

The dust cycle in the atmosphere

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chair of the WMO SDS-WAS Steering Committee



Summary

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

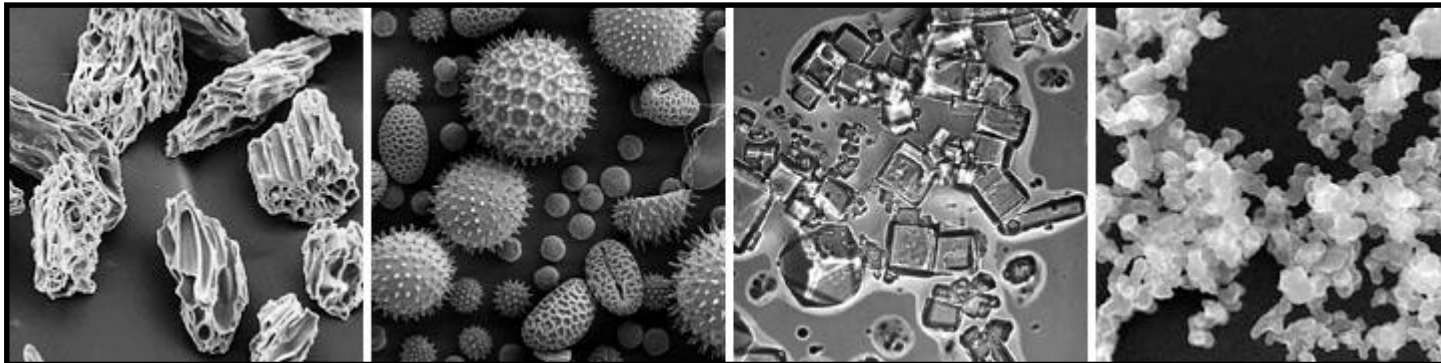
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Atmospheric aerosol

Solid or liquid particles suspended in the air

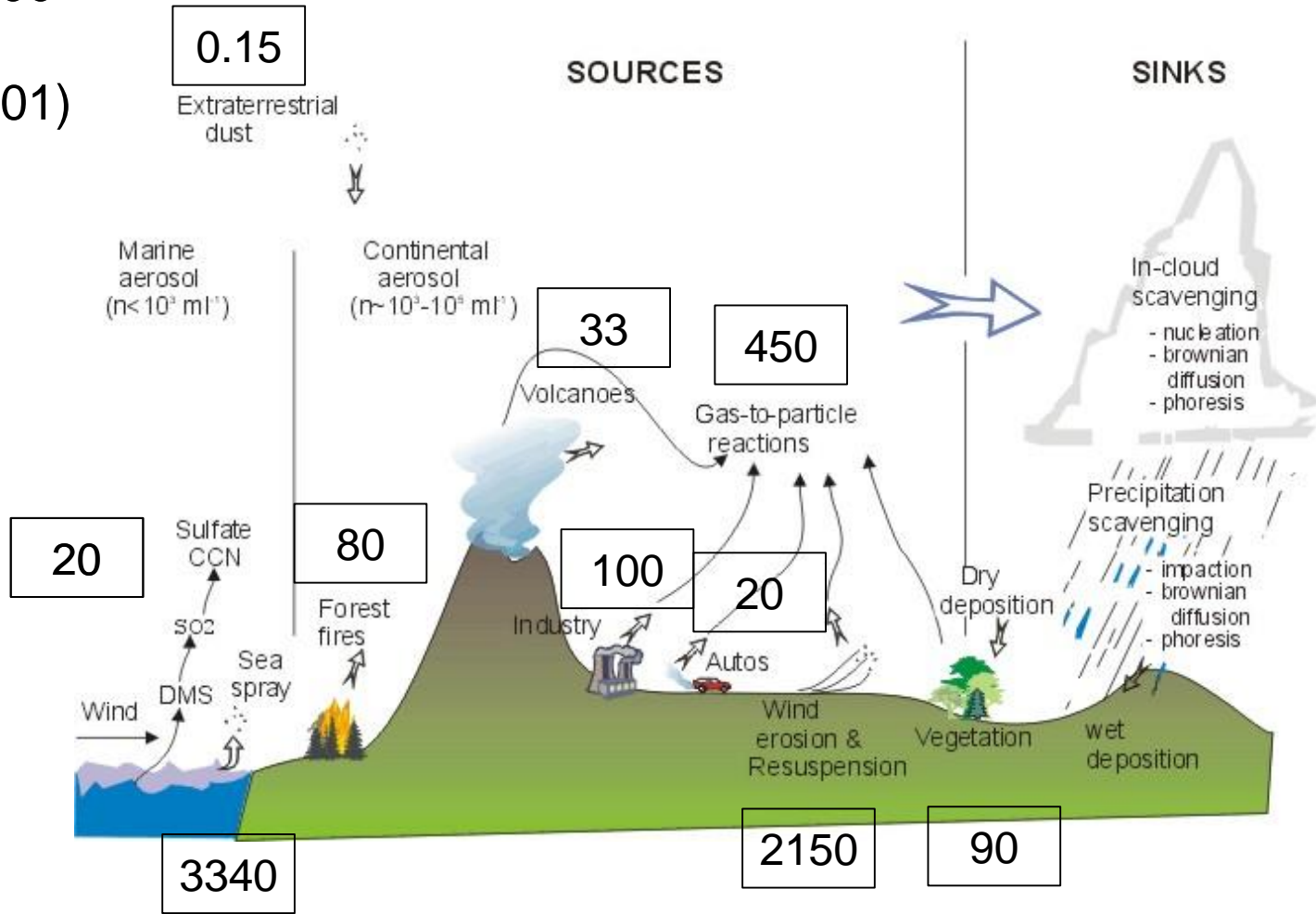
- **Types**: primary / secondary, natural / anthropogenic particles
- **Size**: diameter between 0.001 μm (1 nm) and 100 μm approx.
- **Chemical and mineralogical composition**: diverse
- **Optical properties** (absorption, scattering): diverse



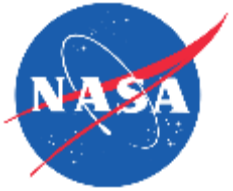
Sources

Year 2000
(Tg)
IPCC (2001)

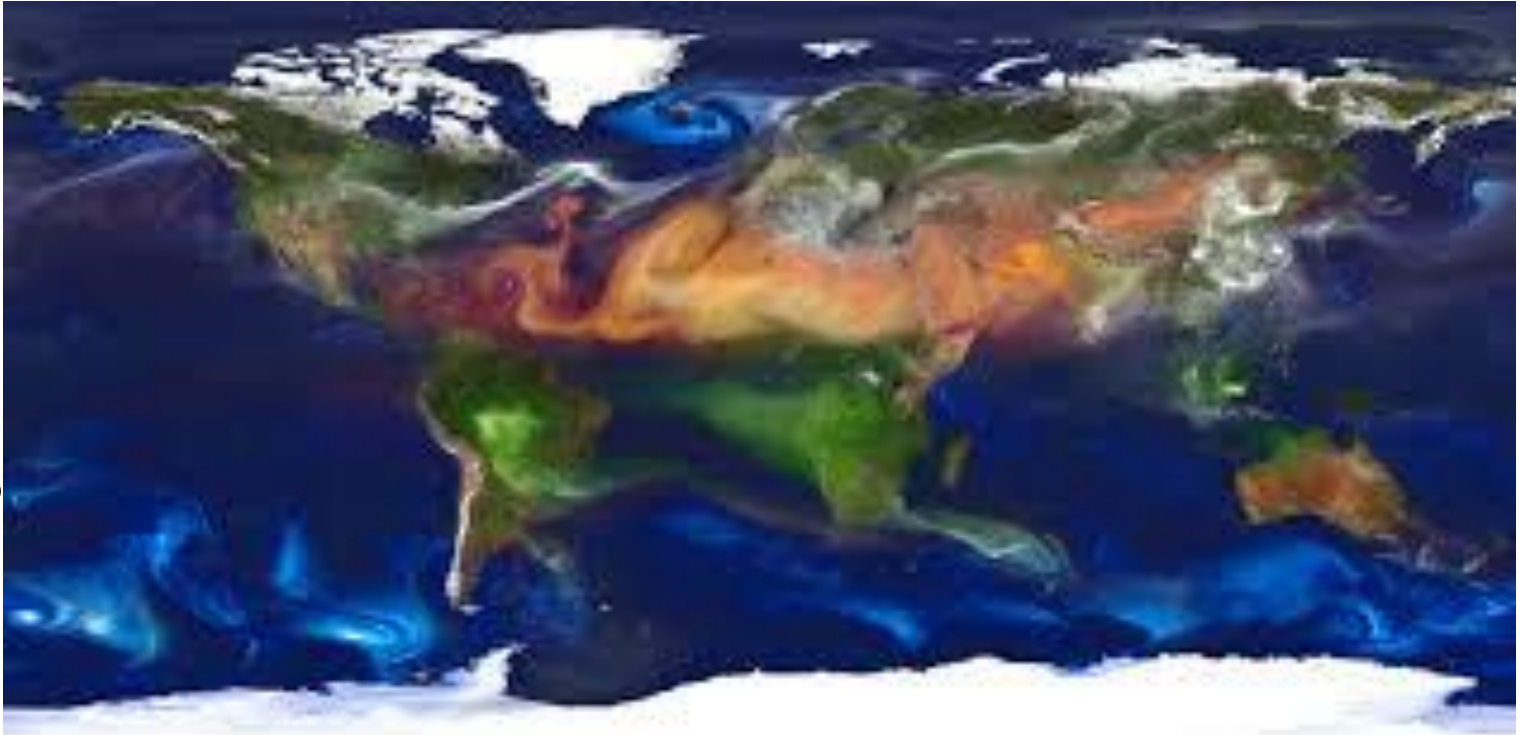
ATMOSPHERIC AEROSOL



Distribution



NASA
GEOS-5



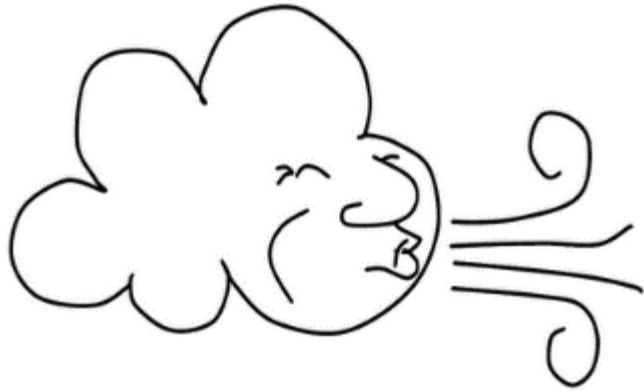
- Mineral dust (reddish)
- Sea salt (blue)
- Products from biomass burning (green)
- Sulphates (white)

https://youtu.be/oRsY_UviBPE

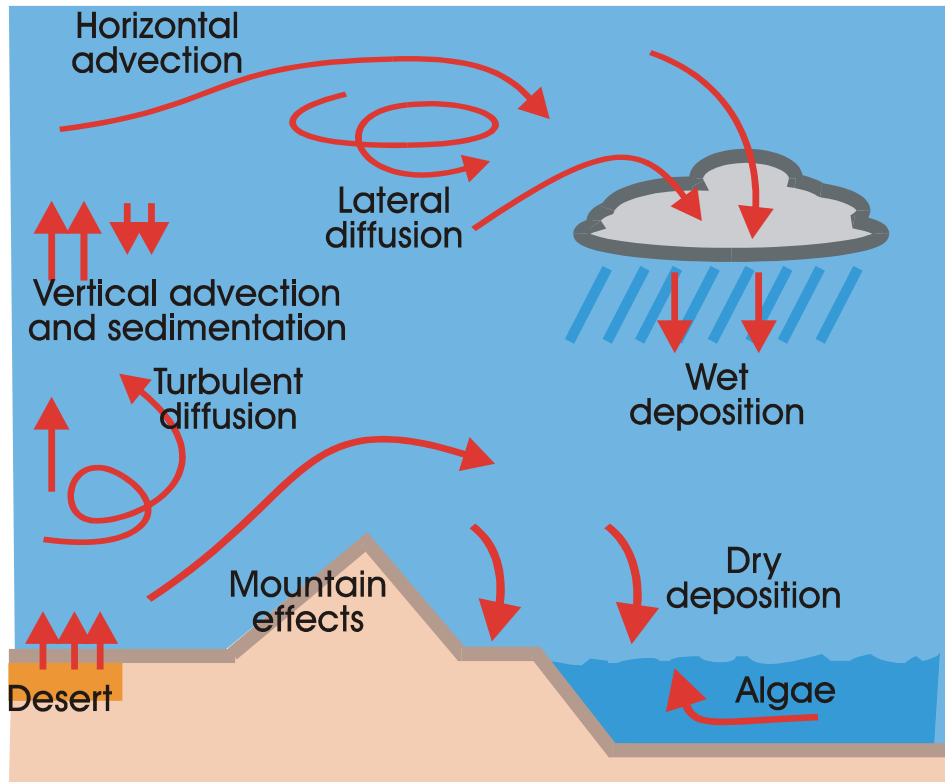
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The dust cycle

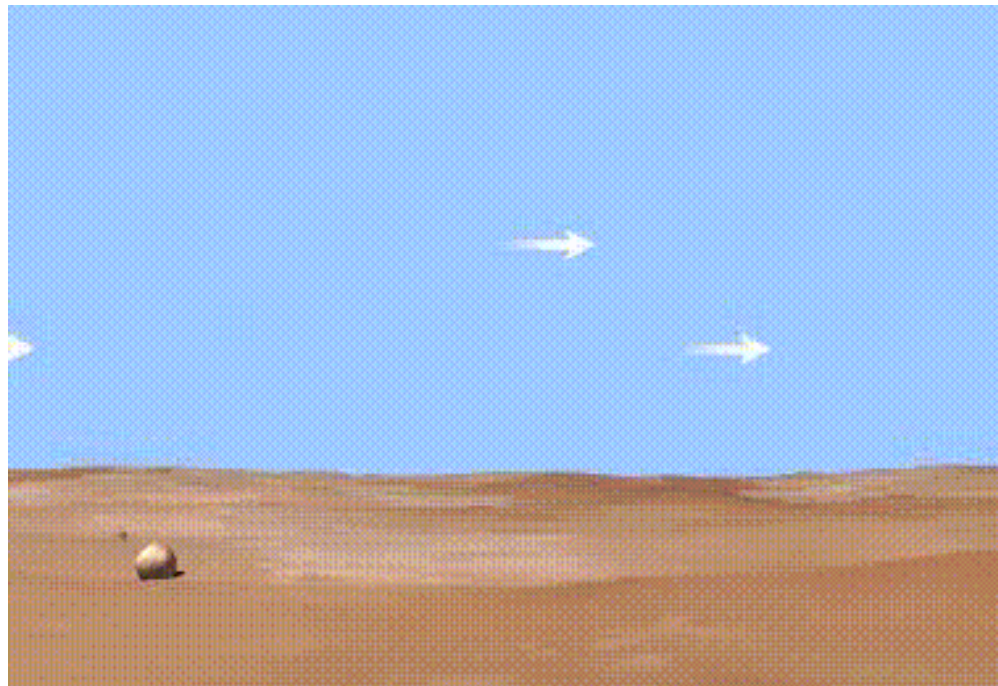
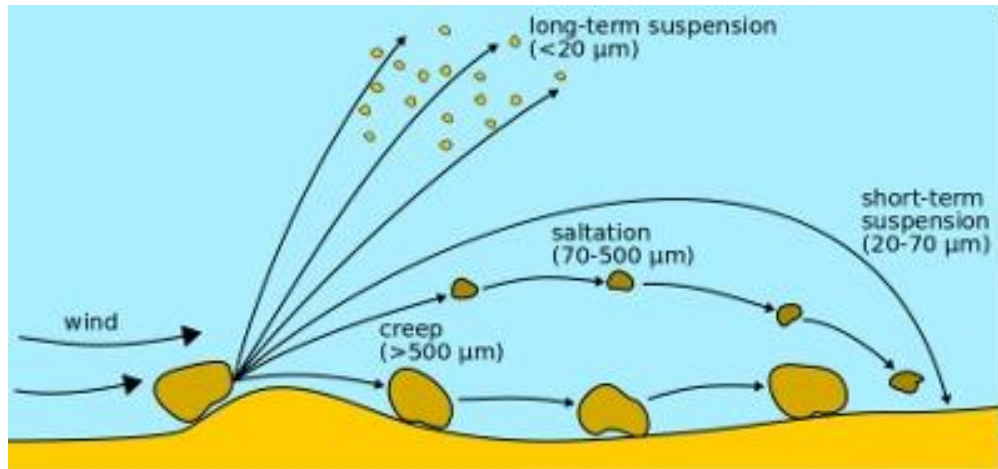


The dust cycle

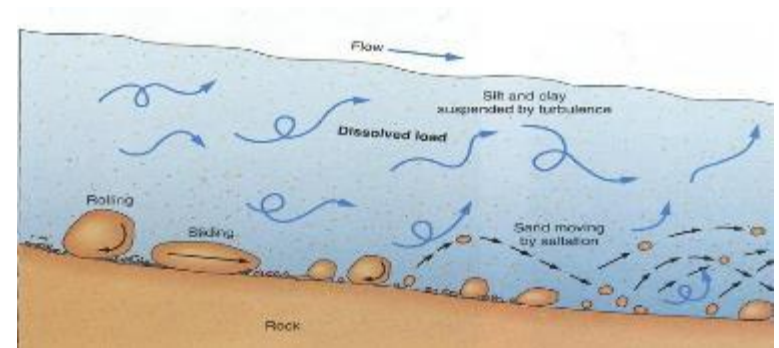


- Emission
- Turbulent diffusion
- Transport
- Dry / wet deposition

Emission

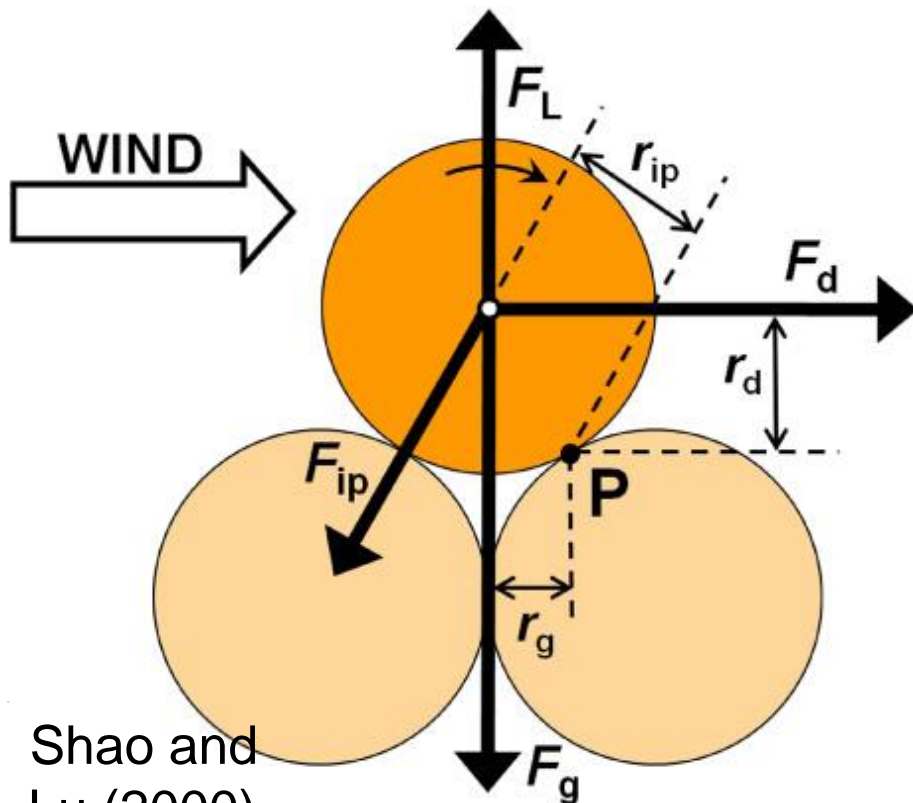


- The wind moves the loose particles according to its speed and the size of those particles
- The process is similar to sediment transport by rivers



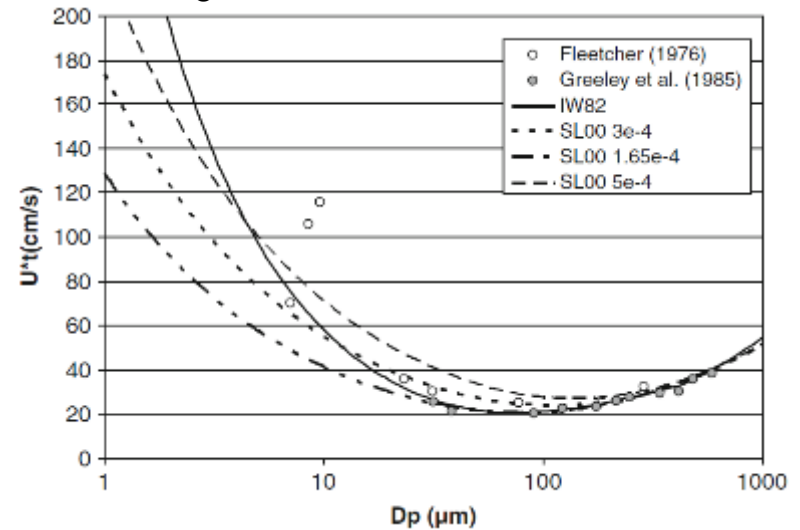
Erosion threshold

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)

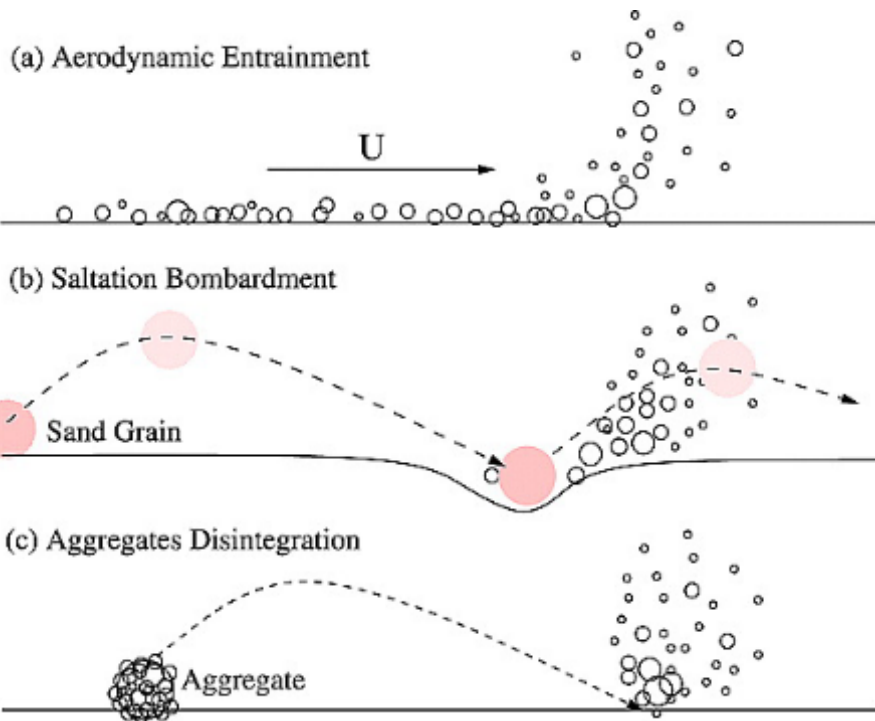


Shao and
Lu (2000)

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



Saltation & sandblasting



- 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.

Shao et al. (2011)

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

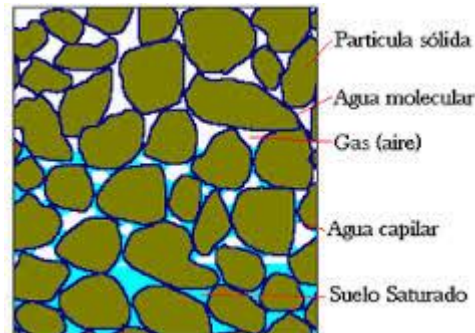


Non-erodible elements
(i.e. vegetation)



Crusted soils

Soil humidity



Emission

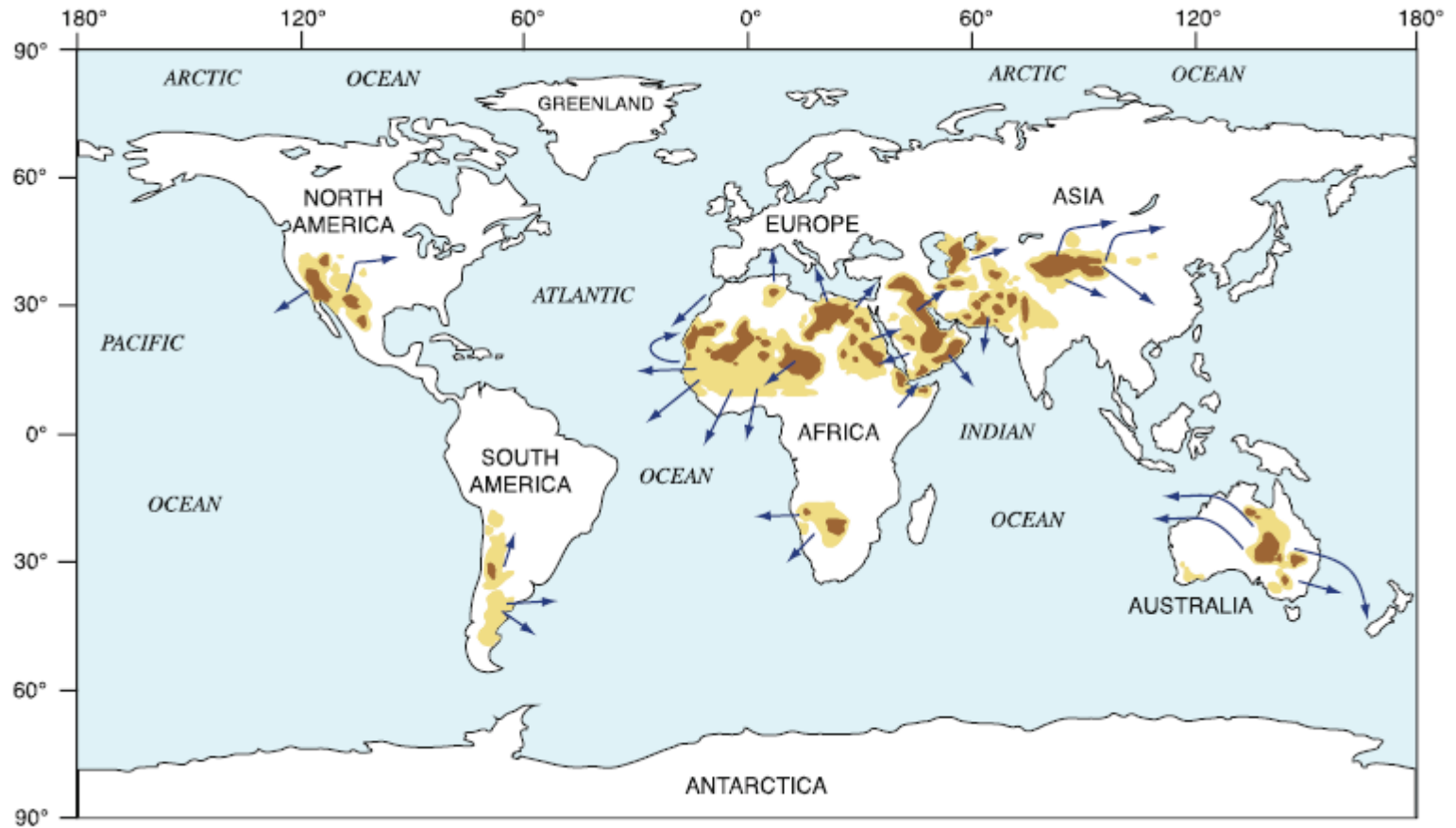
Soil factors

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

Meteorological factors

- Wind speed
- Near-surface turbulence

Sources



Anthropogenic sources

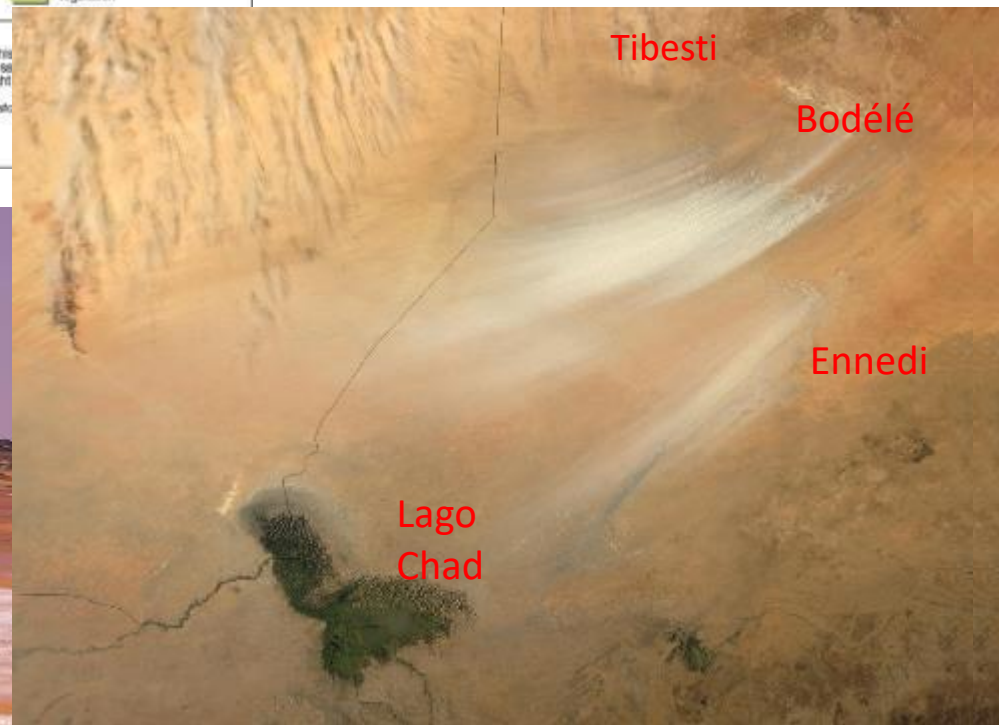
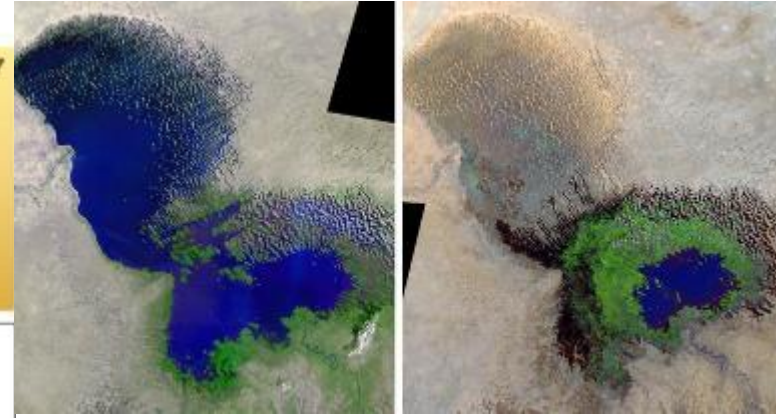
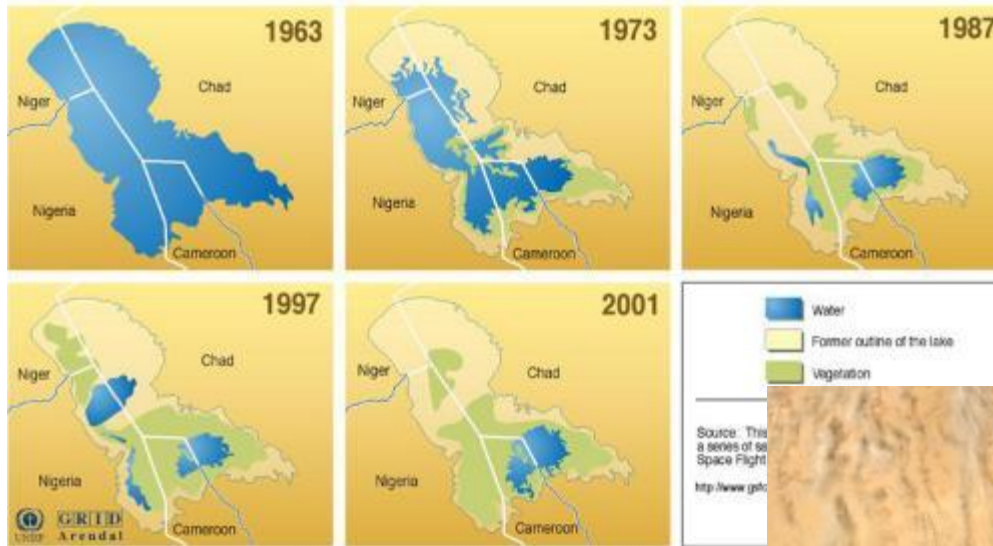
A significant part (25-30%) of the dust sources are anthropogenic:

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

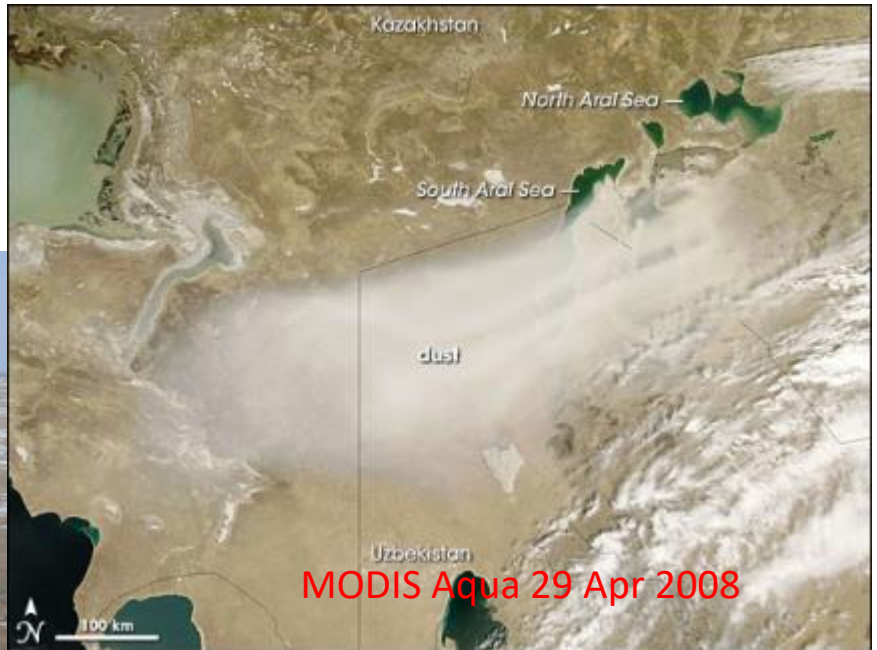


Bodélé depression

The Disappearance of Lake Chad in Africa



Aral Sea

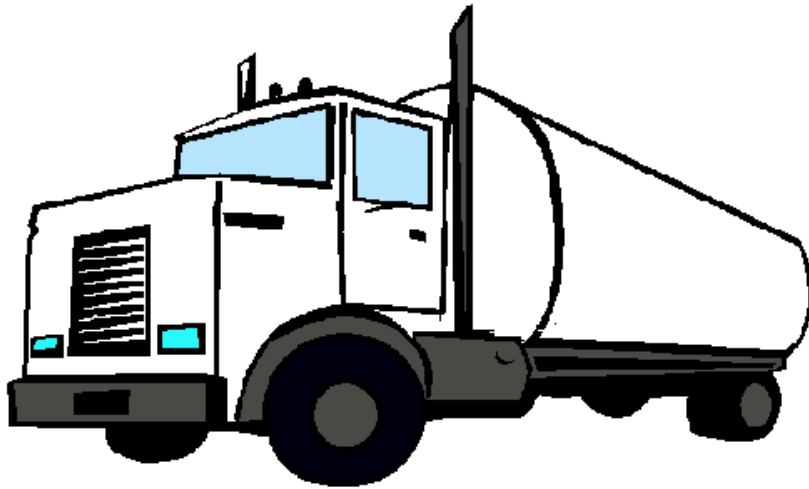


Total emission

~ 30–60 Tm/s

~ 1000–2000 Tg/yr

50,000,000 lorries

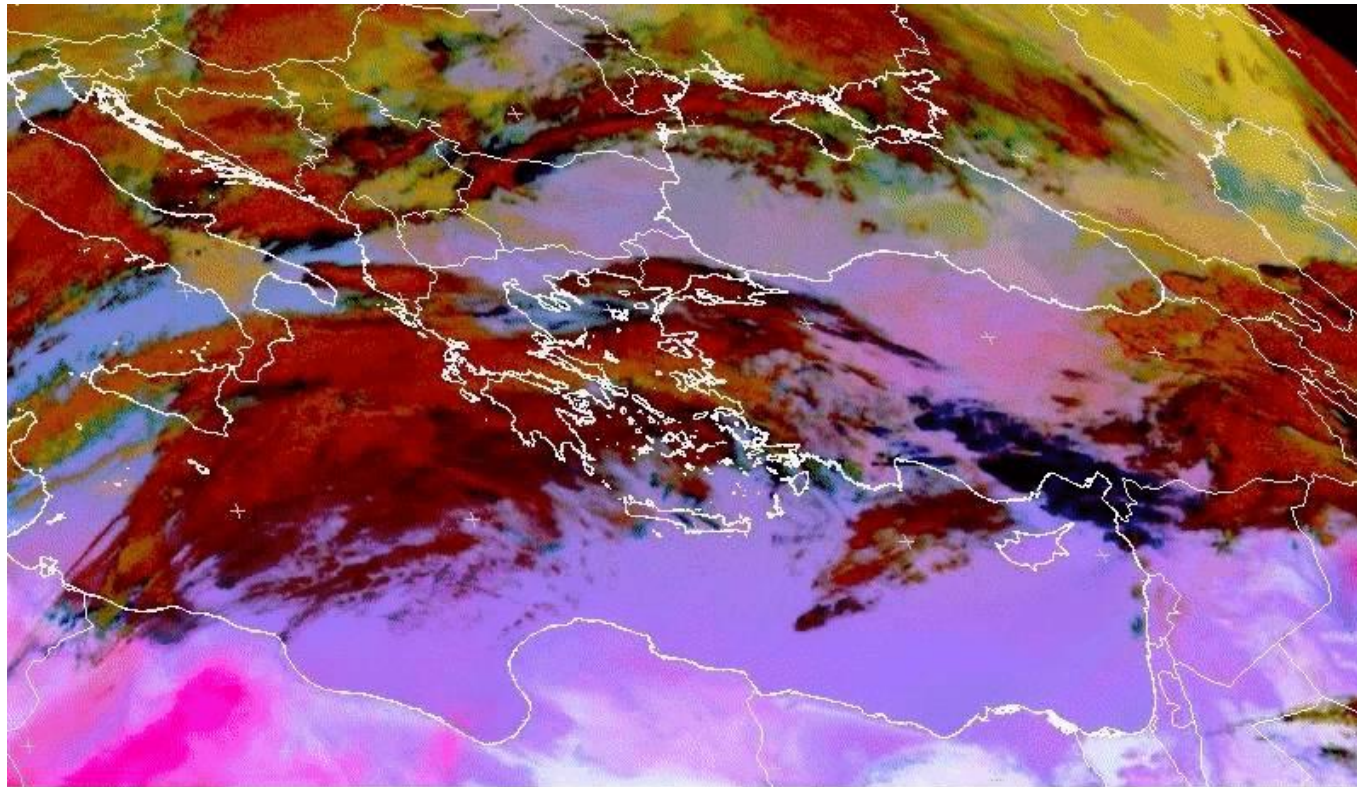


3,000 ULCC



Meteorological conditions

22-24 Mar 2008



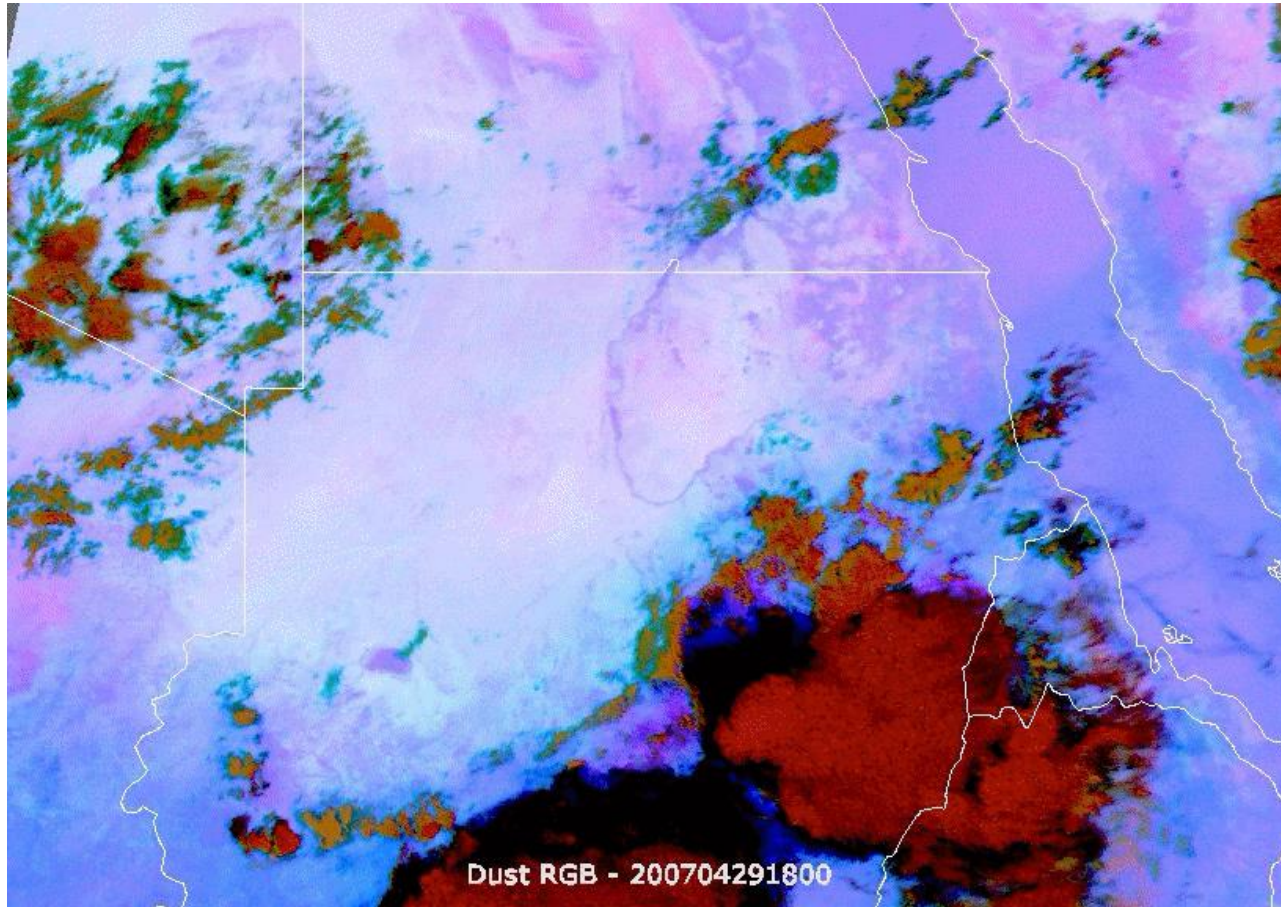
RGB-dust 2008-03-22 16:00 UTC



SYNOPTIC SCALE

- Frontal systems
- Reinforcing trade winds

Meteorological conditions

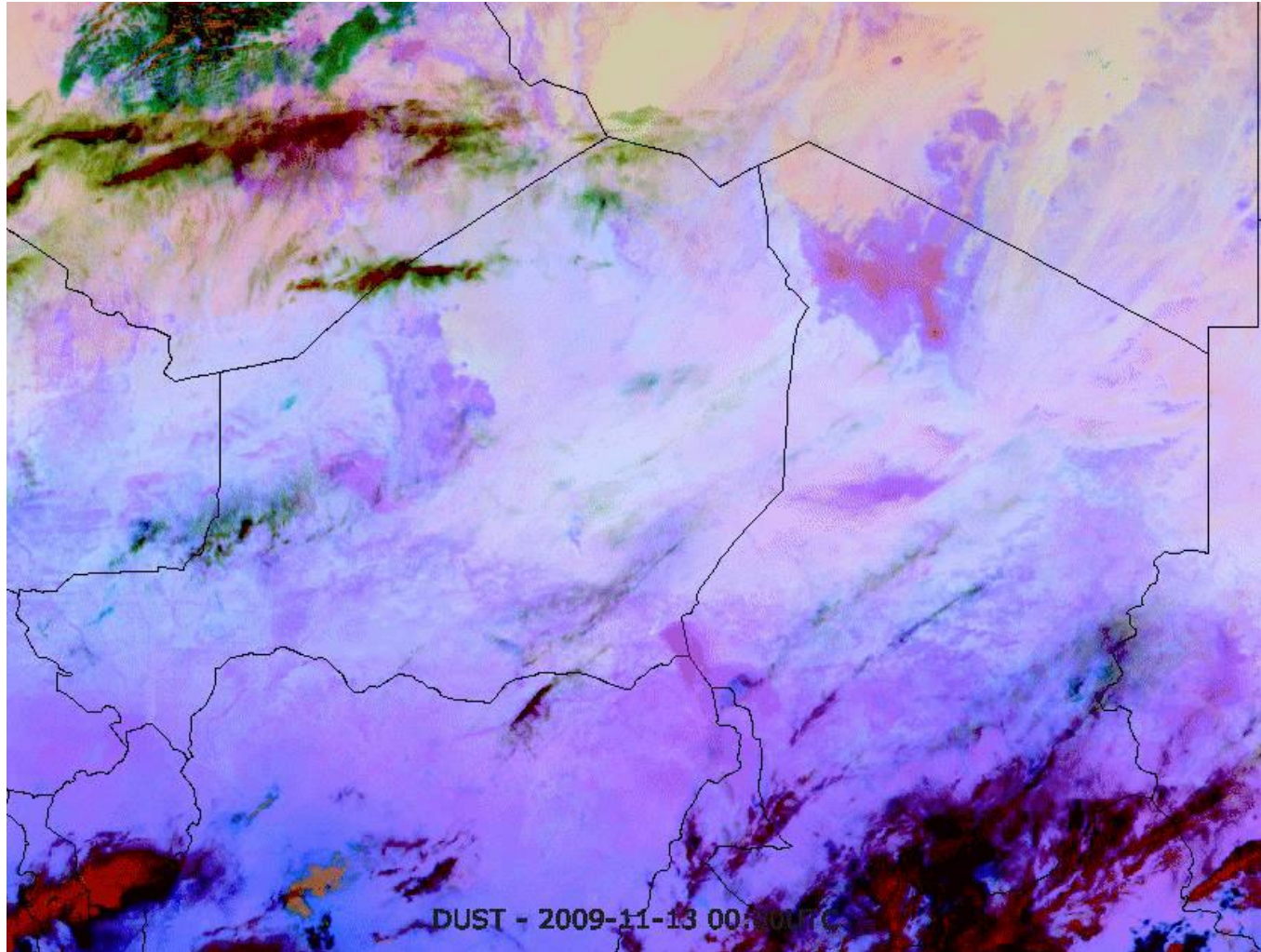


MESOSCALE- MICROSCALE

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

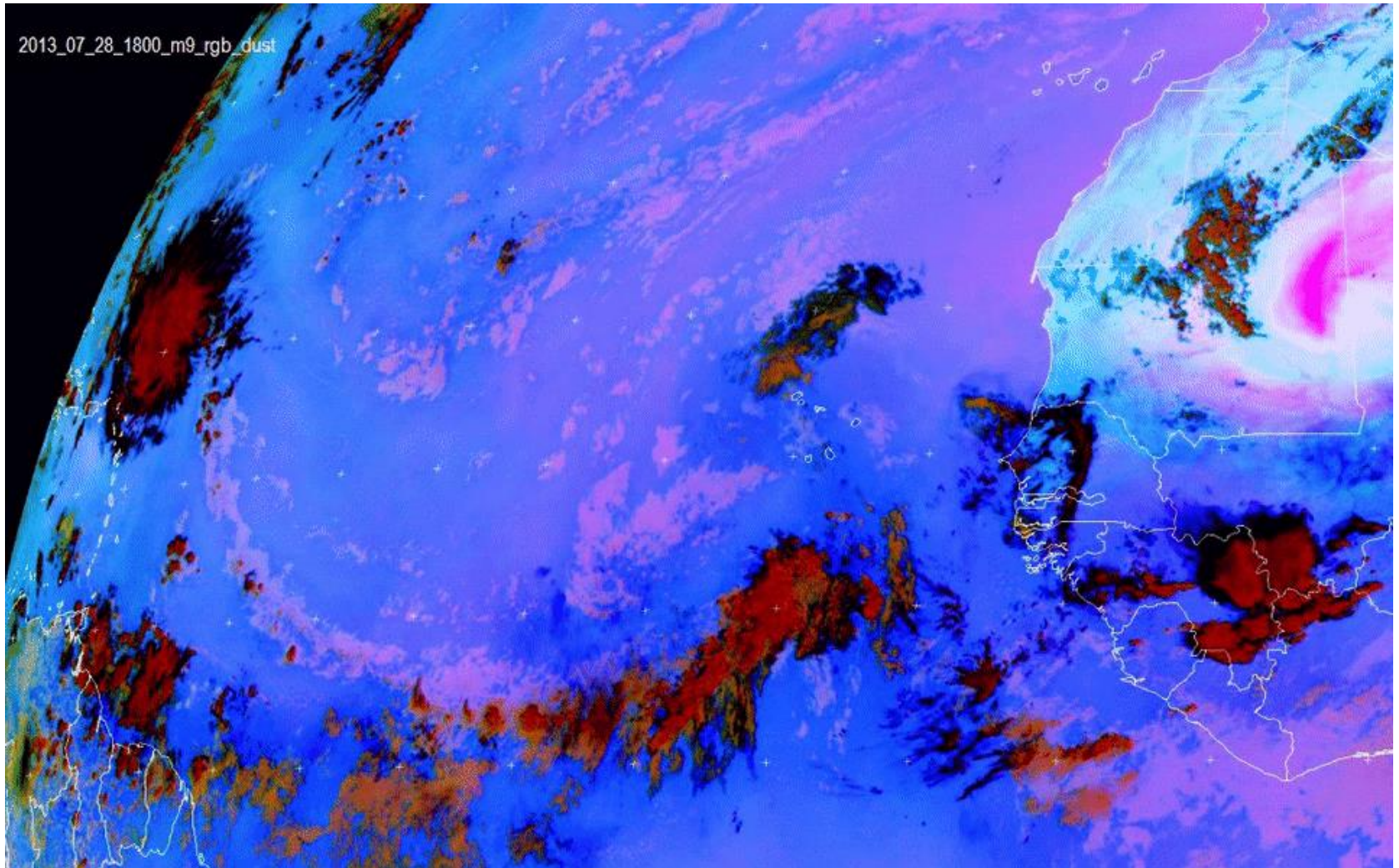
29 Apr – 1 May 2007

Meteorological conditions



13 – 14 Nov
2009

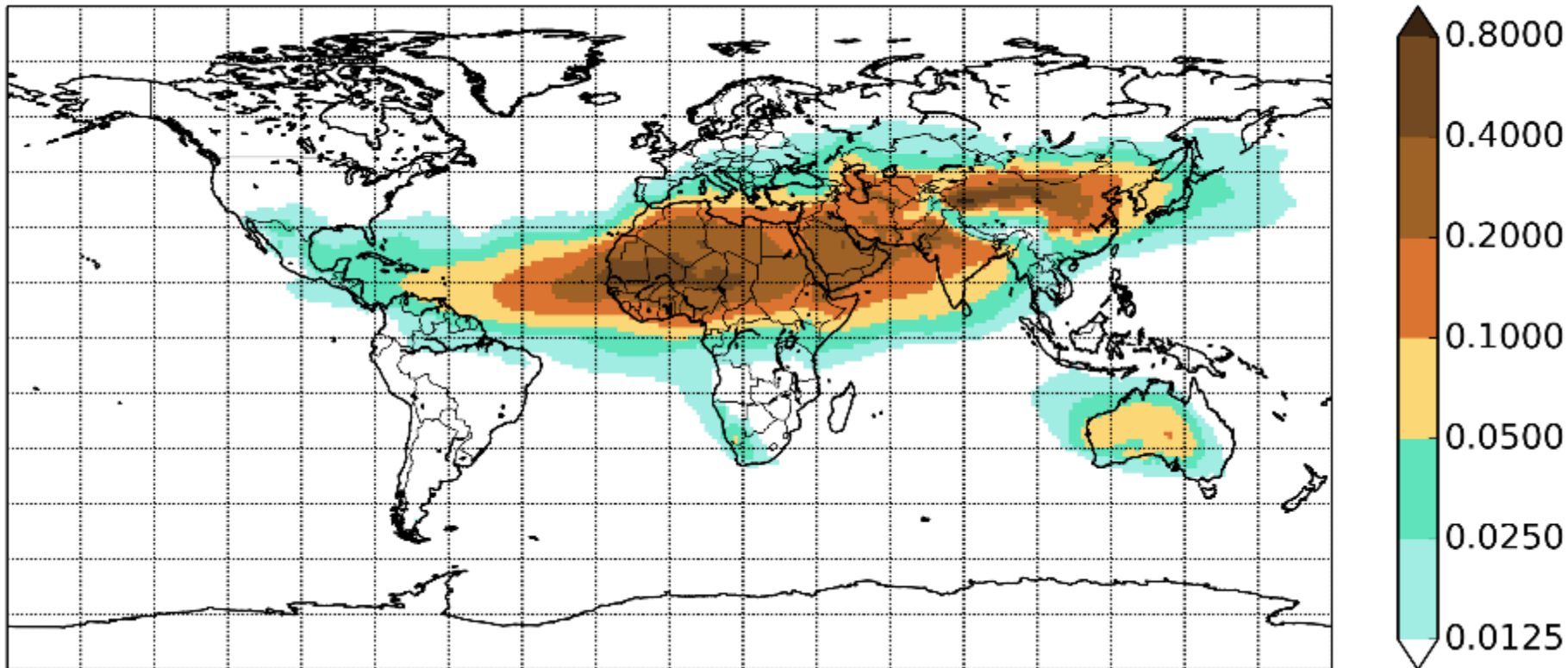
Transport



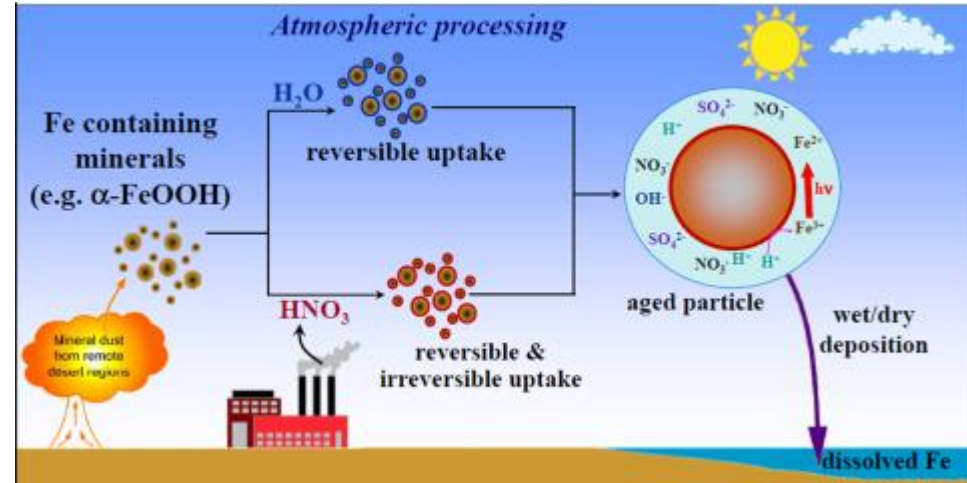
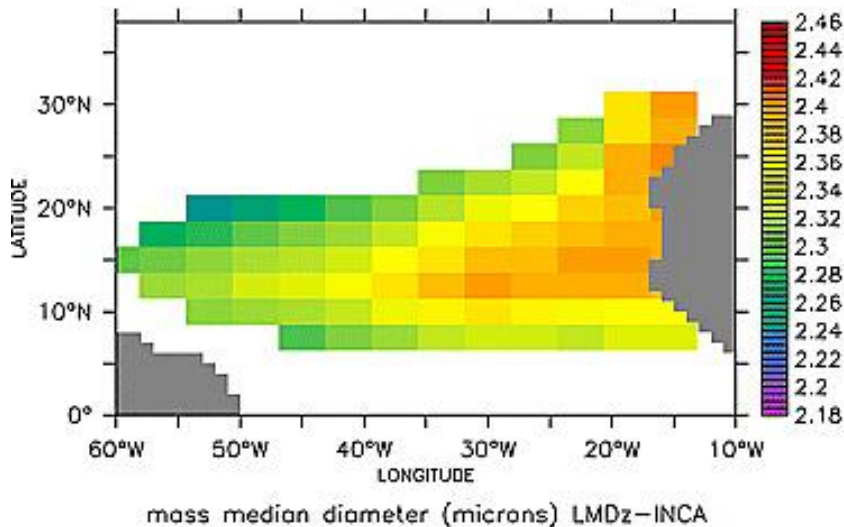
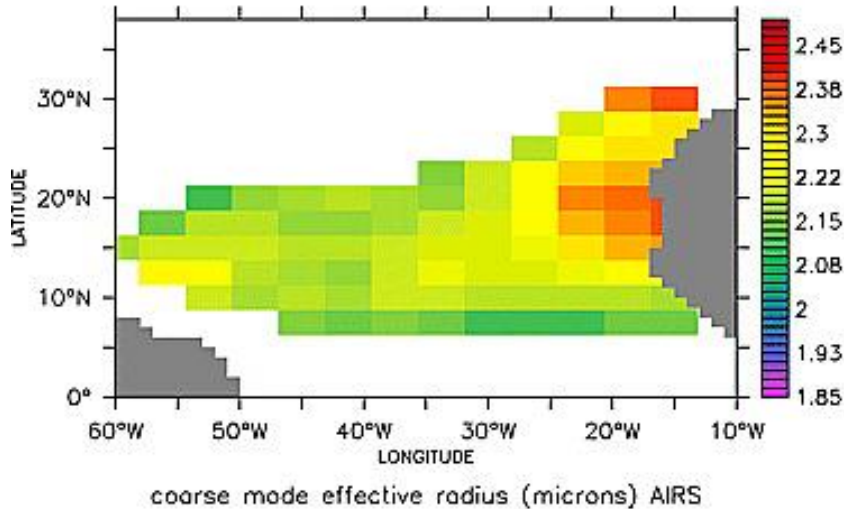
29 – 30 Jul 2013

Average distribution

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

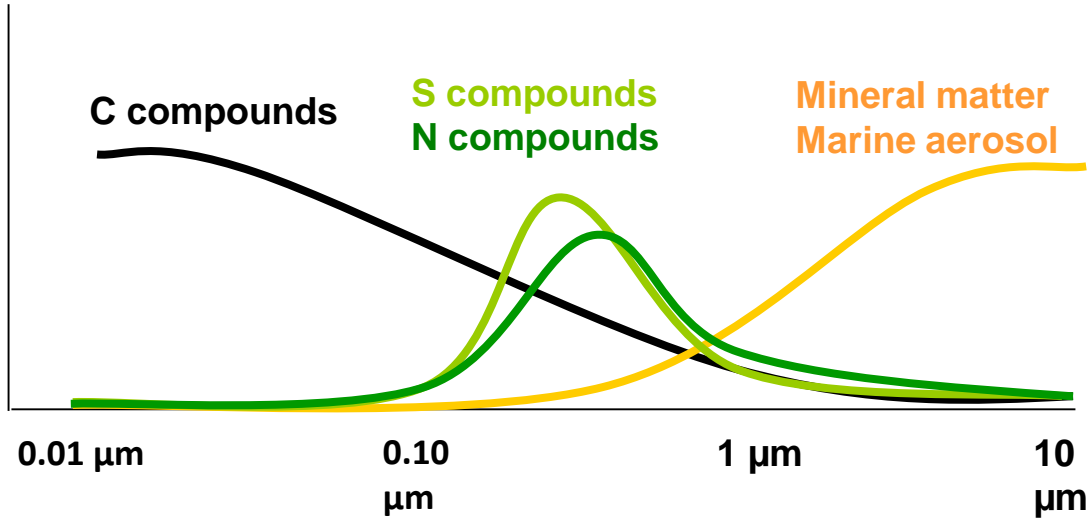


Transport

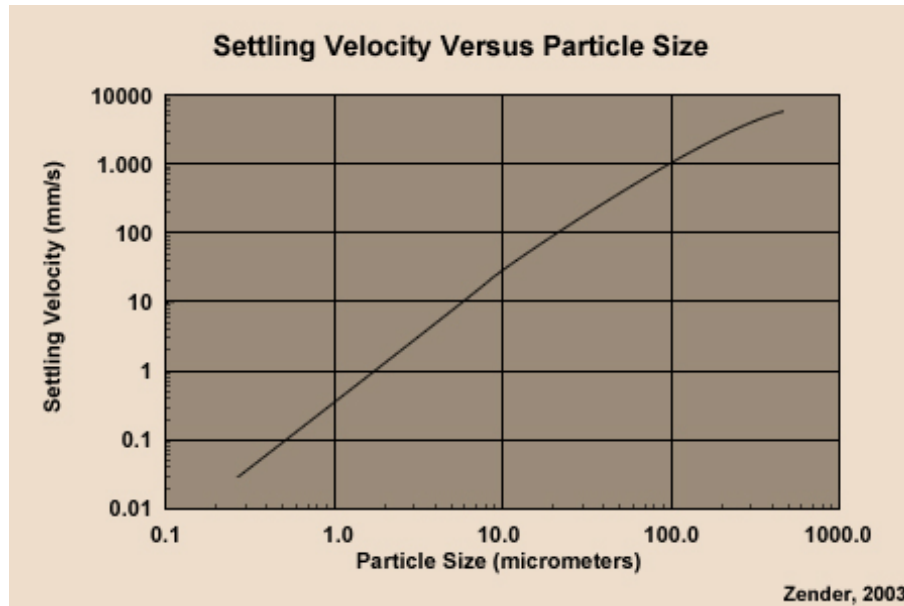


- The average particle size decreases
- Chemical composition may vary
- Optical properties may vary
- Increasing ability of particles to act as CN
- Increasing solubility of Fe

Deposition

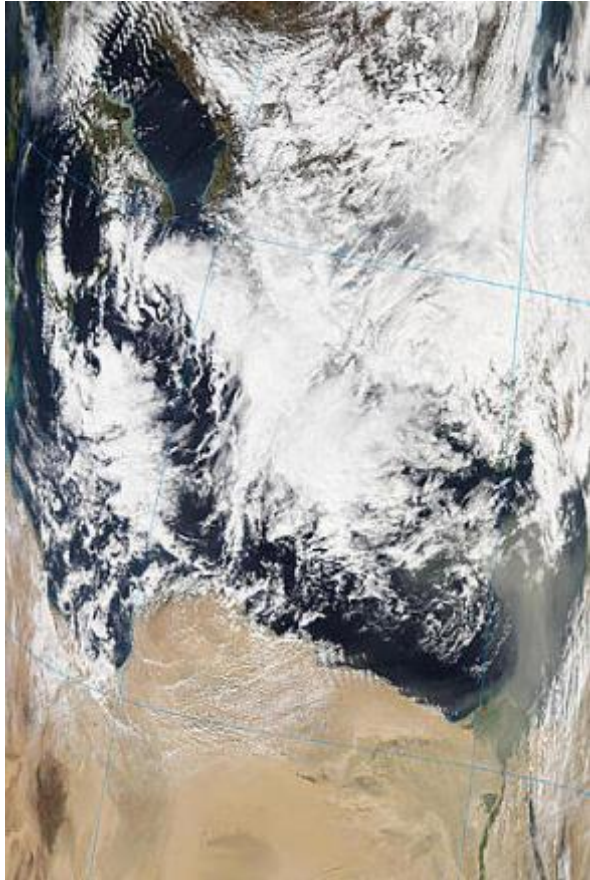


SIZE (μm)	AVERAGE LIFETIME (h)
0.1 - 0.18	231
0.18 - 0.3	229
0.3 - 0.6	225
0.6 - 1	219
1 - 1.8	179
1.8 - 3	126
3 - 6	67
6 - 10	28

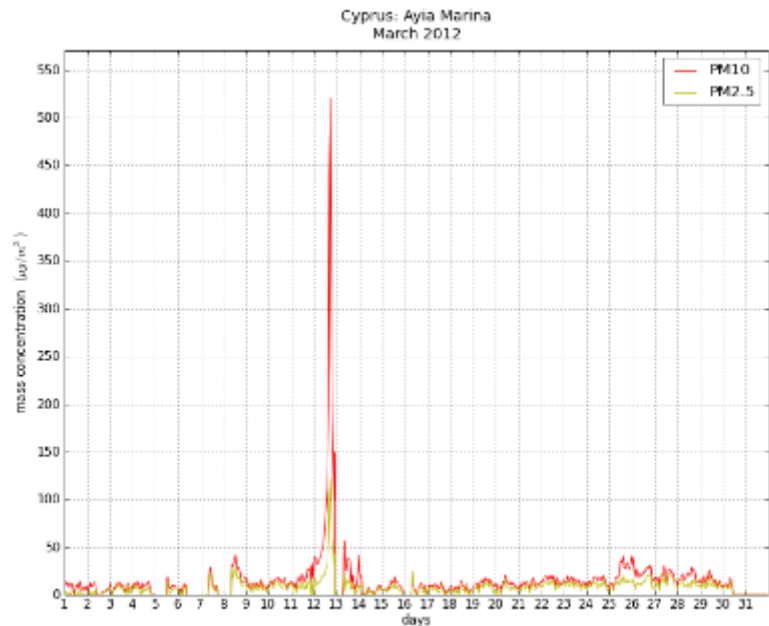
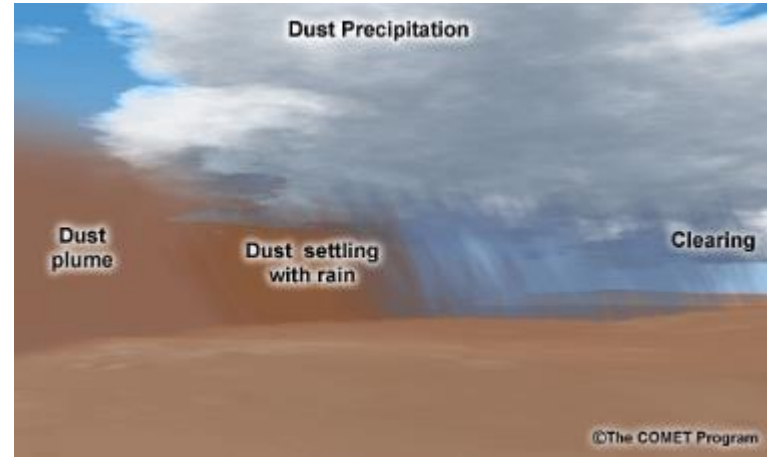


Tegen and Lacis (1996)

Wet deposition



MODIS 12 Mar 2012



PM Aya Marina, Cyprus, Mar 2012

Composition

MINERALOGICAL (X-ray diffractometry)

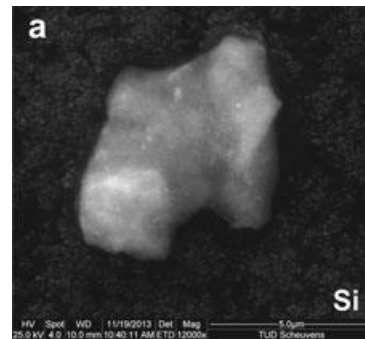
- Silicates: quartz, feldspar, phyllosilicates (ilite, kaolinite, smectite)
- Carbonates (calcite, dolomite)
- Hematite, gypsum, halite, ...

ISOTOPICAL (Sr, Nd, Pb)

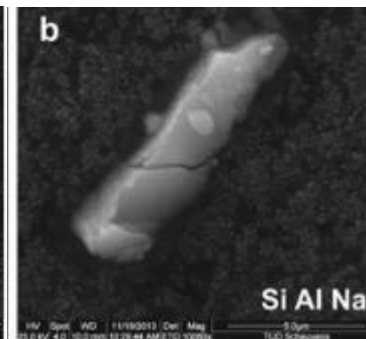
CHEMICAL (spectroscopy)

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

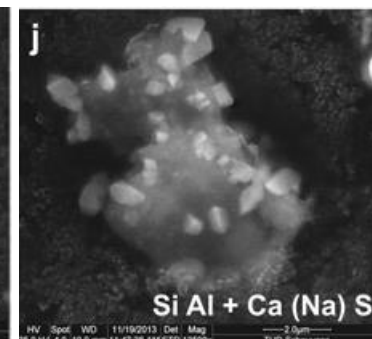
- Information about the source region
- Influence on optical properties
- Influence the impact on health, ecosystems, ...



Quartz

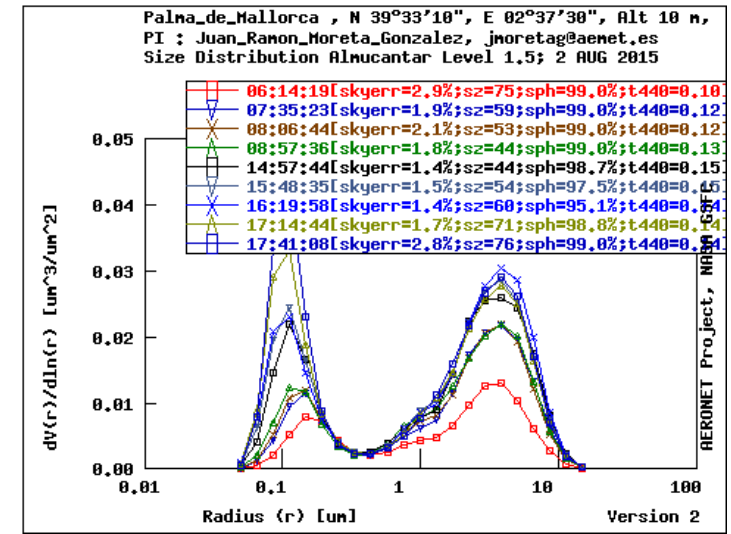
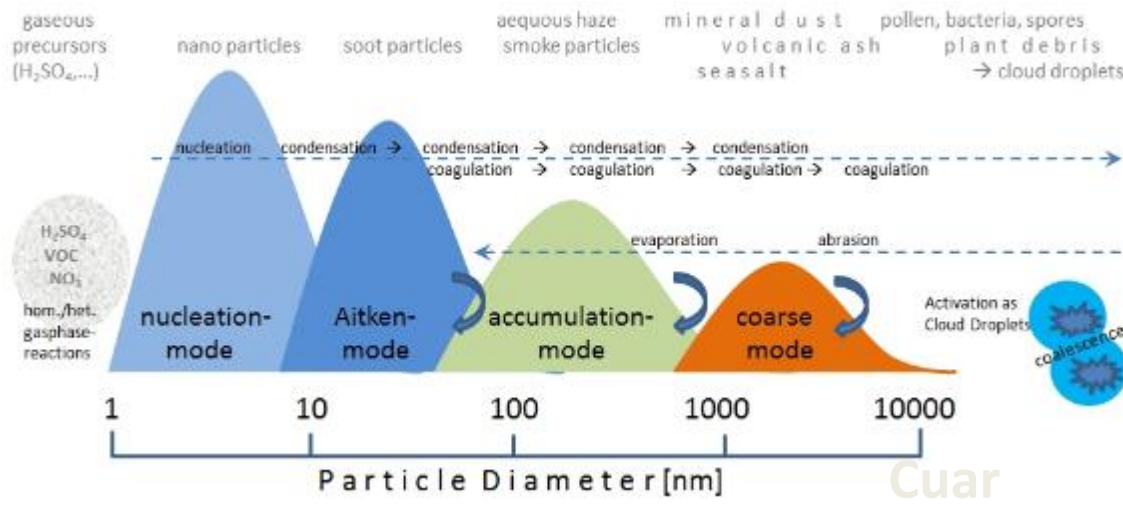


Albite

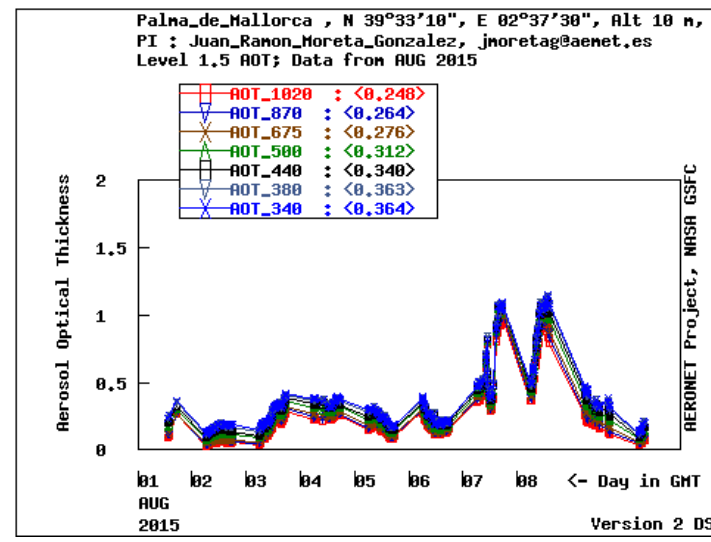


Gypsum

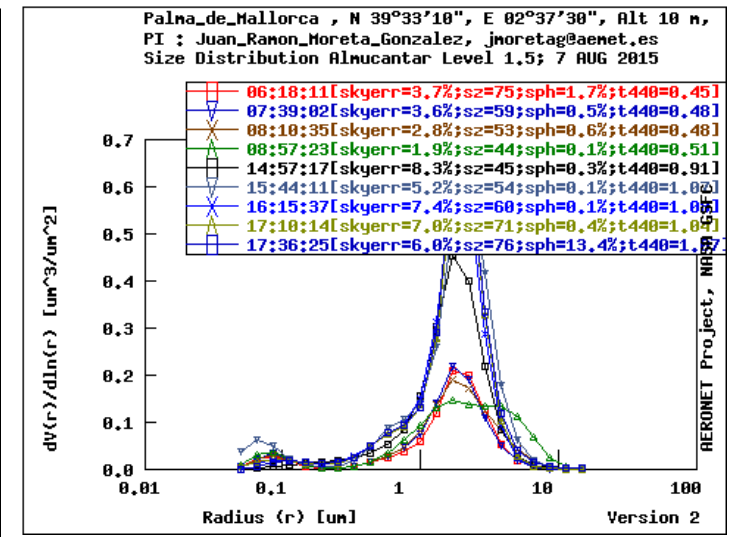
Particle size



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

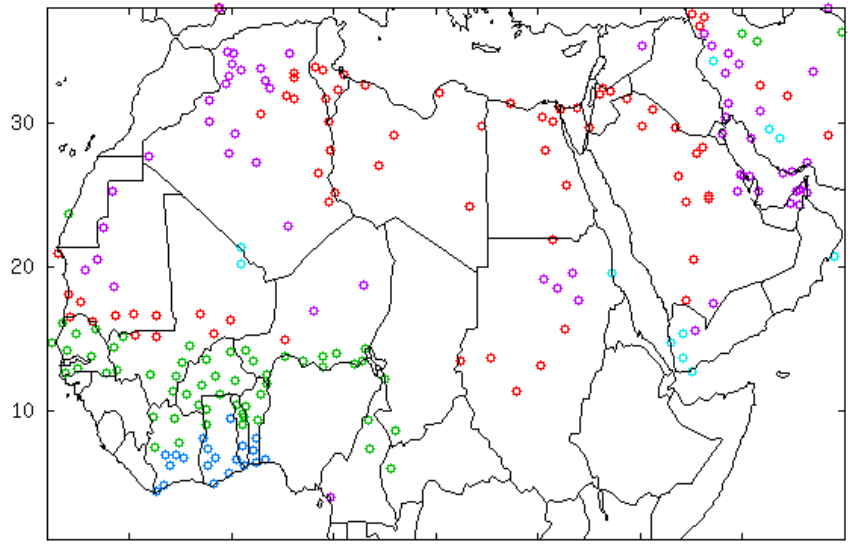


AOD. Palma de Mallorca. Aug 2015

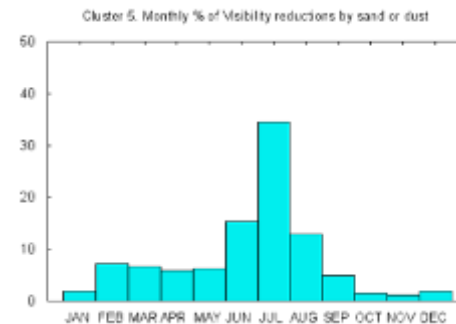
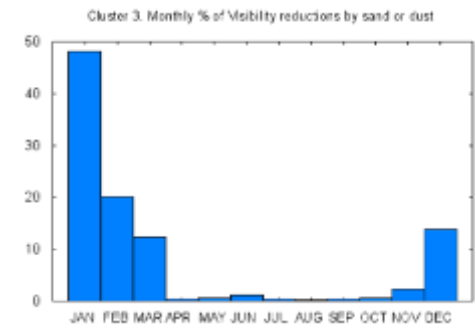
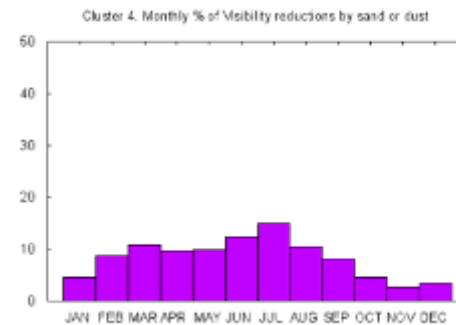
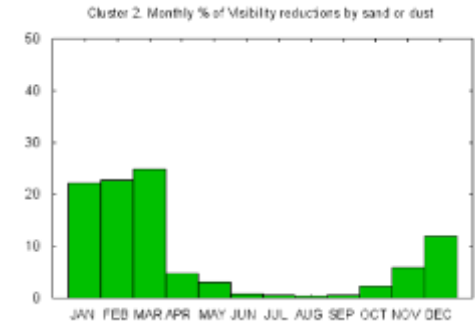
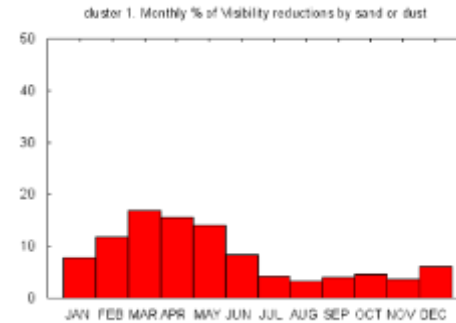


Palma de Mallorca 2 / 7 Aug 2015

Seasonal variability



1996-2010



Terradellas et al. (2012)

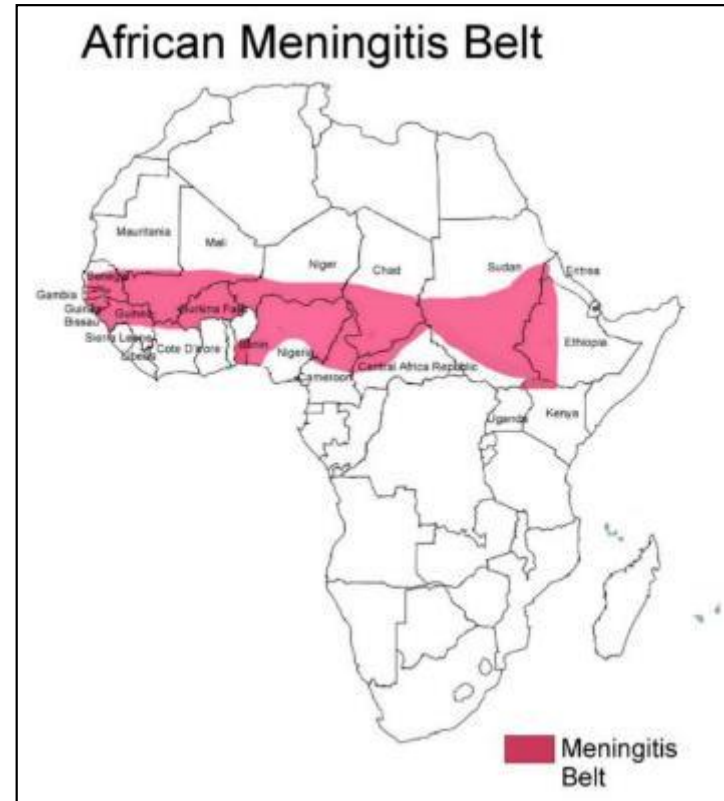
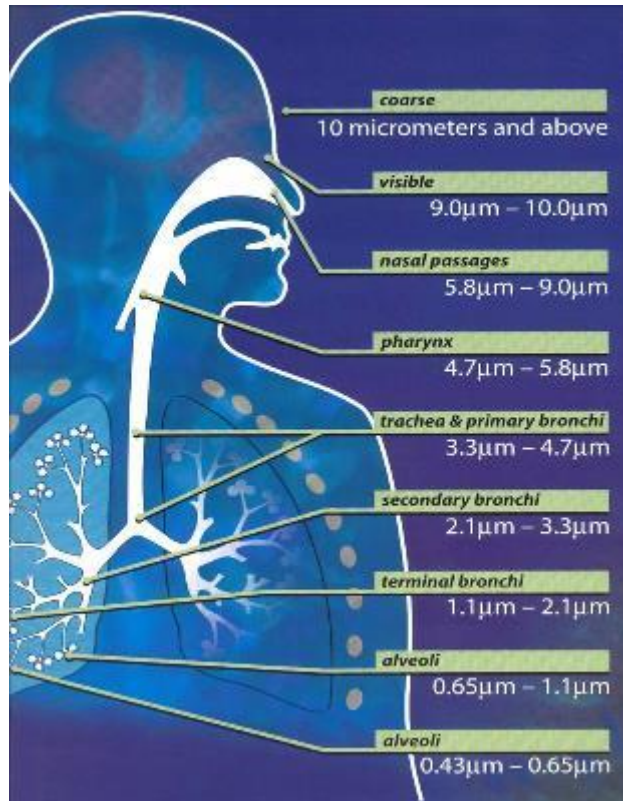
Impacts

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



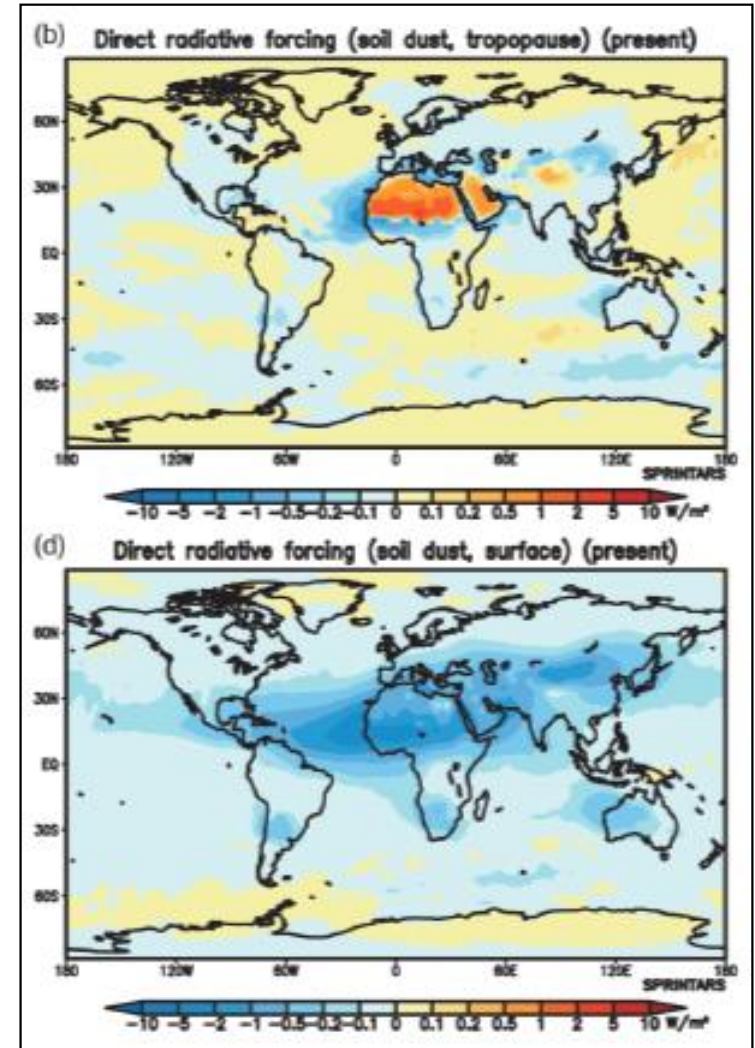
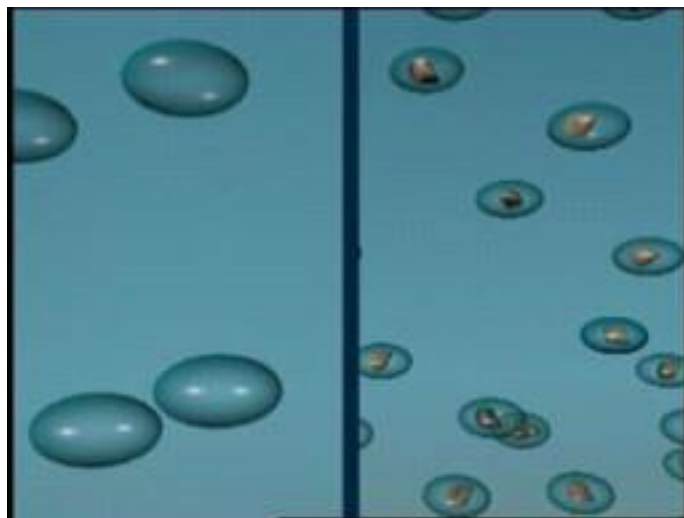
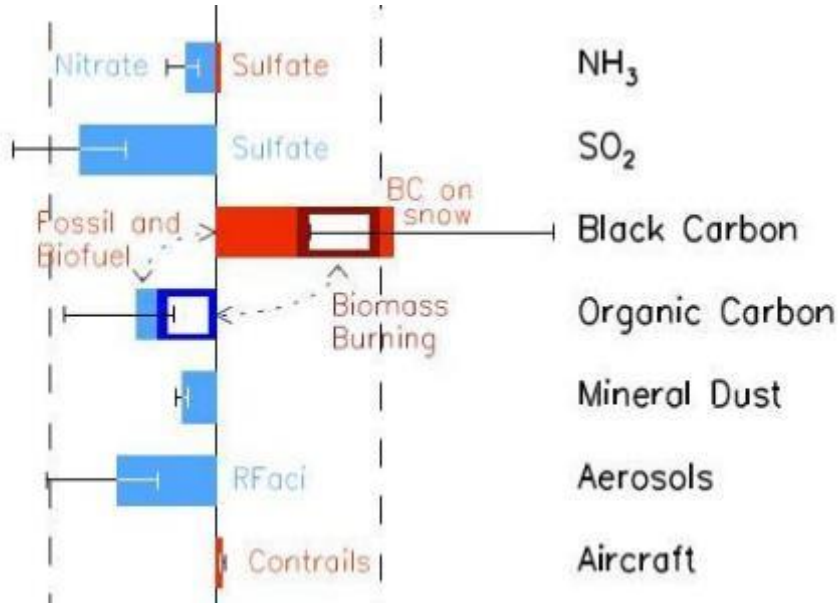
3:35P	On Time
3:45P	Cancelled
4:15P	On Time
4:24P	Delayed
4:30P	Cancelled
5:00P	On Time
5:12P	On Time
5:15P	On Time

Health impact



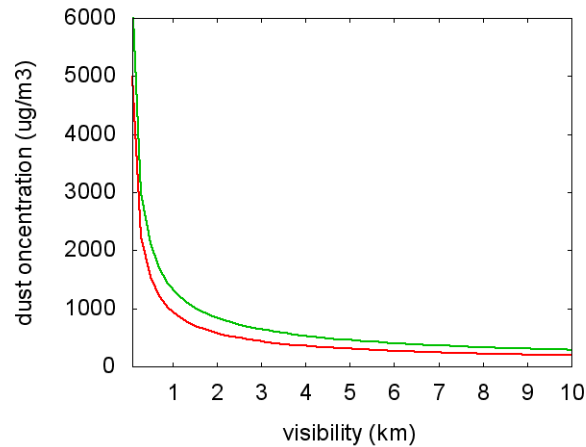
- Particle size
- Chemical and mineralogical composition
- Carrying bacteria, viruses, fungi, ...
- Time and intensity of exposure

Impact on weather and climate



Takemura et al. (2009)

Impact on transportation



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



Arizona, 29 Oct 2013

11:16 A	CANCELLED
5A 10:30 A	CANCELLED
5A 10:15 A	CANCELLED
7A 6:50 A	DELAYED
7A 7:20 A	DELAYED
10:00 A	CANCELLED
17A 10:10 A	DELAYED



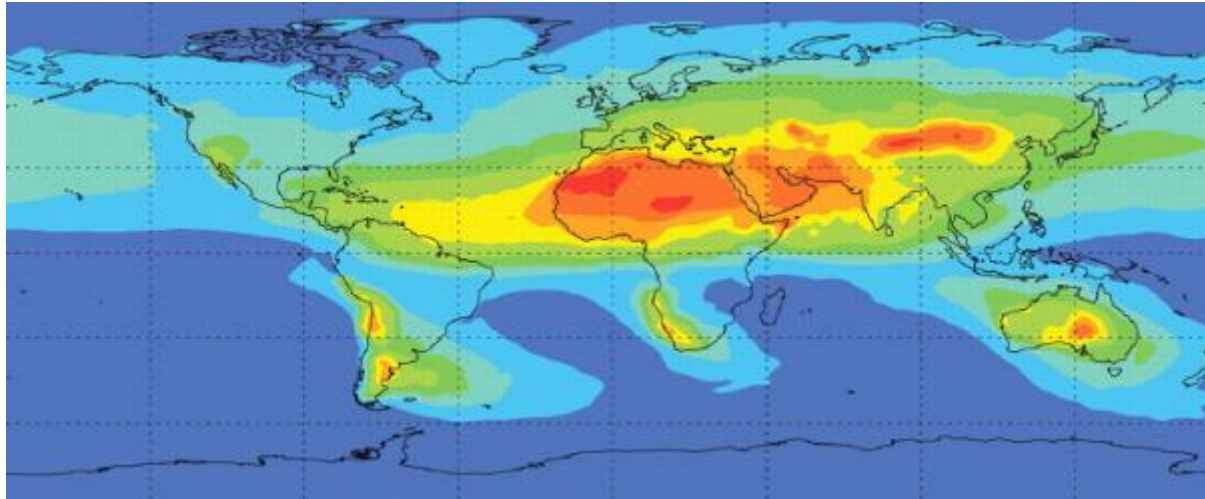
Tunis, 7 May 2002

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



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- The cycle of mineral dust
- **WMO SDS-WAS**
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- 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



UPC Campus. Nexus II building



MareNostrum III supercomputer



SDS-WAS Regional Center NAMEE

NORTHERN AFRICA-MIDDLE EAST-EUROPE (NA-ME-E) REGIONAL CENTER
WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS)

Log in

WMO Meteorological Organization
Aemet
European Centre for Medium-Range Weather Forecasts

WMO SDS-WAS | Asia Regional Center

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Northern Africa-Middle East-Europe (NA-ME-E) Regional Center

by Francisco Benito — last modified May 29, 2012 02:32 PM

Outstanding

- Guidance for forecasters
- 11 lectures on atmospheric mineral dust
- Forecast evaluation
- Compared dust forecasts

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Latest News

- SackTrajectories are now available
Sep 04, 2012
- Comparison of dust models
Aug 29, 2012
- User date and quicklooks
Aug 29, 2012

Upcoming Events

- European Aerosol Conference EAC-2012
Sep 02, 2012 - Sep 07, 2012 — Granada, Spain
- 2012 EUMETSAT Meteorological Satellite Conference
Sep 02, 2012 - Sep 07, 2012 — Scop, Poland
- 90th International Symposium on Tropospheric Profiling

Dust forecasts

WMO SDS-WAS - N. Africa-Middle East-Europe RC
MISSION: Dust Surface Concentration (µg/m³)
Run: 01 SEP 2012 - 0600 000 03 SEP 2012 24 x 24

Compared Dust Forecasts

Forecast Evaluation

Dust observations

<https://sds-was.aemet.es>
sdswas@aemet.es

Barcelona Dust Forecast Center

Log in Register

BARCELONA DUST FORECAST CENTER

 WMO SDS-WAS | NA-ME-E Regional Center

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LATEST NEWS

[Establishing a WMO SDS-WAS Regional Node for West Asia](#)

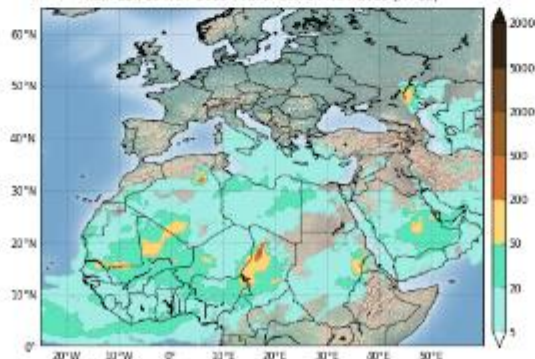
Training events in Muscat, Oman

Dust-related training events organized by the Regional Center for Northern Africa, Middle East and Europe of WMO SDS-WAS

[Read More](#)



Barcelona Dust Forecast Center
NMMB/BSC-Dust Res: 0.1°x0.1° Dust Surface Conc. (µg/m³)
Run: 12h 13 NOV 2013 Valid: 00h 14 NOV 2013 (H+12)



Dust forecast

Latest dust forecast for Northern Africa, Middle East and Europe

[Check it here](#)

<https://dust.aemet.es>

dust.aemet.es

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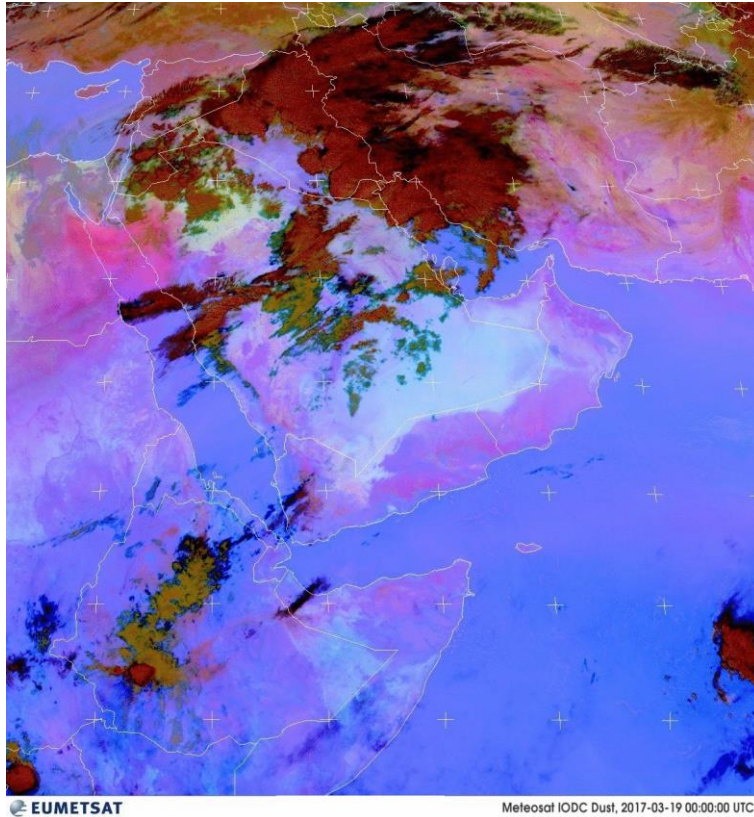
Why do we need dust observation?

- 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



- 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)

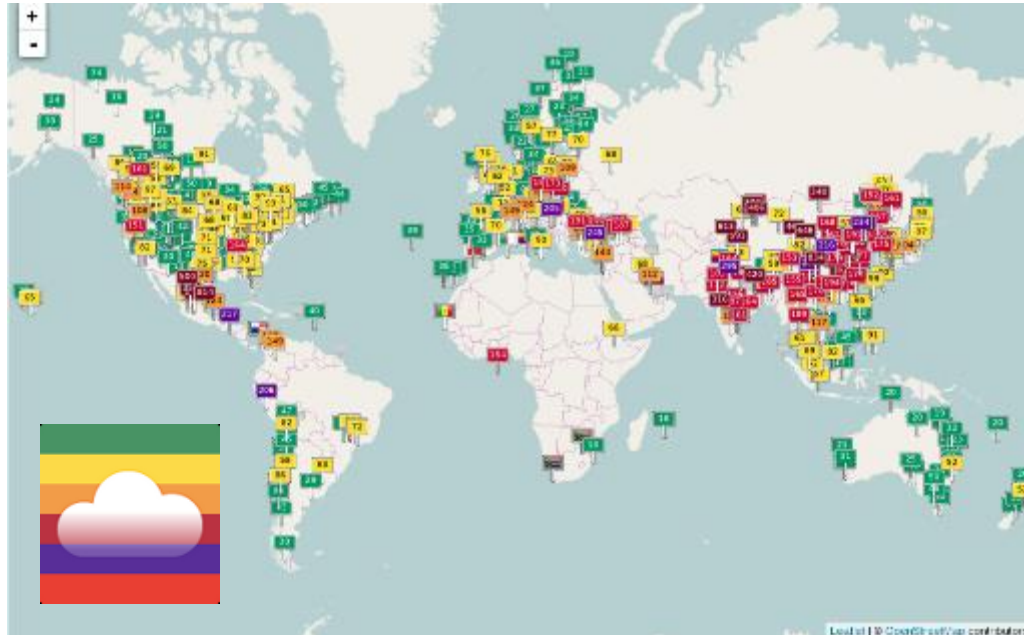
Drawbacks:

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



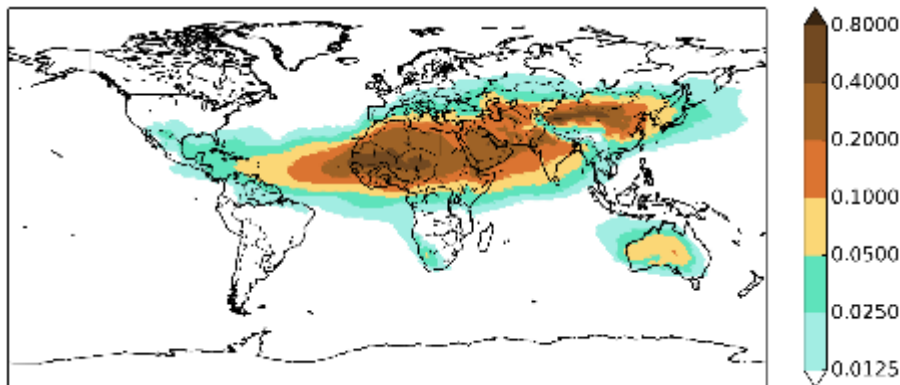
19 Mar 2017: The sandstorm named Madar, originated in Libya, swept through Egypt, Saudi Arabia, Iraq, Kuwait and Iran

Monitoring: AQ stations



Drawbacks:

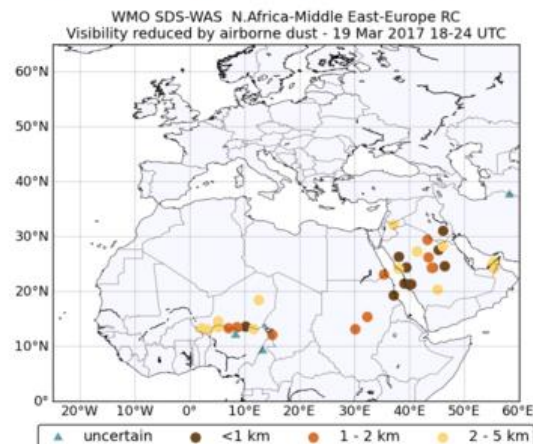
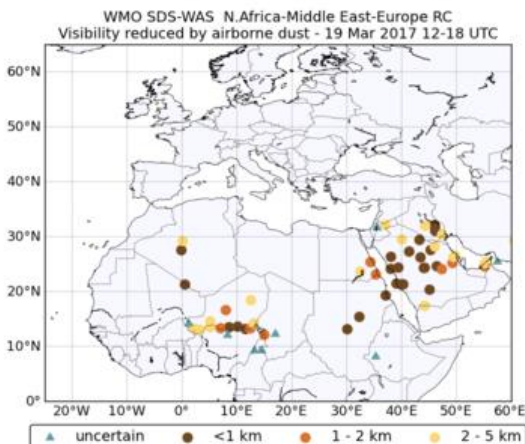
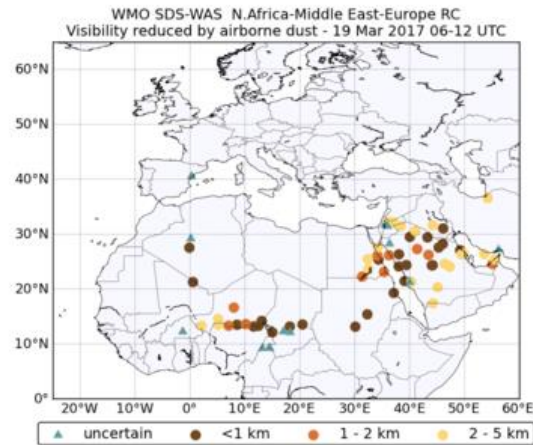
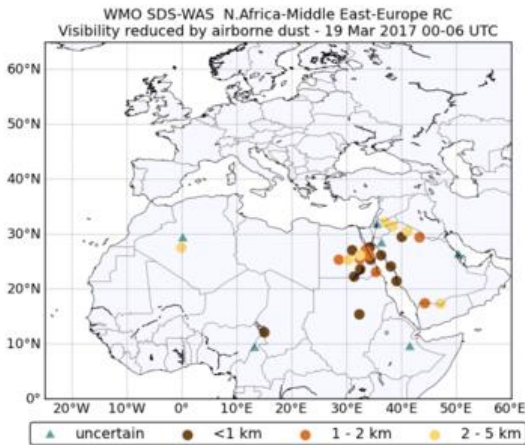
- Few stations near dust sources
- No protocol for data exchange
- Lack of harmonization in measurements
- Integration of all particles
- Many stations located in urban environments



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



Monitoring: meteorological reports



Drawbacks:

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

<https://sds-was.aemet.es>

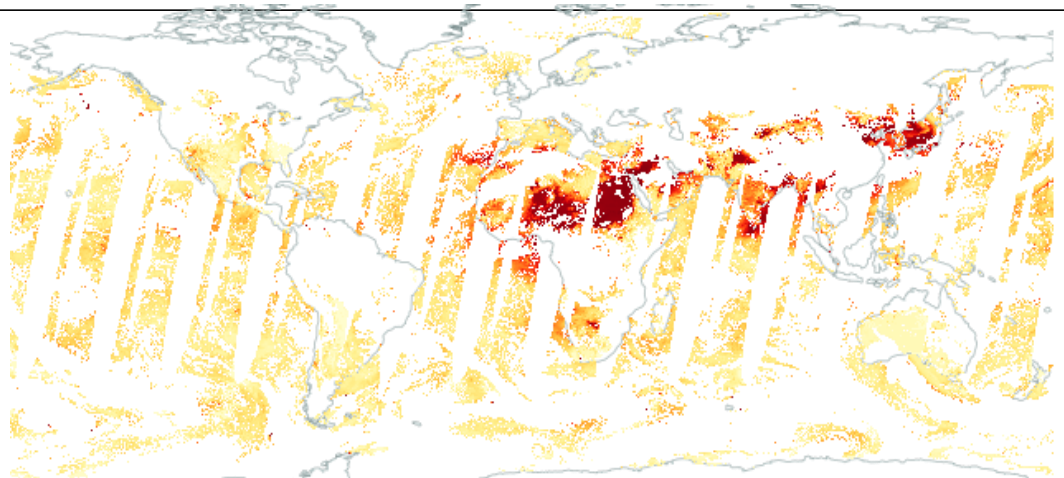
19 Mar 2017



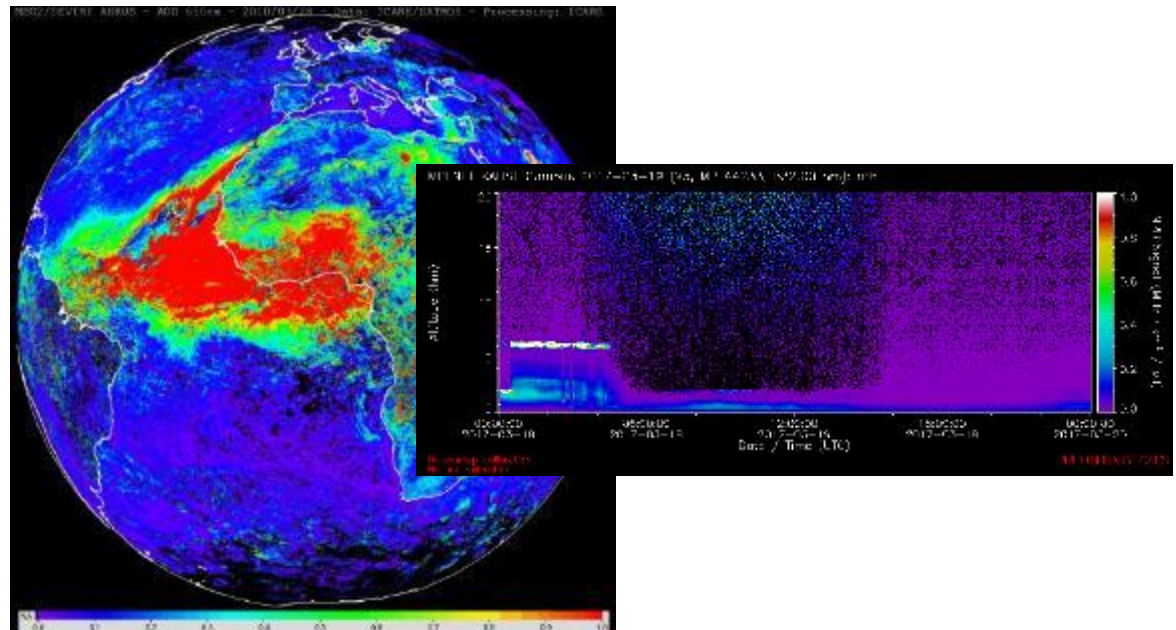
Data assimilation

Drawbacks:

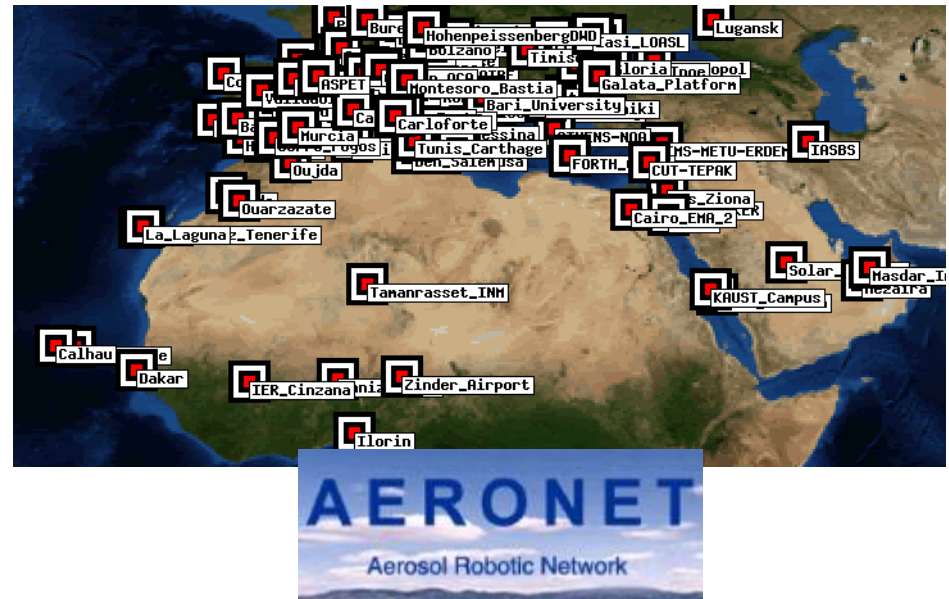
- Lack of suitable observations
- Complexity of extracting the dust signal from the measured radiance
- Modellers often use processed products rather than raw observations
- They normally assimilate MODIS AOD using variational techniques (ECMWF) or EKF (JMA, BSC)
- Efforts are now aimed at assimilating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



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



Verification: sun photometers



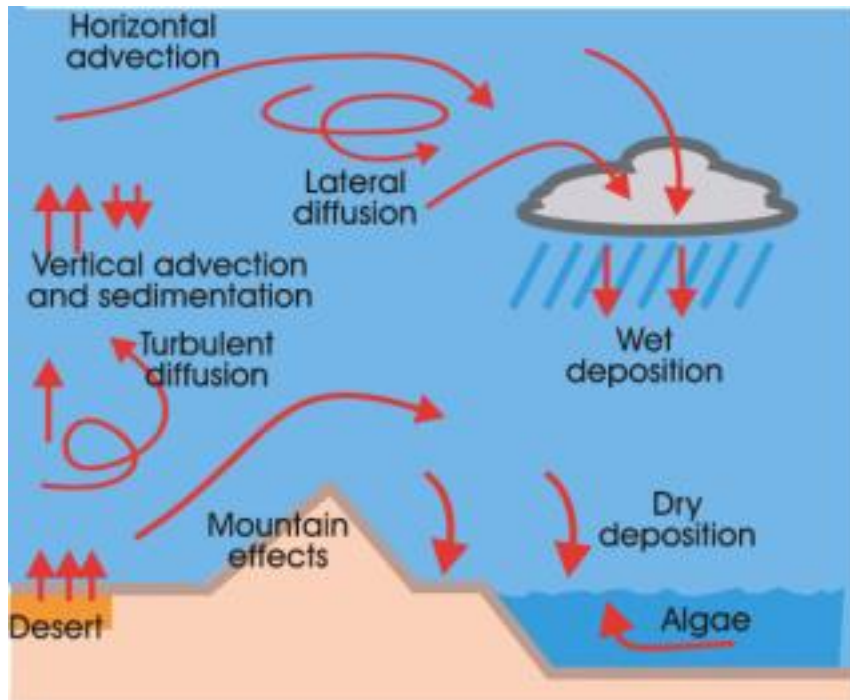
- Solar radiation at the top of the atmosphere is known
- Airborne particles attenuate the direct radiation (absorption, scattering)
- The sun-photometers measure the direct radiation that reach the surface
- Measurement at different wavelengths allows retrieval of total aerosol contents and some of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

Summary

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

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)

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

Ginoux et al. (2001)

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

Summary

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

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:

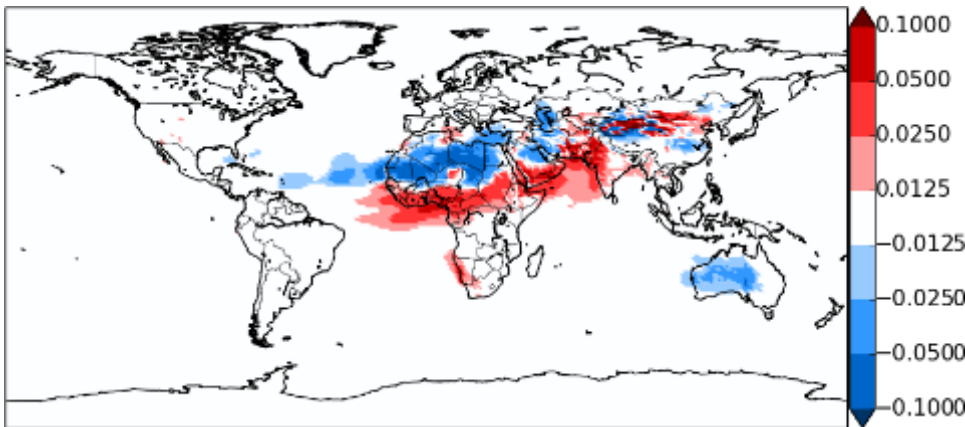
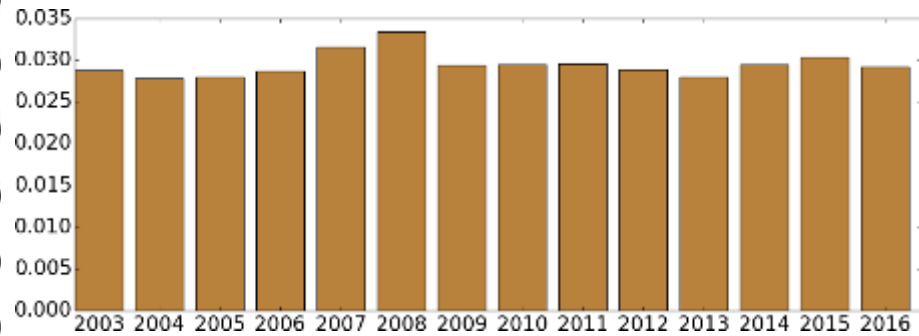
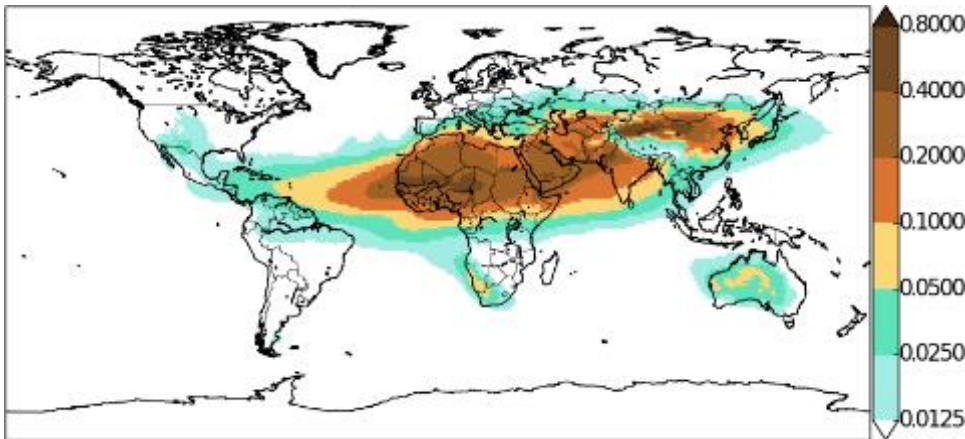
Morocco (Min. of Health), Egypt (EMA, Cairo Univ.), Jordan (Univ. of Jordan)

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
Climate Services in Northern
Africa, Middle East and Europe**
PI: Sara Basart (BSC)



*European Research Area
for Climate Services*

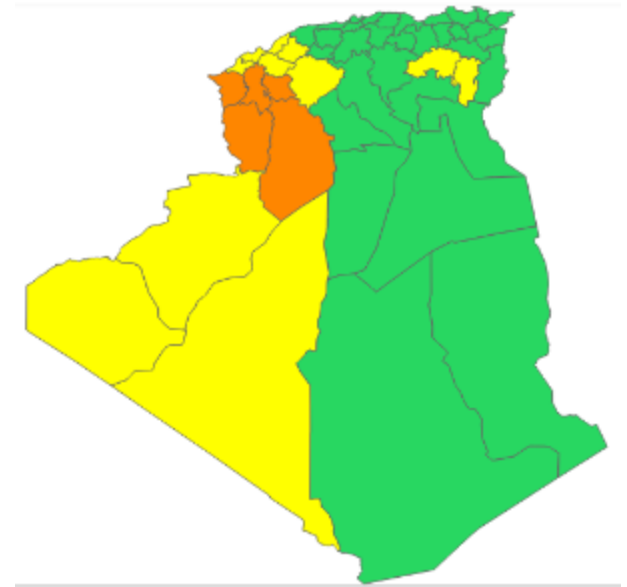
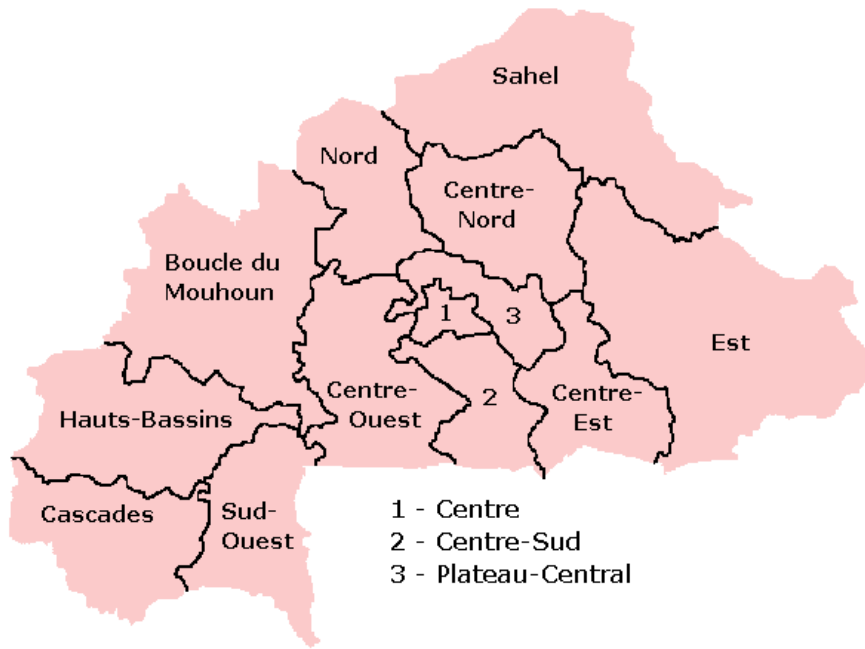


FINNISH METEOROLOGICAL
INSTITUTE



<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.

Capacity building



- TRAINING**
- Accra
 - Addis-Ababa
 - Ankara
 - Antalya
 - Barcelona
 - Cairo
 - Casablanca
 - Istanbul
 - Madrid
 - Muscat
 - Niamey
 - Ouagadougou
 - Sta. Cruz de Tfe.
 - Tehran
 - Tbilisi

