The dust cycle in the atmosphere

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

Summary

- Atmospheric aerosol
- The cycle of mineral dust
- WMO SDS-WAS
- Dust observation
- Dust forecast
- Also...

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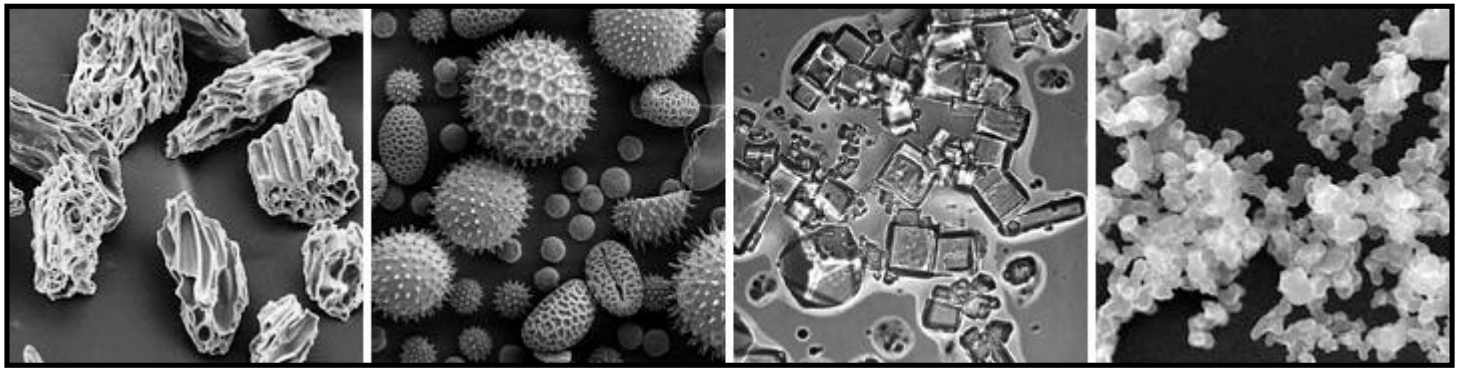
Atmospheric aerosol

Solid or liquid particles suspended in the air

- Types: primary / secondary, natural / anthropogenic particles
- Size: diameter between 0.001 µm (1 nm) and 100 µm approx.
- Chemical and mineralogical composition: diverse
- Optical properties (absorption, scattering): diverse

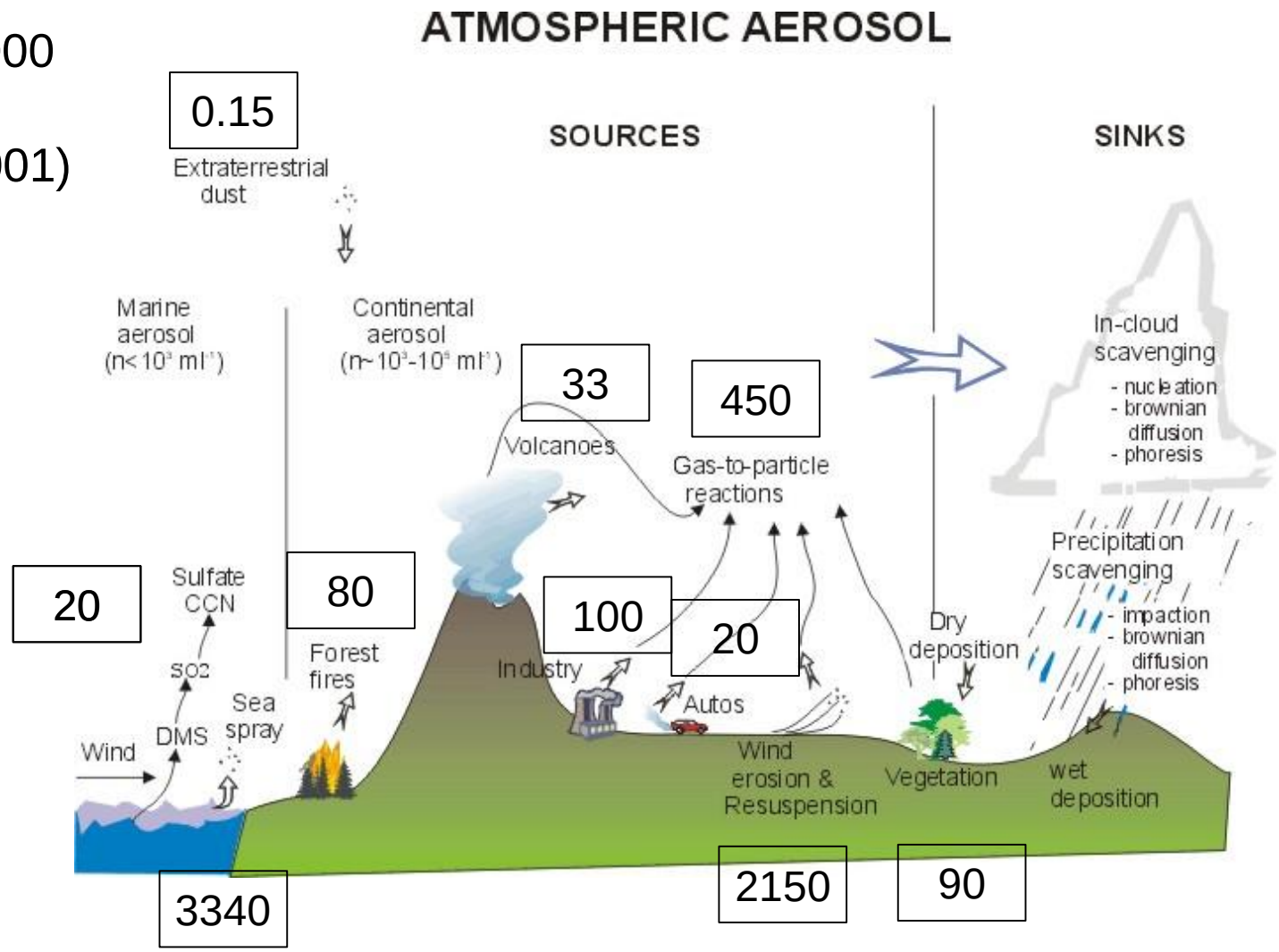


USGS science for a changing world

ASU Arizona State University

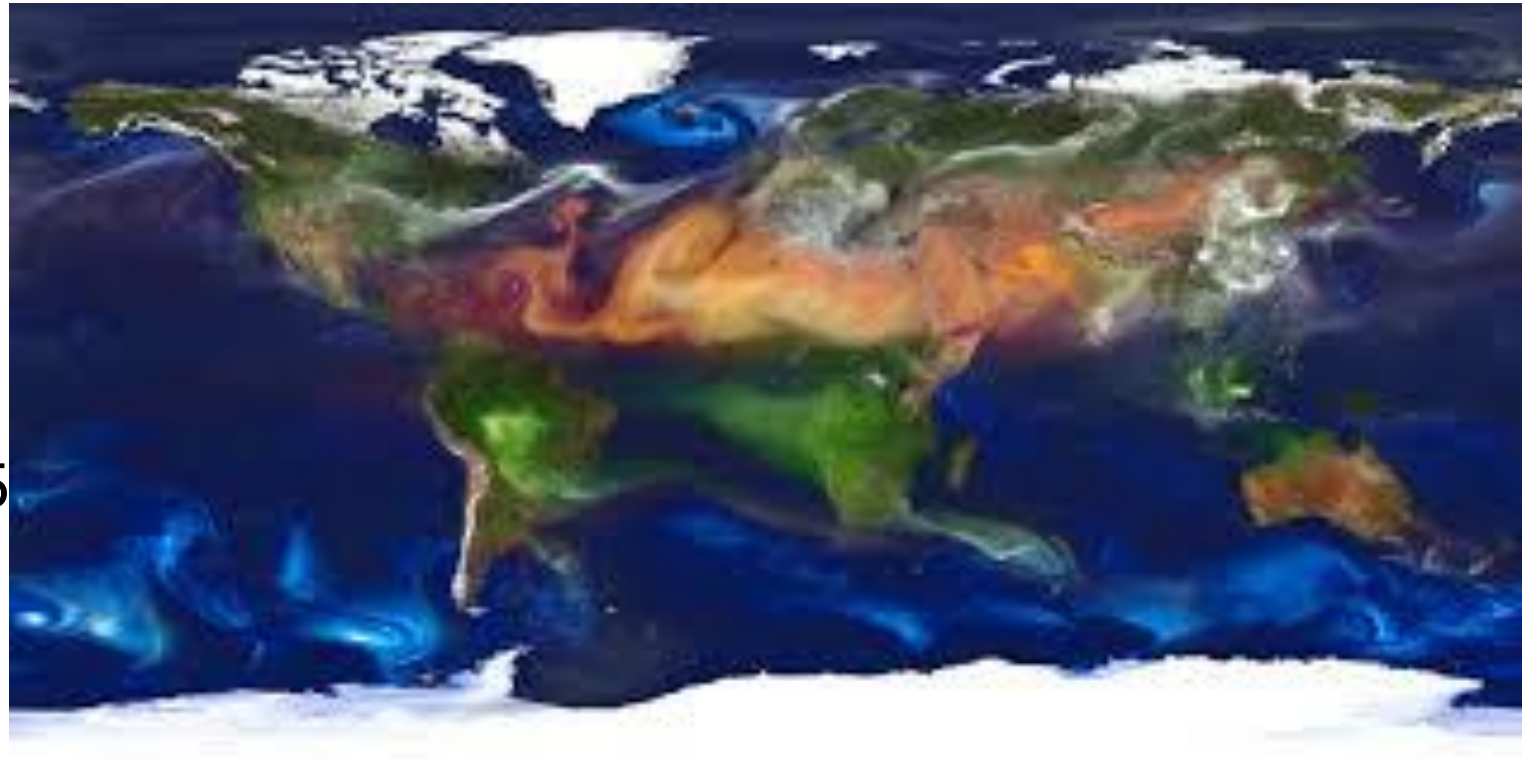
Sources

Year 2000
(Tg)
IPCC (2001)



Distribution

NASA
GEOS-5



- Mineral dust (reddish)
- Sea salt (blue)
- Products from biomass burning (green)
- Sulphates (white)

https://youtu.be/oRsY_UviBPE

Summary

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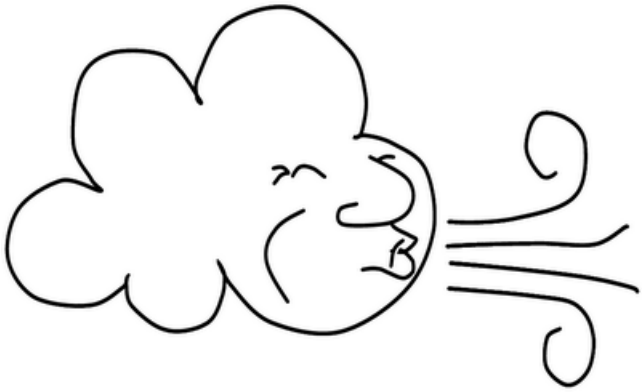
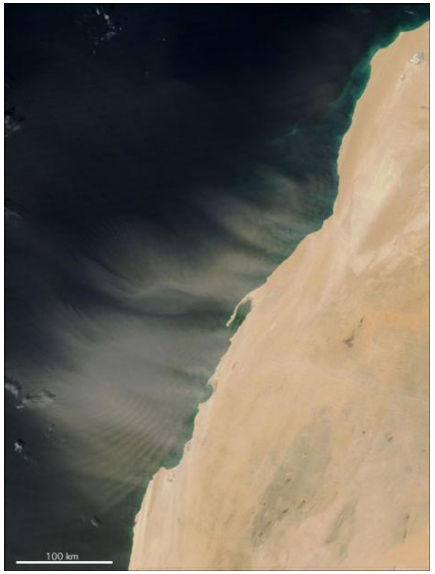
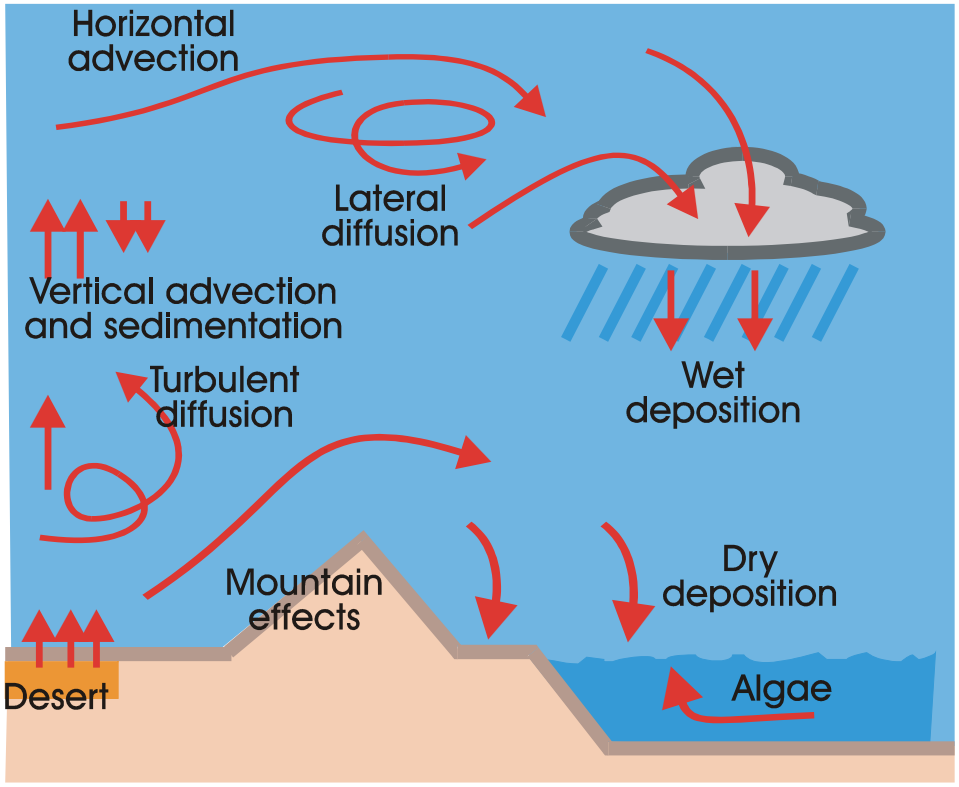
- Also...

The dust cycle



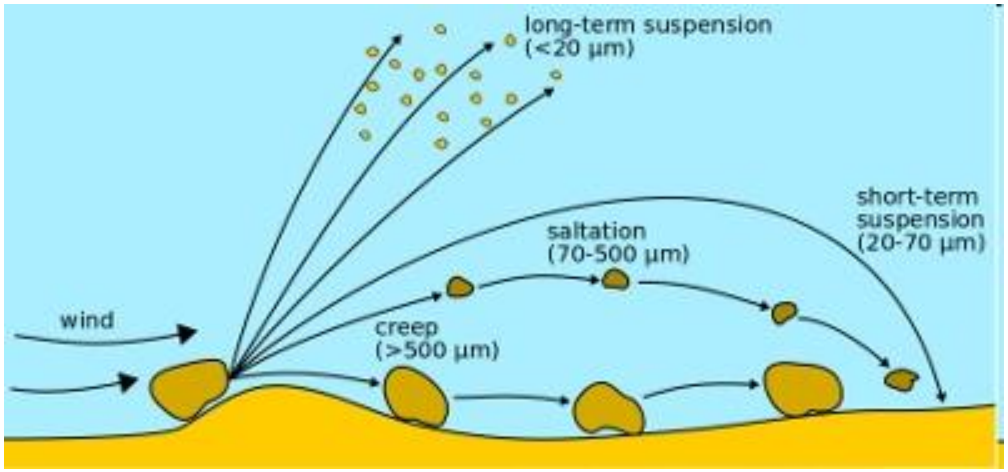


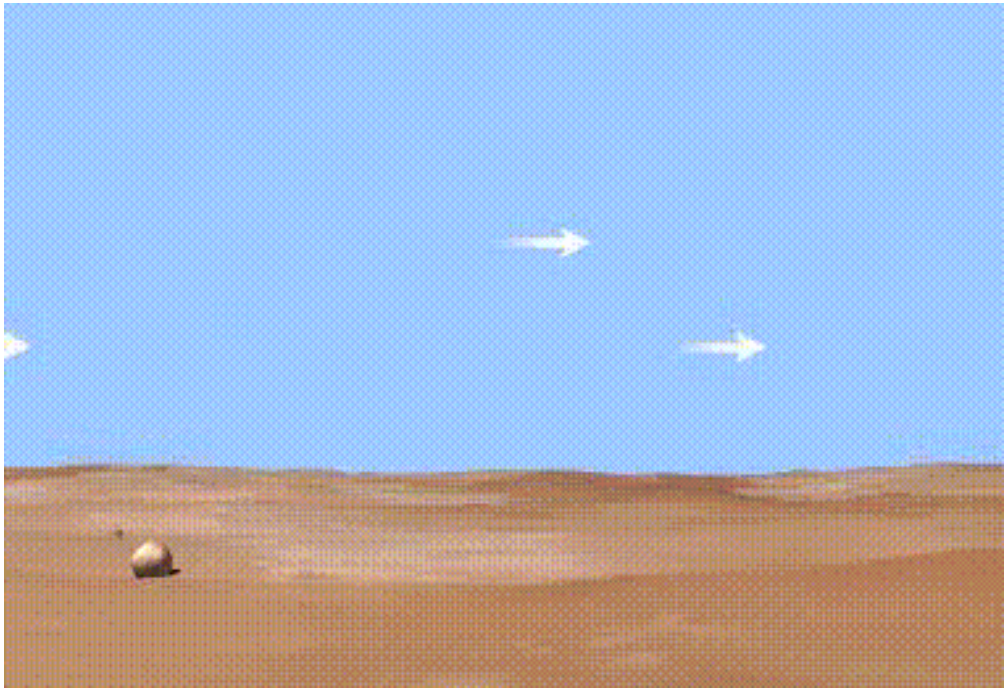
The dust cycle



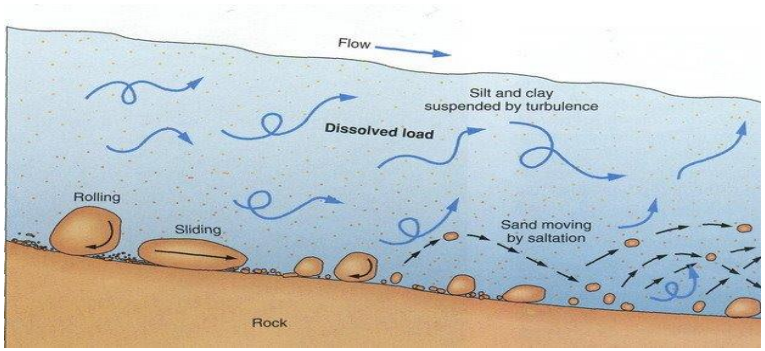
- Emission
- Turbulent difussion
- Transport
- Dry / wet deposition

Emission



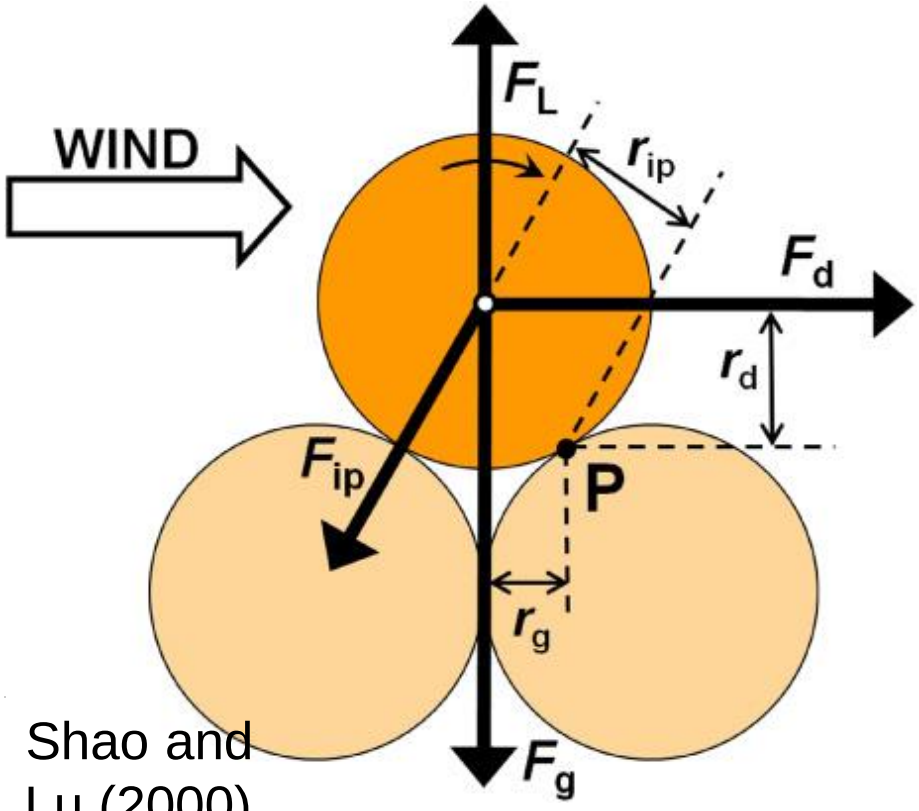


- The wind moves the loose particles according to its speed and the size of those particles
- The process is similar to sediment transport by rivers



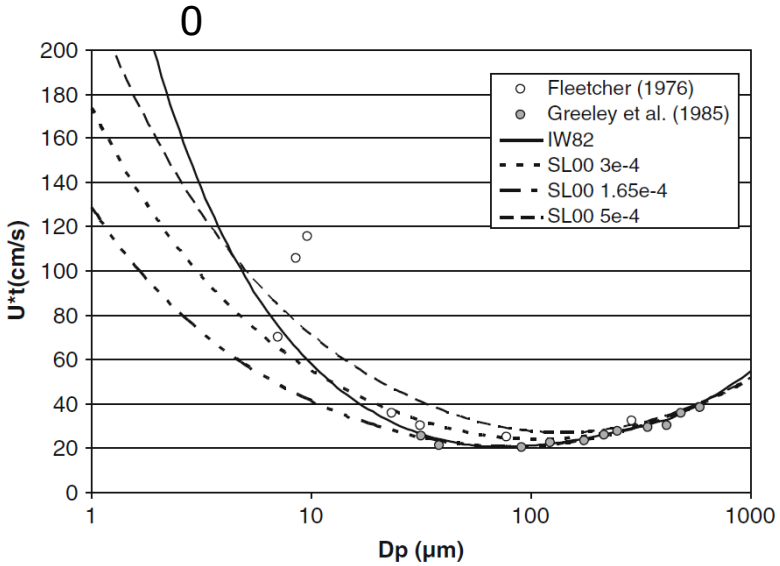
Erosion threshold

The threshold for particle mobilization is the result of the balance between the wind-shear stress and the forces acting to keep the particles on the soil (weight, cohesive forces between particles)

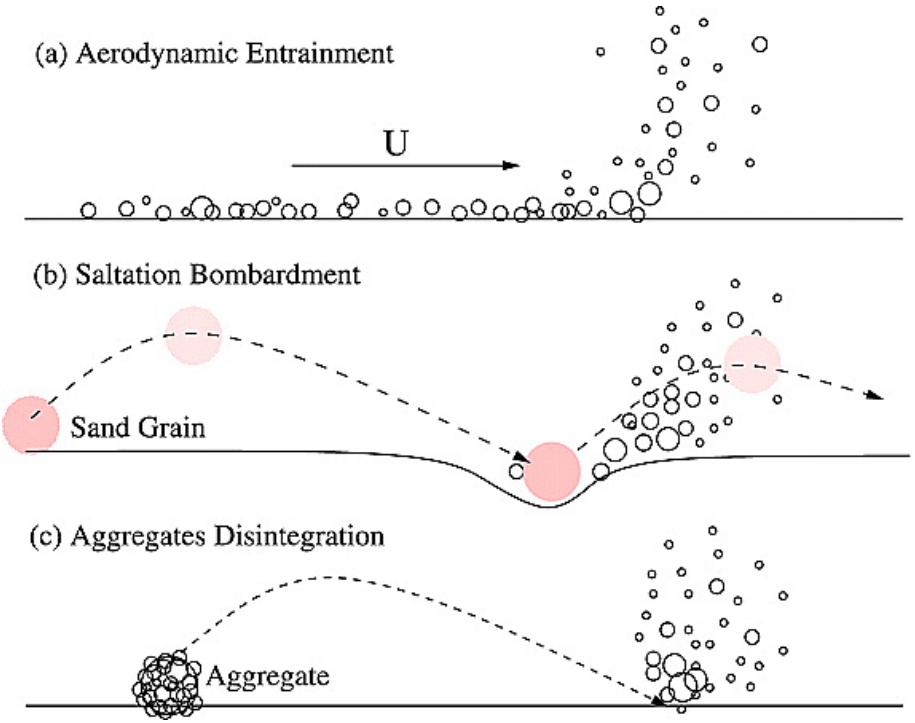


Shao and Lu (2000)

$$u^* = (\tau / \rho)^{0.5} = ku / \ln(z/z_0)$$



Saltation & sandblasting



Shao et al. (2011)

- Direct suspension is not so common, because it needs very strong winds.
- Normally, the dust emission is the result of the combination of two different physical processes: saltation (horizontal flux) and sandblasting (vertical flux).
- Sandblasting is a consequence of the breaking of particle aggregates.

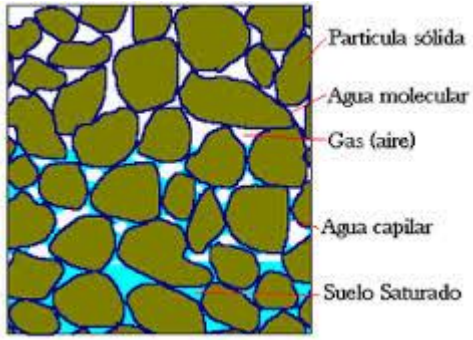
Erosion threshold

A crude estimation of the threshold wind speed for dust emission would be around **8 m/s**, although it depends on many factors (soil nature and state, turbulence). Different elements modify this threshold

Non-erodible elements (i.e. vegetation)

Crusted soils

Soil humidity



Snow

Emission

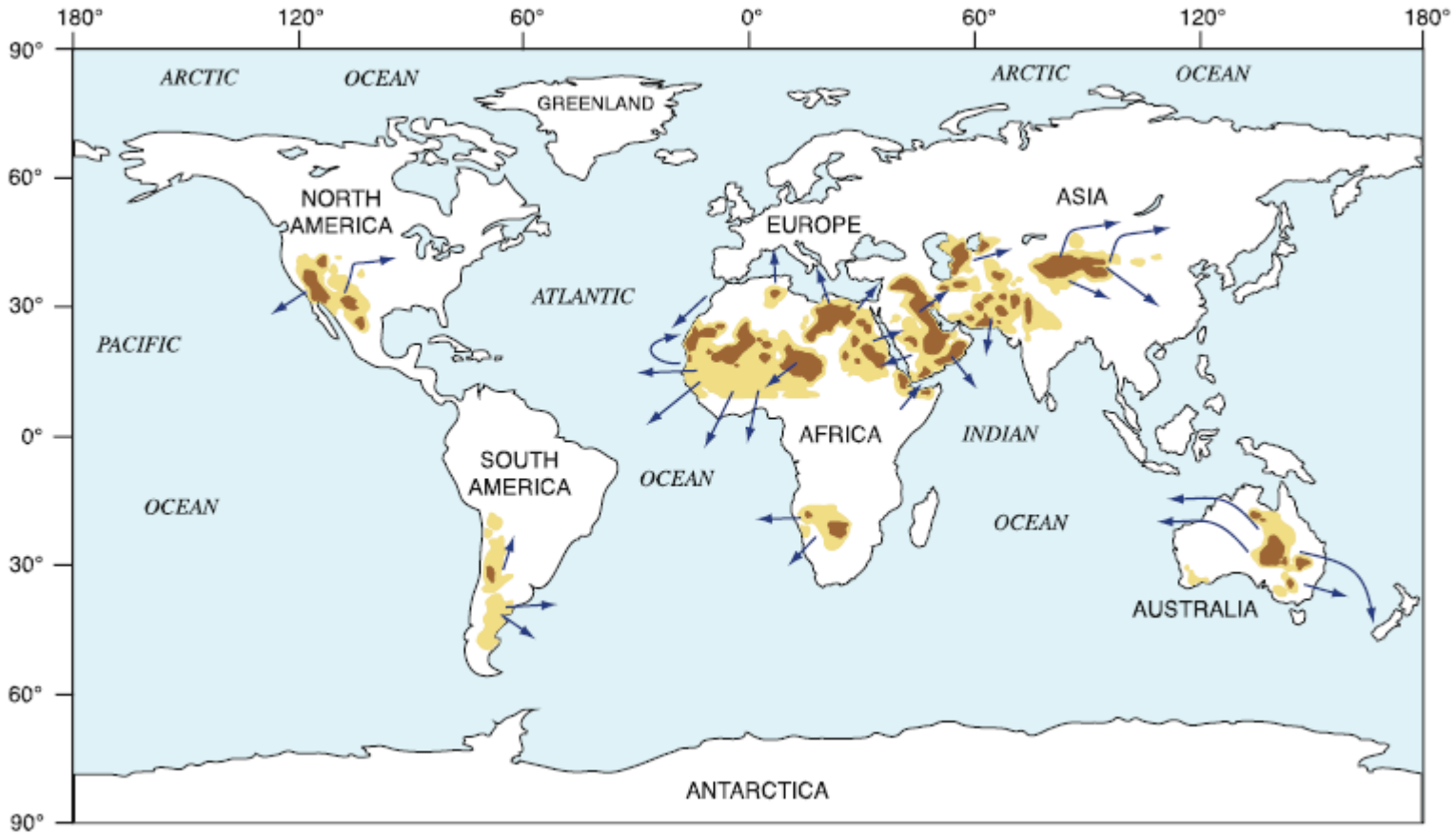
Soil factors

- Soil texture (particle size)
- Soil moisture
- Vegetation
- Snow cover

Meteorological factors

- Wind speed
- Near-surface turbulence

Sources

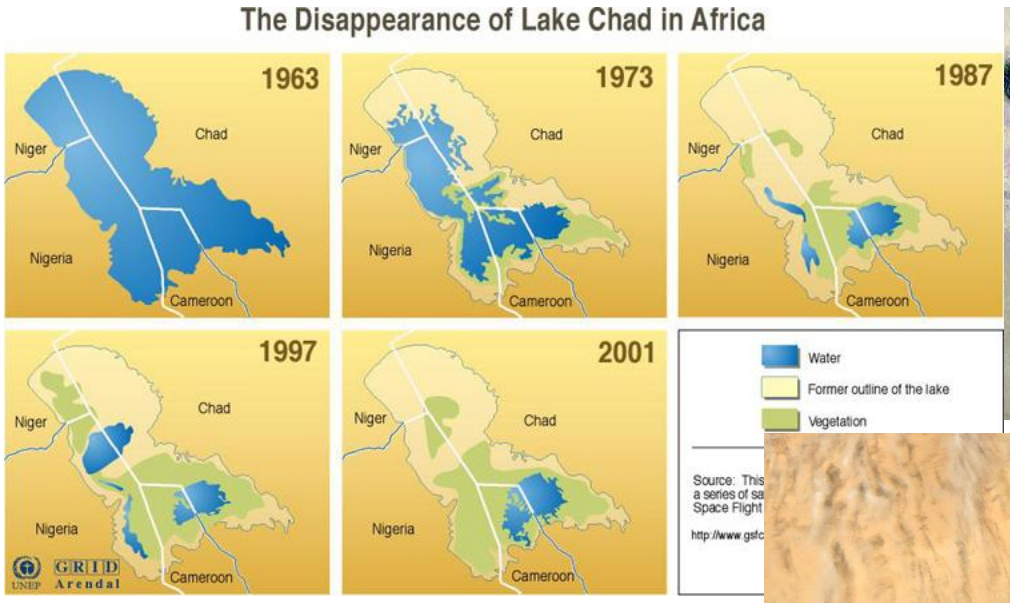

180°
120°
60°
0°
60°
120°
180°
90°
60°
30°
0°
30°
60°
90°
ARCTIC
OCEAN
GREENLAND
ARCTIC
OCEAN
NORTH
AMERICA
EUROPE
ASIA
ATLANTIC
PACIFIC
AFRICA
INDIAN
SOUTH
AMERICA
OCEAN
OCEAN
OCEAN
AUSTRALIA
ANTARCTICA

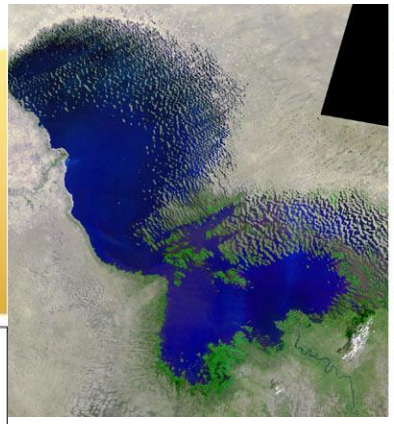
Anthropogenic sources

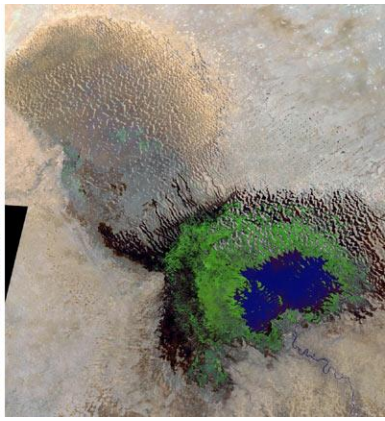
A saignificant part (25-30%) of the dust sources are anthropogenic:

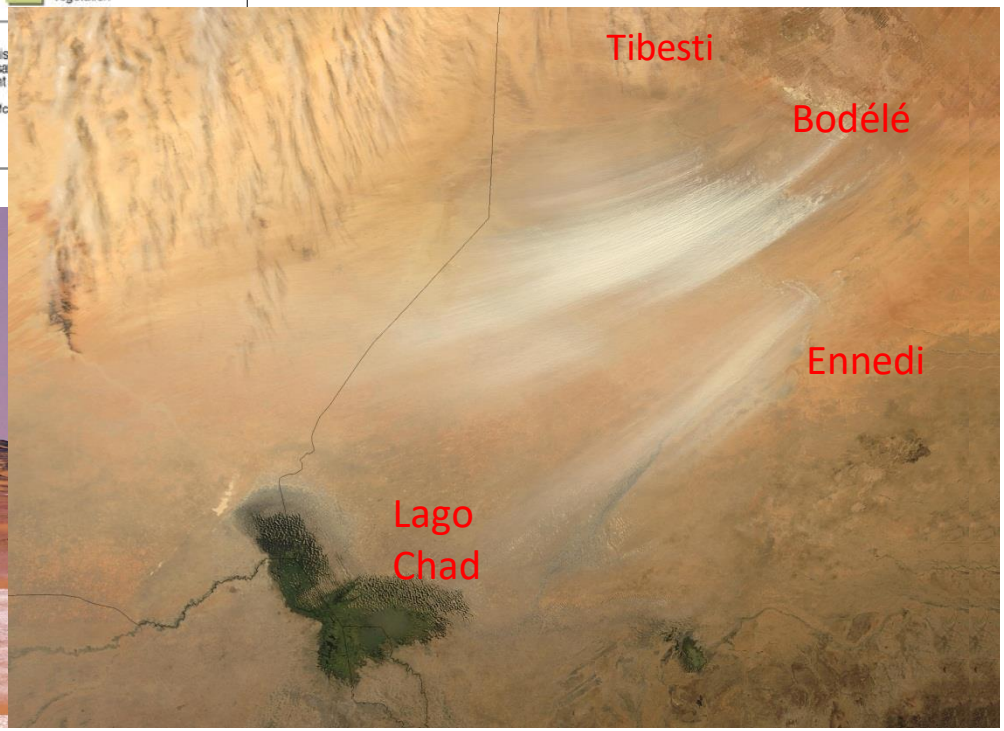
- Perturbed soils: dried lakes, marshes and other water bodies by water overuse, agricultural lands, etc.
- Direct human activity: overcast minery, construction, ...

Bodélé depression

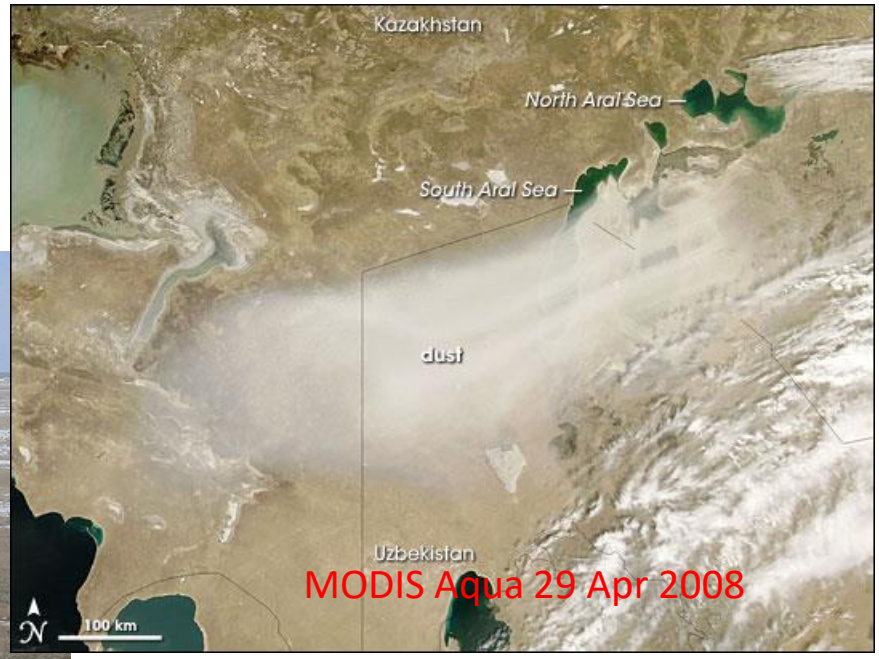








Aral Sea

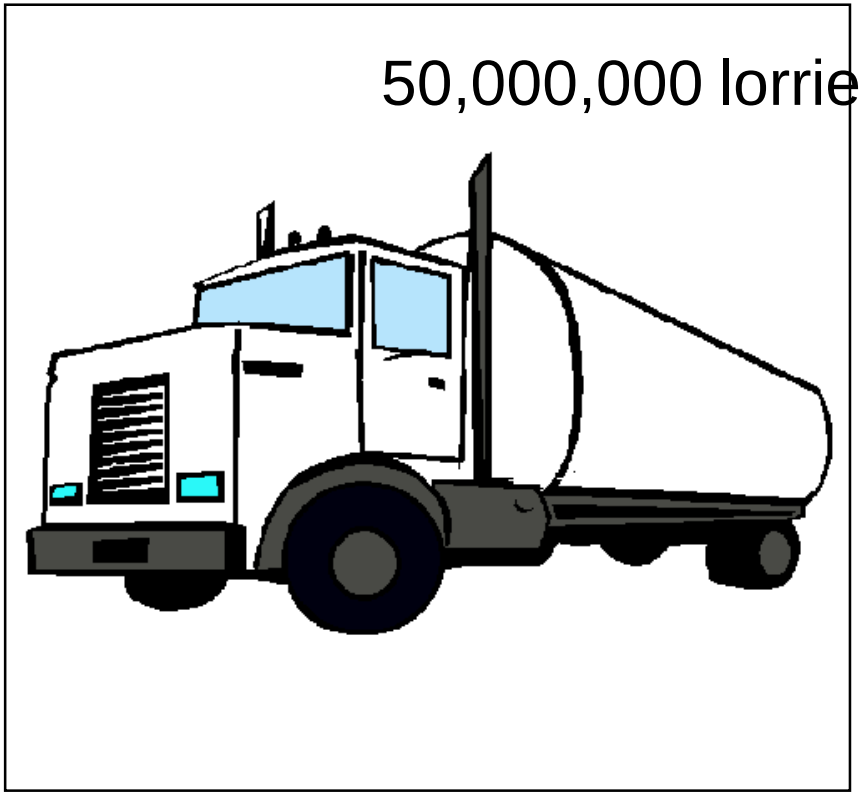


MODIS Aqua 29 Apr 2008

Total emission

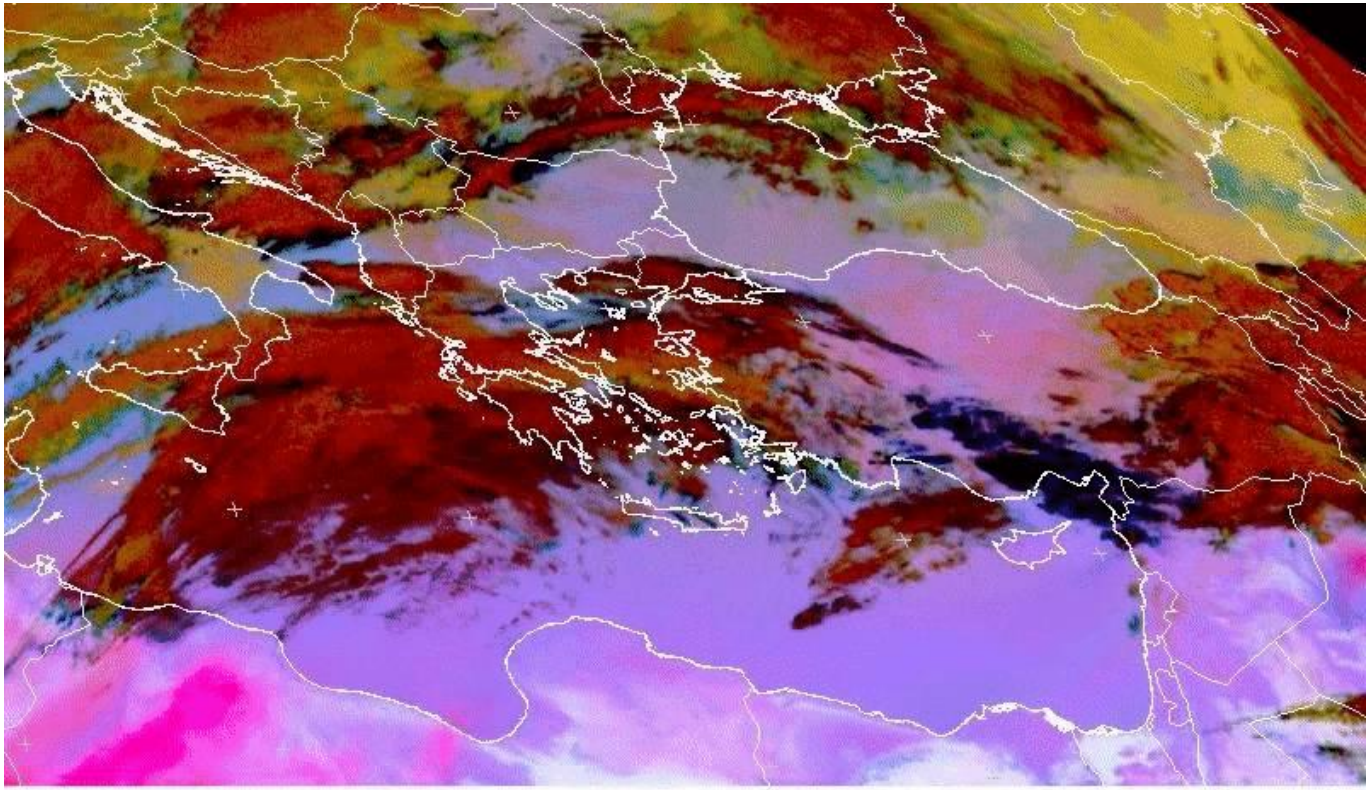
~ 30–60 Tm/s
~ 1000–2000 Tg/yr

50,000,000 lorries



3,000 ULCC

Meteorological conditions



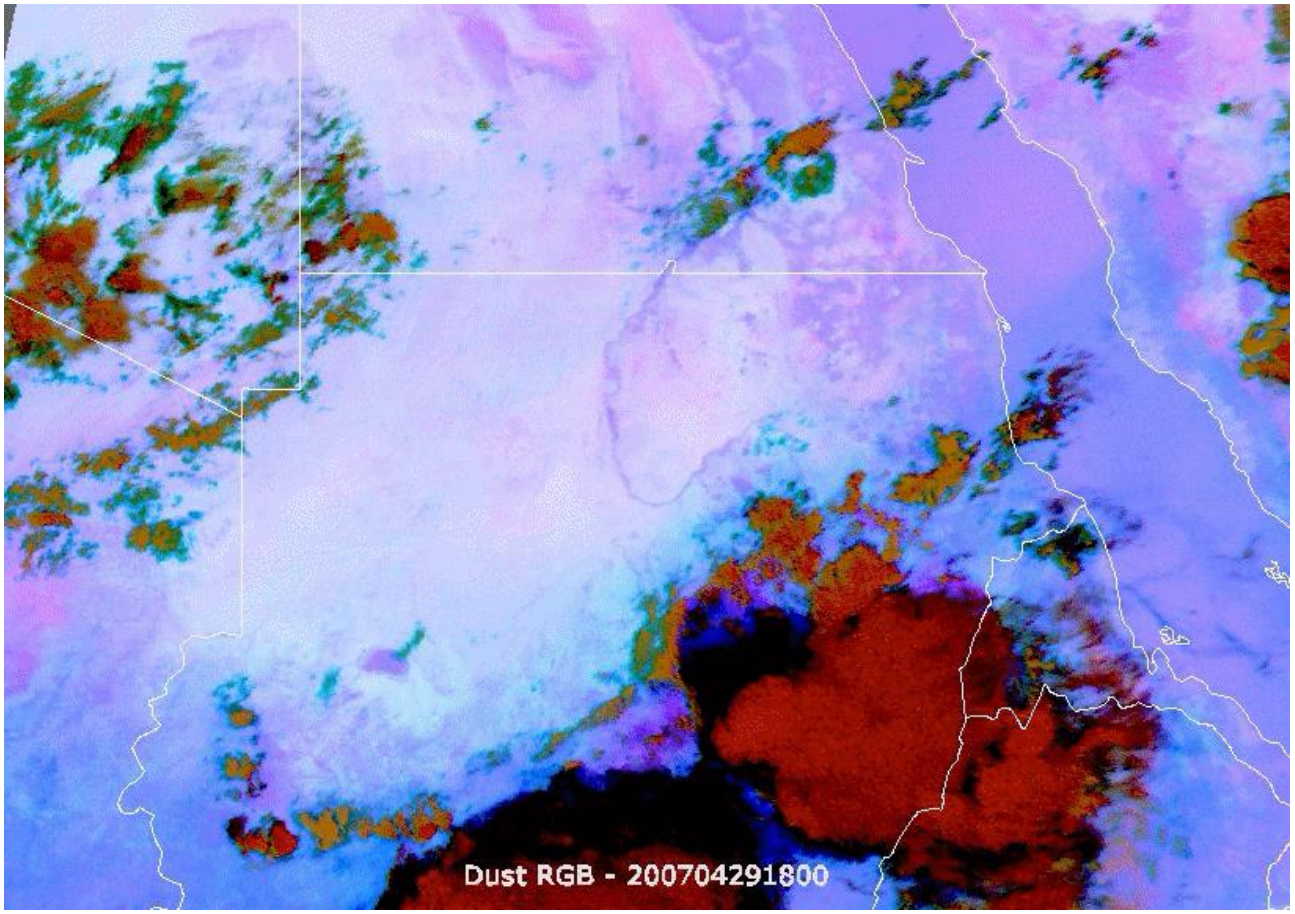
22-24 Mar 2008

EUMETSAT

SYNOPTIC SCALE

- Frontal systems
- Reinforcing trade winds

Meteorological conditions

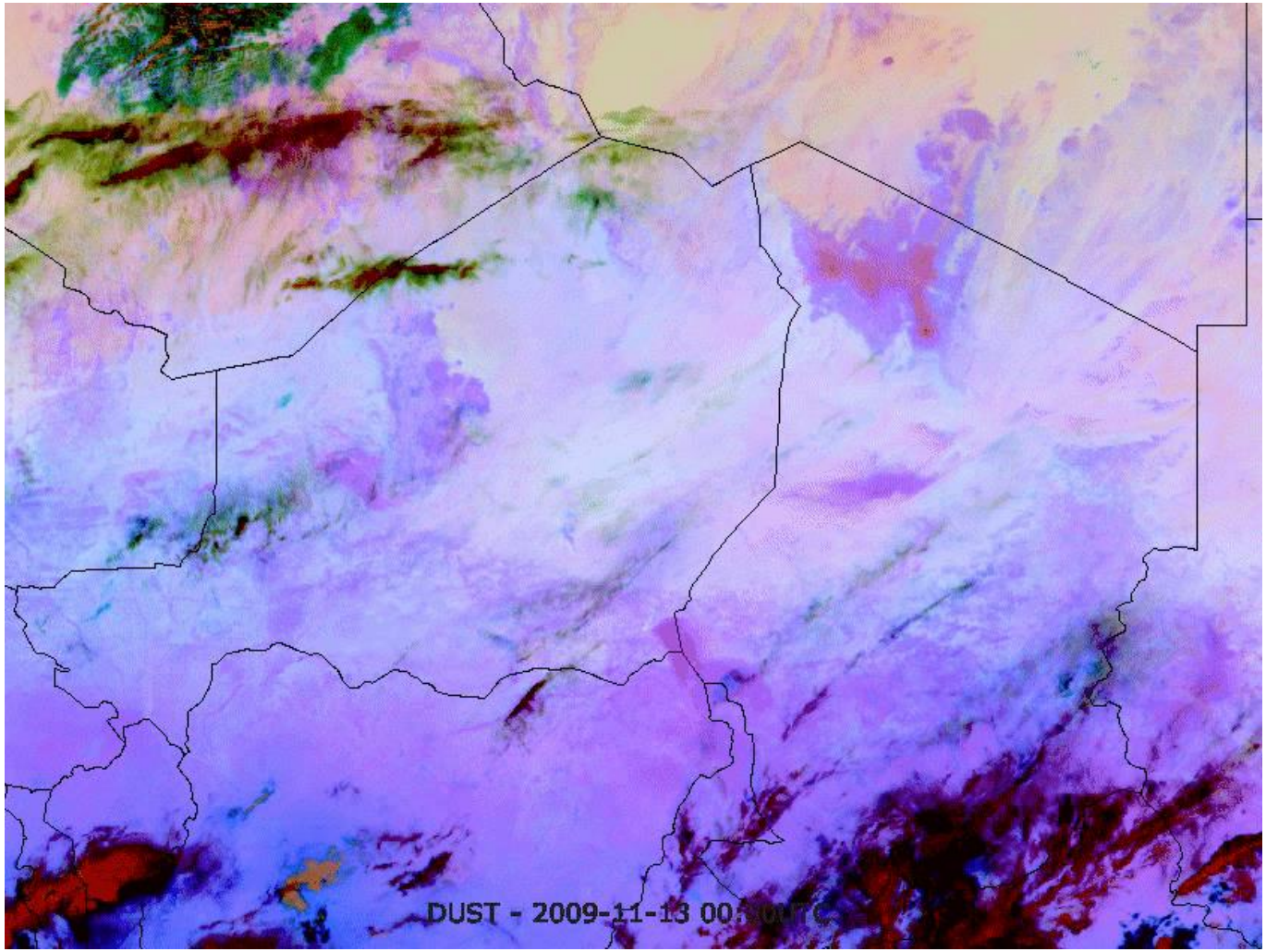


MESOSCALE-MICROSCALE

- Convection
- Drainage winds
- Low-level jets (LLJ)
- Gap winds
- ...

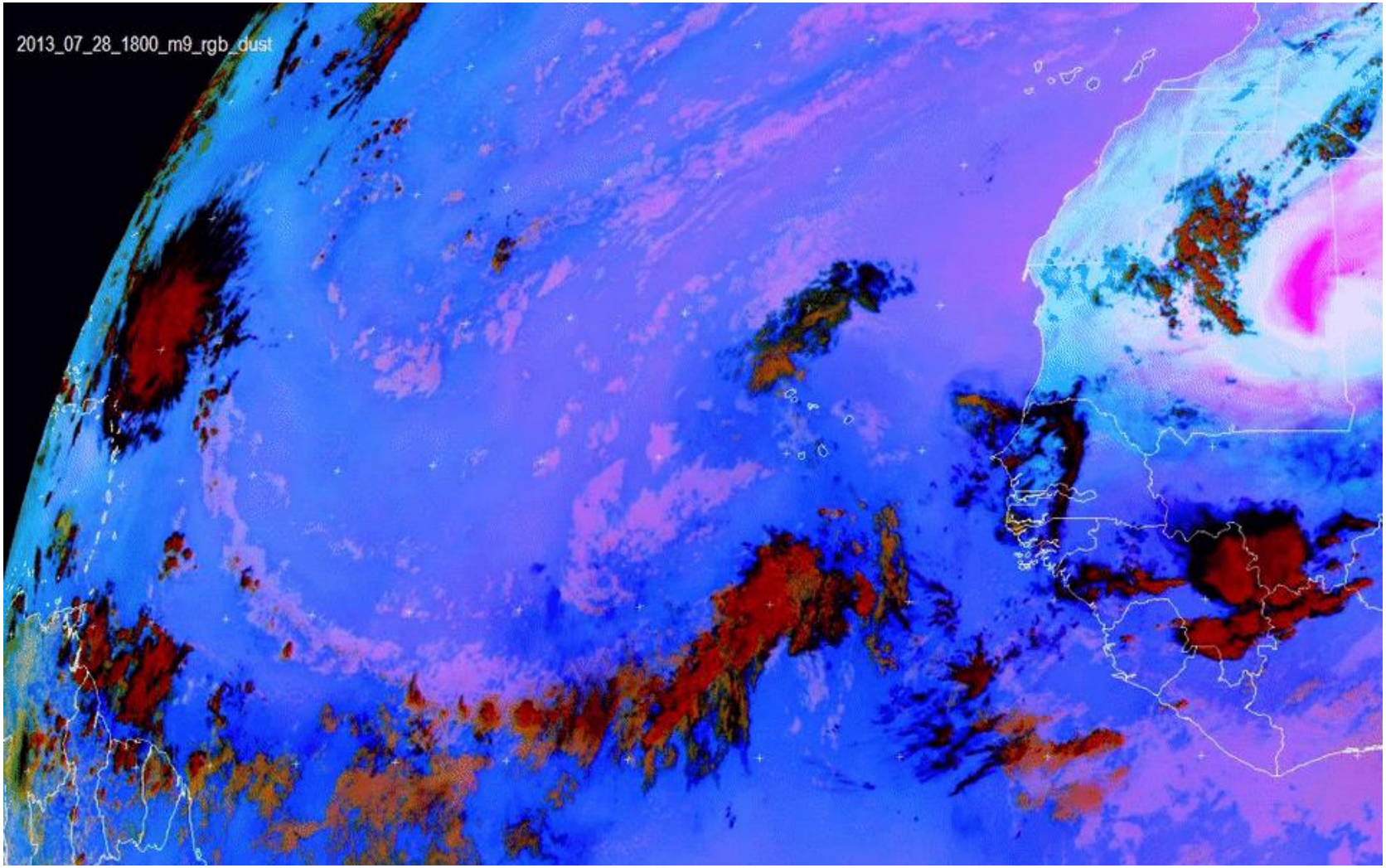
29 Apr – 1 May 2007

Meteorological conditions



13 – 14 Nov 2009

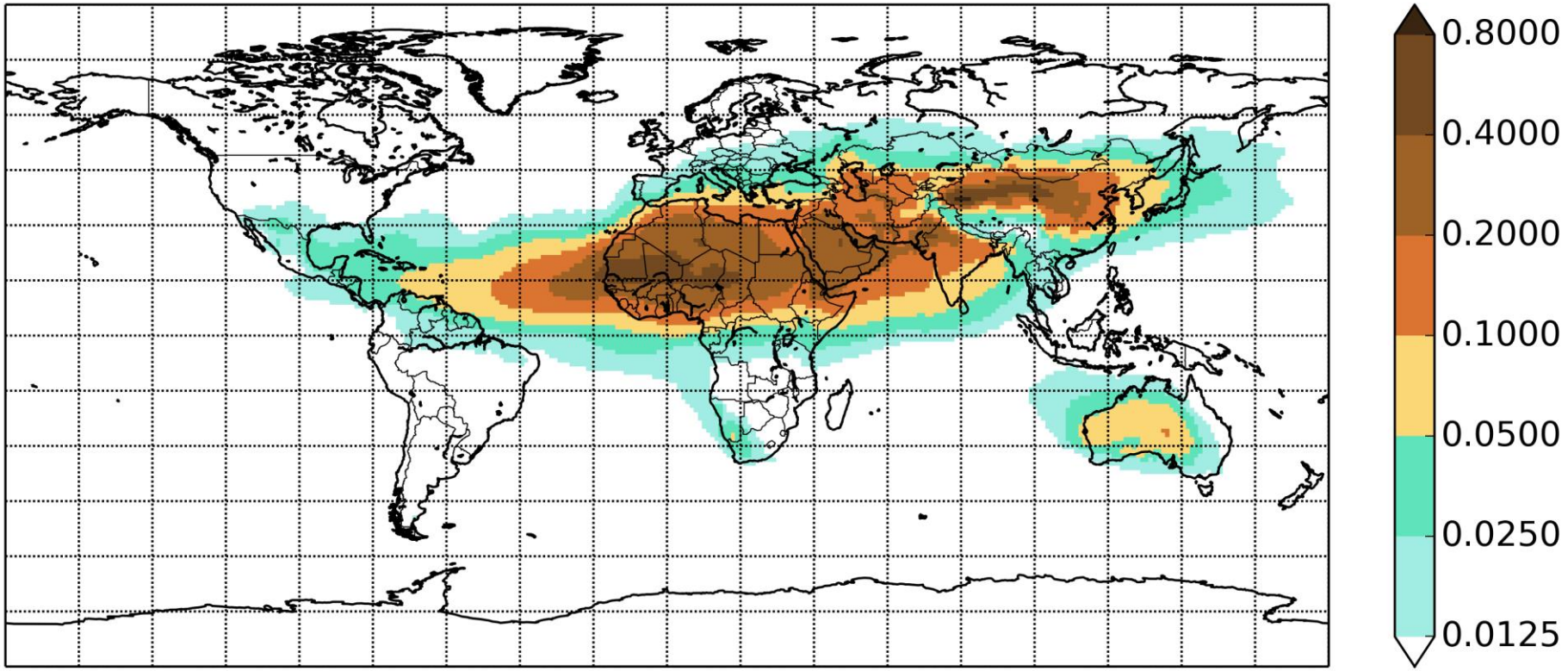
Transport



29 – 30 Jul 2013

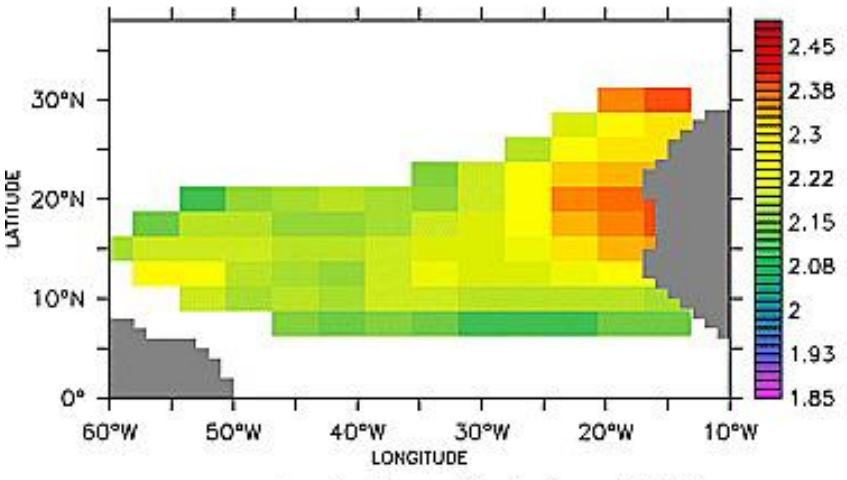
Average distribution

Dust optical depth at 550 nm. Average value 2003-2015

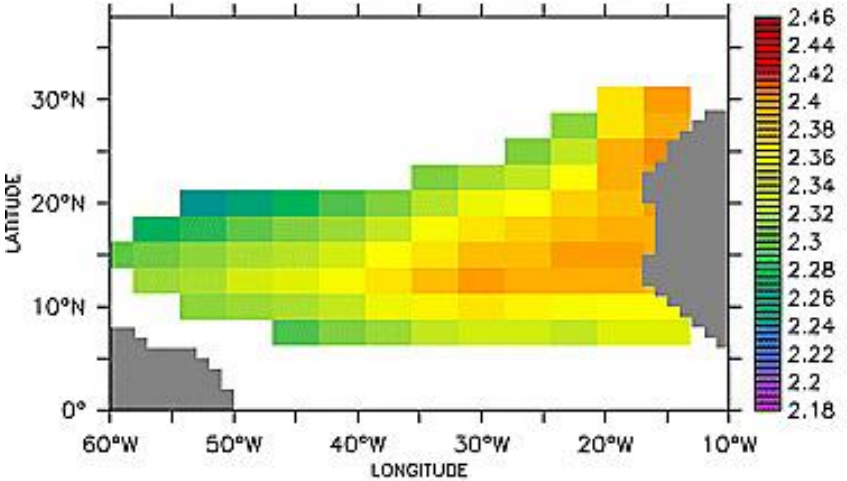


Data: CAMS reanalysis
Picture: WMO SDS-WAS

Transport

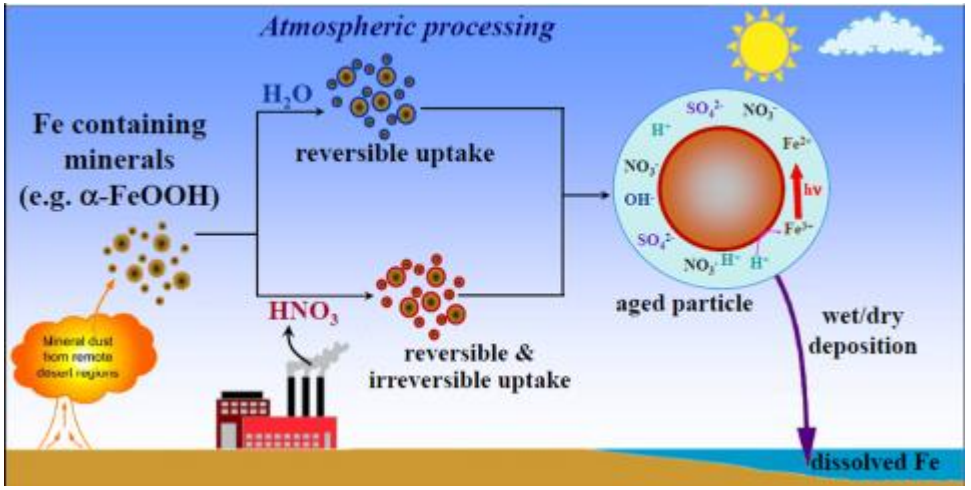


coarse mode effective radius (microns) AIRS



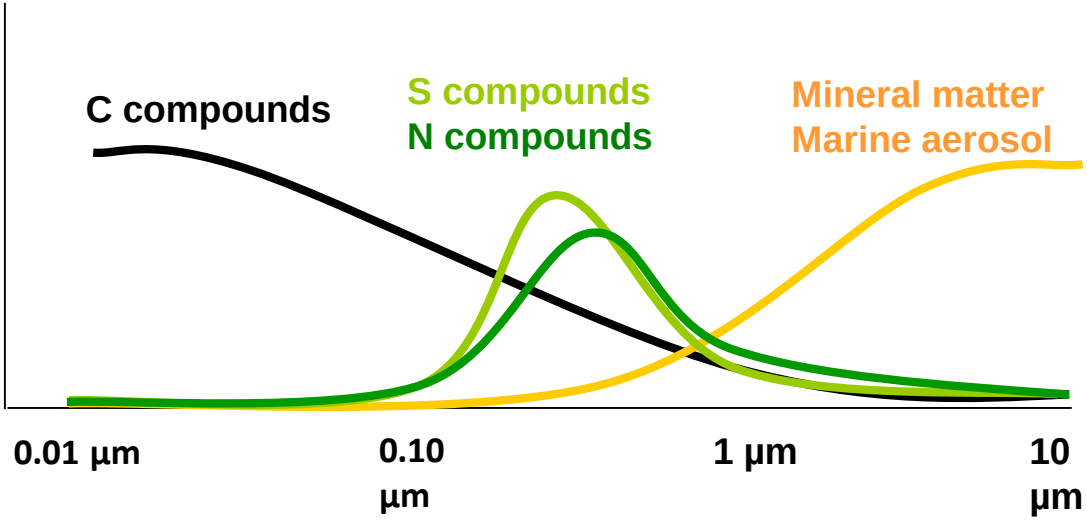
mass median diameter (microns) LMDz−INCA

Pierangelo et al. (2005)

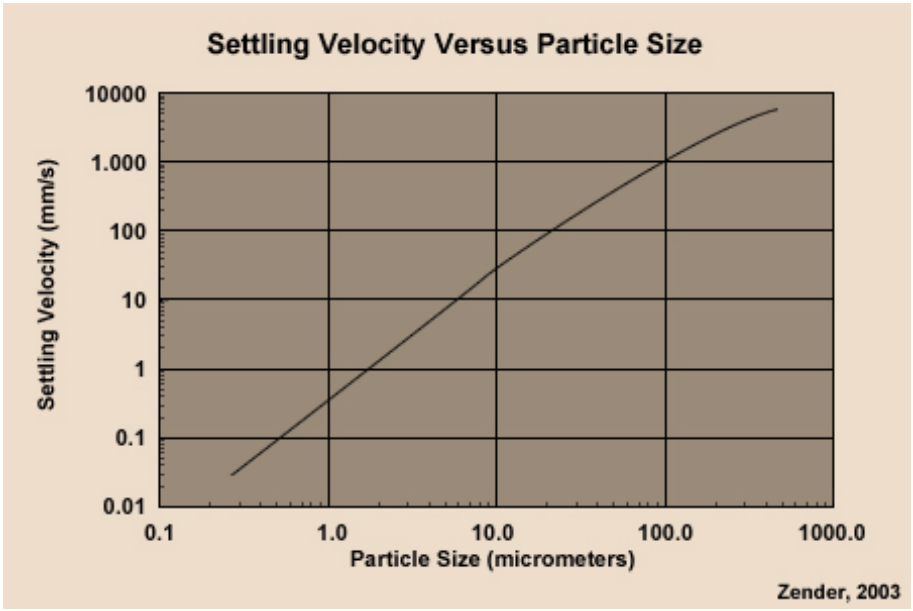


- The average particle size decreases
- Chemical composition may vary
- Optical properties may vary
- Increasing ability of particles to act as CN
- Increasing solubility of Fe

Deposition

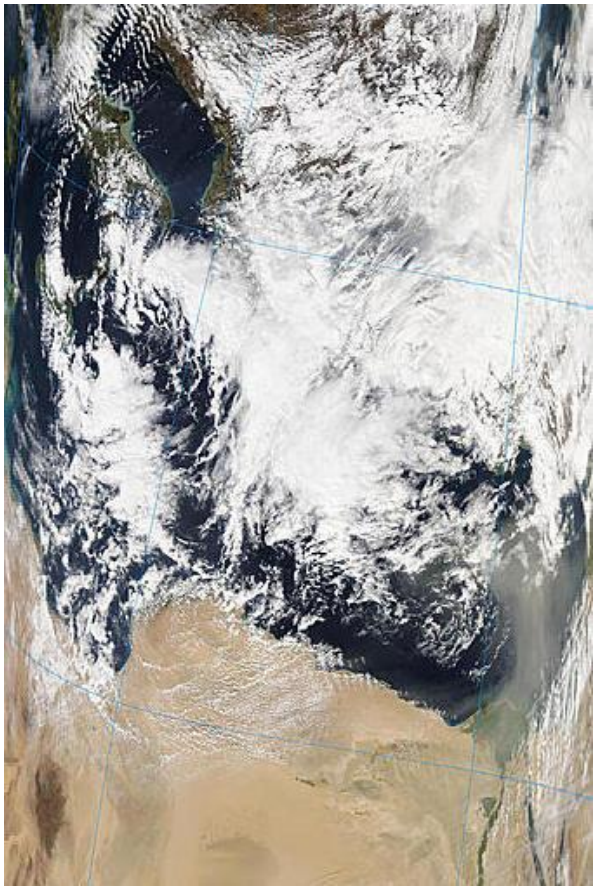


SIZE (µm)	AVERGE LIFETIME (h)
0.1 - 0.18	231
0.18 - 0.3	229
0.3 - 0.6	225
0.6 – 1	219
1 - 1.8	179
1.8 – 3	126
3 – 6	67
6 - 10	28

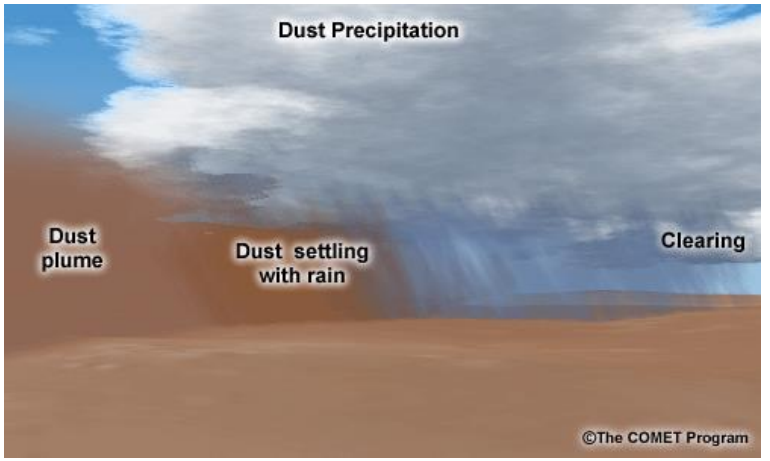


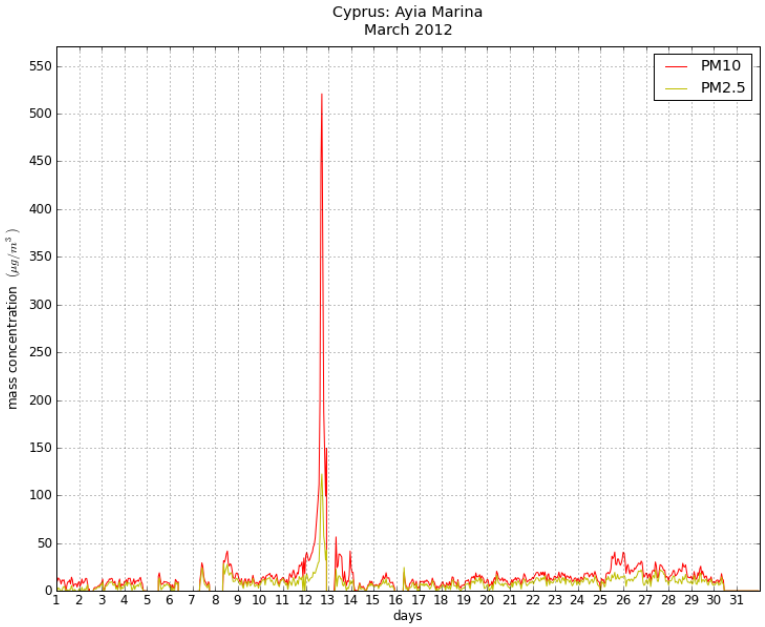
Tegen and Lacis (1996)

Wet deposition



MODIS 12 Mar 2012





PM Ayia Marina, Cyprus, Mar 2012

Composition

MINERALOGICAL (X-ray diffractometry)

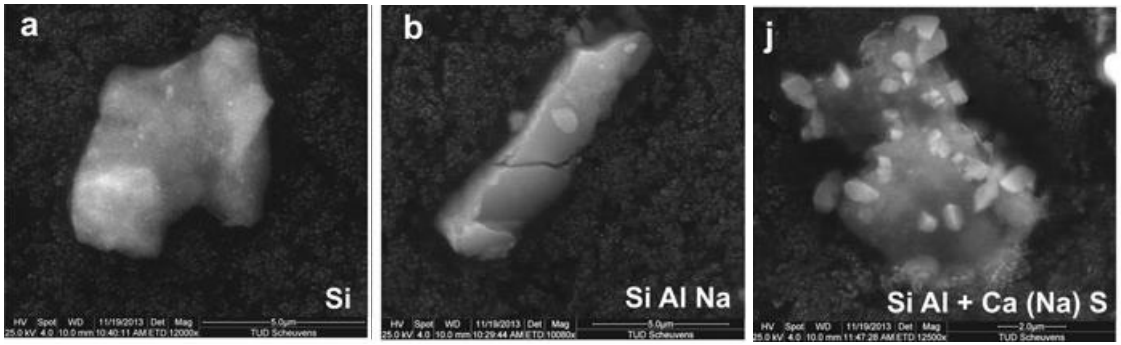
- Silicates: quartz, feldspar, phyllosilicates (ilite, kaolinite, smectite)
- Carbonates (calcite, dolomite)
- Hematite, gypsum, halite, …

ISOTOPICAL (Sr, Nd, Pb)

CHEMICAL (spectroscopy)

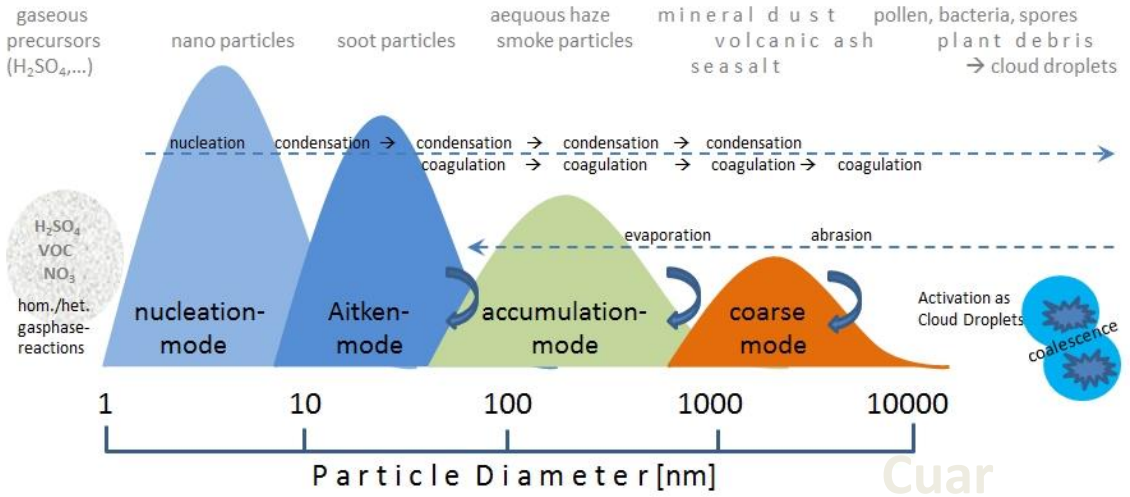
- Si, Al, Ca, Mg, Fe, K, Na, Mn, Ti, P

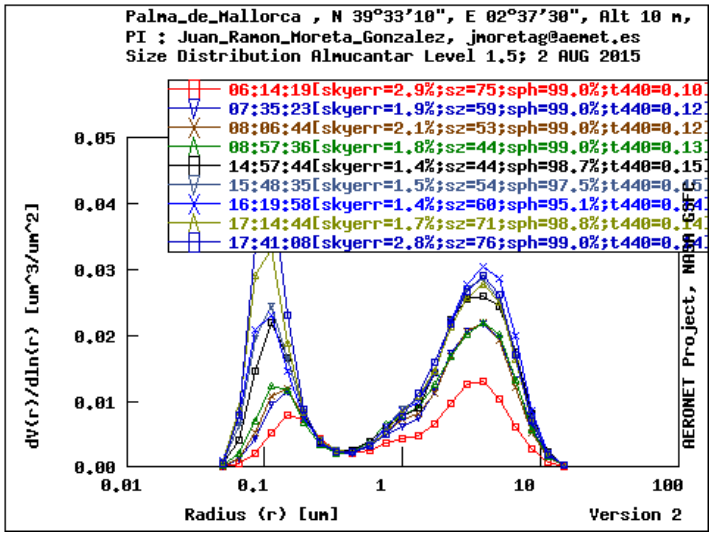
- Information about the source region
- Influence on optical properties
- Influence the impact on health, ecosystems, ...



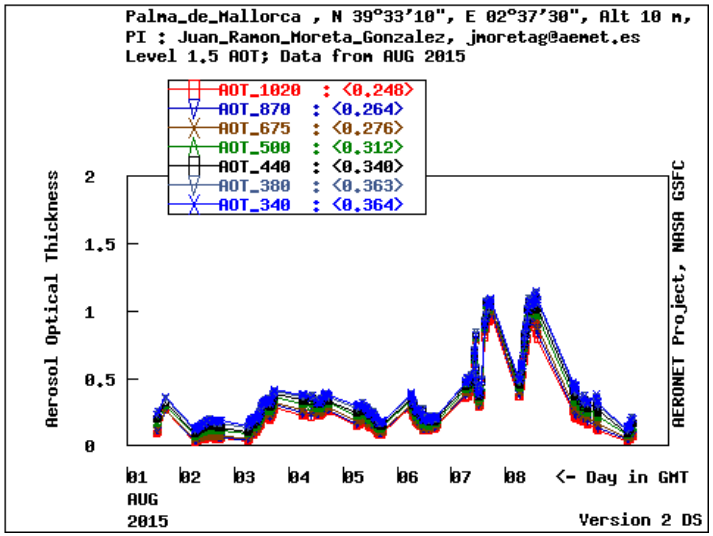
Quartz Albite Gypsum

Particle size

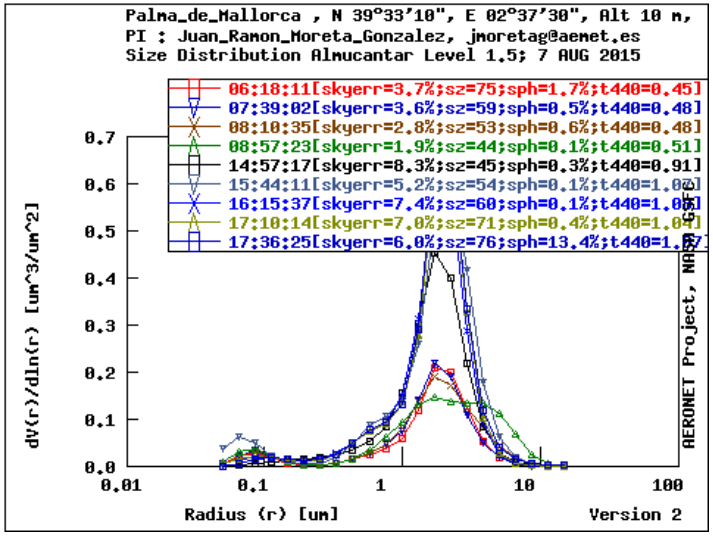




$$\tau = \ln(\frac{I_0}{I_1})\cos(\theta)$$

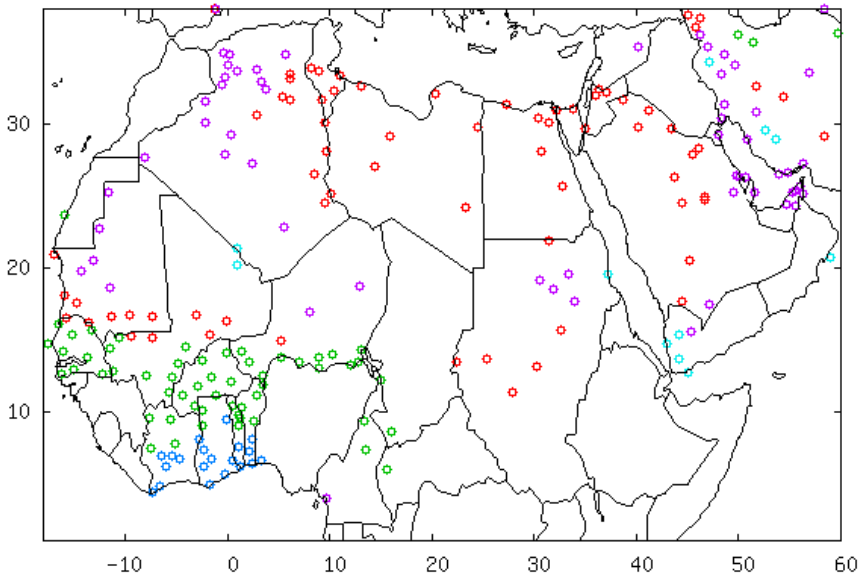


AOD. Palma de Mallorca. Aug 2015

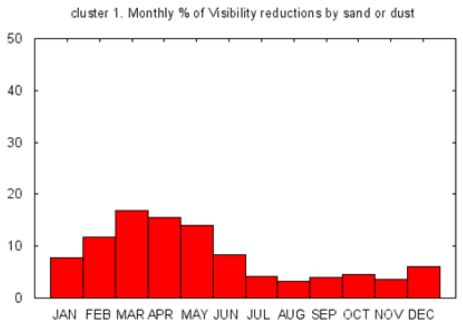


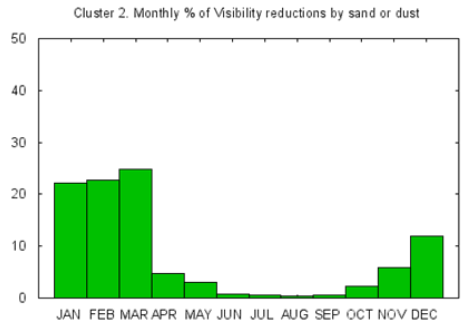
Palma de Mallorca 2 / 7 Aug 2015

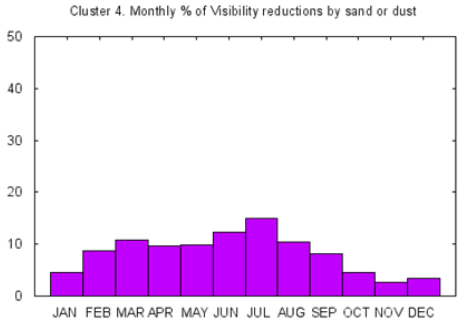
Seasonal variability

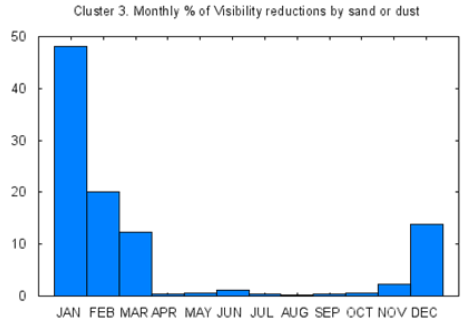


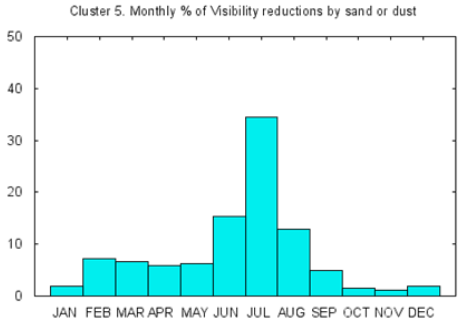
1996-2010









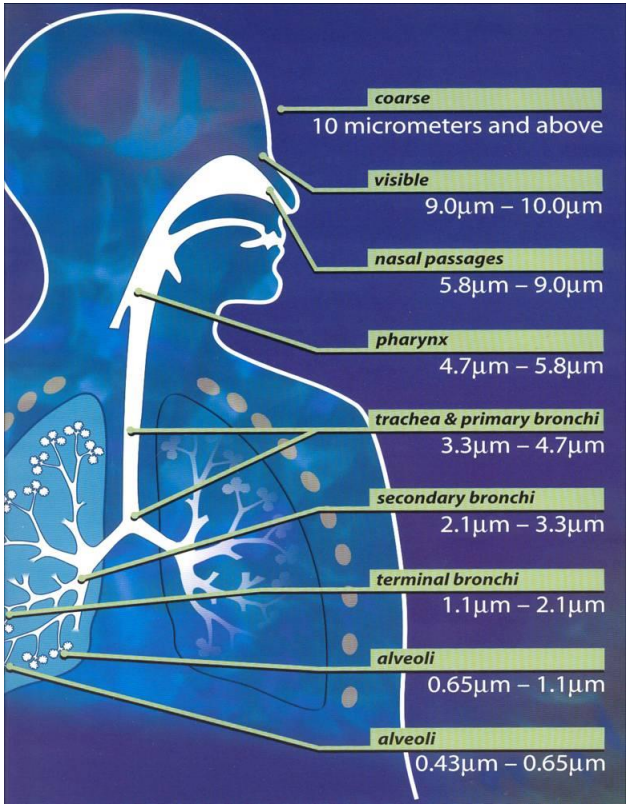


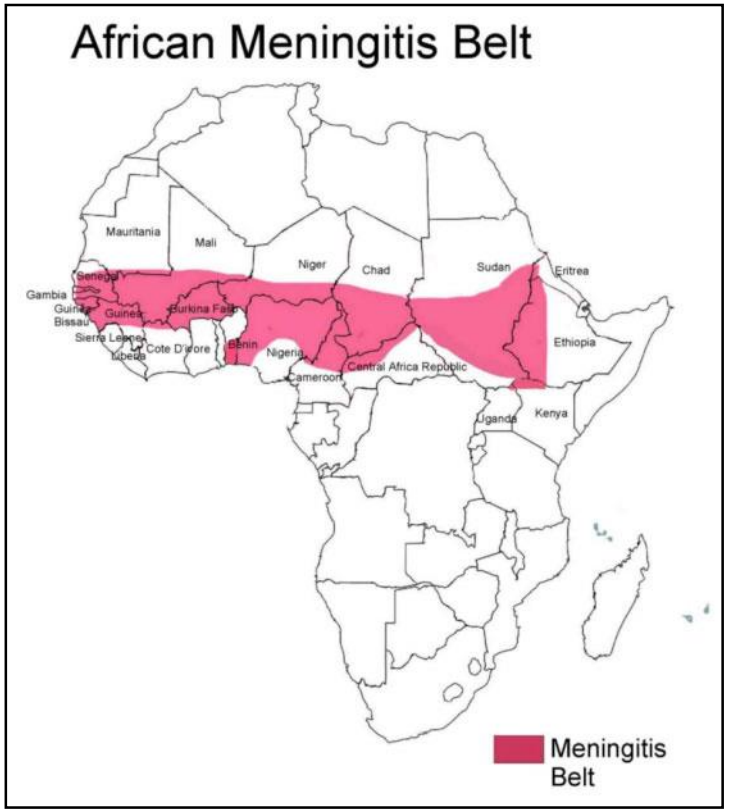
Terradellas et al. (2012)

Impacts

- Air quality and health
- Weather and climate
- Transportation (visibility reduction)
- Energy
- Agriculture, fisheries…

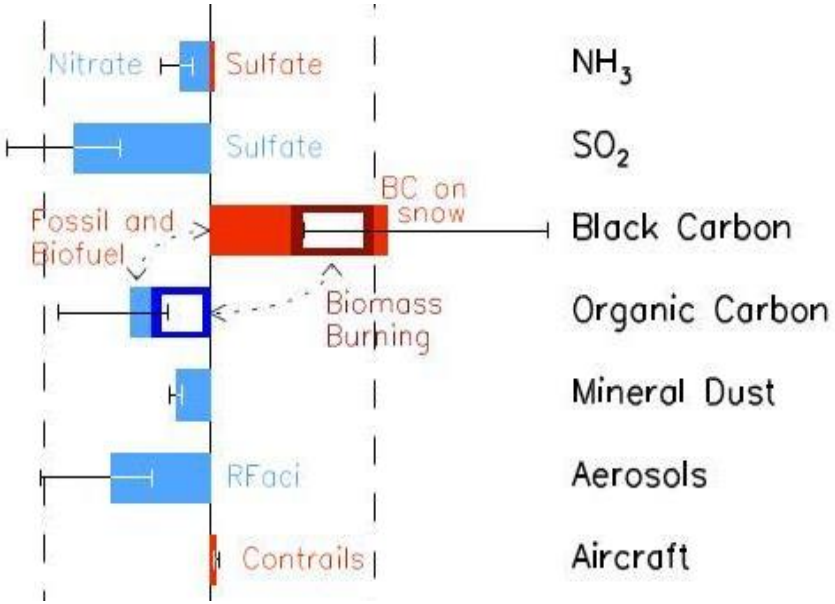
Health impact

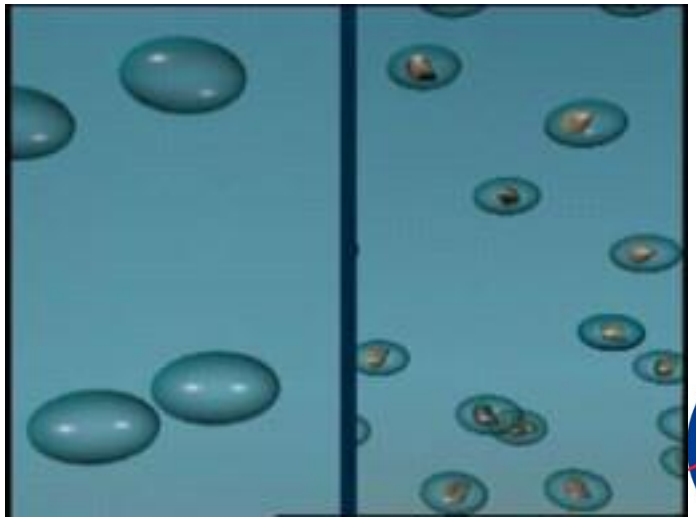


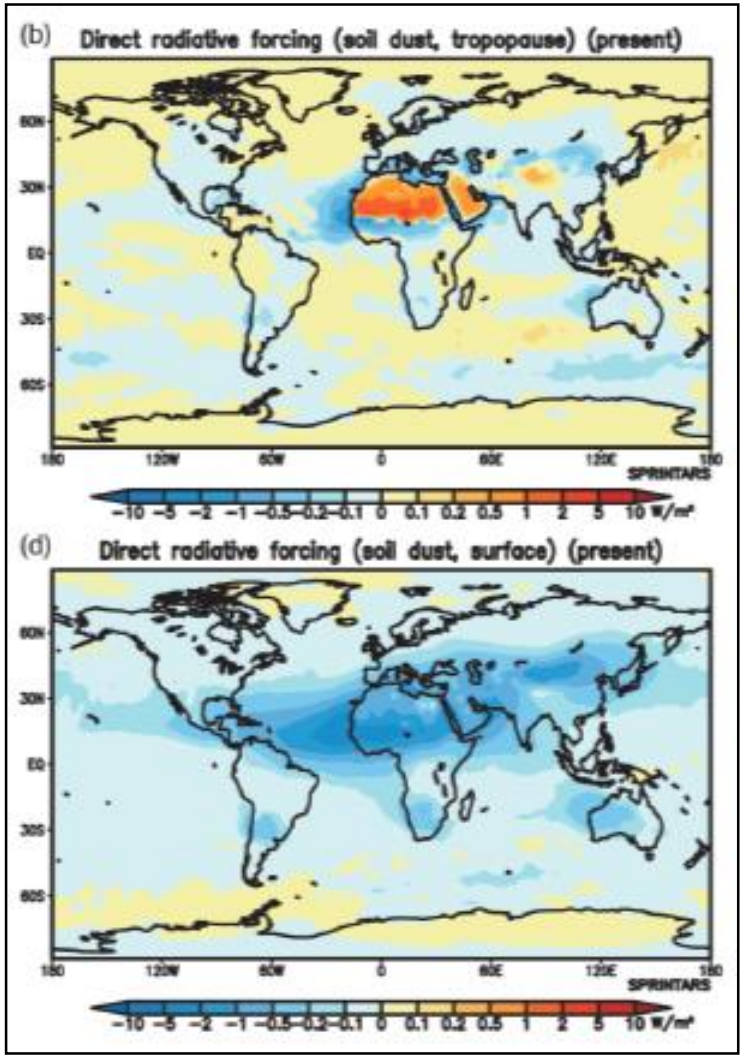


- Particle size
- Chemical and mineralogical composition
- Carrying bacteria, viruses, fungi, ...
- Time and intensity of exposure

Impact on weather and climate

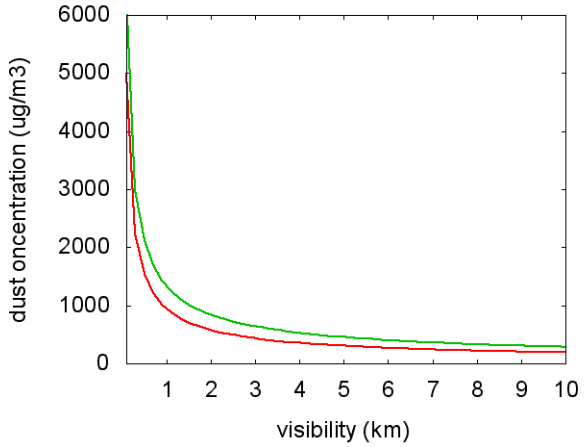






Takemura et al. (2009)

Impact on transportation



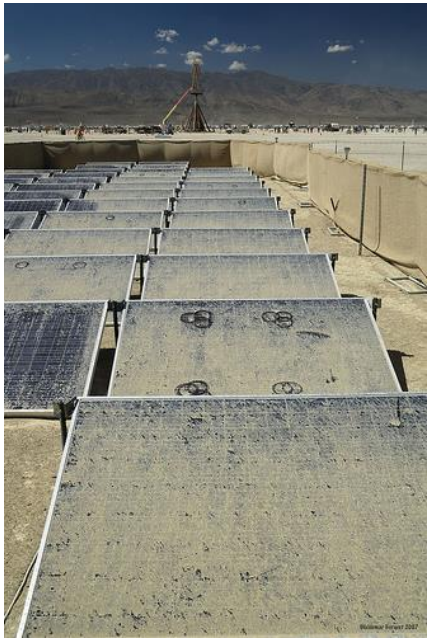
D'Almeida (1986)
Ben Mohamed et al. (1992)

Arizona, 29 Oct 2013

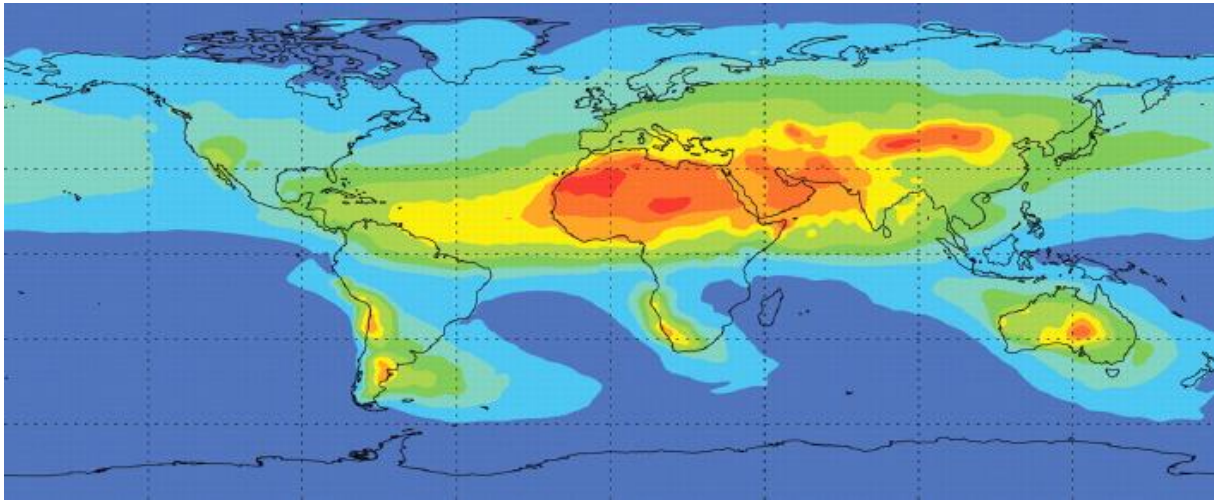
Tunis, 7 May 2002

Solar energy

- Reduction of available energy
- Reduced efficiency due to dust deposition

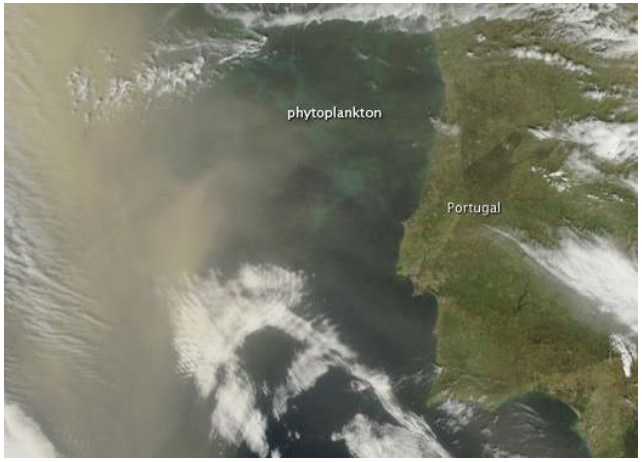


… also positive impacts



Dust deposition
Jickells et al. (2005)

- Dust deposition is a source of micro-nutrients for continental and marine ecosystems
- Saharan dust has been shown to fertilize the Amazon rainforest
- The contribution of Fe and P benefits the production of marine biomass in oceanic areas that suffer from shortage of such elements



Summary

- Atmospheric aerosol
- The cycle of mineral dust
- WMO SDS-WAS
- Dust observation
- Dust forecast
- Also...

WMO SDS-WAS

Mission:

Enhance the capacity of countries to generate and distribute to end-users dust observations, forecasts, information and knowledge

Structure:

- Regional Center for Northern Africa, Middle East and Europe, Barcelona
- Regional Center for Asia, Beijing
- Regional Center for Pan-America, Bridgetown
- Regional Center for West Asia (??)

SDS-WAS Regional Center NAMEE

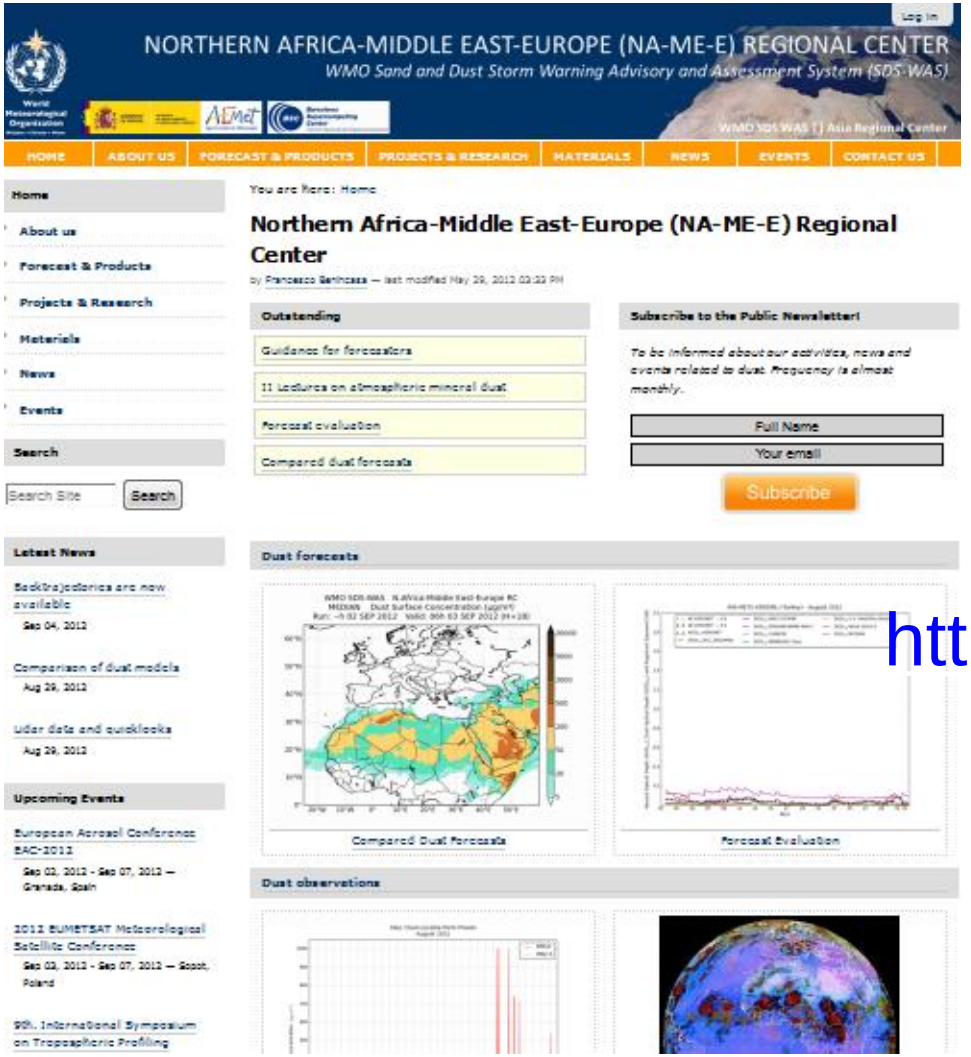
The Center is jointly managed by AEMET and the Barcelona Supercomputing Center

GOBIERNO DE ESPAÑA
MINISTERIO DE MEDIO AMBIENTE Y MEDIO RURAL Y MARINO
AEMet Agencia Estatal de Meteorología
BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación

UPC Campus. Nexus II building

MareNostrum III supercomputer

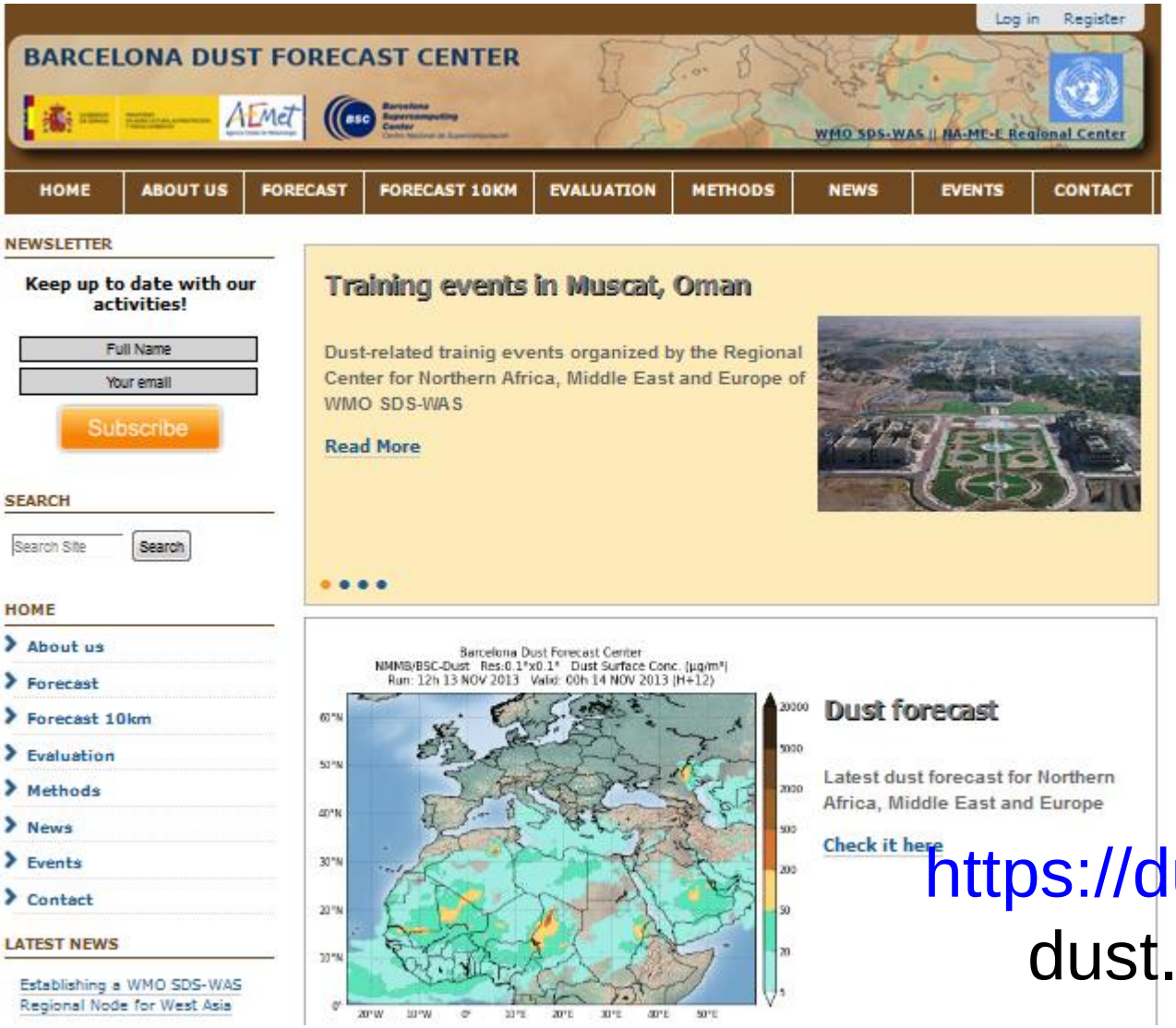
SDS-WAS Regional Center NAMEE



https://sds-was.aemet.es

sdswas@aemet.es

Barcelona Dust Forecast Center



https://dust.aemet.es

dust.aemet.es

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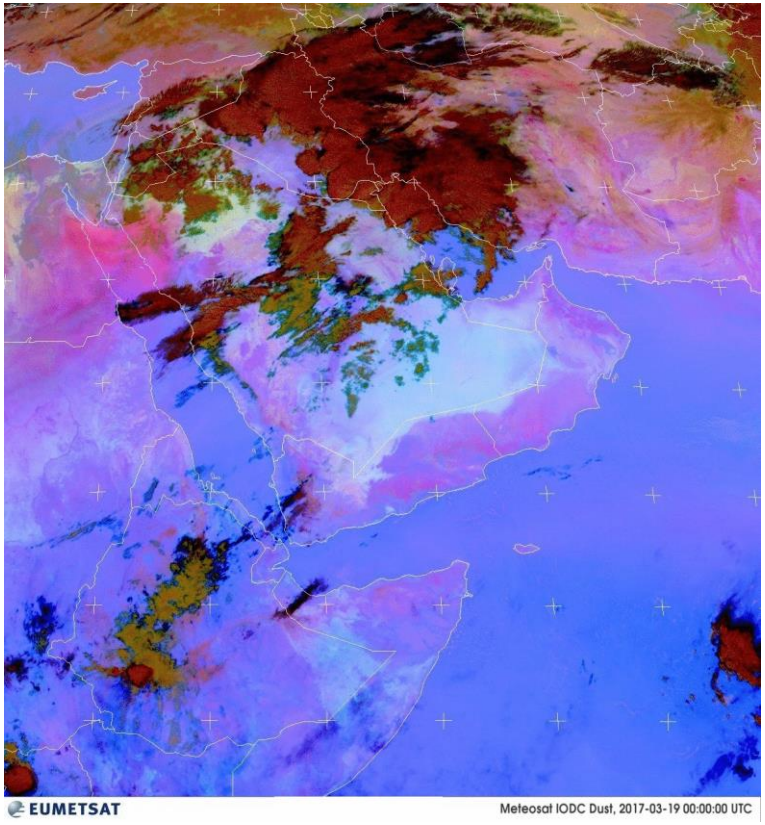
Why do we need dust observation?

- Monitoring dust events
- Data assimilation into models
- Forecast verification
- Validation of other observations (i. e. ground observations to validate satellite products)

Mali, 2001
Foto: Remi Benali/Corbis

Monitoring: satellite products



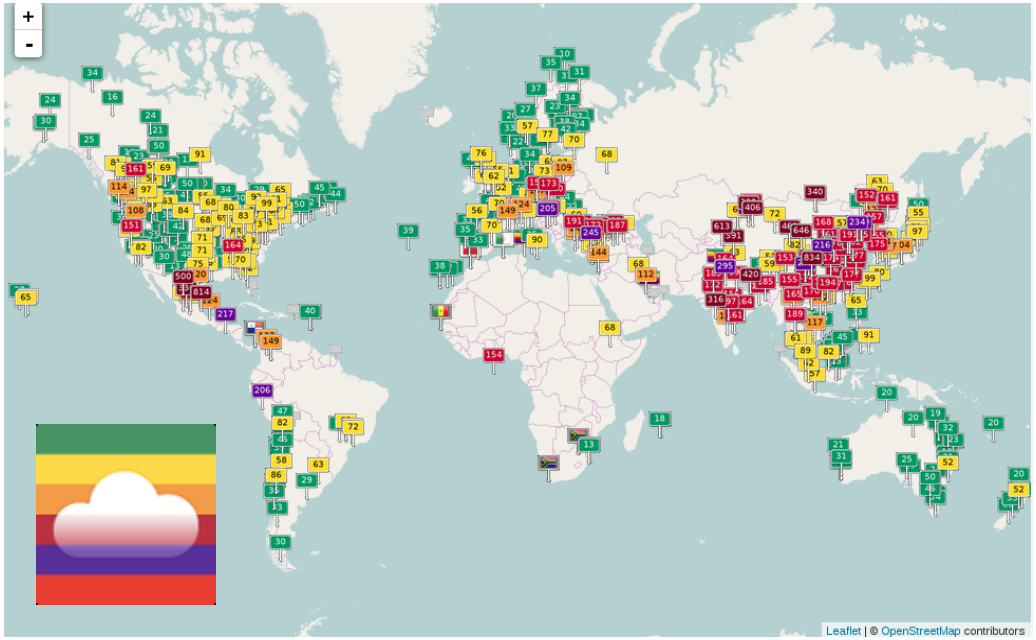
19 Mar 2017: The sandstorm named Madar, originated in Libya, swept through Egypt, Saudi Arabia, Iraq, Kuwait and Iran

- The basic tool for monitoring dust events is satellite imagery
- The EUMETSAT RGB dust product is a composition based on three infrared channels from SEVIRI (Meteosat Second Generation)

Drawbacks:

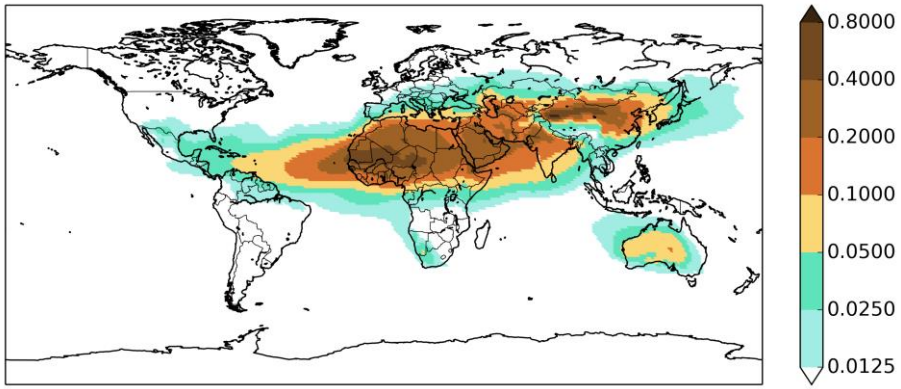
- Qualitative product
- Without information from cloudy areas
- Vertical integration. Without information on near-surface conditions

Monitoring: AQ stations



Drawbacks:

- Few stations near dust sources
- No protocol for data exchange
- Lack of harmonization in measurements
- Integration of all particles
- Many stations located in urban environments

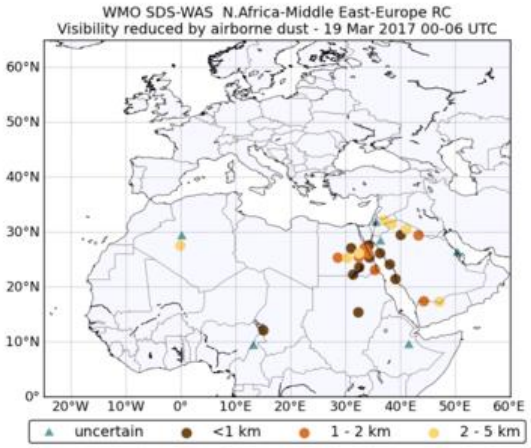


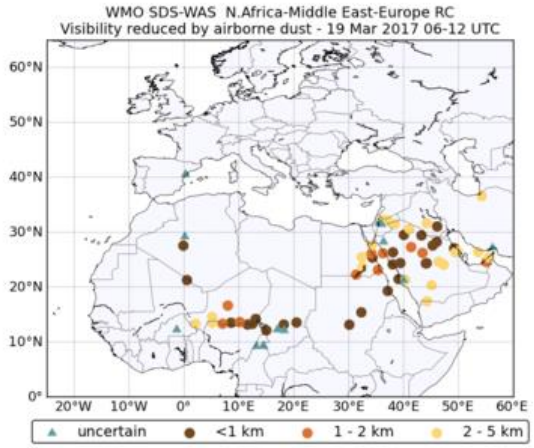
Average columnar dust contents 2003-2015 (WMO Airborne Dust Bulletin, 1)

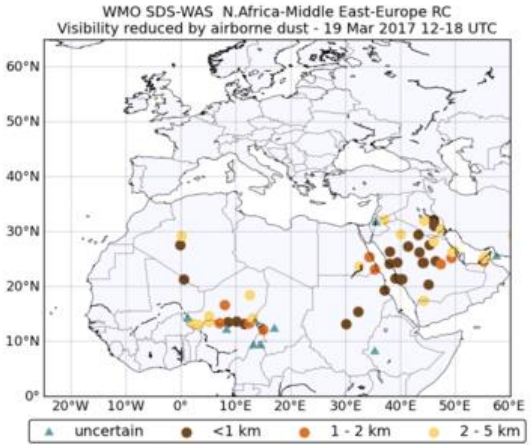
WMO

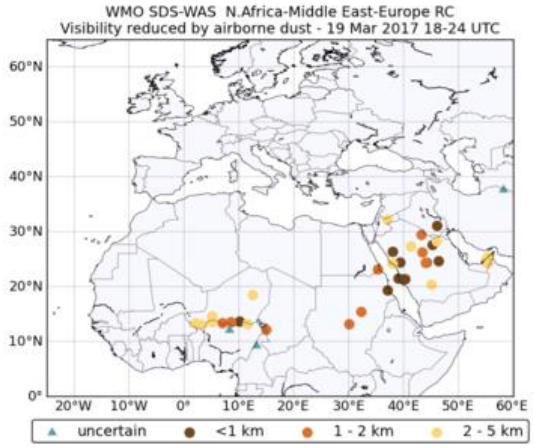
Copernicus

Monitoring: meteorological reports









19 Mar 2017

Drawbacks:

- Indirect estimation (not mass concentration)
- Subjective nature
- Limited to severe events

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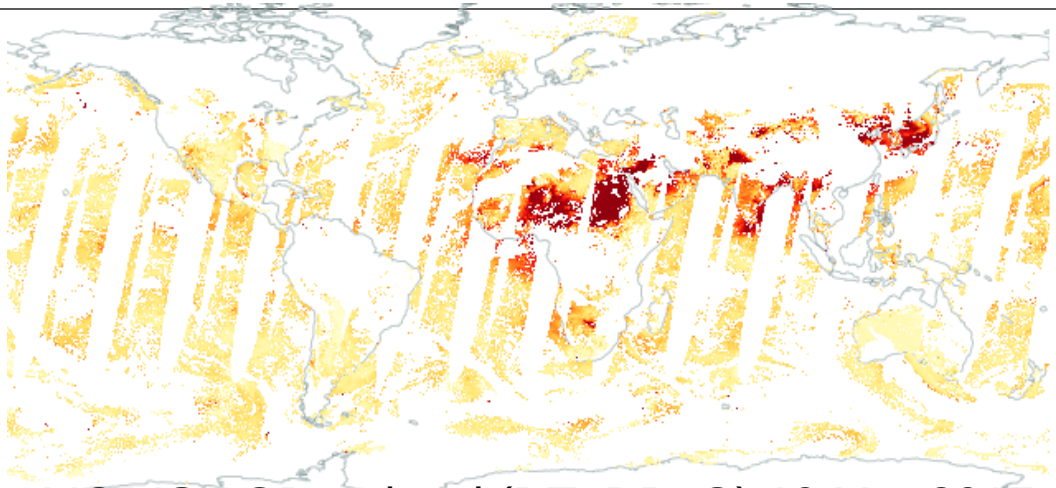
BSC Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Data assimilation

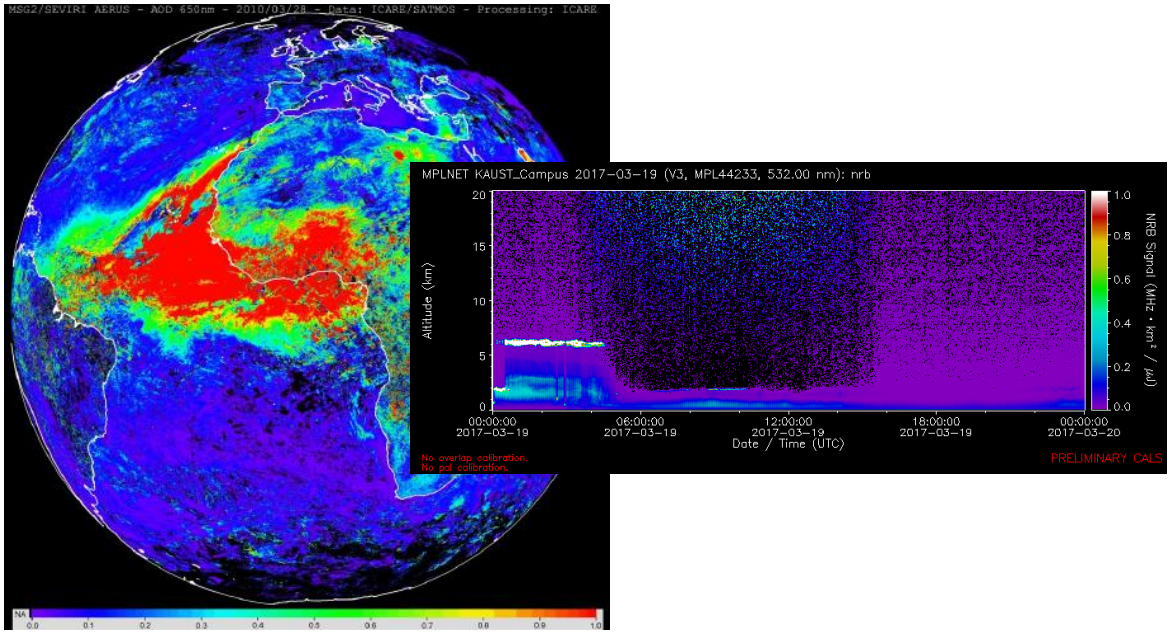
Drawbacks:

- Lack of suitable observations
- Complexity of extracting the dust signal from the measured radiance

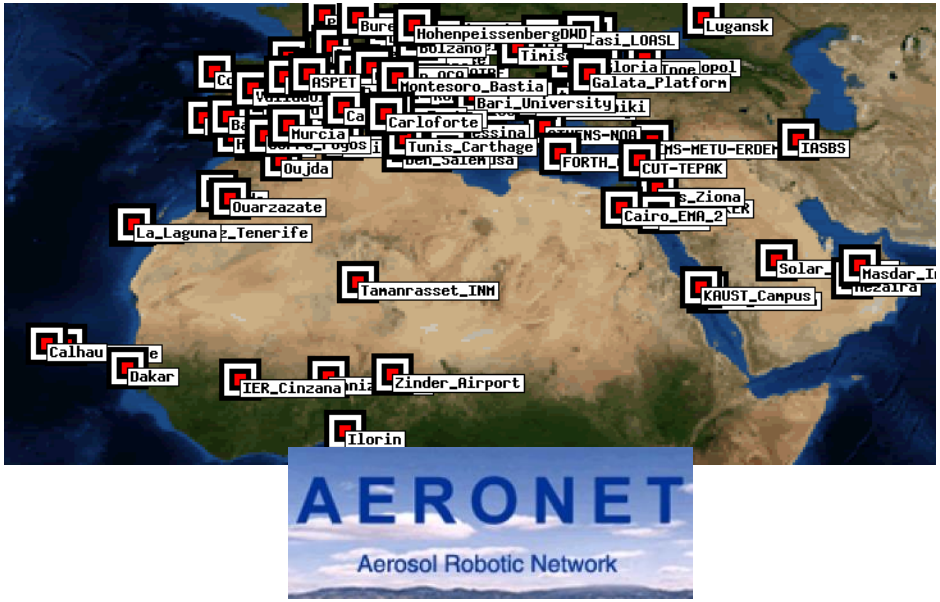


MODIS AODretrieval (DT+DB+O) 19 Mar 2017

- Modellers often use processed products rather than raw observations
- They normally assimilate MODIS AOD using variational techniques (ECMWF) or EKF (JMA, BSC)
- Efforts are now aimed at assimilating products from GEO satellites and lidar/ceilometer profiles



Verification: sun photometers



- Solar radiation at the top of the atmosphere is known
- Airborne particles attenuate the direct radiation (absorption, scattering)
- The sun-photometers measure the direct radiation that reach the surface
- Measurement at different wavelengths allows retrieval of total aerosol contents and some of its properties (e. g. size spectrum)

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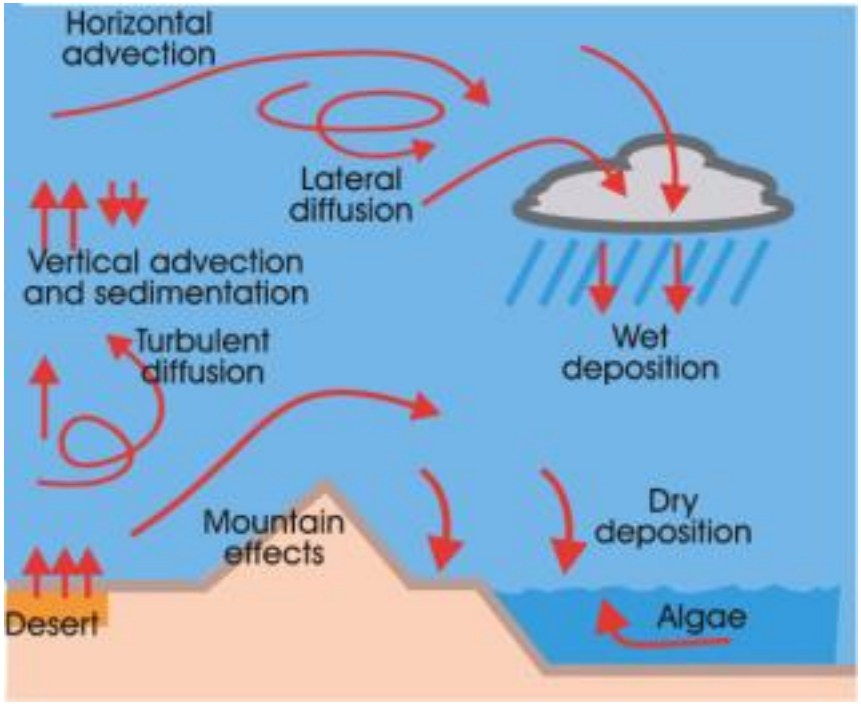
Dust prediction models

Meteorological model (NWP)
+
Parameterization of the dust cycle
=
Dust prediction model



- Emission
- Transport (diffusion, convection, advection)
- Dry / wet deposition

- Interaction with radiation
- Interaction with cloud droplets
- Atmospheric chemistry
- …

Problems

- Incomplete knowledge of the physical processes involved in the dust cycle
- Processes of very diverse scale
- Need for a very accurate wind forecast
- Lack of adequate observations for assimilation and verification

Tegen et al. (1994)

$$F = \sum_i C_i u^2 (u - 6.5)$$

Marticorena et al. (1997)

$$F = \propto \frac{\rho}{g} u_*^3 \sum_i s_i \left(1 + \frac{u_{*tri}}{u_*}\right)\left(1 - \frac{u_{*tri}^2}{u_*^2}\right)$$

Ginoux et al. (2001)

$$F = CS \sum_i u^2 s_i w_0 (u - u_{tri})$$

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InDust

International Network to Encourage the Use of Monitoring and Forecasting **Dust** Products

MC chair: Sara Basart (BSC)

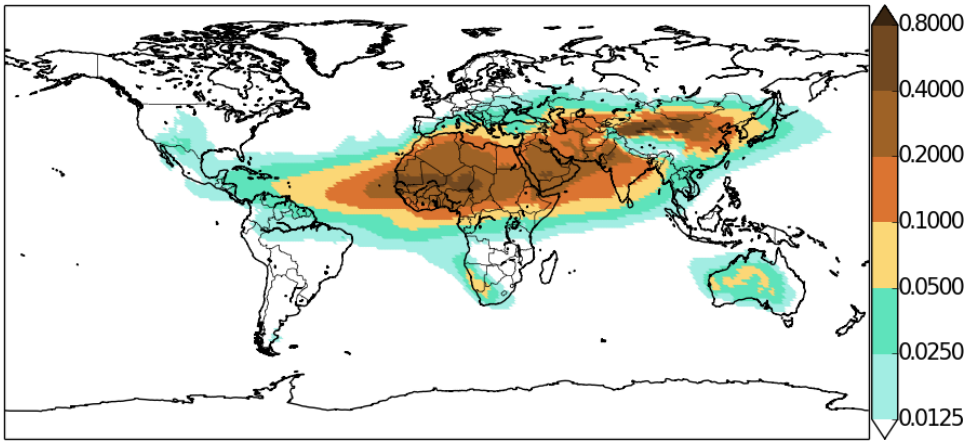
28 countries
Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Cyprus, Denmark, Finland, France, fYR Macedonia, Germany, Greece; Hungary, Iceland, Ireland, Israel, Italy, Lithuania, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Spain, Switzerland, Turkey, United Kingdom

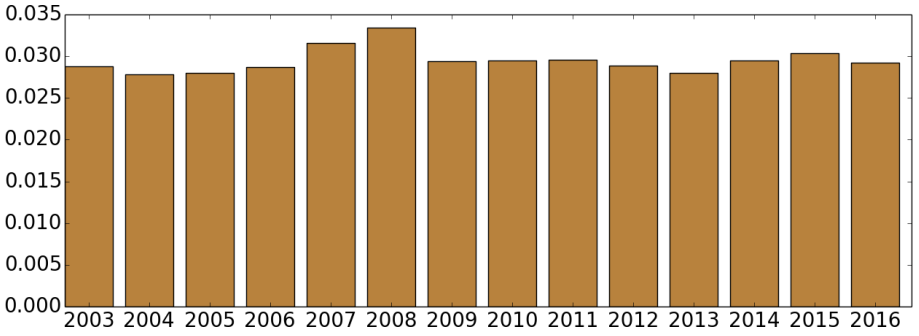
Near-neighbour countries:
Morocco (Min. of Health), Egypt (EMA, Cairo Univ.), Jordan (Univ. of Jordan)

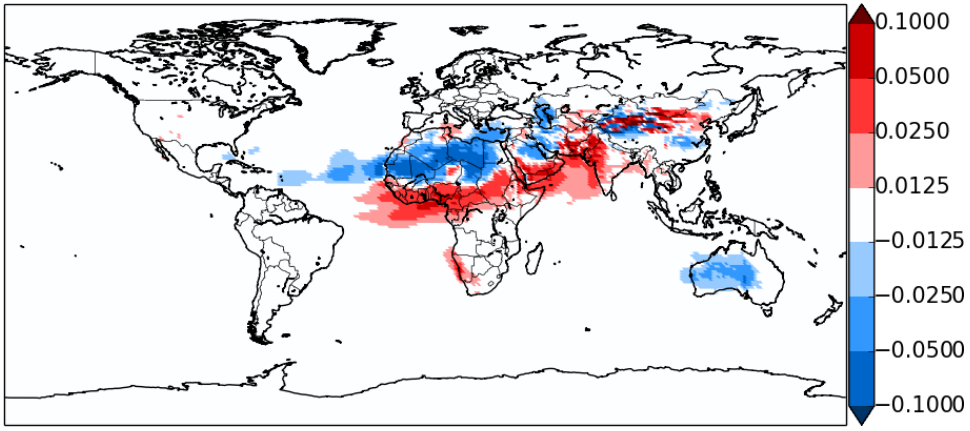
International organizations:
World Meteorological Organization

Climate monitoring

https://sds-was.aemet.es/materials/WMO_Airborne_Dust_Bulletin_No1_en.pdf







Terradellas et al. (eds.)

Average dust AOD at 550 nm in 2016 and its anomaly

DustClim

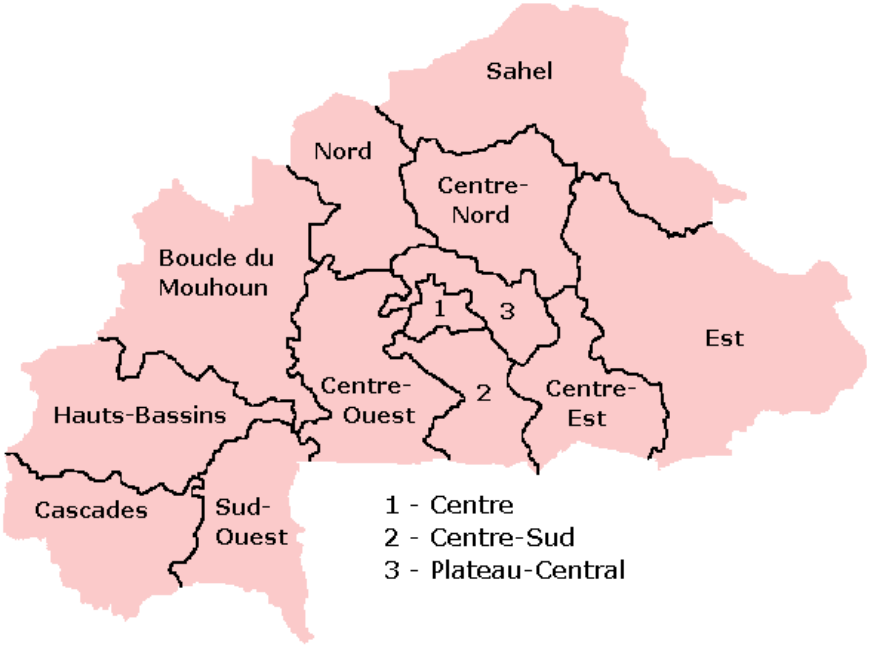
Dust Storms Assessment for the Development of User-oriented **Clim**ate Services in Northern Africa, Middle East and Europe

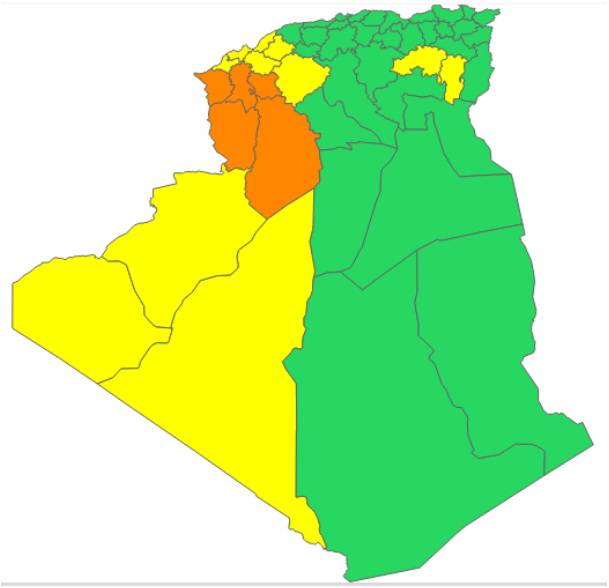
PI: Sara Basart (BSC)

European Research Area for Climate Services

https://sds-was.aemet.es/projects-research/dustclim

Early Warning System for Burkina Faso





This project covers the design, implementation and operation of an EWS for airborne dust at the thirteen regions in which Burkina Faso is administratively divided

Early Warning Systems

- **Risk knowledge**. The impact of airborne dust on air quality, human health, weather and climate, the environment and different economic sectors is generally known, although some aspects require further investigation.
- **Monitoring and warning services**. Most NMHS have the ability to obtain and use the basic products of dust monitoring and prediction.
- **Dissemination and communication**. Warnings must reach those at risk. Clear messages containing simple, useful information are critical to enable proper responses.
- **Response capability**. It is essential that communities understand their risks; respect the warning service and know how to react.

UNISDR
The United Nations Office for Disaster Risk Reduction

Capacity building

EUMETSAT

TURKISH STATE METEOROLOGICAL SERVICE
METEOR
TSMS

CILSS

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AEMet
Agencia Estatal de Meteorología

UPC
UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

WMO

GHANA METEOROLOGICAL AGENCY

Sultan Qaboos University

BSC
Barcelona Supercomputing Center

MAROC METEO

Atmospheric Science & Meteorological Research Center
ASMERC

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Ouagadougou
Sta. Cruz de Tfe.
Tehran
Tbilisi