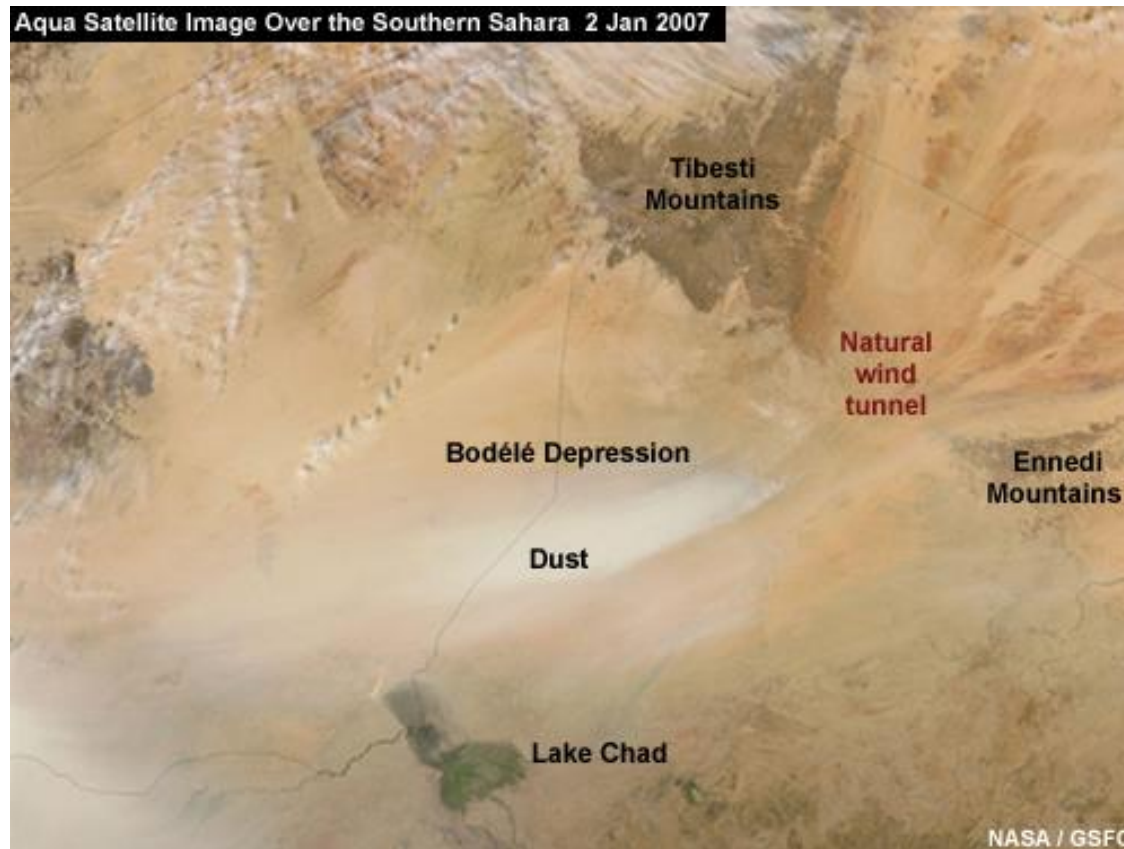
# Dust cycle and associated processes

Mesoscale dust storms: Downslope winds



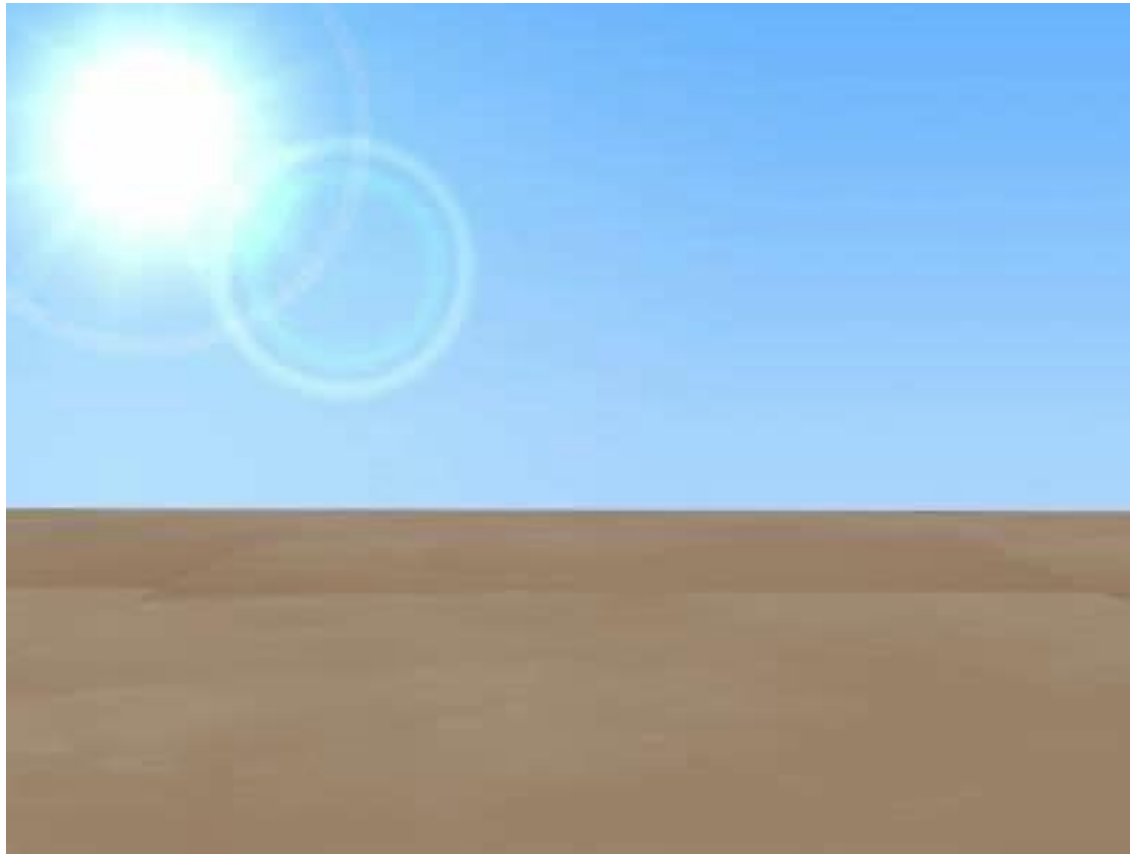
# Dust cycle and associated processes

## 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

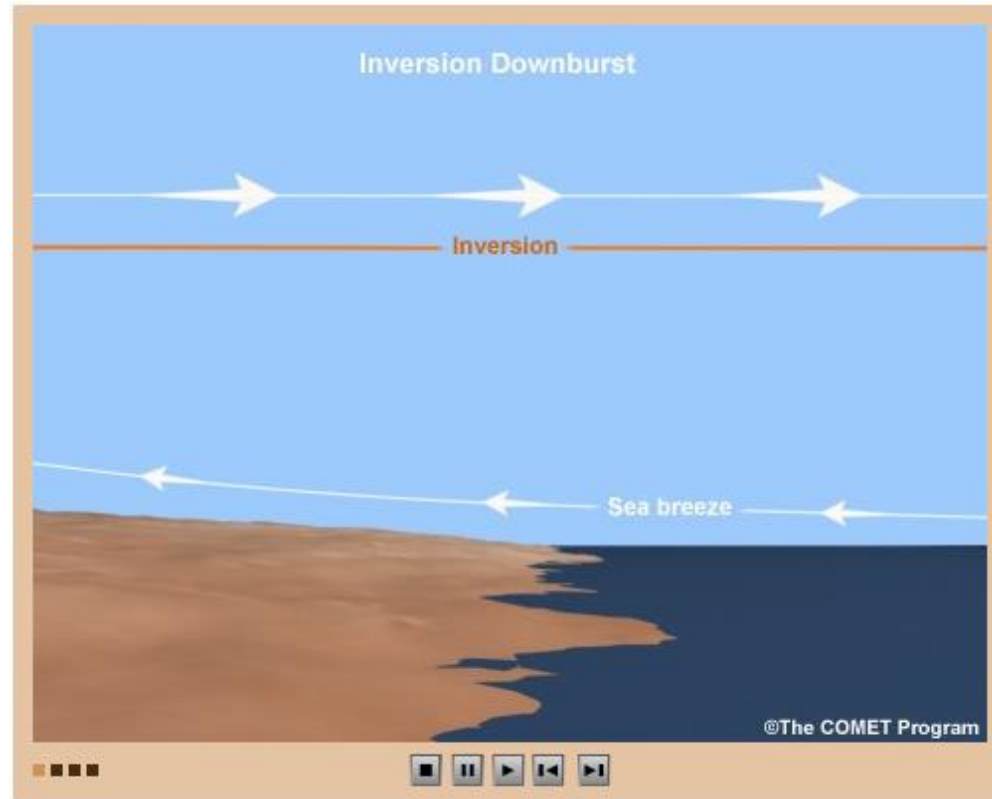
Mesoscale dust storms: Haboobs



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

# Dust cycle and associated processes

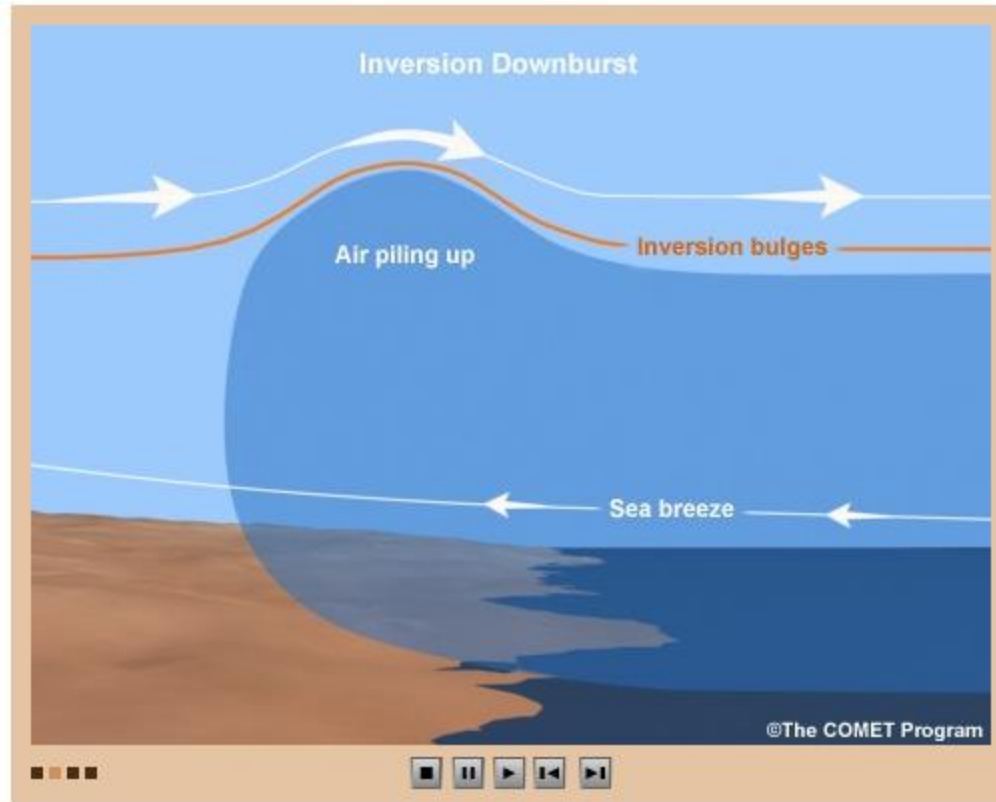
## Mesoscale dust storms: Inversion downbursts



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

# Dust cycle and associated processes

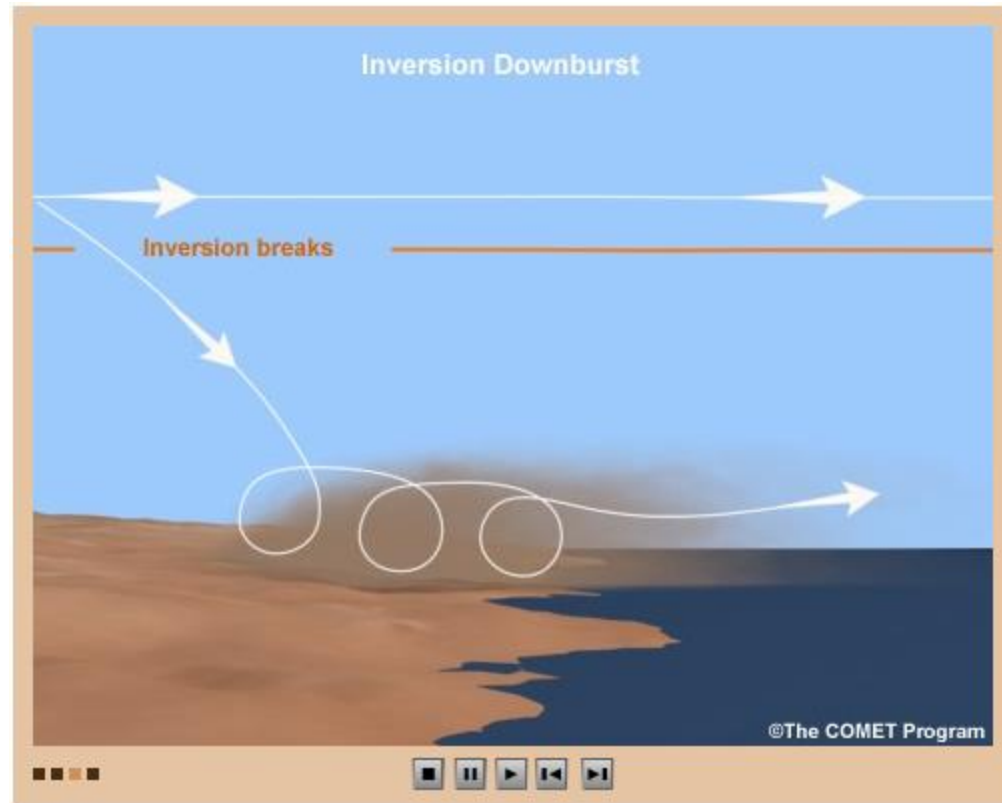
## Mesoscale dust storms: Inversion downbursts



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# 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

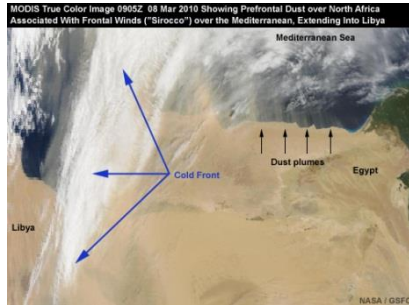
## Mesoscale dust storms: Inversion downbursts



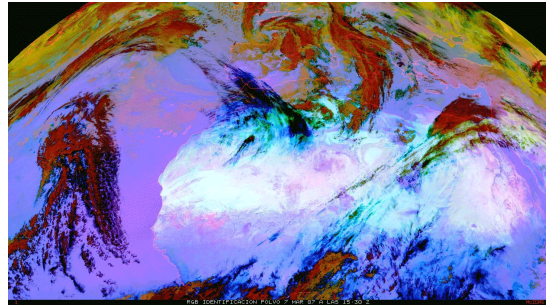
Movie from the COMET program at <http://meted.ucar.edu/> of the University Corporation for Atmospheric Research (UCAR)

# Dust cycle and associated processes

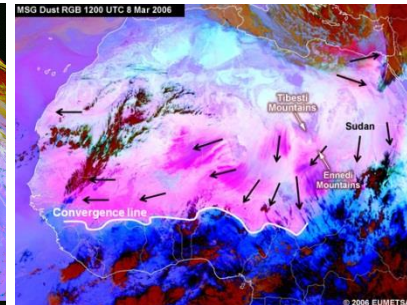
**Synoptic dust storms** (large scale weather systems) **Well captured by models.**



*Pre-frontal winds*

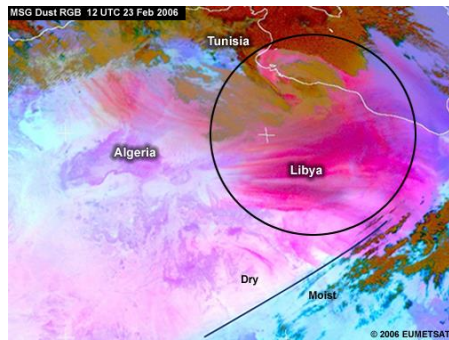


*Post-frontal winds*

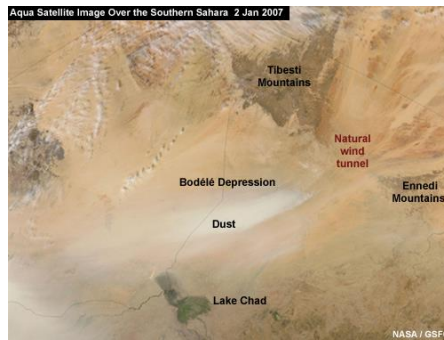


*Large-scale trade winds*

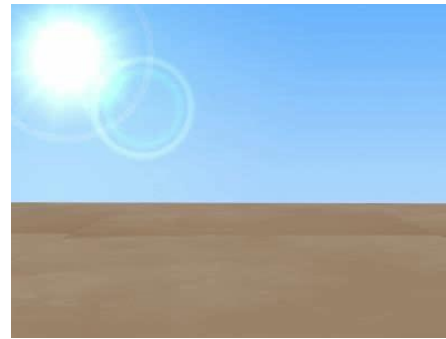
**Mesoscale dust storms** **Poorly captured by models.**  
**Some types improve in regional models.**



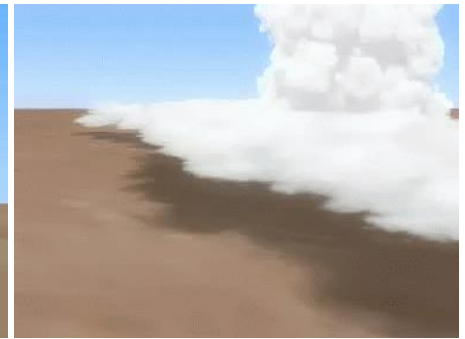
*Downslope winds*



*Gap flow*



*Dust devils*



*Haboobs*

# Dust forecasting models

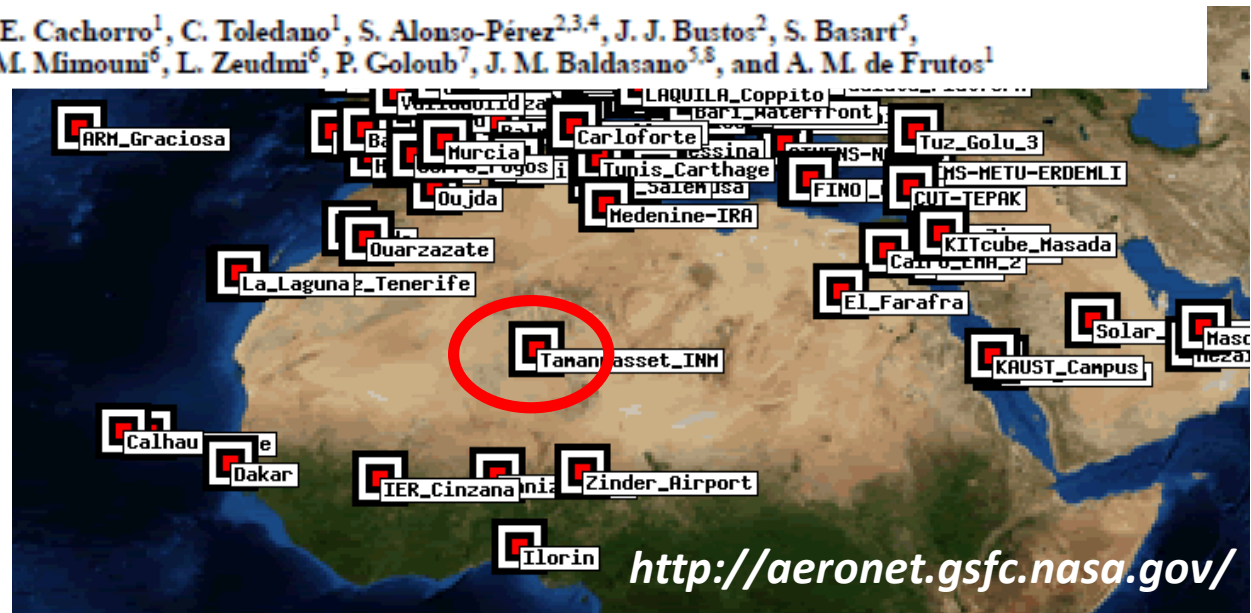
Atmos. Chem. Phys., 14, 11753–11773, 2014  
www.atmos-chem-phys.net/14/11753/2014/  
doi:10.5194/acp-14-11753-2014  
© Author(s) 2014. CC Attribution 3.0 License.

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Chemistry  
and Physics  
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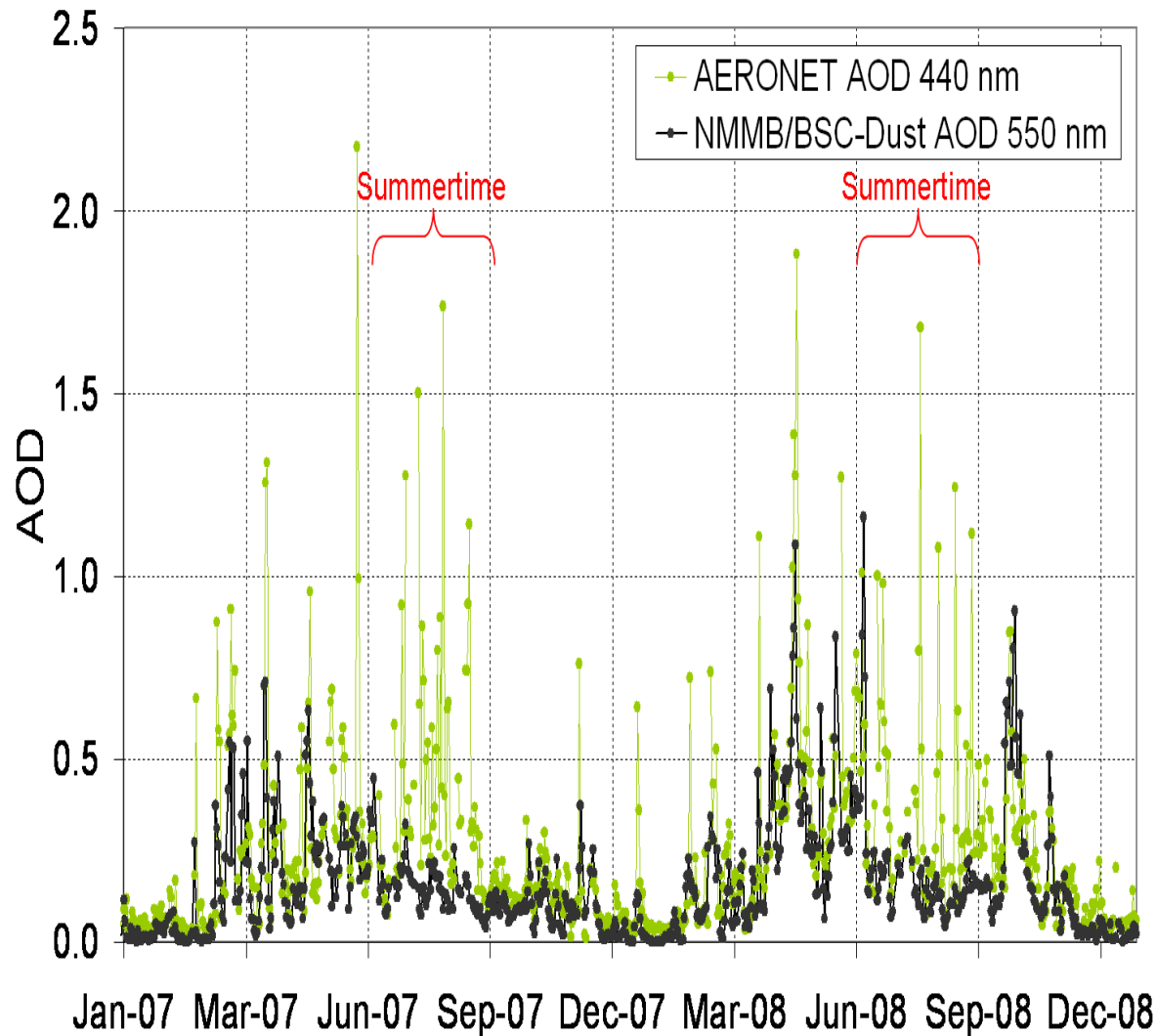


## Aerosol characterization at the Saharan AERONET site Tamanrasset

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

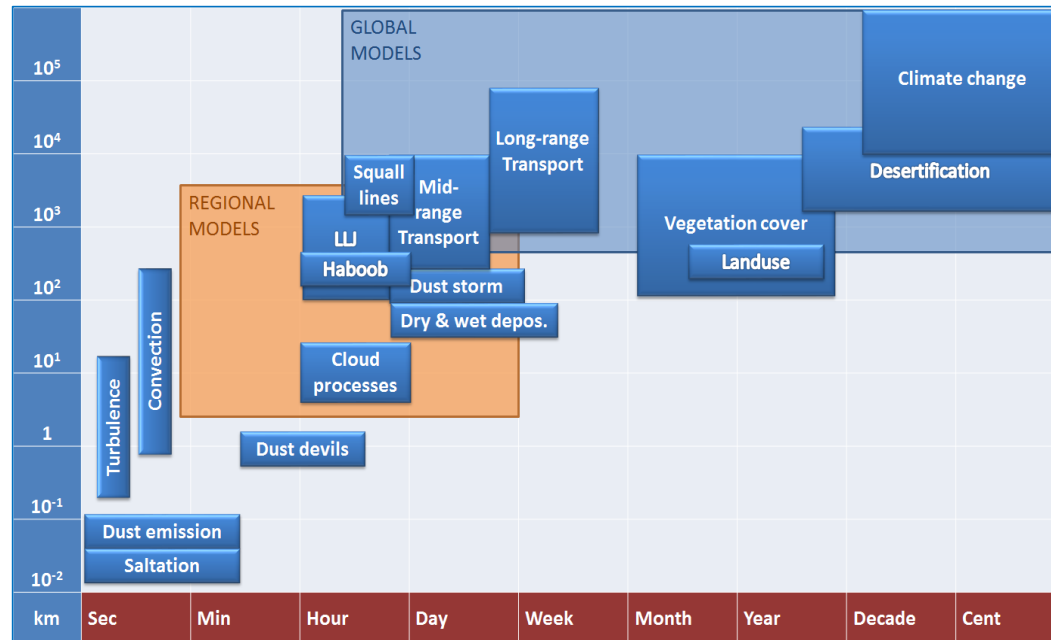


# Dust forecasting models



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.**

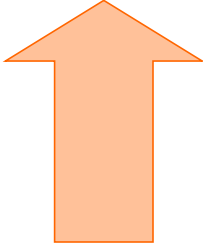


# Dust forecasting models

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

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

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



# Dust forecasting models: Emission

## 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;

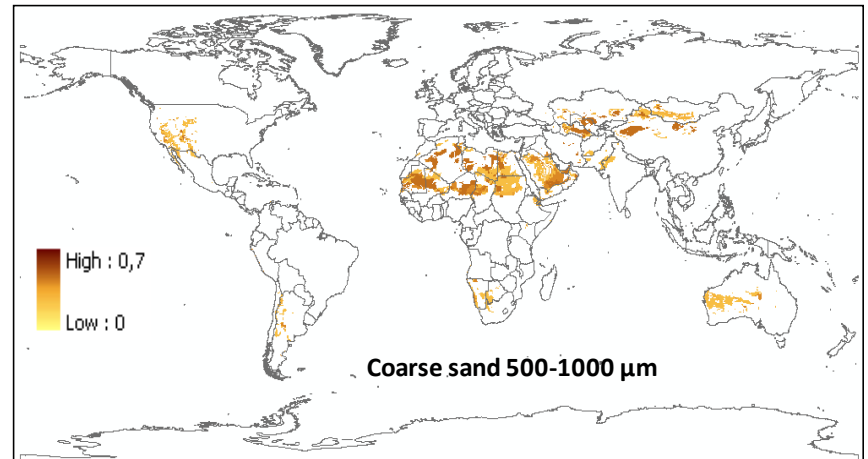
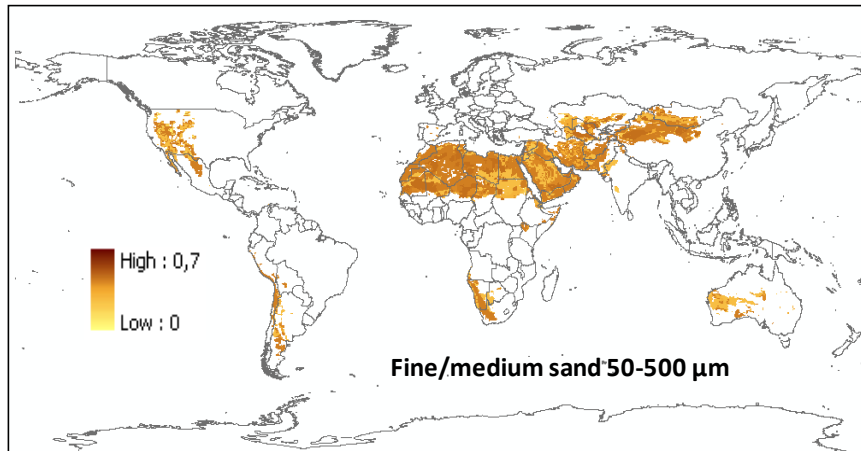
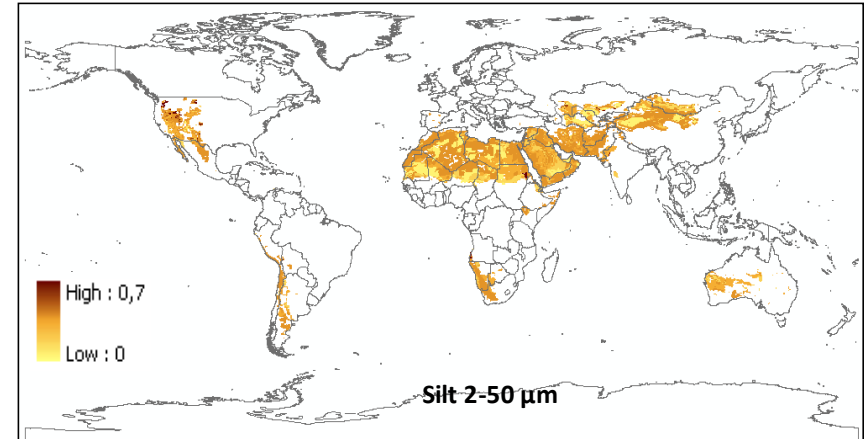
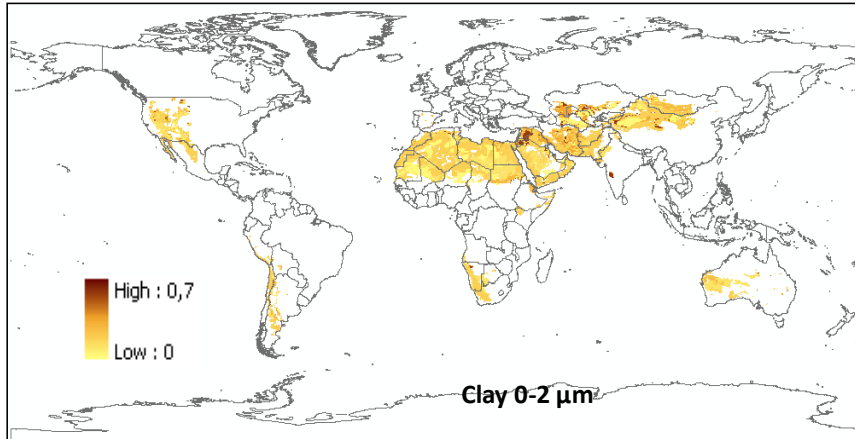
E) North-east of the Great Western Erg: coarse sand interdune corridor with deflation cauldron and palaeolake deposits;

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



# Dust forecasting models: Emission

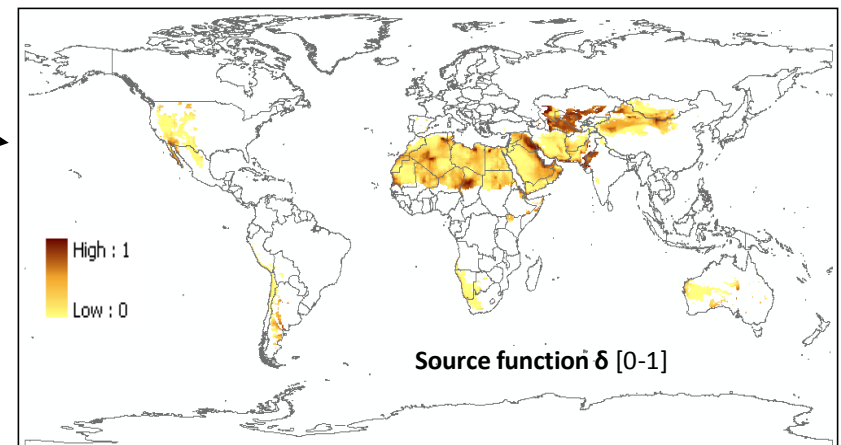
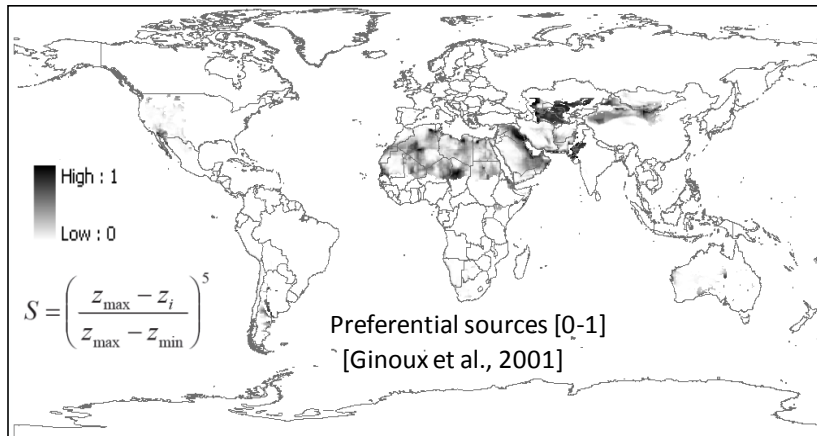
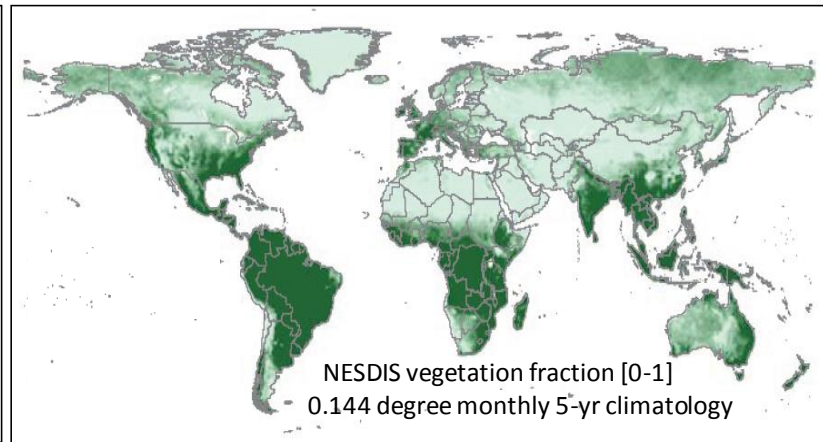
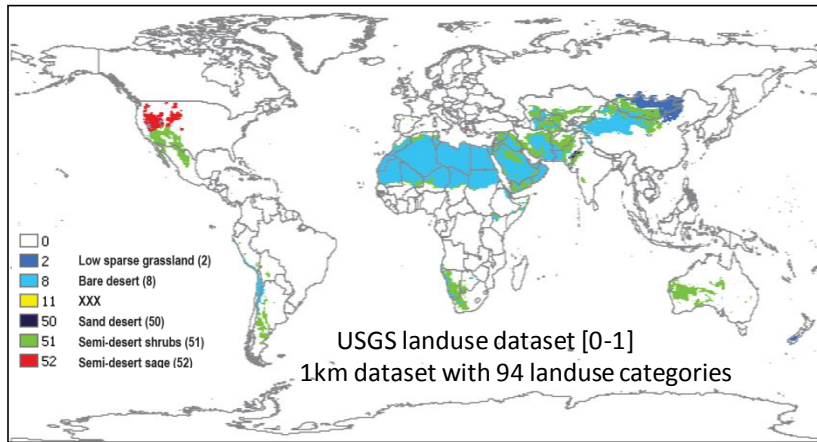
## Parent soil size distribution



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

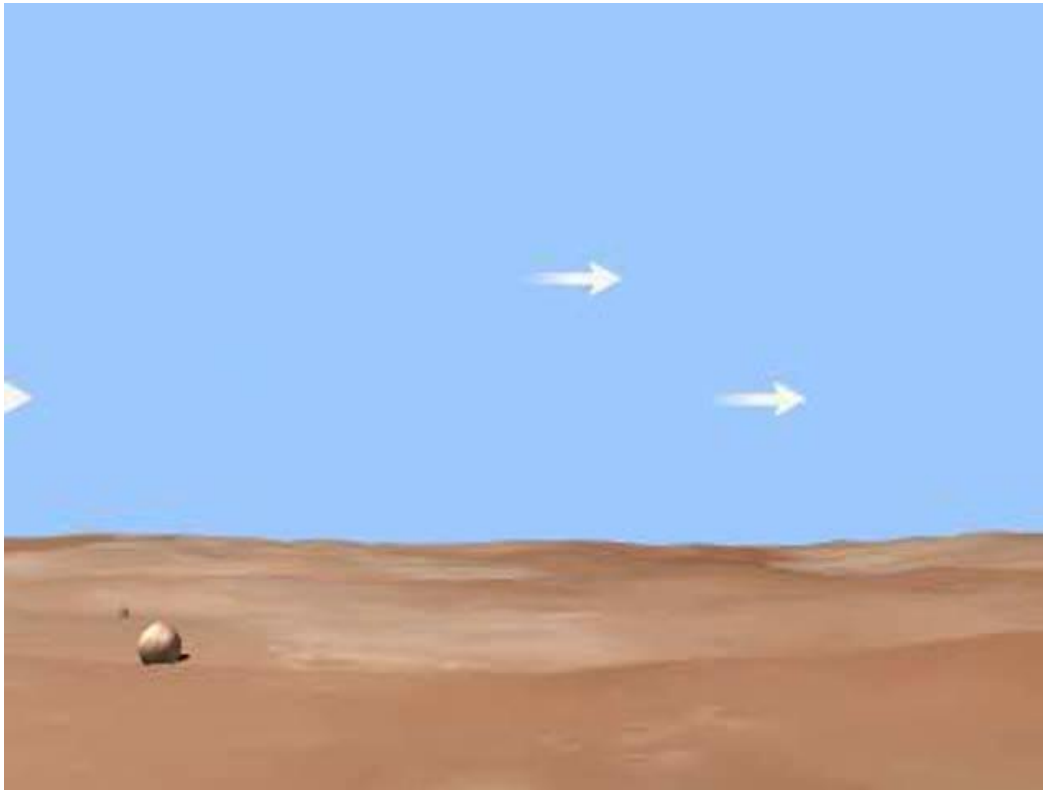
## Dust source function: the NMMb/BSC-Dust model



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

# Dust forecasting models: Emission

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

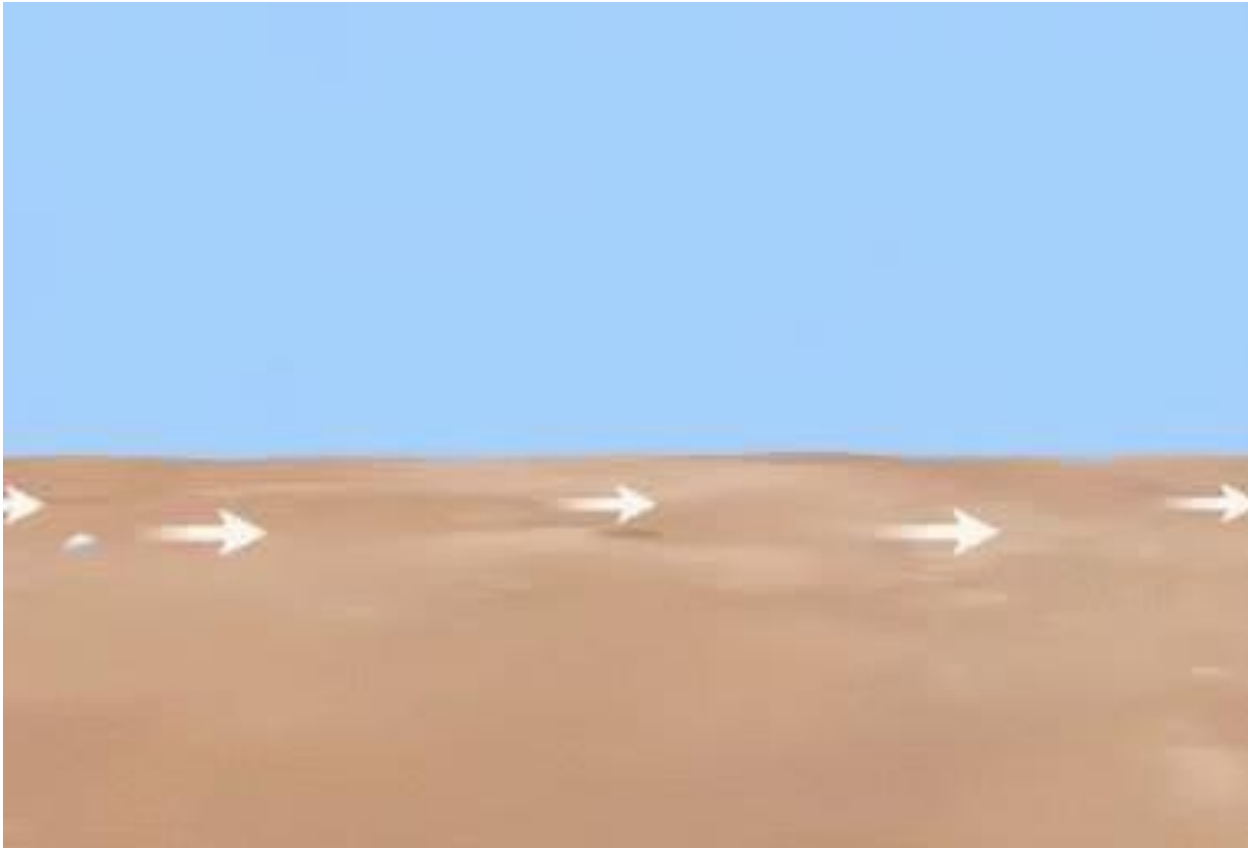


- Creep or rolling motion of the largest particles ( $> 500 \mu\text{m}$ )
- Saltation or horizontal motion of large soil grains (sand) ( $50\text{-}500\mu\text{m}$ )
- Suspension of dust (after sandblasting or saltation bombardment) ( $0.1\text{-}50 \mu\text{m}$ )

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

# Dust forecasting models: Deposition

## 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: Deposition

## Wet scavenging

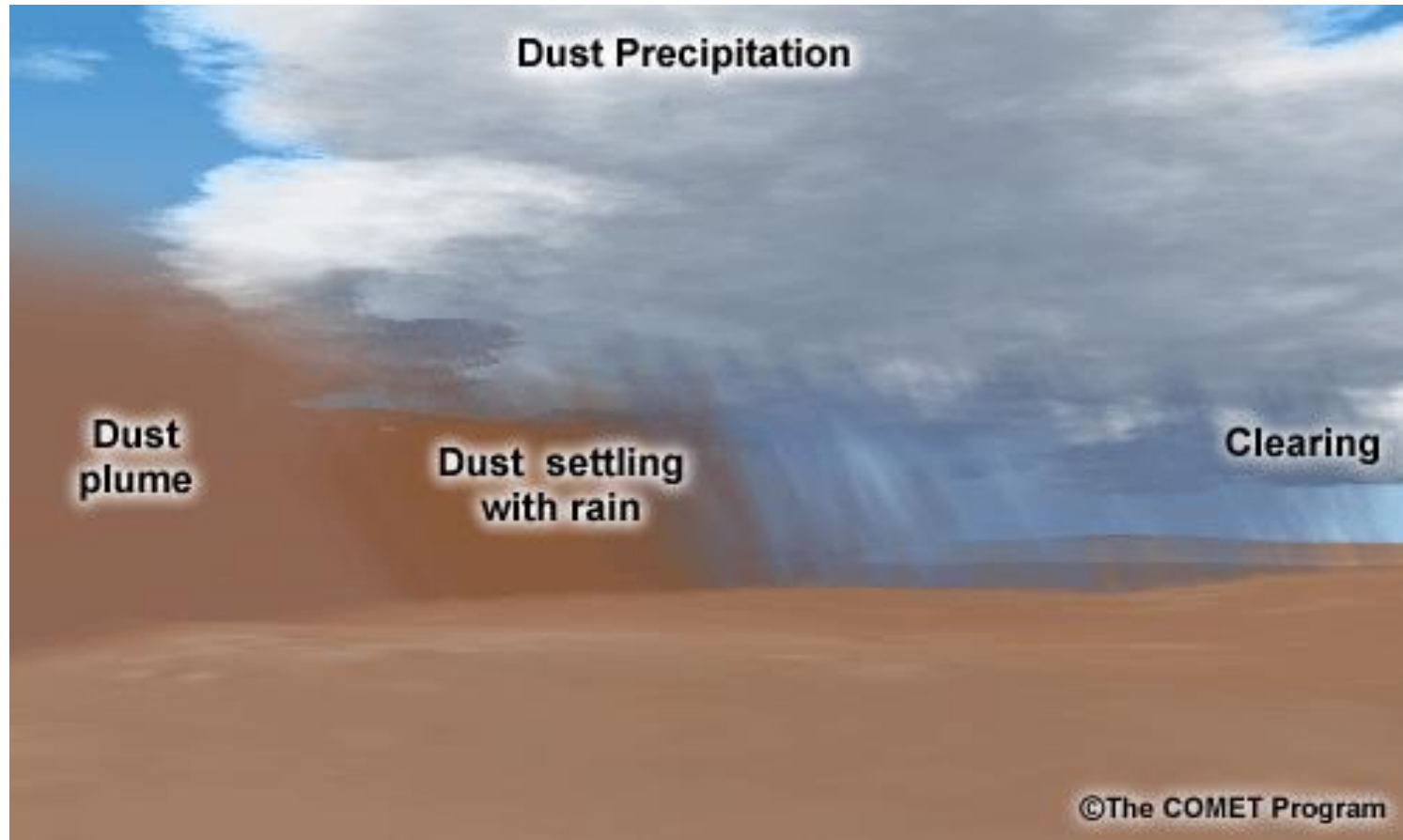


Image from the COMET program at <http://meted.ucar.edu/> of the University Corporation for Atmospheric Research (UCAR)

# Dust forecasting models

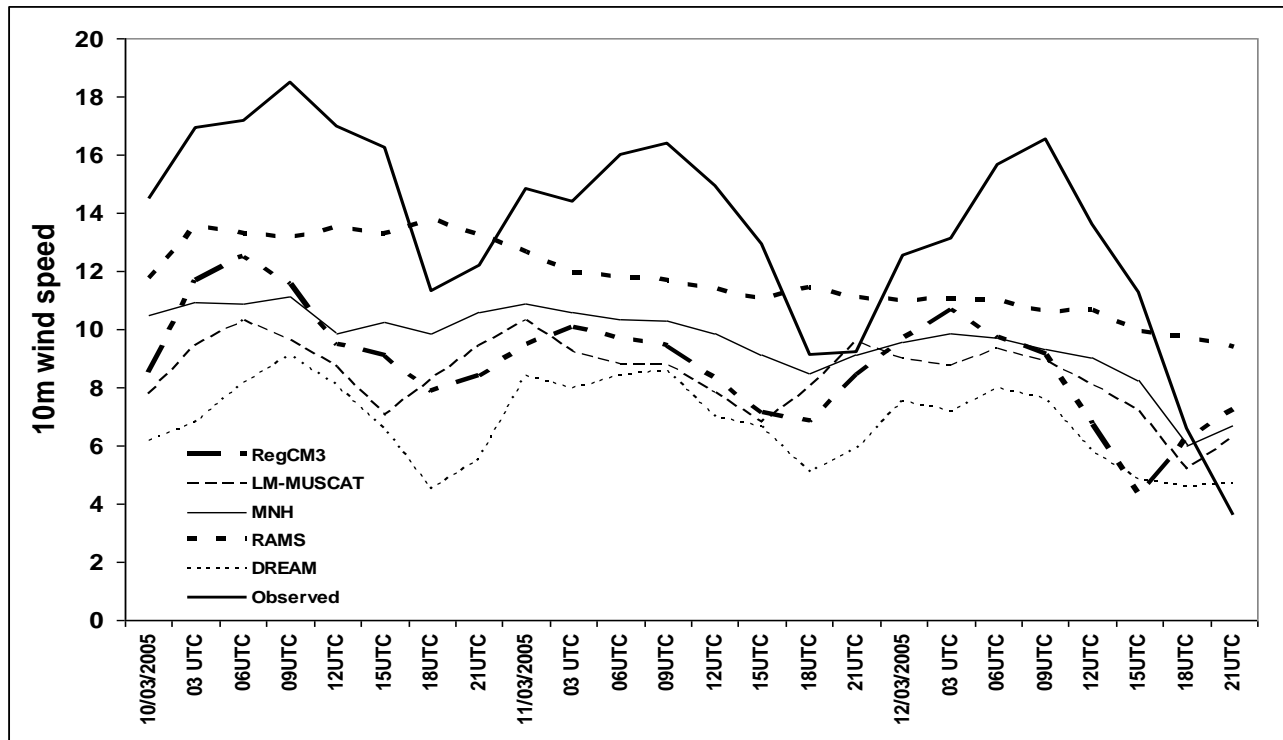
## Main differences between dust models

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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# 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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