The dust cycle

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5th Training course on WMO SDS-WAS Products, IRIMO, Tehran, 5-9 Nov 2016

Summary

- Atmospheric aerosol
- The cycle of mineral dust
- WMO SDS-WAS
- Barcelona Dust Forecast Center
- Dust observation
- Dust forecast

Summary

- **Atmospheric aerosol**
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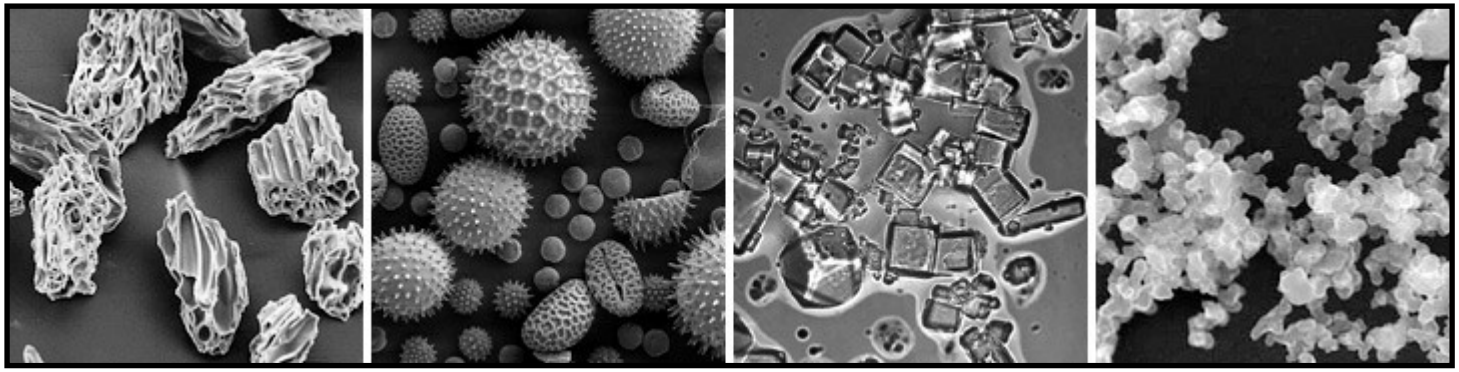
Atmospheric aerosol

Atmospheric aerosol
Solid or liquid particles suspended in the air
Origin (primary / secondary particles, natural / anthropogenic)
Size (Diameter: ~ 0.002 – 100 µm)
Chemical, mineralogical composition
Optical properties (absorption, scattering)

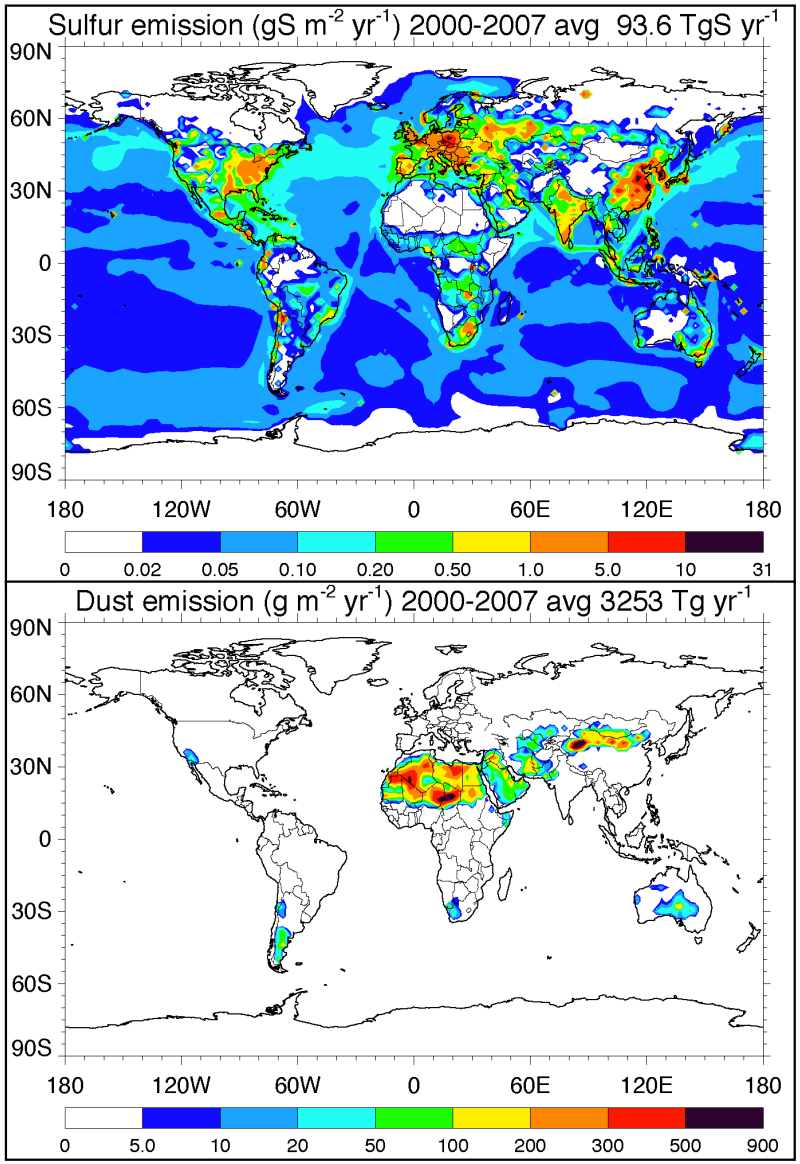


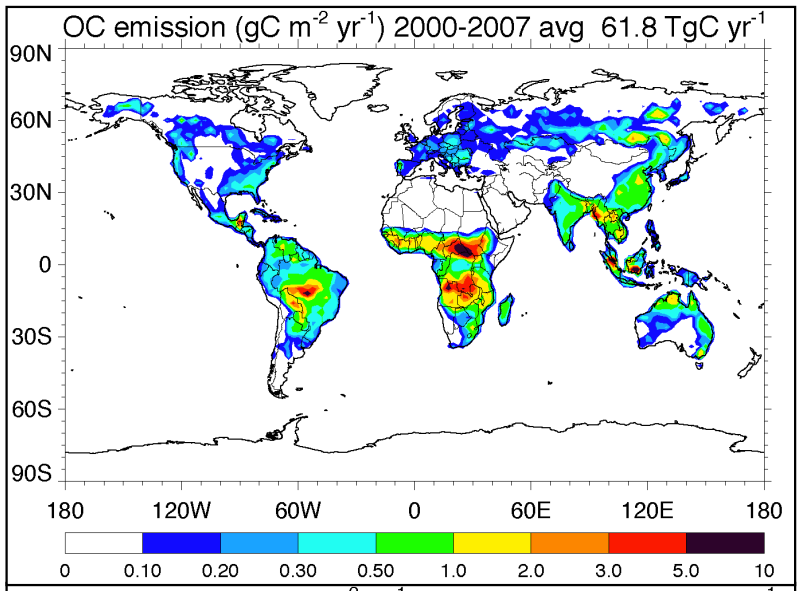
USGS science for a changing world
UMBC AN HONORS UNIVERSITY IN MARYLAND
ASU ARIZONA STATE UNIVERSITY

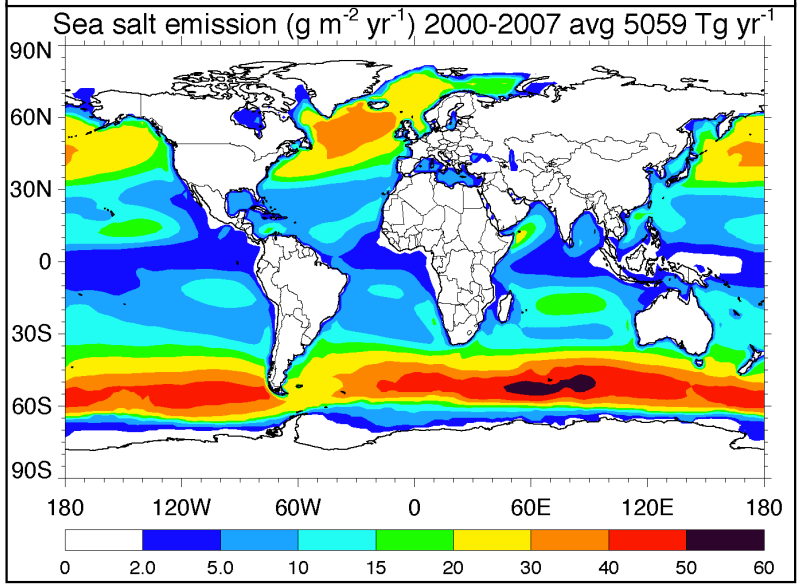
Atmospheric aerosol. Sources

Volcanoes, sea salt, products from biomass burning, anthropic pollution, organic particles, MINERAL DUST

Atmospheric aerosol. Emissions



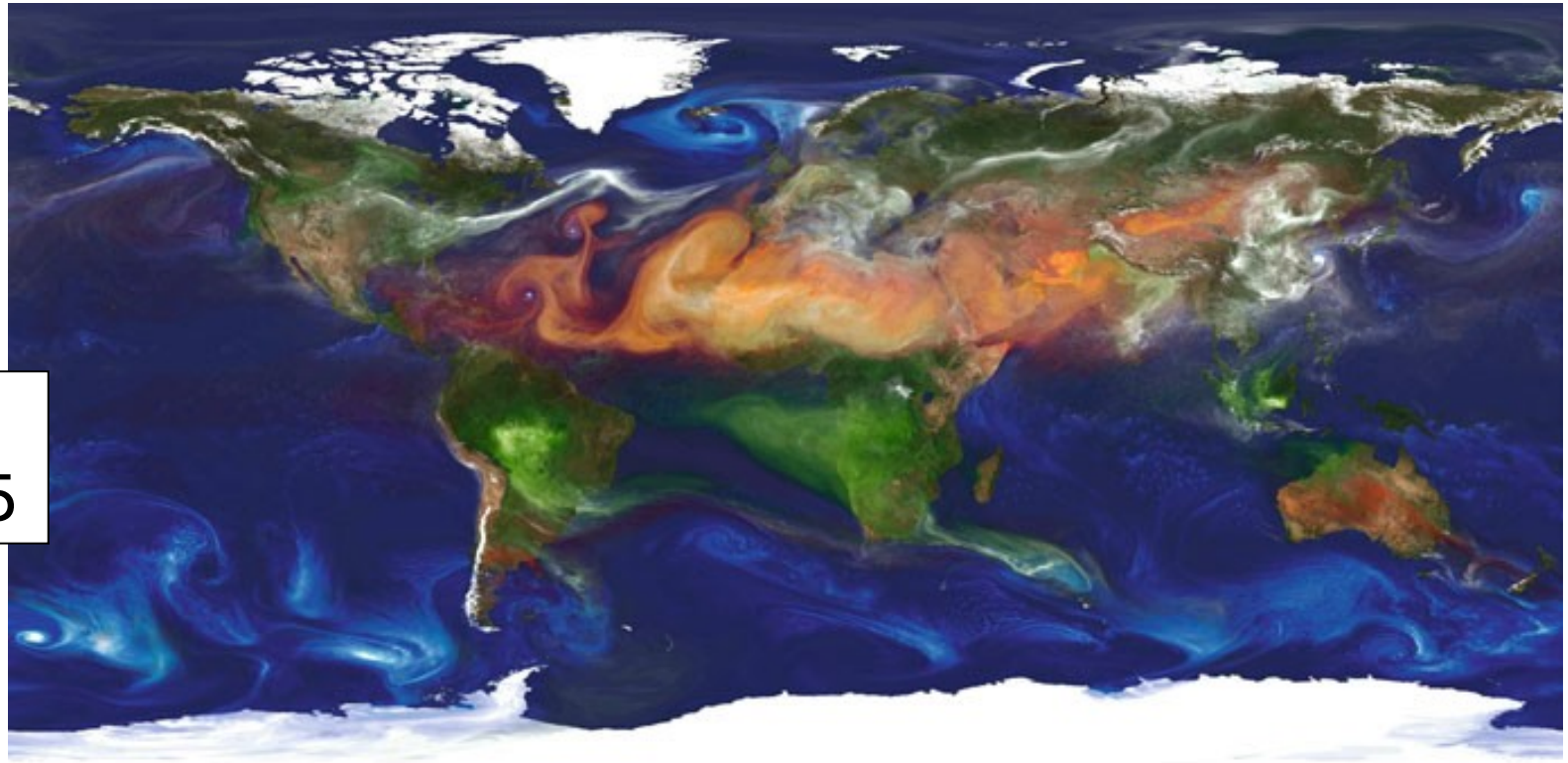




Chin et al. (2009)

Atmospheric aerosol. Distribution

NASA GEOS-5



- Mineral dust (reddisah)
- Sea salt (blue)
- Products of biomass burning (green)
- Sulphates (white)

Summary

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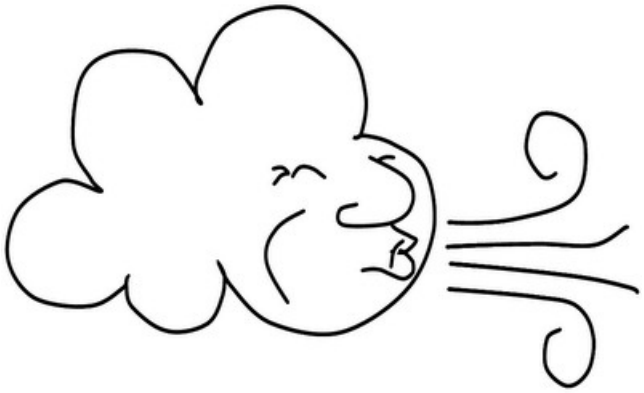
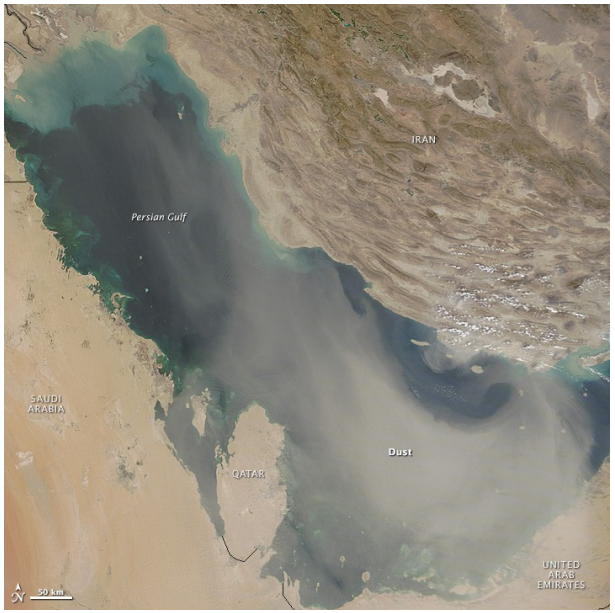
- Dust forecast

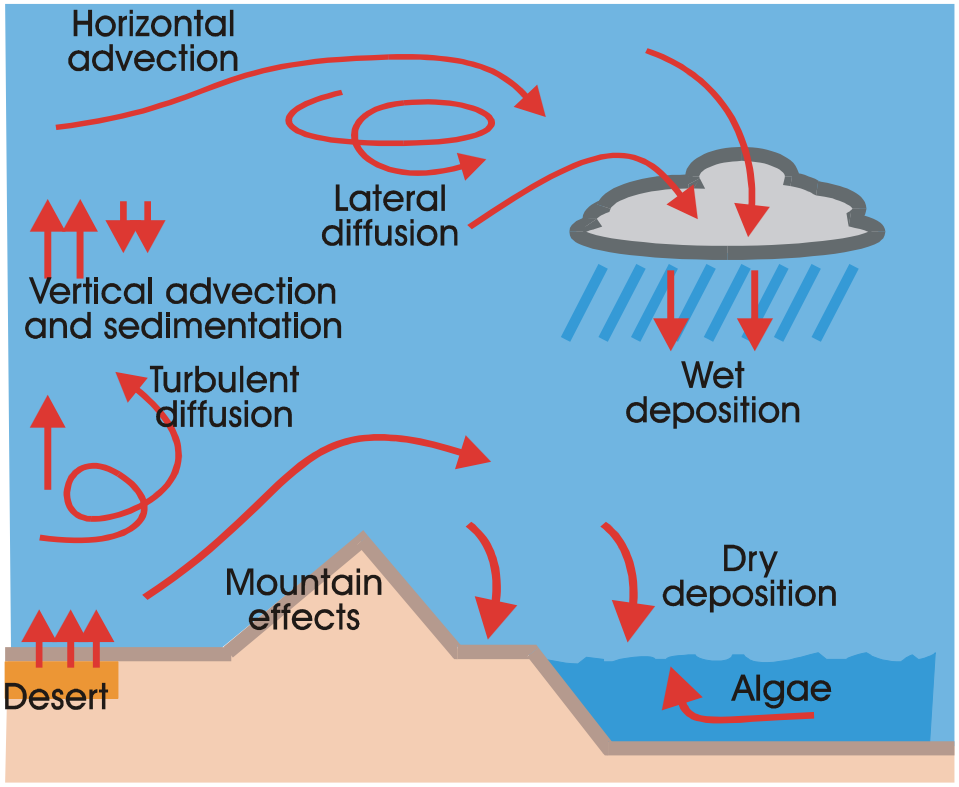
The dust cycle





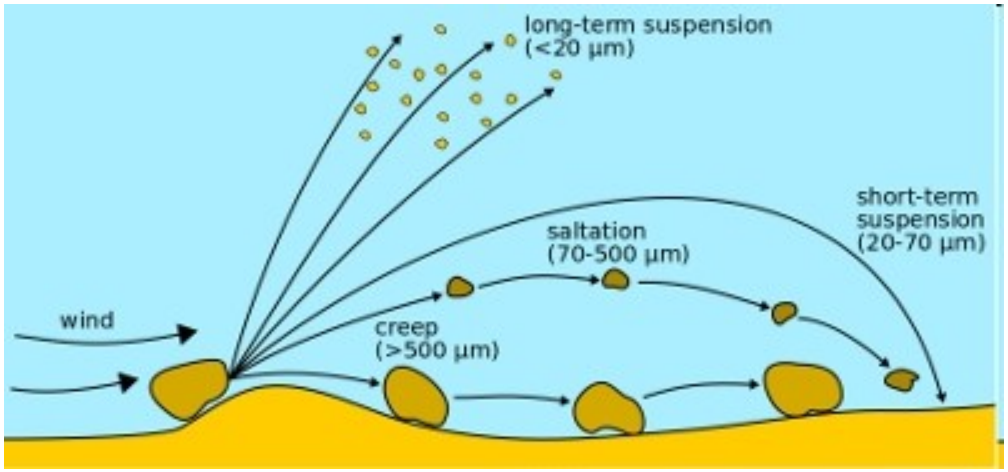
MODIS 3 Sep 2015

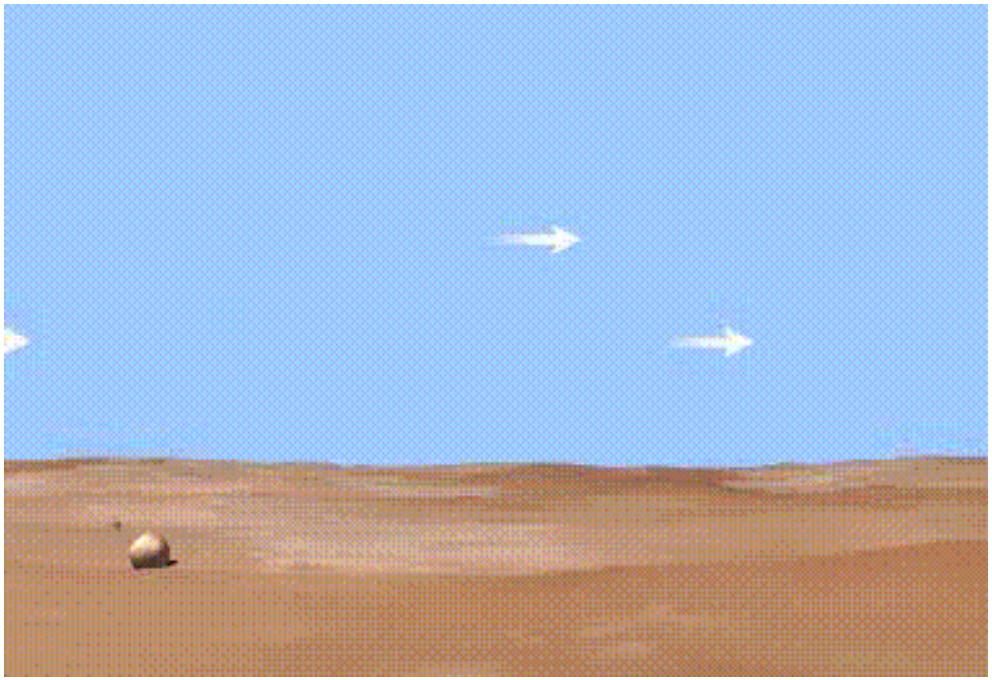
The dust cycle



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

The dust cycle. Emission





Soil factors

- Soil texture
- Soil humidity
- Vegetation

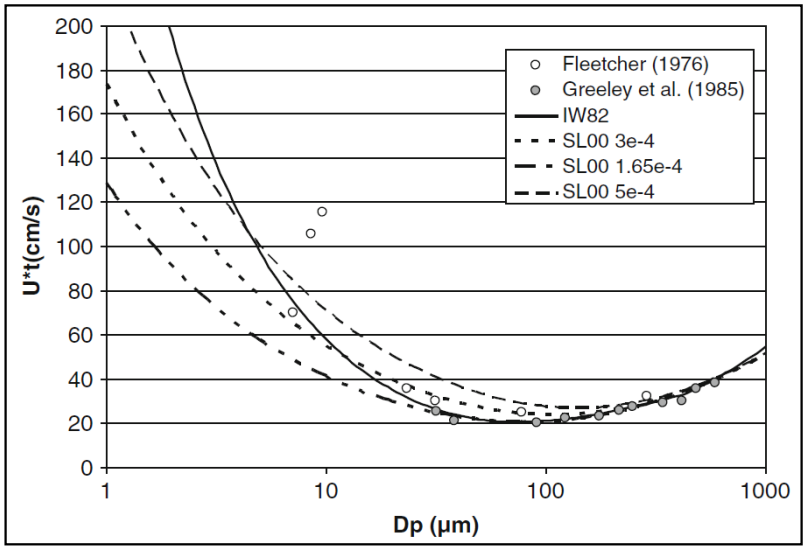
Meteorological factors

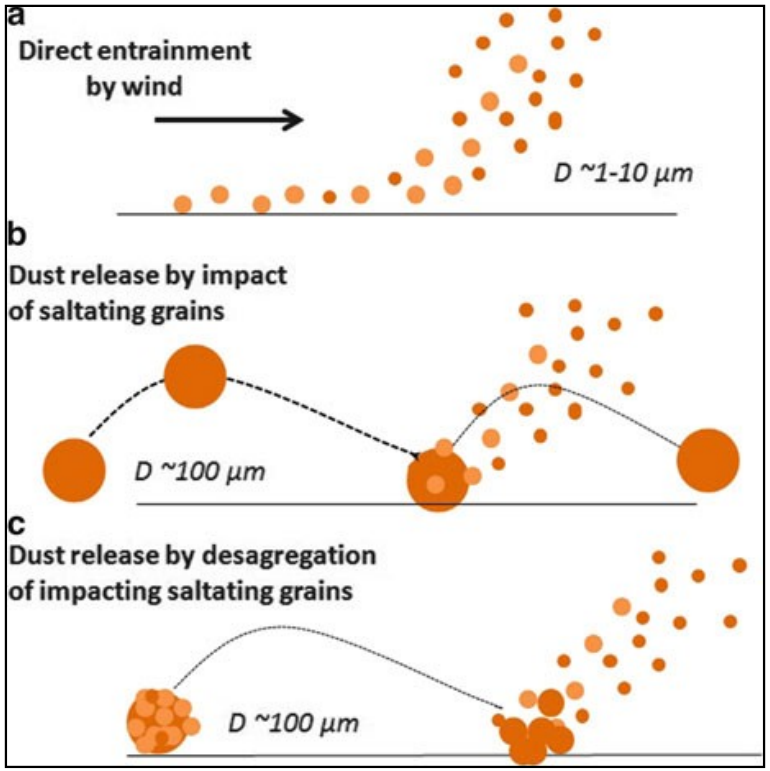
- Wind
- Near-surface turbulence

The dust cycle. 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 in the soil (weight, cohesive force between particles, cohesive forces induced by moisture)

$$u^* = (\tau / \rho)^{0.5}$$





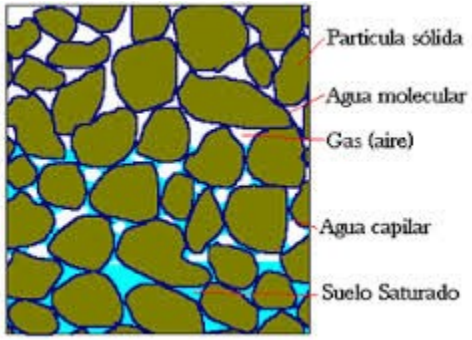
The dust cycle Erosion threshold

Elements increasing the erosion threshold

Non-erodible elements (i. e. vegetation)

Crusted soils

Soil humidity



Nieve

The dust cycle. Saltation

$$Q = c\frac{\rho}{g}U^{*3}\left(1-\frac{U_t^*}{U^*}\right)\left(1+\frac{U_t^{*2}}{U^{*2}}\right)$$

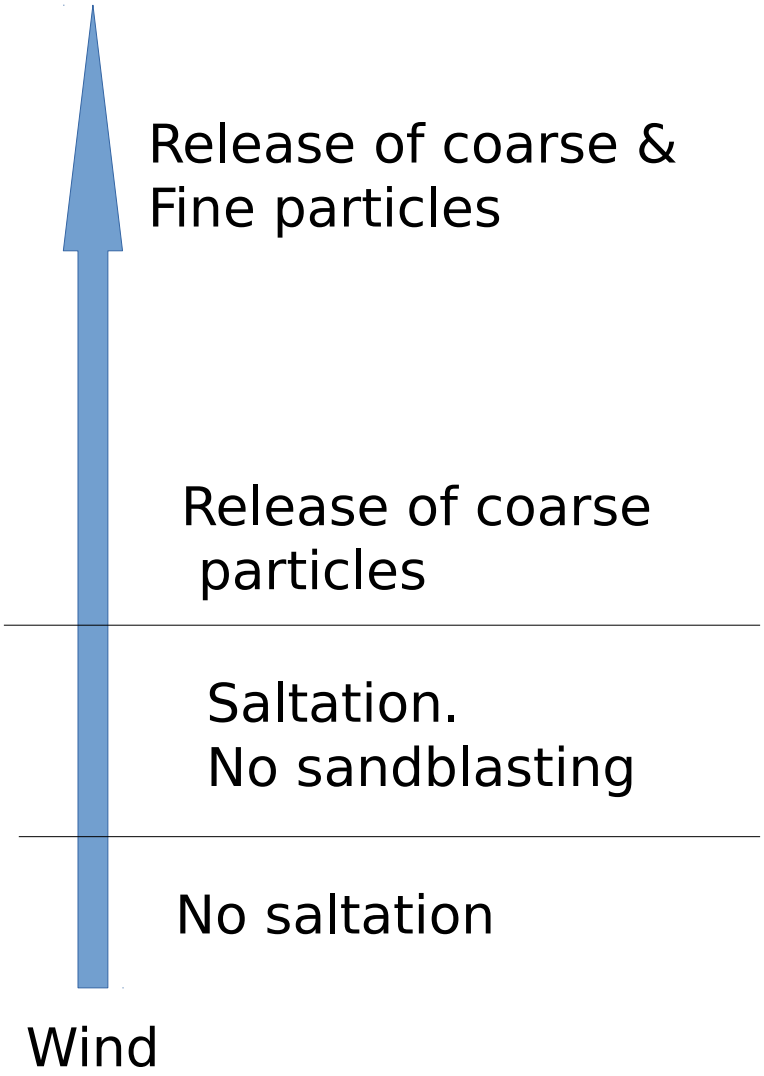
White (1979

- Strong dependence on wind speed (proportional to u^{*3})
- Strong dependence on particle size (through u^*_t)

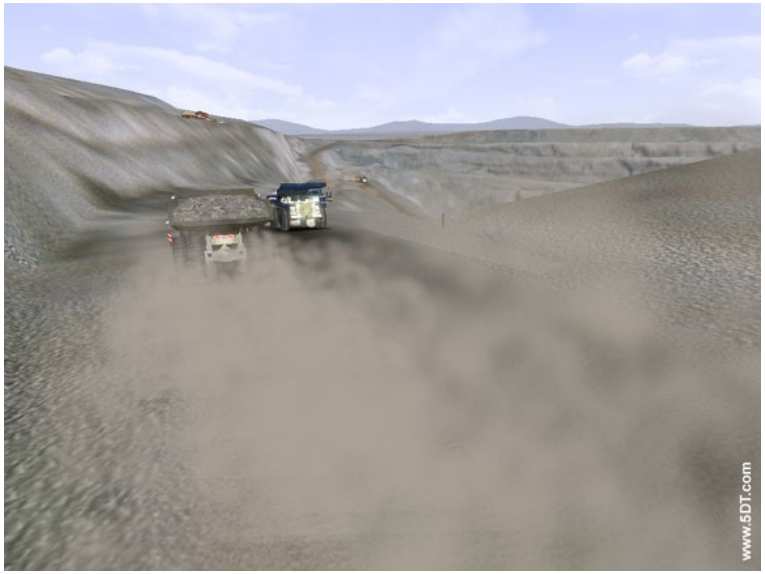
- Need for a very precise wind forecast
- The horizontal flux must be computed for different size bins

The dust cycle. Sandblasting

- The kinetic energy of the saltation breaks the particle aggregates and originates a vertical flow (sandblasting)
- There is a threshold (minimum kinetic energy) to trigger the 'sandblasting'
- The larger particles are less cohesive and are the first to be released
- Only the most intense episodes cause the emission of fine particles



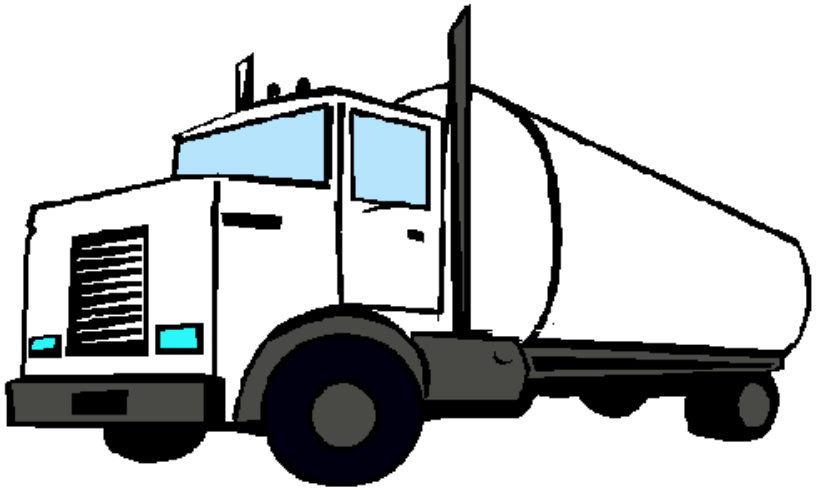
The dust cycle. Anthropic emissions



The dust cycle. Total emissions

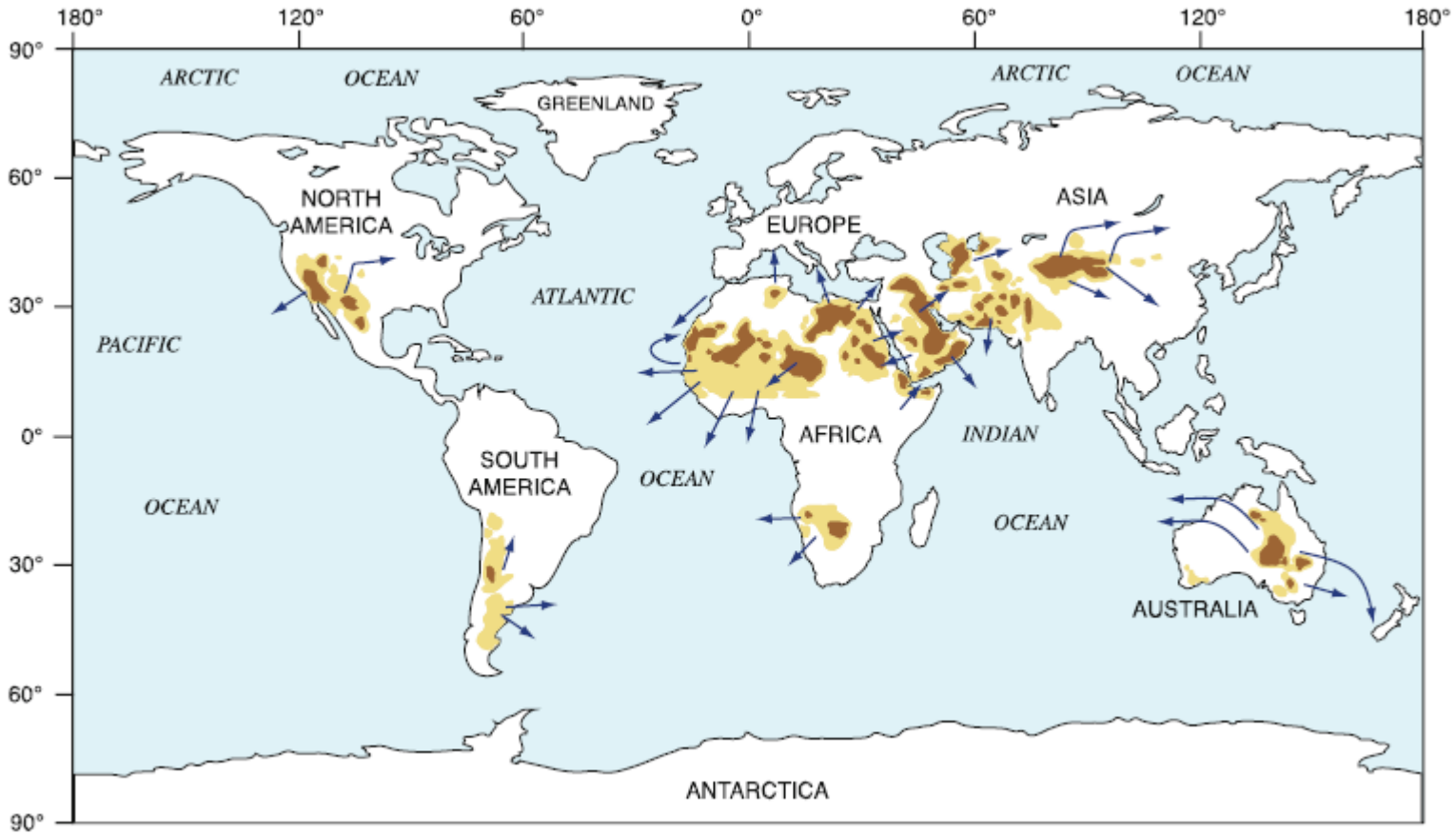
~ 30,000 – 60,000 kg / s
~ 1 – 3•10^{12} kg / year

50,000,000 trucks



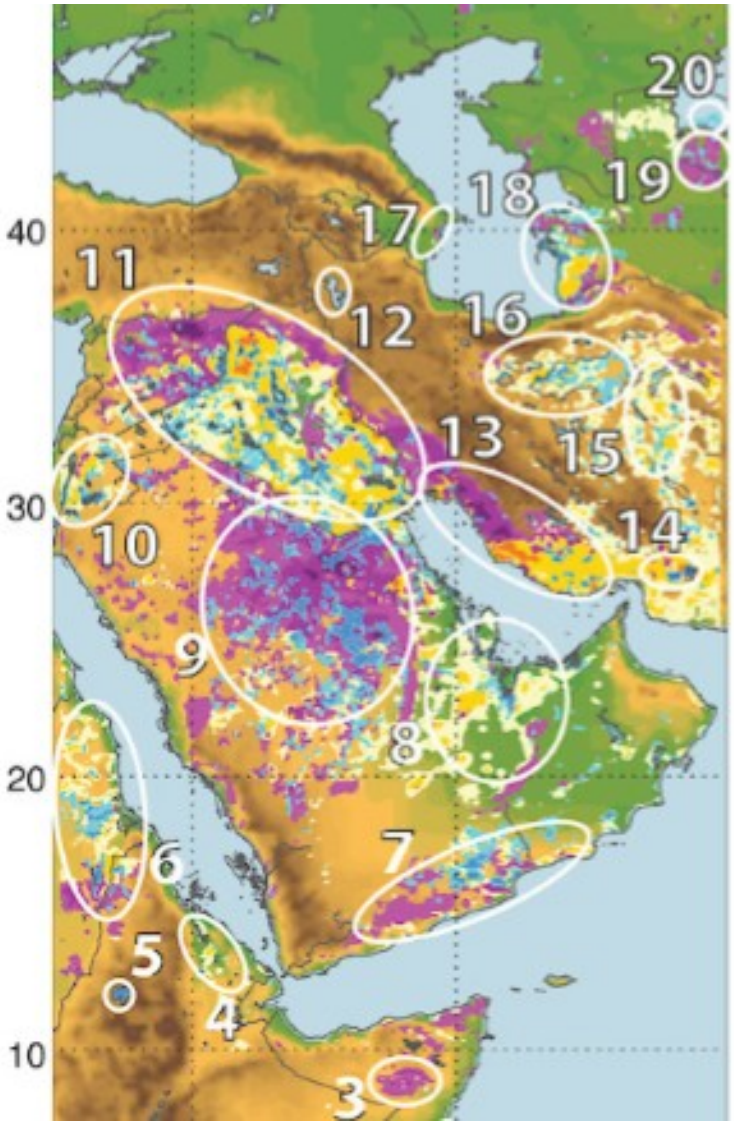
3,000 ULCC

The dust cycle. Sources



Identification of dust sources based on the TOMS' Absorbing Aerosol Index (AAI)
AAI > 0 for absorbing aerosols at 360 nm

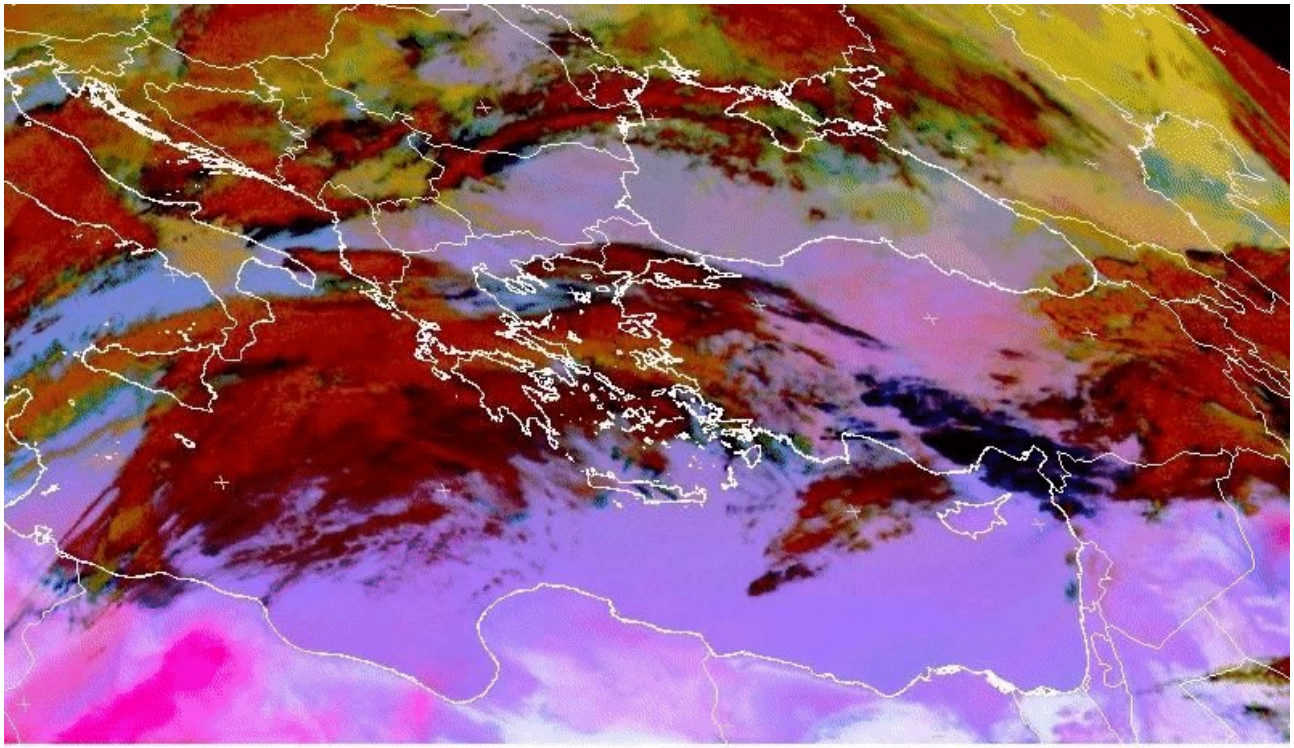
The dust cycle. Sources



Identification of dust sources based on the number of days with AOD > 0.2 (Ginoux et al., 2012)

8. Empty Quarter
9. Highlands of Saudi Arabia
10. Jordan basin of Jordan river
11. Mesopotamia
12. **Urumia lake**
13. **Coastal desert of Iran**
14. Hamun-i Mashkel
15. **Dasht-e Lut desert of Iran**
16. **Dash-e Kavir desert of Iran**
17. Qobustan (Azerbaijan)
18. Atrek delta (Turkmenistan)
19. Turan plain (Uzbekistan)
20. Aral sea

The dust cycle. Meteorological conditions



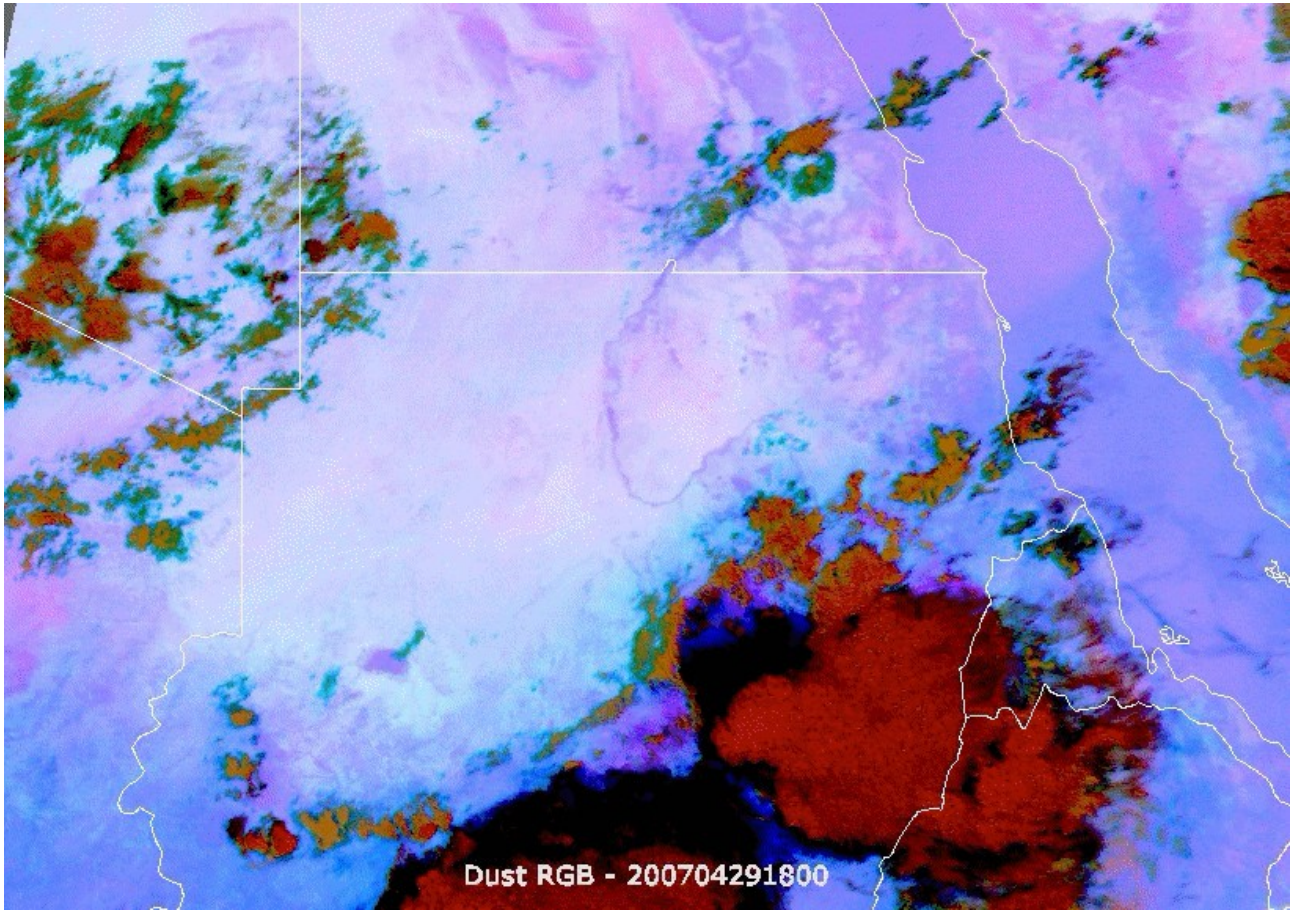
22-24 Mar 2008

EUMETSAT

SYNOPTIC SCALE

- Frontal systems
- Reinforced trade winds

The dust cycle. Meteorological conditions

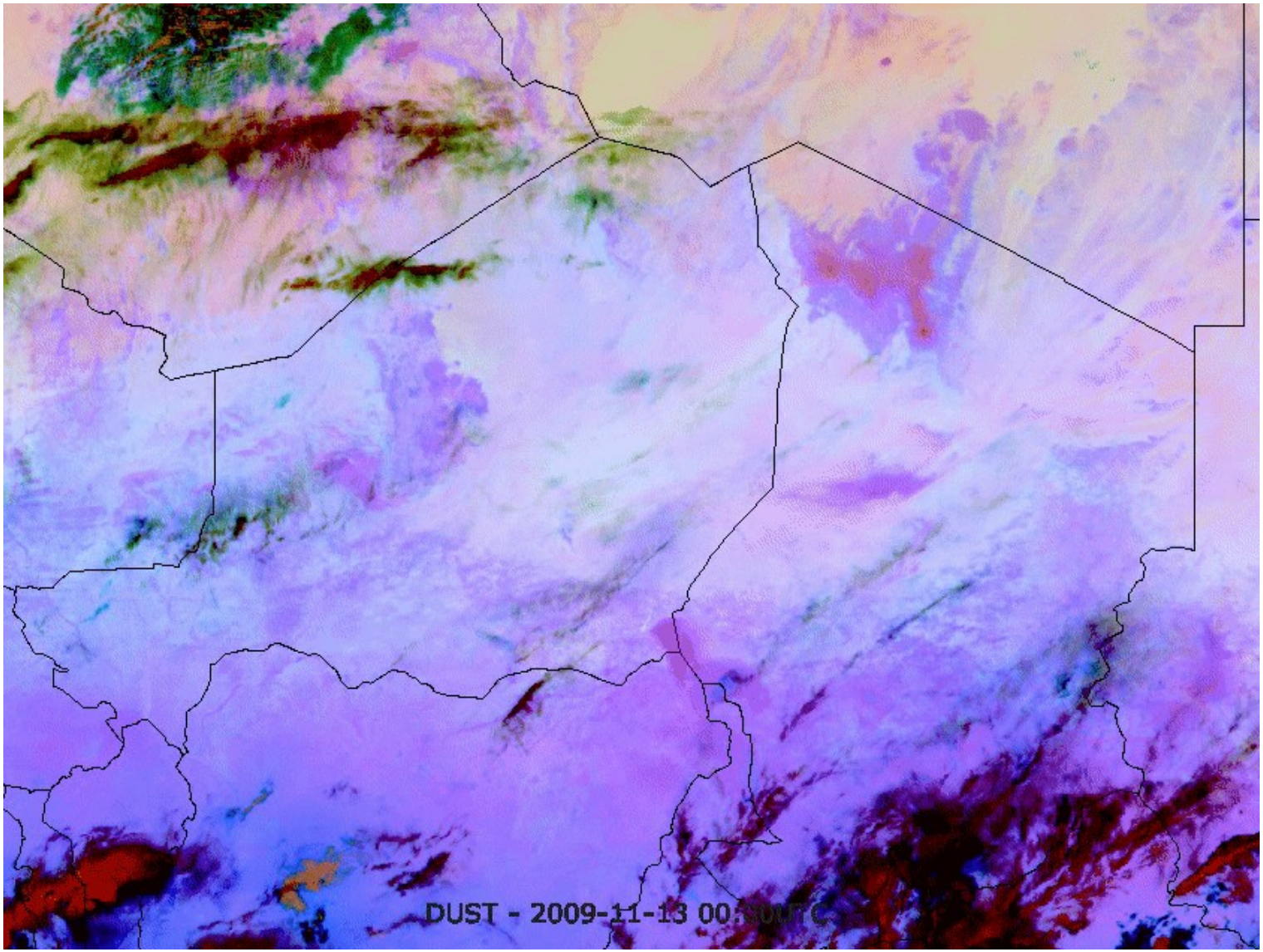


29 Apr – 1 May 2007

MESOSCALE-MICROSCALE

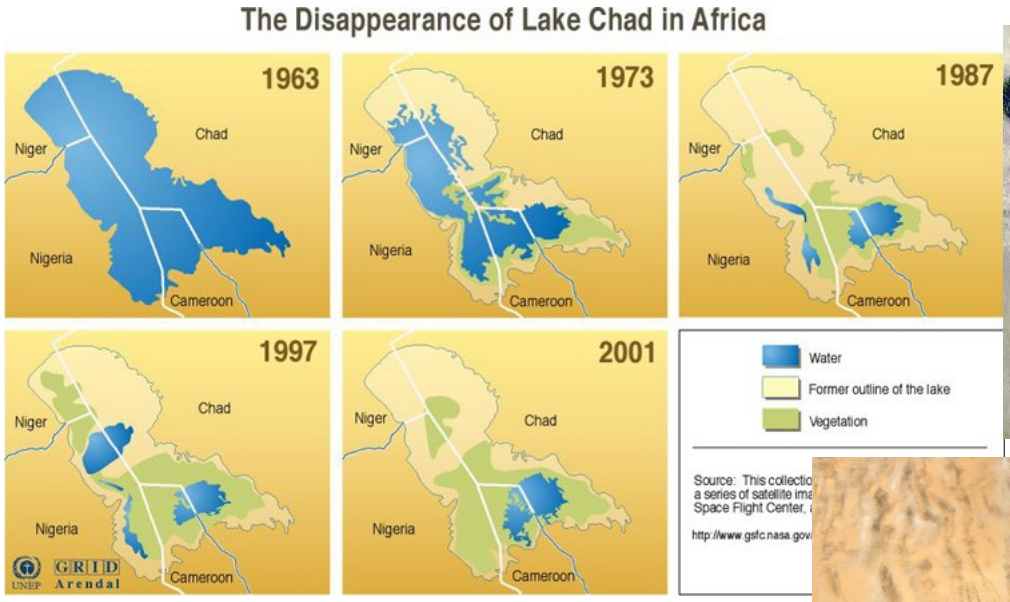
- Convection
- Drainage winds
- Low-leval jets
- Gap winds
- ...

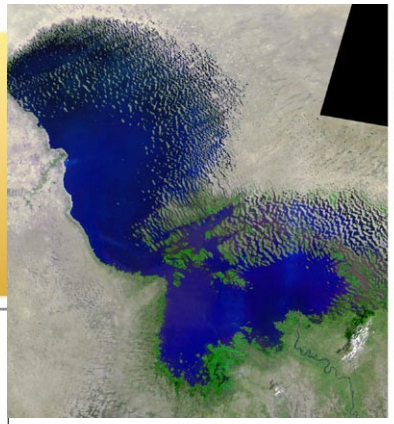
The dust cycle. Meteorological conditions

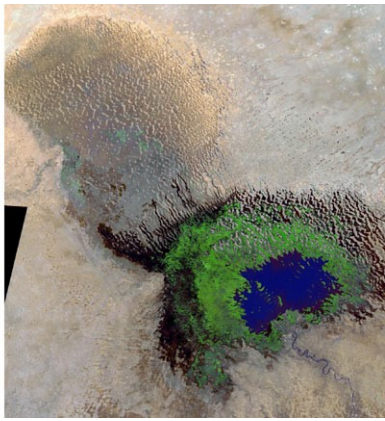


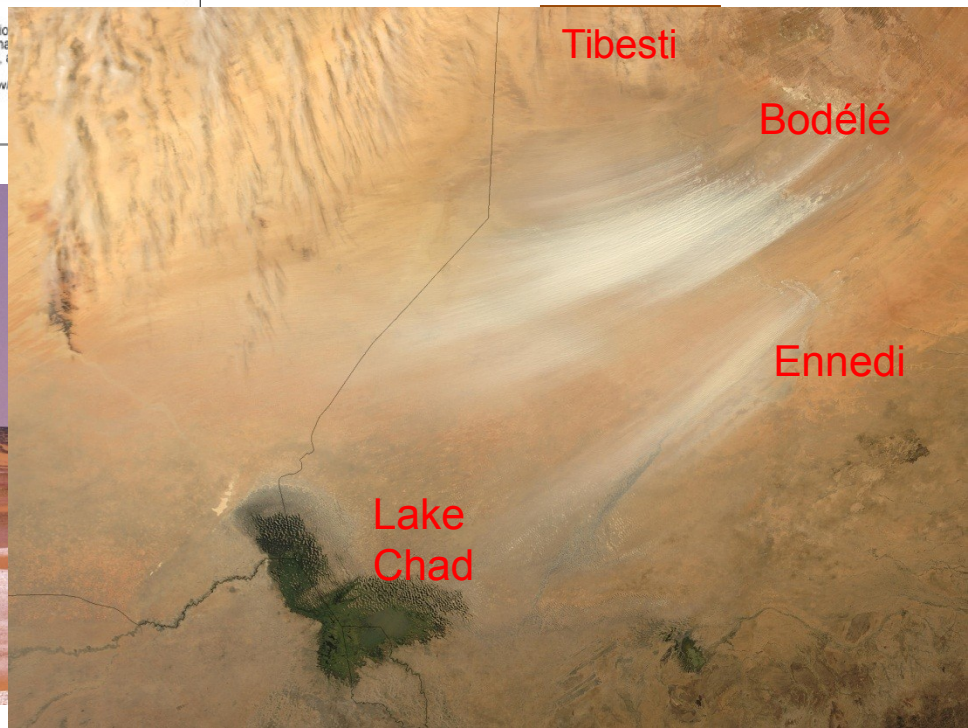
13 – 14 Nov 2009

The dust cycle: the Bodélé depression

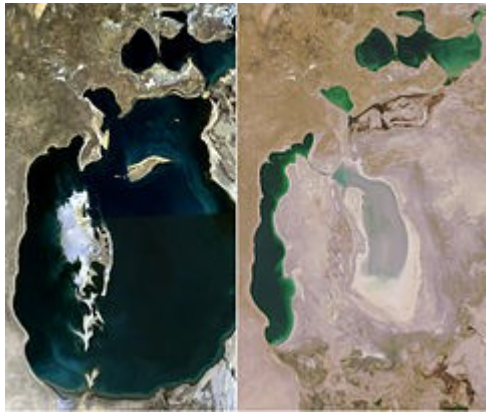


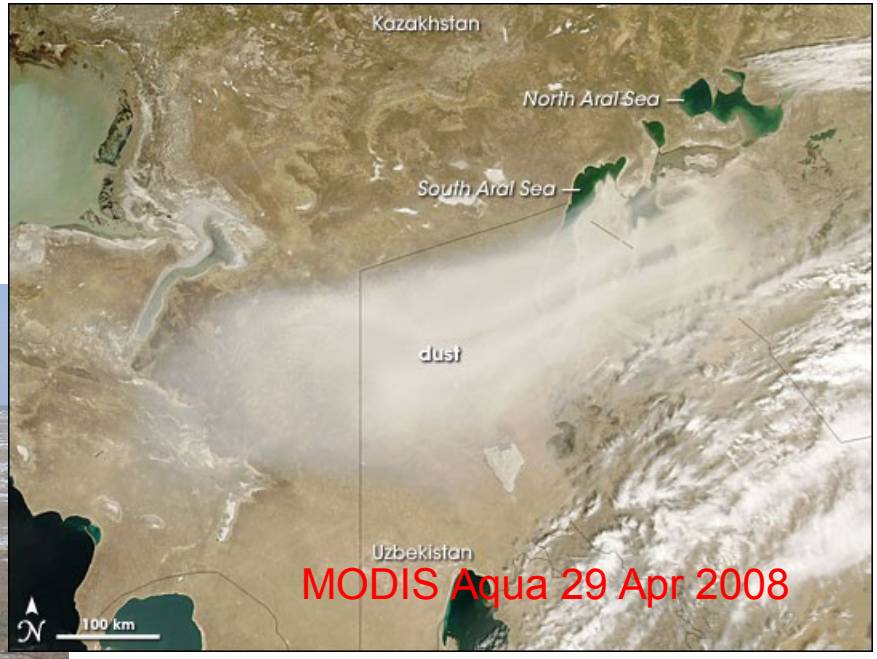




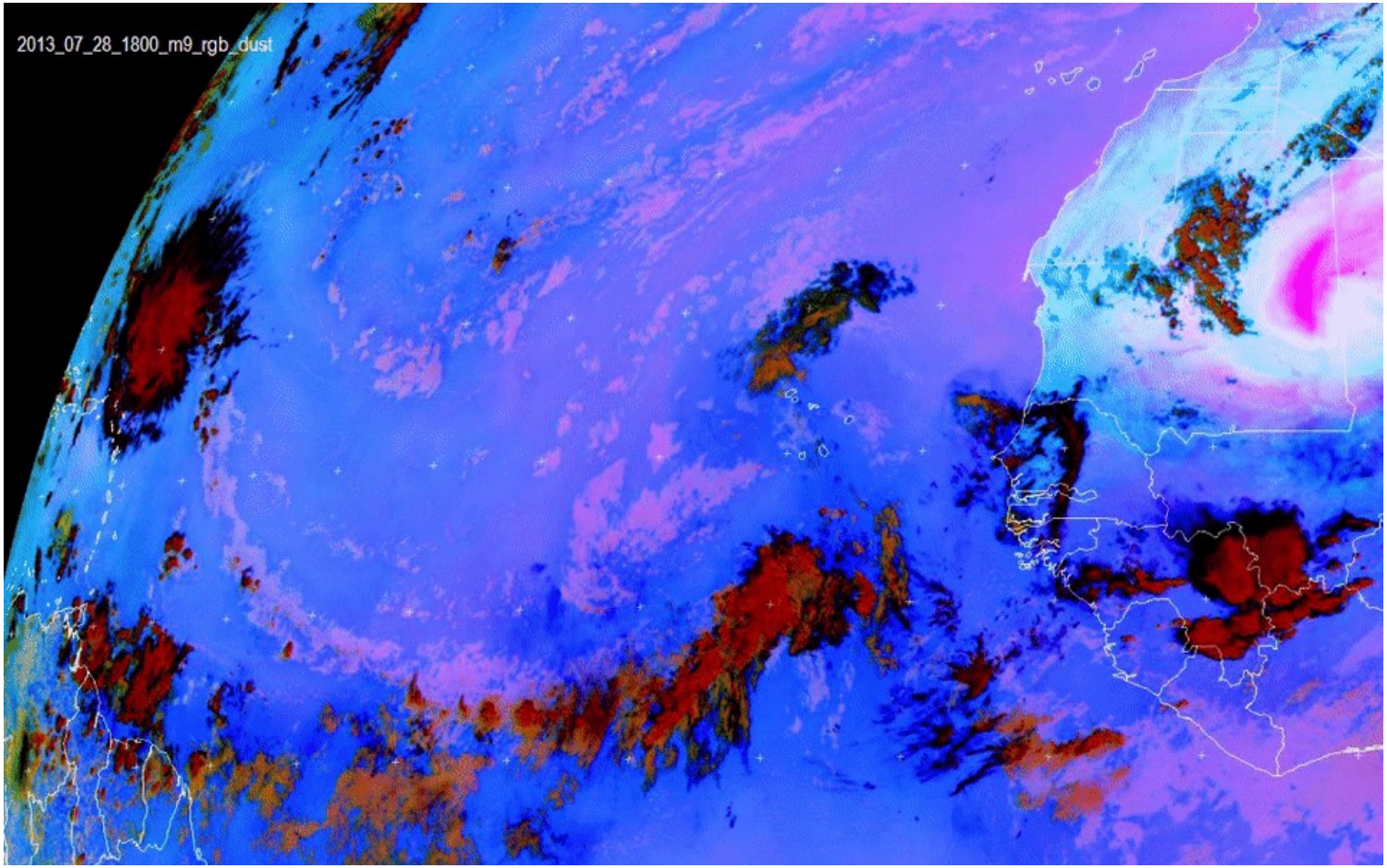


The dust cycle: the Aral sea



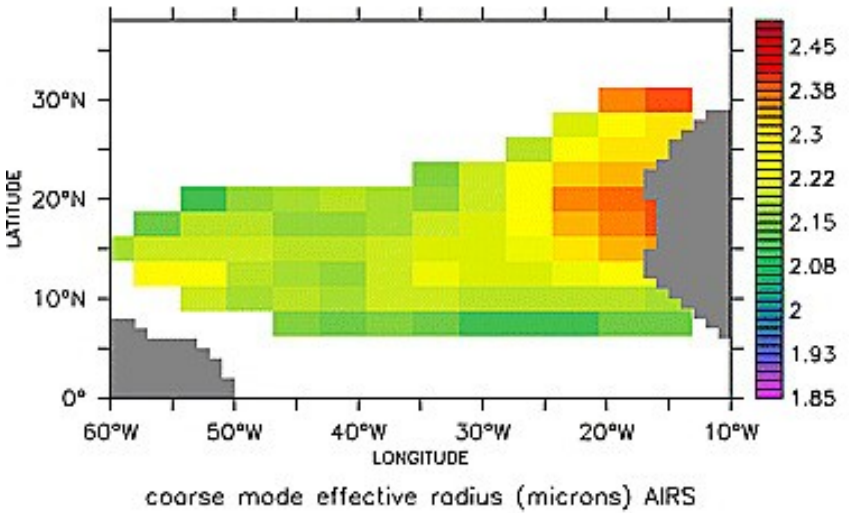


The dust cycle. Transport

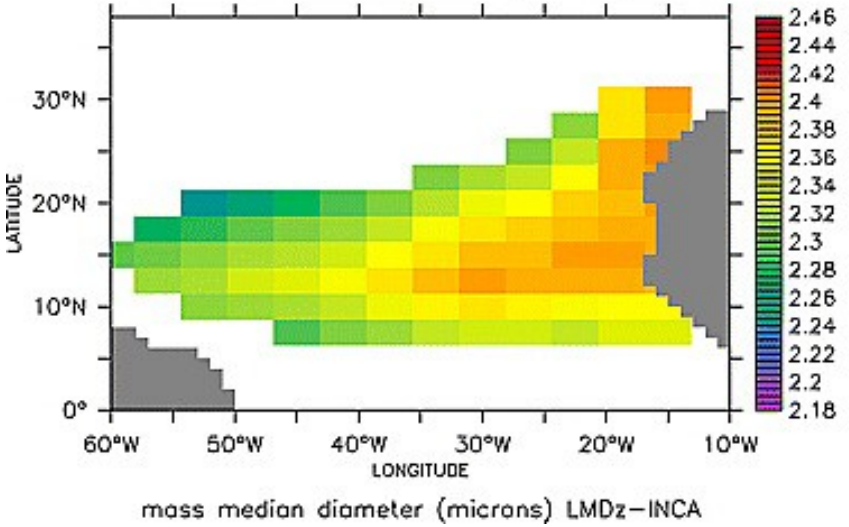


29 – 30 Jul 2013

The dust cycle. Transport

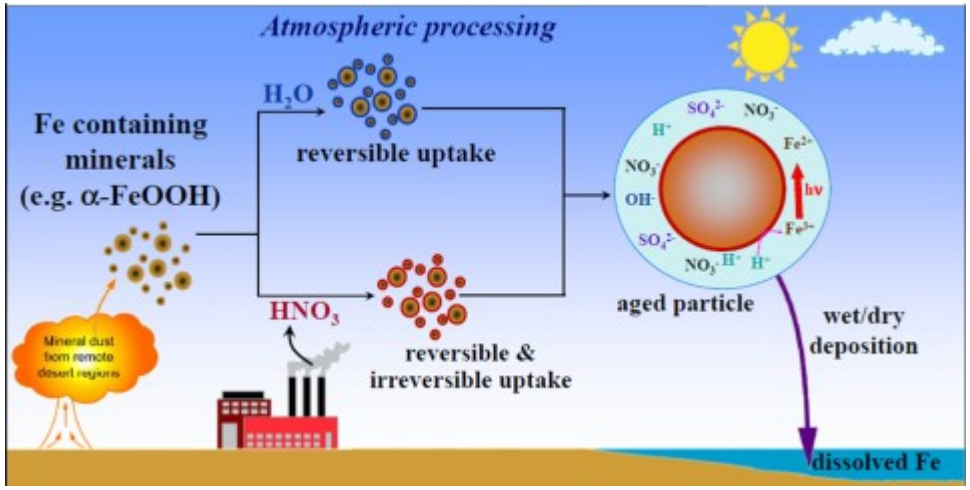


coarse mode effective radius (microns) AIRS



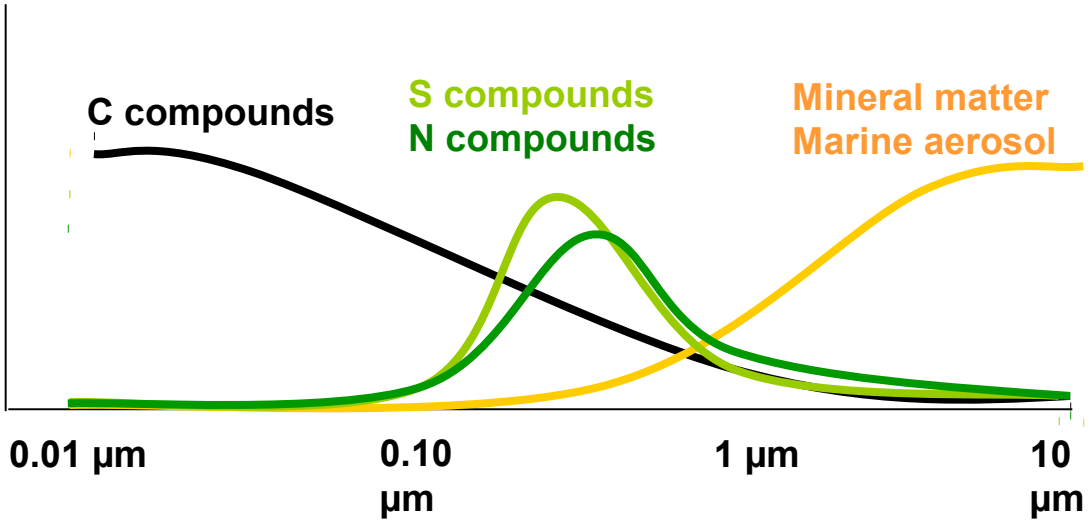
mass median diameter (microns) LMDz−INCA

Pierangelo et al. (2005)

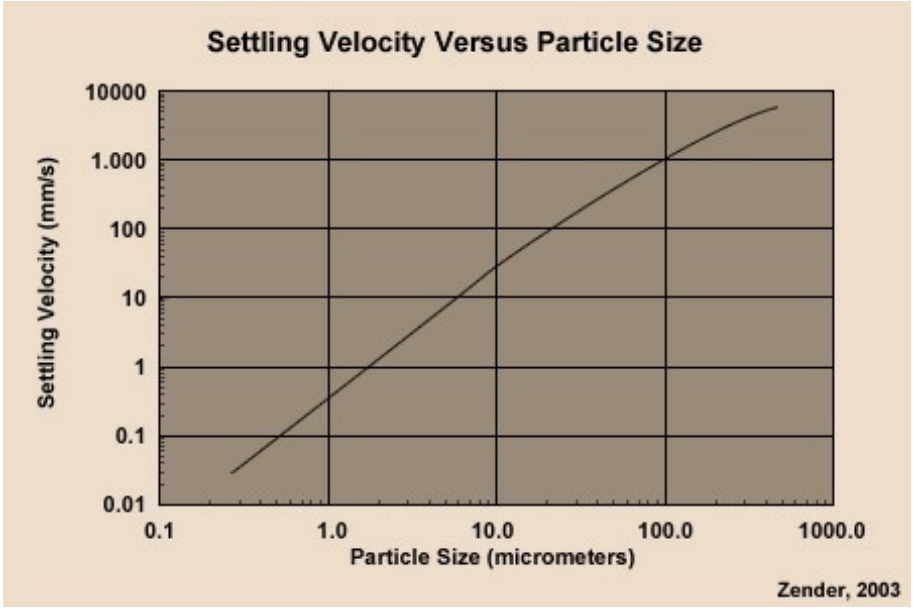


- The average particle size decreases during transport
- The chemical composition may change
- The optical properties may change
- The ability of dust particles to act as CCN increases
- Iron increases its solubility

The dust cycle. Dust deposition

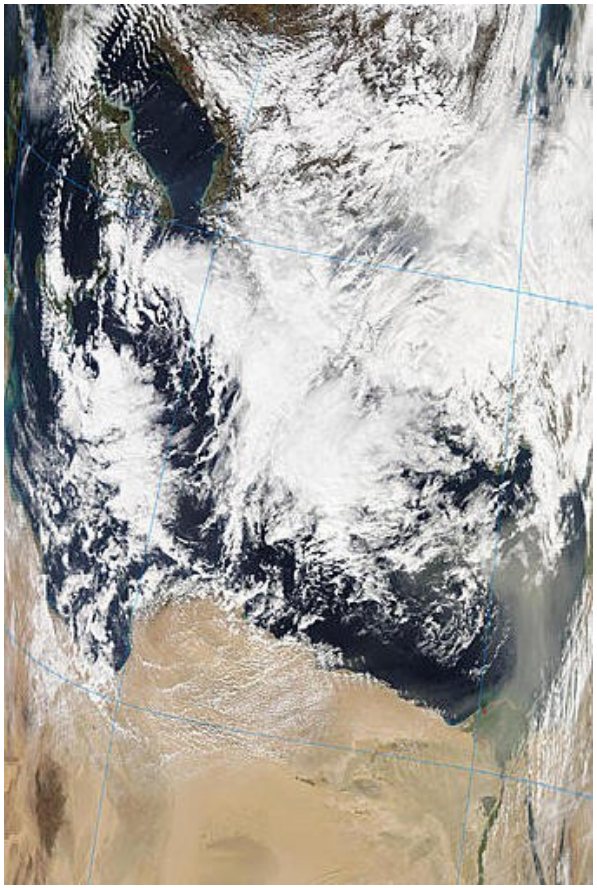


SIZE (µm)	AVERAGE LIFETIME (h)
0.1 - 0.18	231
0.18 - 0.3	229
0.3 - 0.6	225
0.6 – 1	219
1 - 1.8	179
1.8 – 3	126
3 – 6	67
6 - 10	28

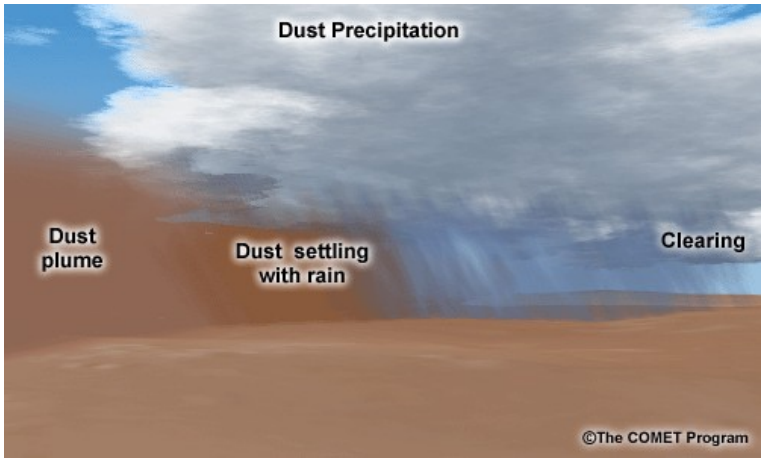


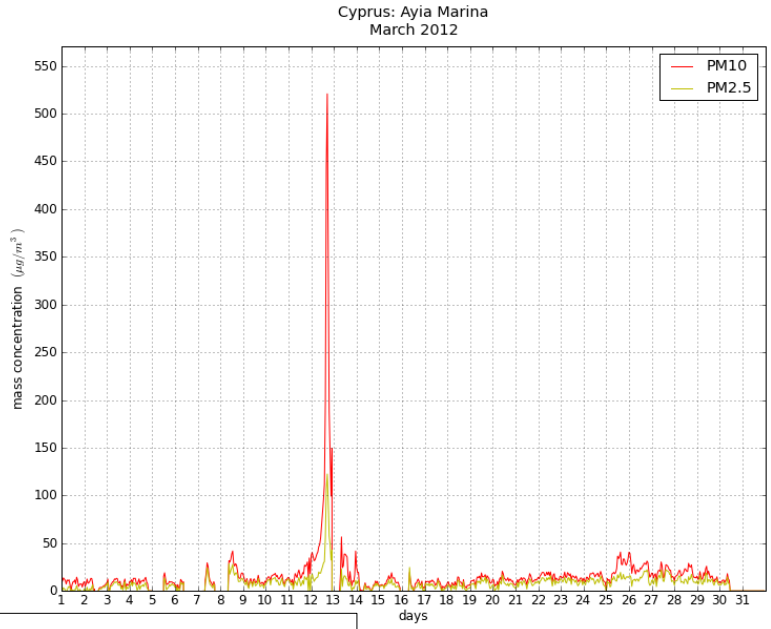
Tegen and Lacis (1996)

The dust cycle. Wet deposition



MODIS 12 Mar 2012





PM Ayia Marina, Cyprus, Mar 2012

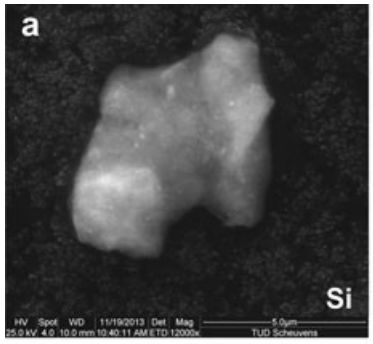
The dust cycle. Composition

MINERALOGICAL (X-ray diffractometry)
- Silicates: quartz, feldspar, phyllosilicates (illite, kaolinite, esmectite)
- Carbonates (calcite, dolomite)
- Hematite, gypsum, halite, ...

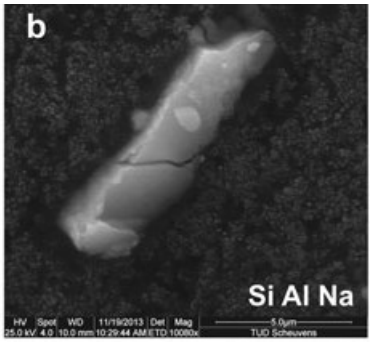
ISOTOPICAL (Sr, Nd, Pb)

CHEMICAL (spectroscopy)
- Si, Al, Ca, Mg, Fe, K, Na, Mn, Ti, P

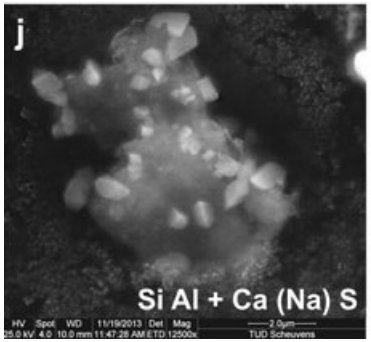
- Information on the source region
- Influence the optical properties
- Influence the impact on health, ecosystems, ...



Quartz

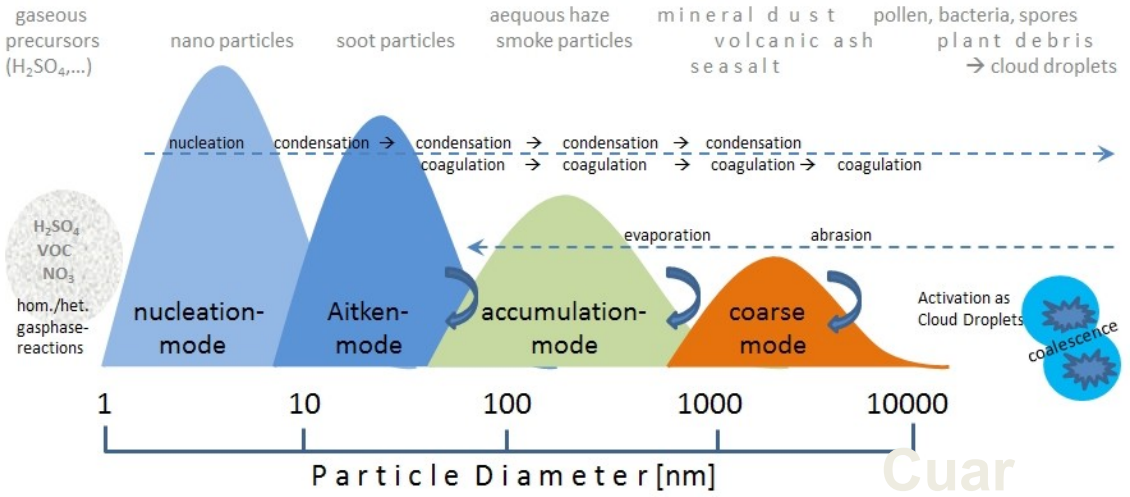


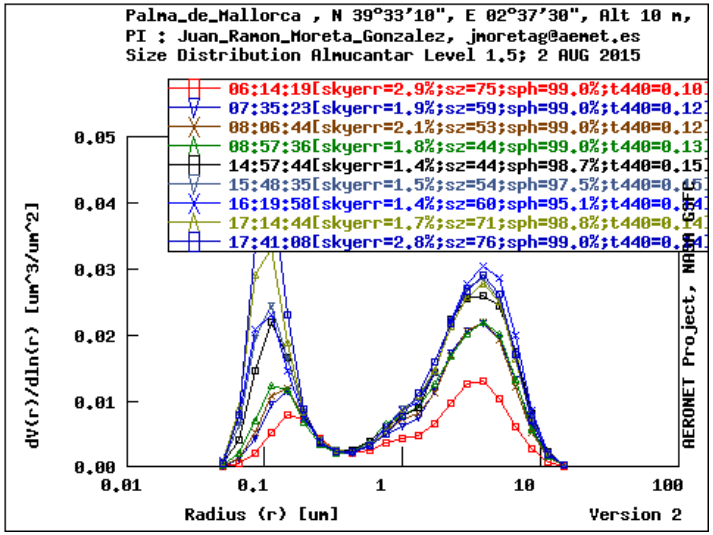
Albite



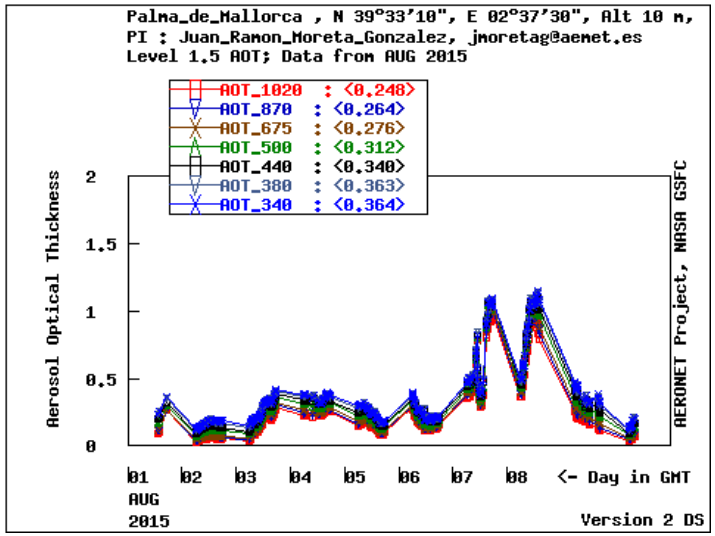
Gypsum

The dust cycle. Particle size

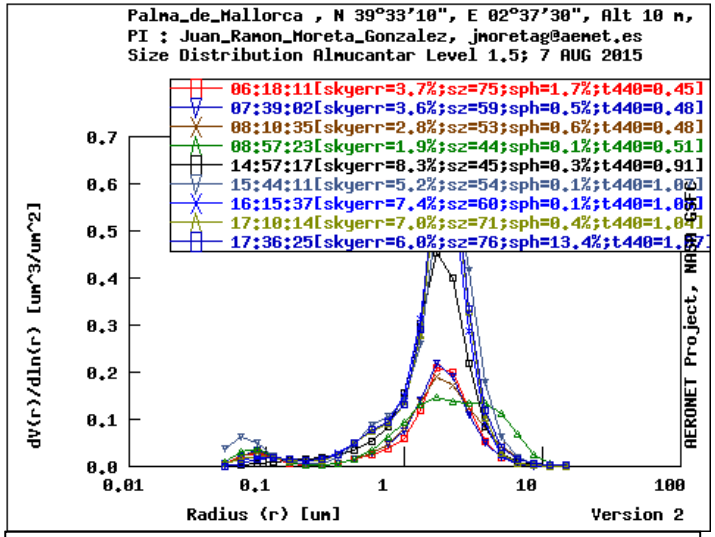




$$\tau = \ln\left(\frac{I_0}{I_1}\right)\cos(\theta)$$

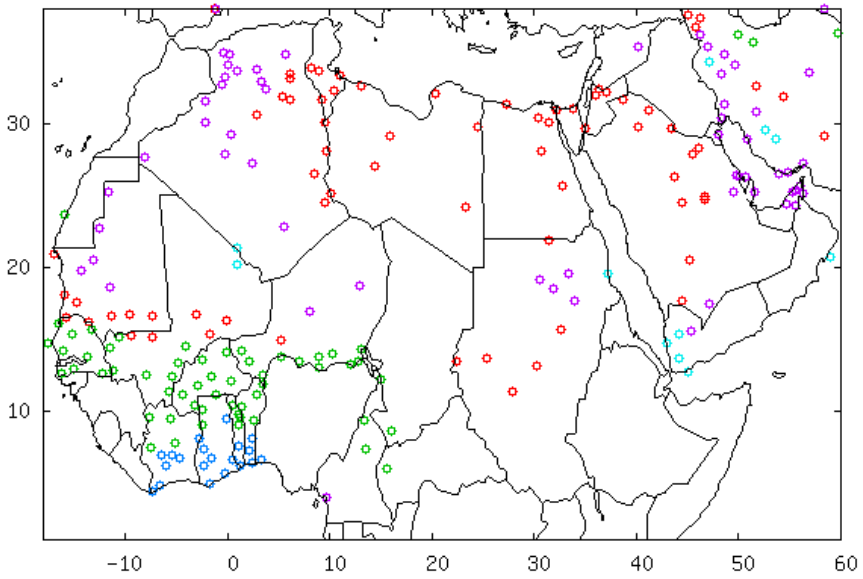


AOD. Palma de Mallorca. Aug 2015

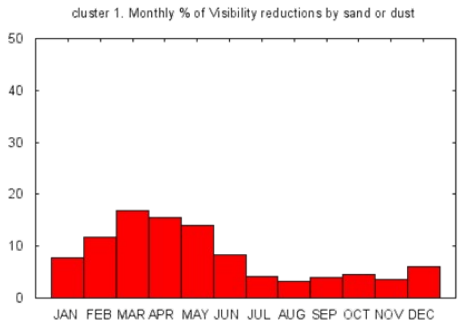


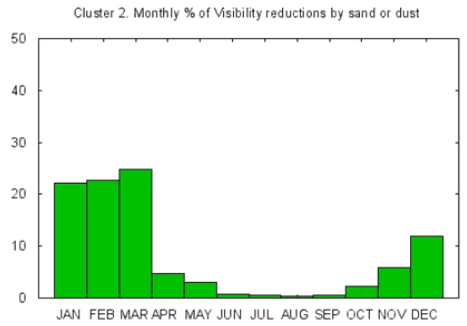
Palma de Mallorca 2 / 7 Aug 2015

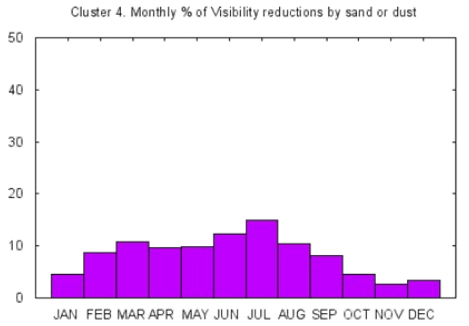
The dust cycle. Seasonal variability

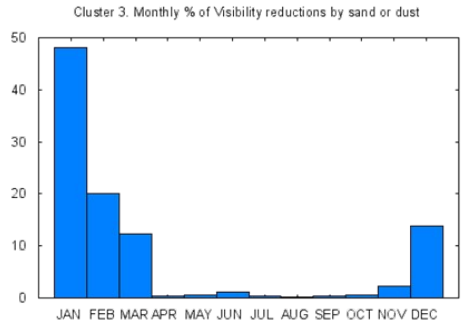


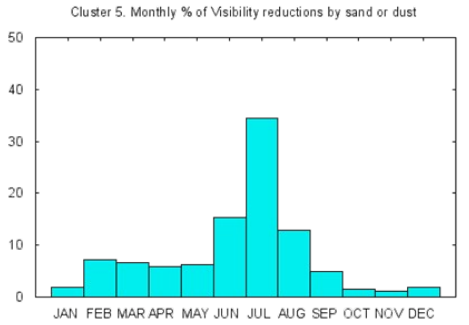
1996-2010









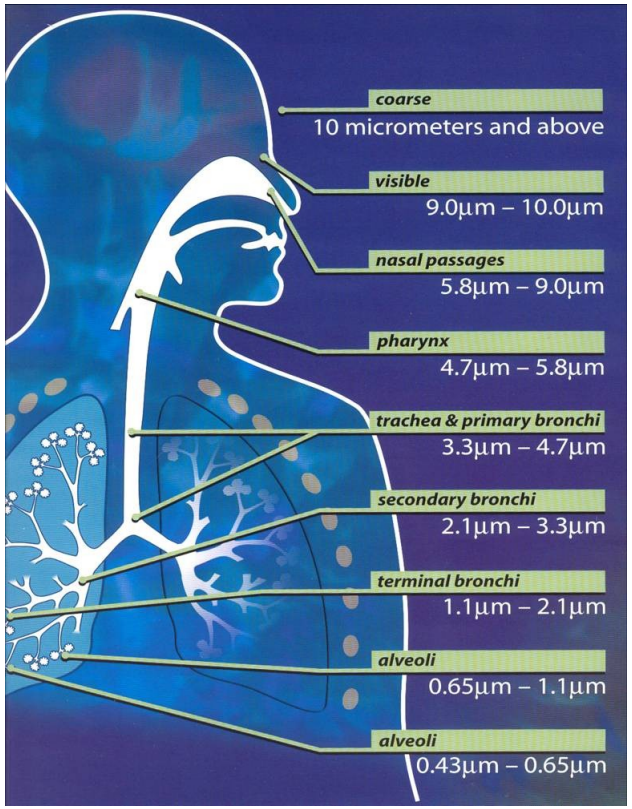


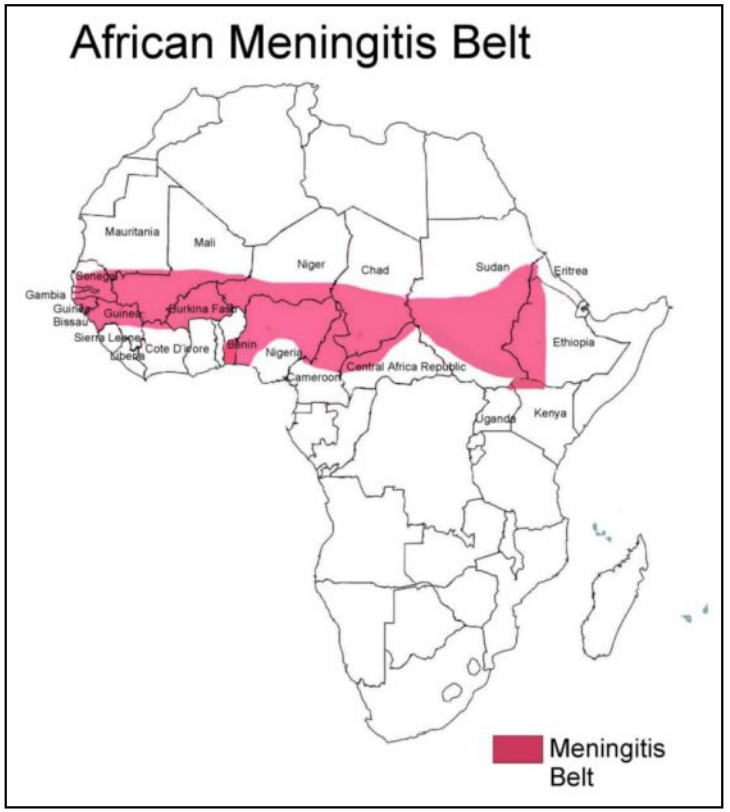
Terradellas et al. (2012)

The dust cycle. Impacts

- Health
- Weather and climate
- Transportation (visibility reduction)
- Energy
- Agriculture, fishing
- …

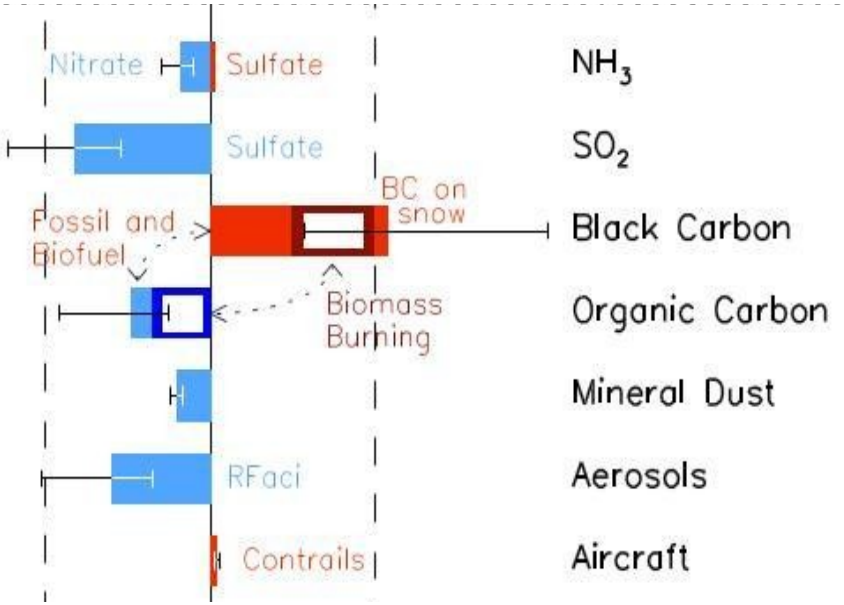
The dust cycle. Health impact

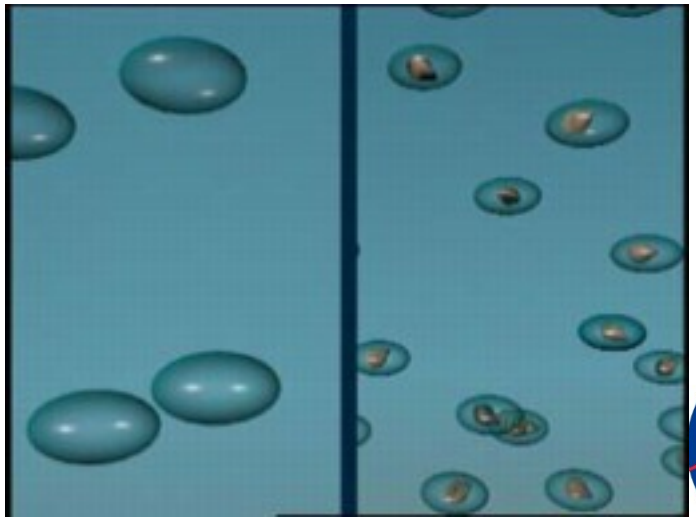


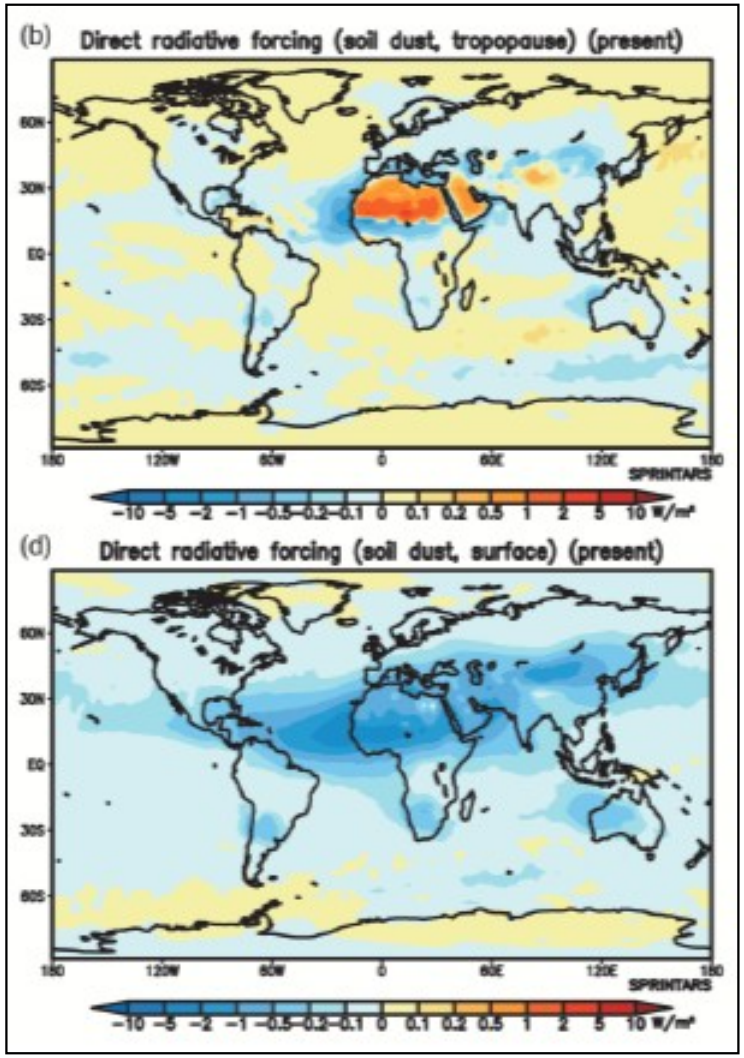


- Particle size
- Chemaical and mineralogical composition
- Carrying bacteria, viruses, funghi, ...
- Time and intensity of exposition

The dust cycle. Impact on weather and climate

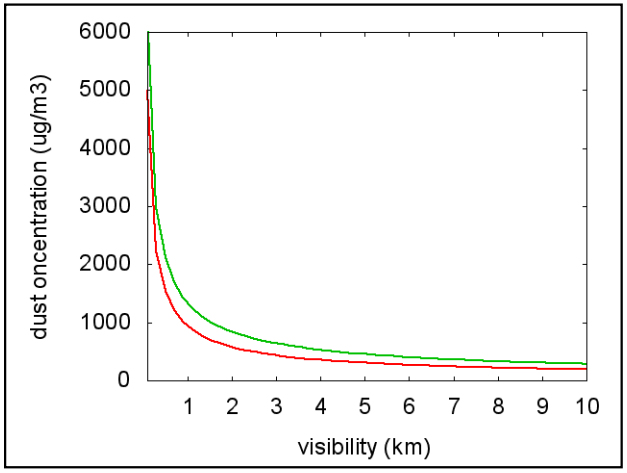






Takemura et al. (2009)

The dust cycle. Impact on transportation



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

Arizona, 29 Oct 2013

Tunis, 7 May 2002

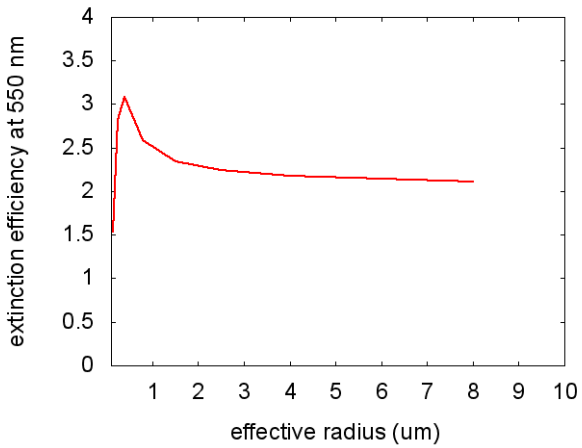
The dust cycle. Impact on transportation

$$V = \frac{3.912}{\beta}$$

Koschmieder eq.

$$\beta_\lambda = \sum_{k=1}^{N} \sigma_k Q_{k\lambda}$$

$$\beta_\lambda = \sum_{k=1}^{N} \frac{3}{4} \frac{C_k Q_{k\lambda}}{r_k \rho_k}$$



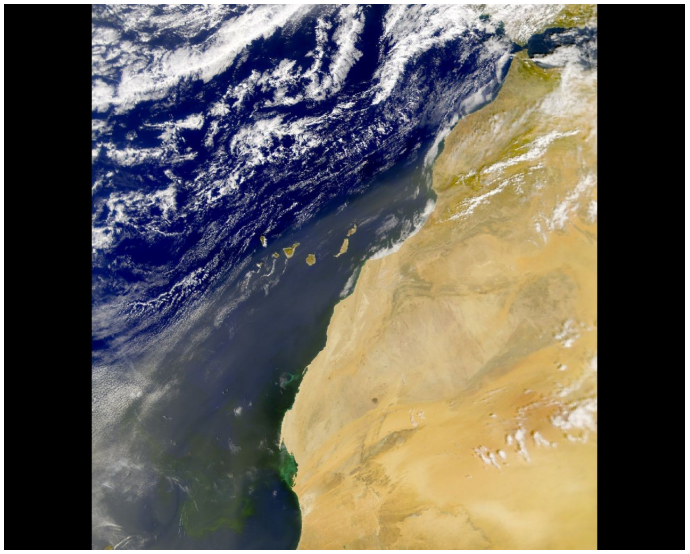
Tegen and Lacis (1996)

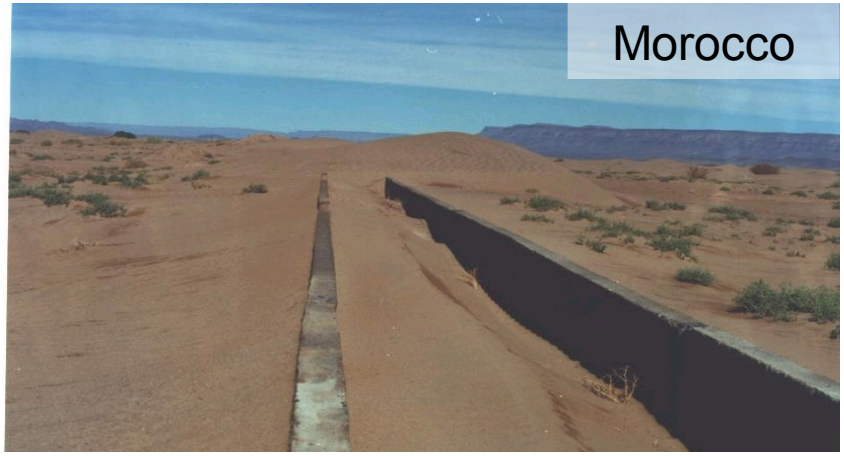
The dust cycle. Solar energy

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

The dust cycle. Agriculture, fishing

SeaWiFS





Summary

- Atmospheric aerosol
- The cycle of mineral dust
- **WMO SDS-WAS**
- Barcelona Dust Forecast Center
- Dust observation
- Dust forecast

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, Barbados
Regional Center for West Asia (??)

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

The Center is jointly managed by the State Meteorological Agency of Spain (AEMET) and the Barcelona Supercomputing Center (BSC)

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

Campus UPC. Edificio Nexus II

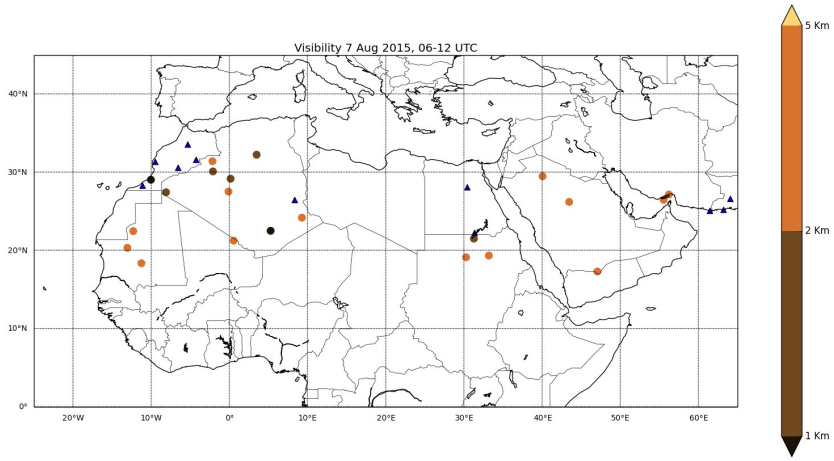
MareNostrum III supercomputer

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

OBJETIVES:

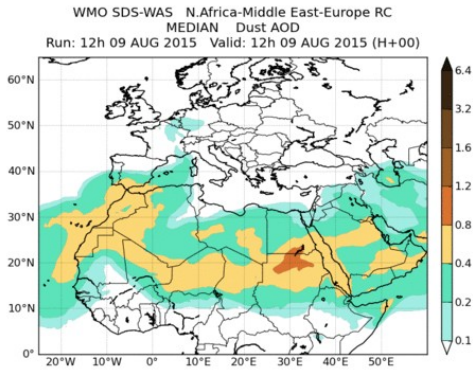
- **Identify and improve products for observation and prediction of airborne dust, in collaboration with research and operational institutions, as well as end-users**
- **Facilitate the user access to information**
- **Build capacity of countries to use the provided products**

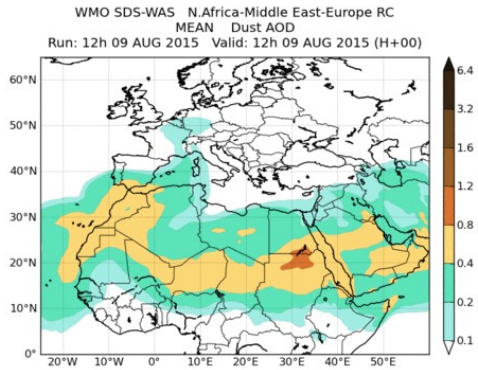
WMO SDS-WAS. RC developments

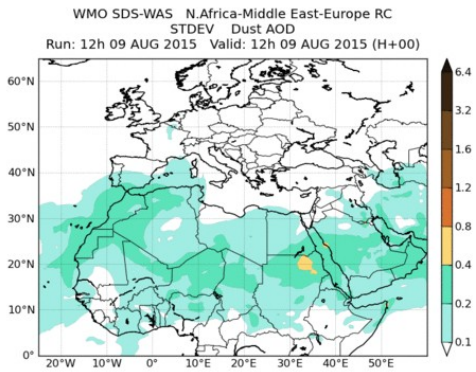


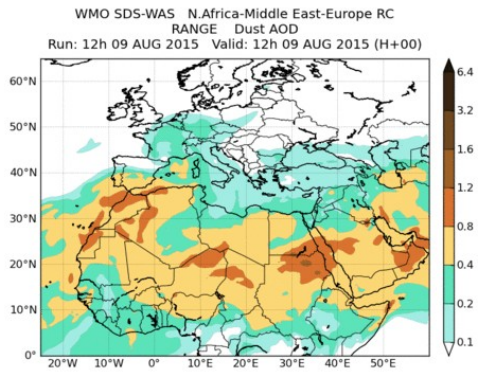
7 Aug 2015 06-12 UTC

9 Aug 2015

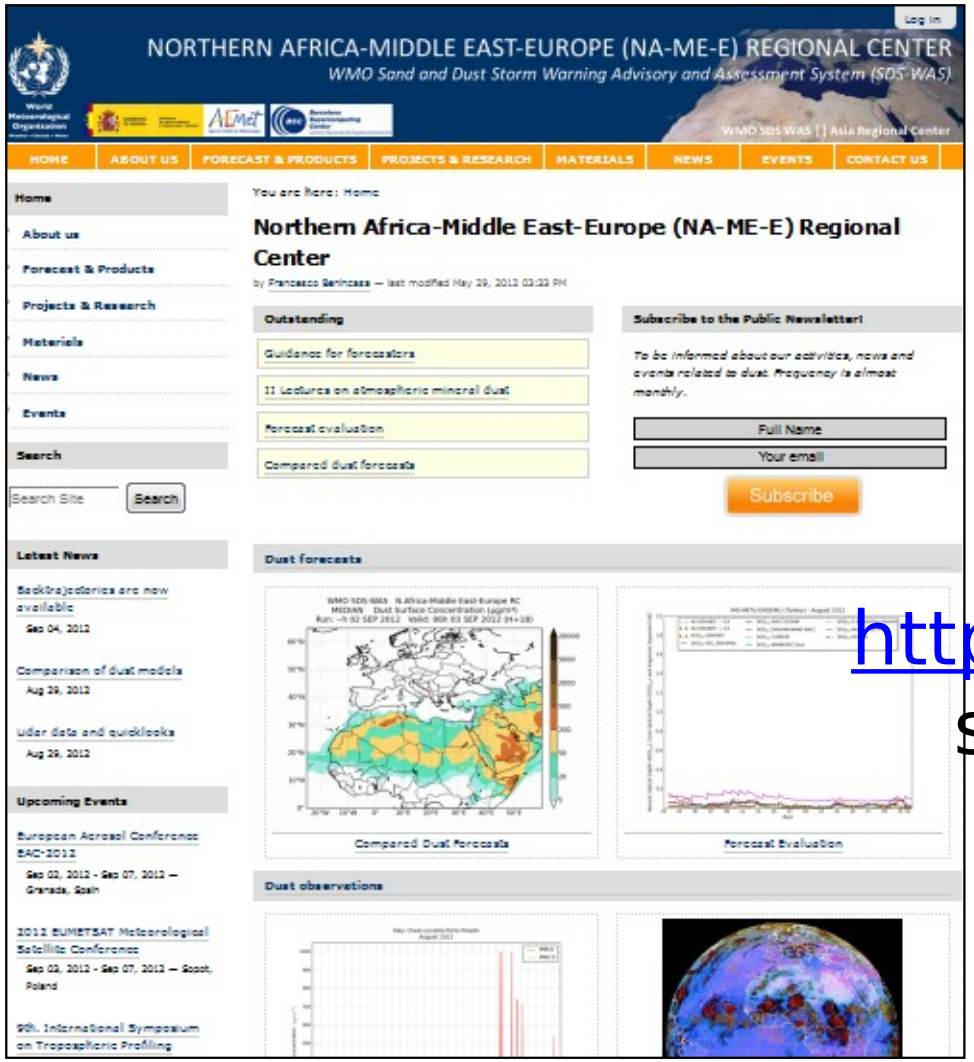








WMO SDS-WAS. RC's web portal

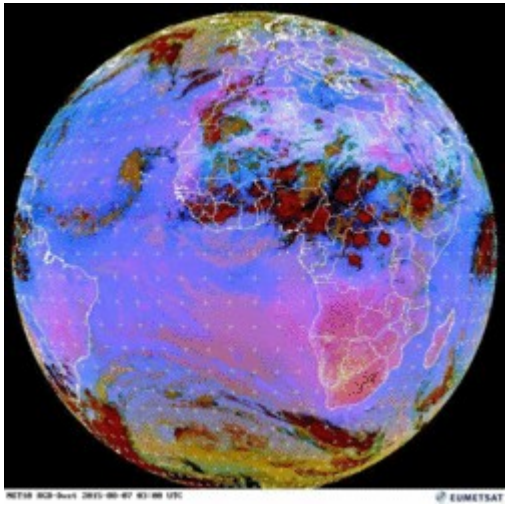


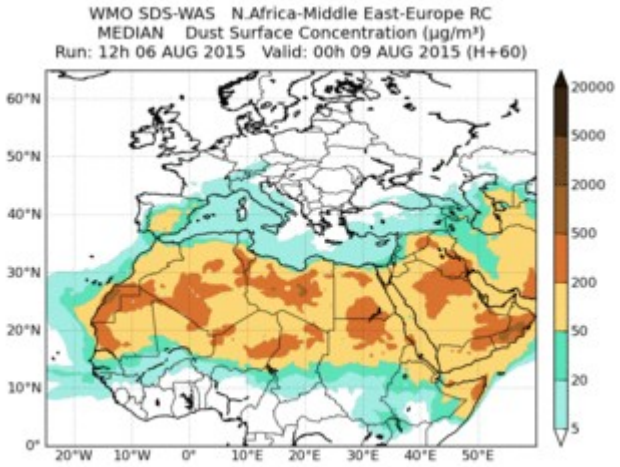
http://sds-was.aemet.es

sdswas@aemet.es

WMO SDS-WAS. RC's web portal

- SDS-WAS
- OBSERVATION
  - In-situ
  - Visibility
  - AERONET
  - Lidar
  - Satellites
- PREDICTION
  - Model comparison
  - Models download
  - Multi-model products
  - Forecast evaluation
- PROJECTS & RESEARCH
- MATERIALS
- NEWS
- EVENTS



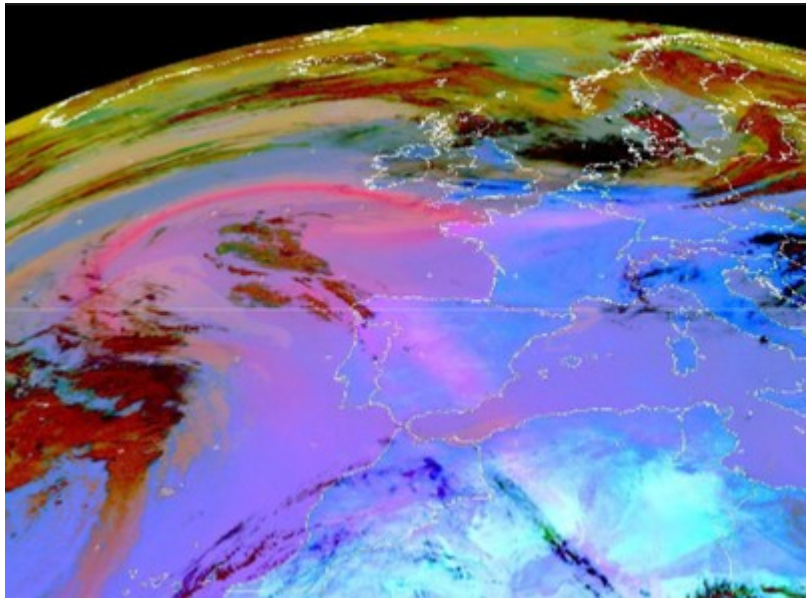


WMO SDS-WAS. Capacity building

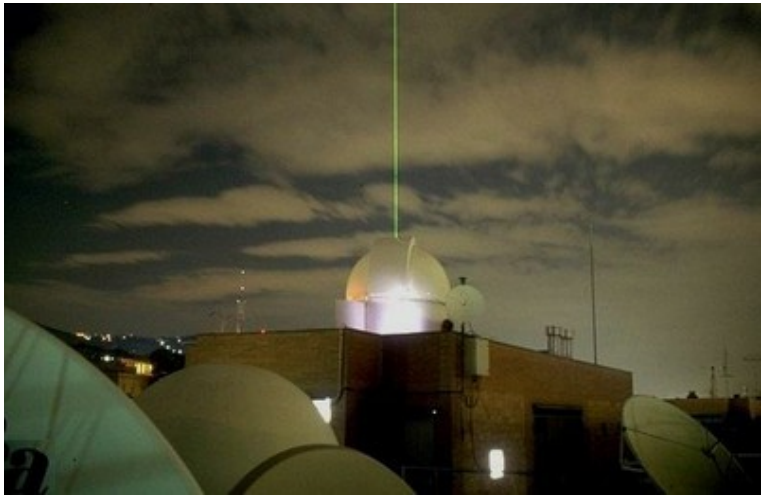
<u>TRAINING COURSES</u>

Accra
Addis-Ababa
Ankara
Antalya
Barcelona
Casablanca
Istanbul
Muscat
Niamey
Ouagadougou
Tbilisi
Tehran

WMO SDS-WAS. Collaborative studies



Prediction of the Saharan dust outbreak into Europe of April 2011. Leader: Nicolas Huneeus



Models / Lidar comparison. Leader: Ioannis Binietoglou

Study of a haboob in Tehran. Leader: Ana Vukovic

Summary

- Atmospheric aerosol
- The cycle of mineral dust
- WMO SDS-WAS
- **Barcelona Dust Forecast Center**
- Dust observation
- Dust forecast

Barcelona Dust Forecast Center

<u>May 2013</u>
WMO designates the consortium of AEMET and BSC to host the first RSMC-ASDF. The Centre will generate and distribute operationally dust forecasts for Northern Africa, Middle East and Europe.

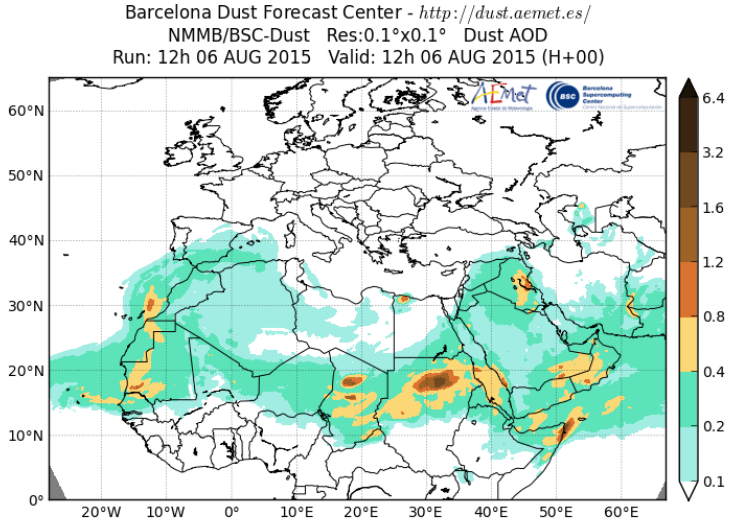
<u>Feb 2014</u>
The Centre starts operations under the name of **Barcelona Dust Forecast Center** (BDFC)

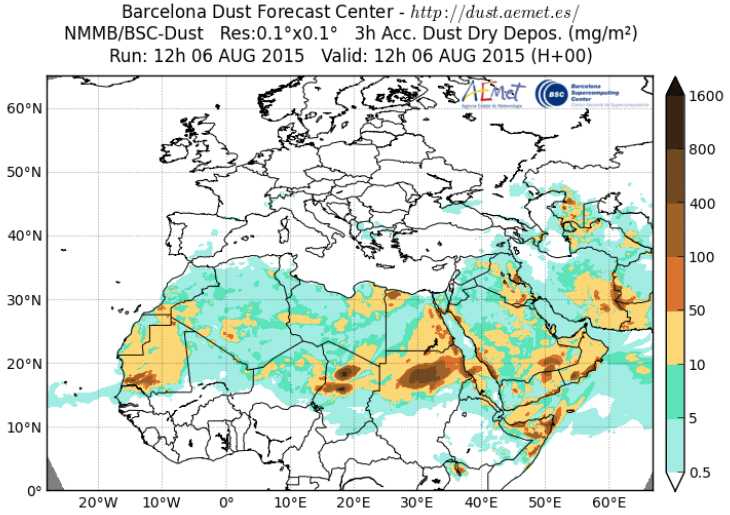
Barcelona Dust Forecast Center

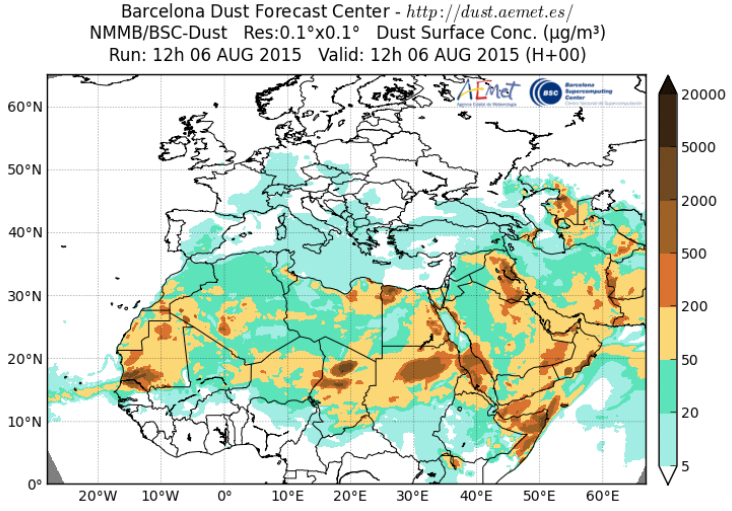
http://dust.aemet.es

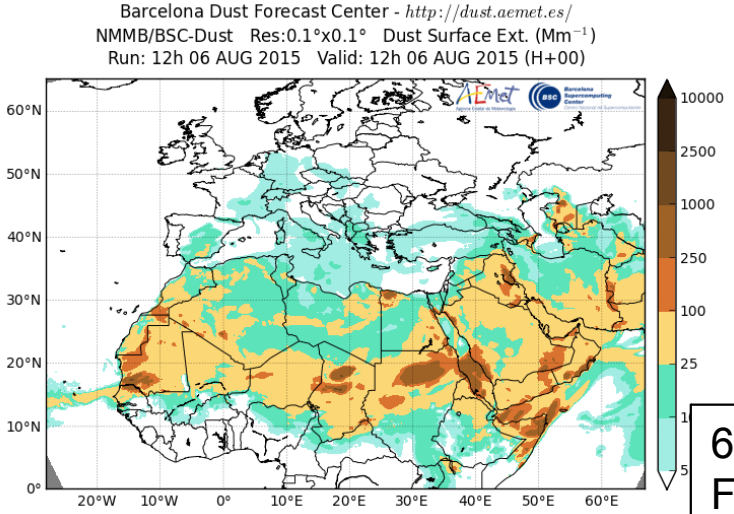
dust.aemet.es

Barcelona Dust Forecast Center. Products



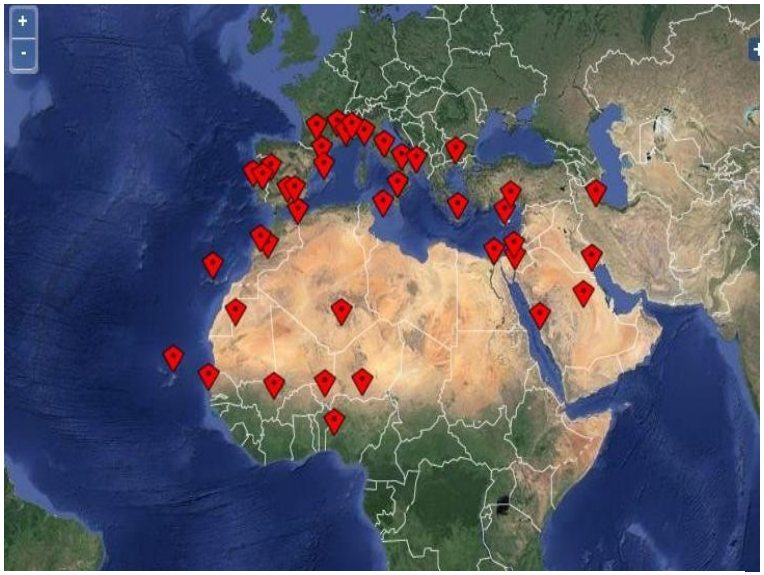


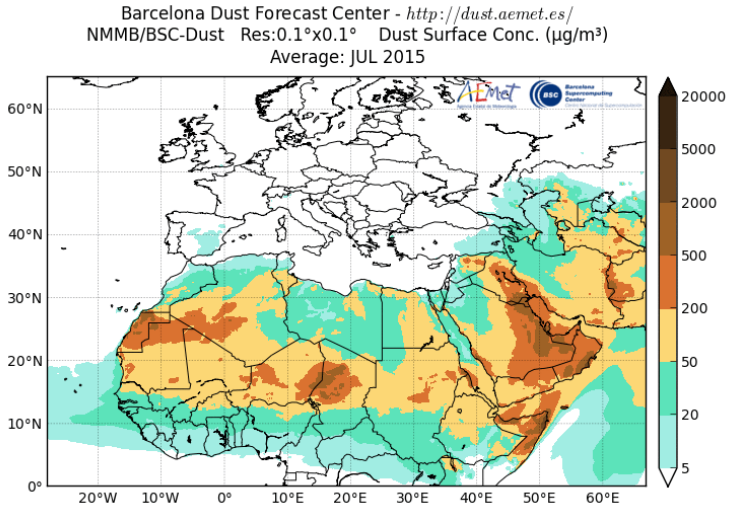


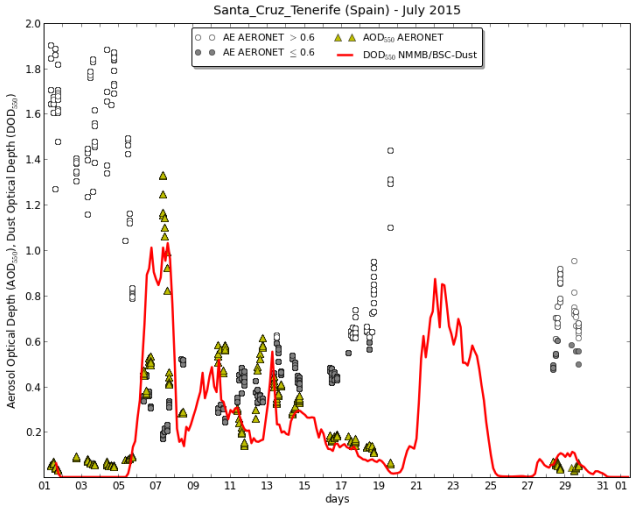


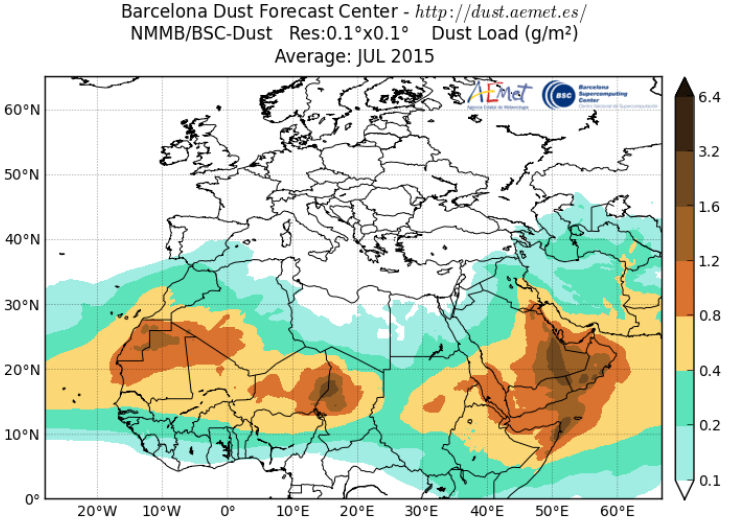
6 variables
Forecast: 0-72 h

Barcelona Dust Forecast Center. Also...

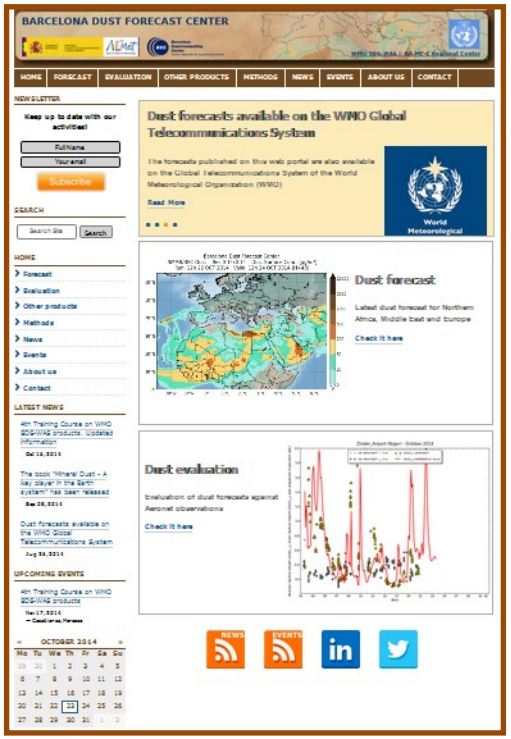








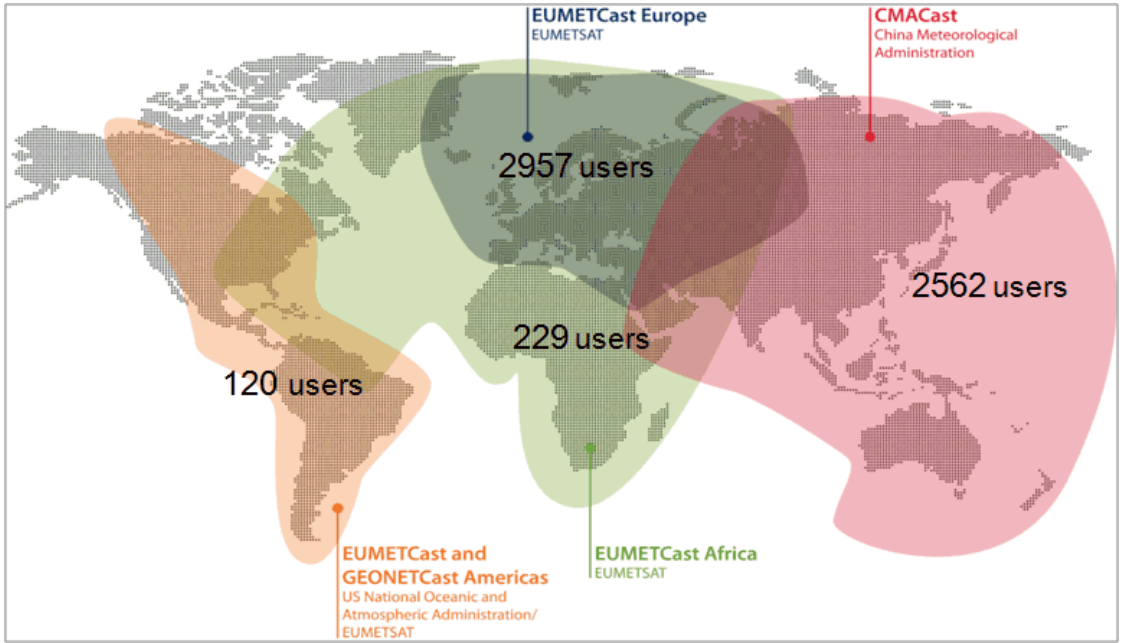
Barcelona Dust Forecast Center. Dissemination



http://dust.aemet.es

WMO Global Telecommunications System

World Meteorological Organization



EUMETCast

Barcelona Dust Forecast Center. Dissemination

http://uneplive.unep.org

ACMAD

COMING SOON

Summary

- Atmospheric aerosol
- The cycle of mineral dust
- WMO SDS-WAS
- Barcelona Dust Forecast Center
- **Dust observation**
- Dust forecast

Dust observation. Why?

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

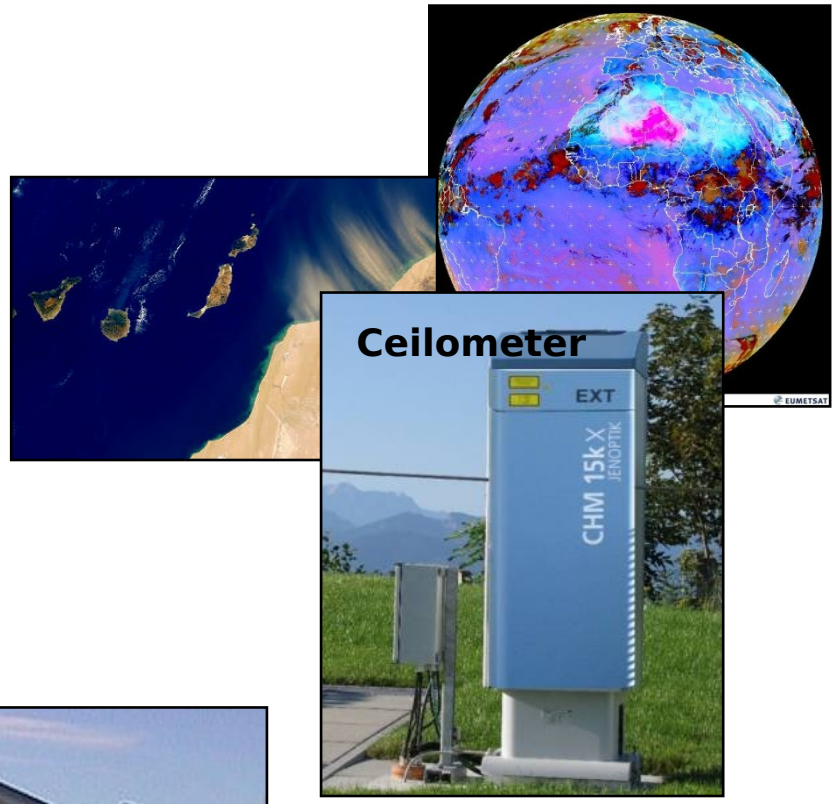
Mali, 2001
Photo: Remi Benali/Corbis

Dust observation. A comprehensive system

Ground observation
- In-situ (ie PM10)
- Indirect (visibility)

Ground-based remote sensig
- Photometers (ie AERONET)
- Lidar/Ceilometers

Satellite observation
- GEO satellites
- Polar satellites



AQ station

Transmissometer

Dust observation. In-situ

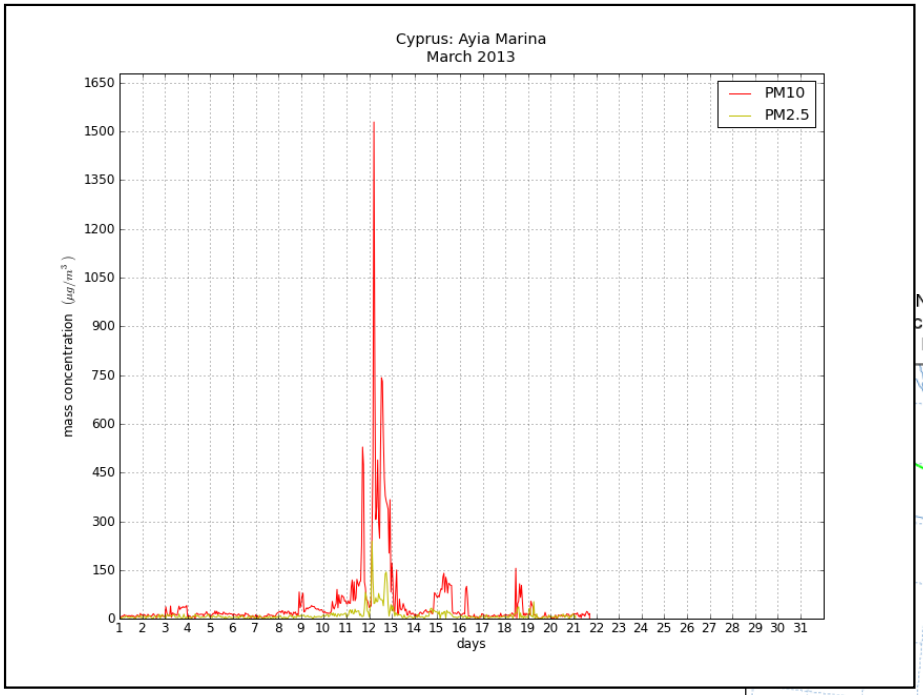
W_1 W_2

Beta

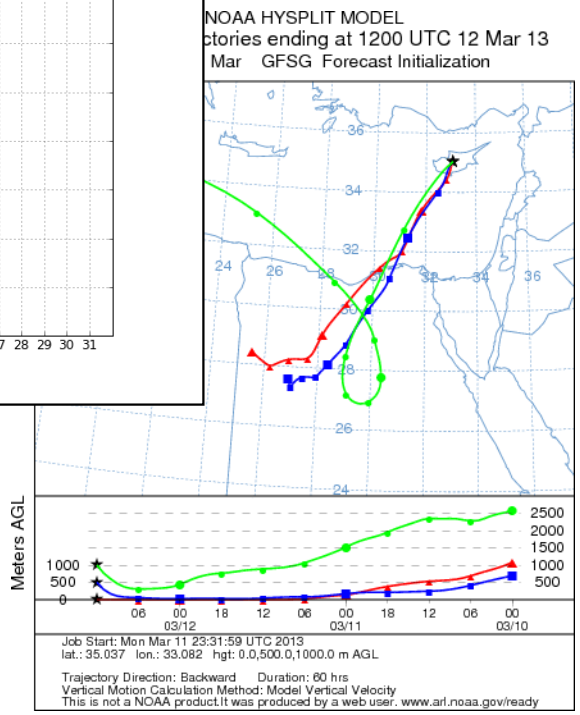
$$PM = \frac{(W2-W1)}{Volume}\ \mu g/m^3$$

Dust observation. In-situ

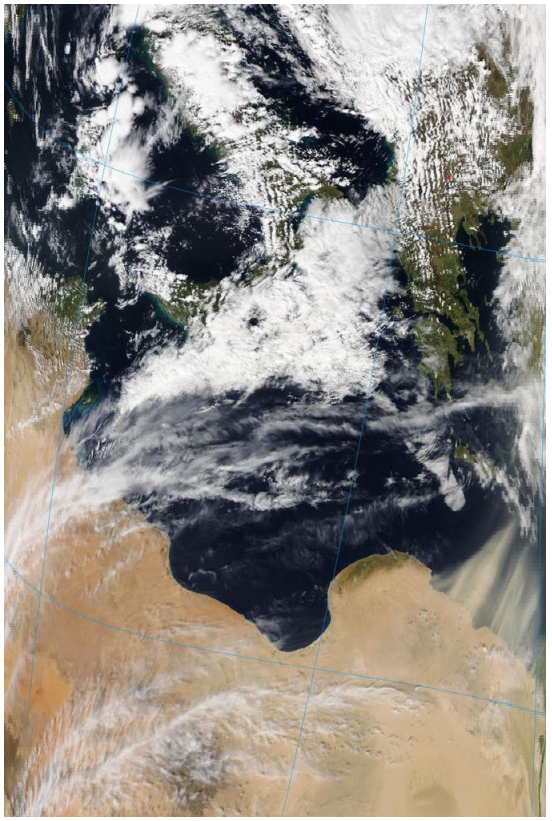
Dust observation. In-situ



March 2013

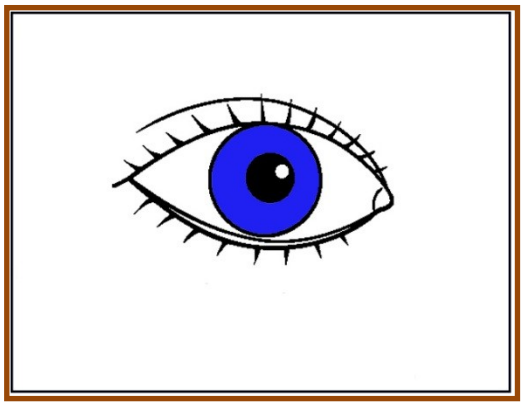


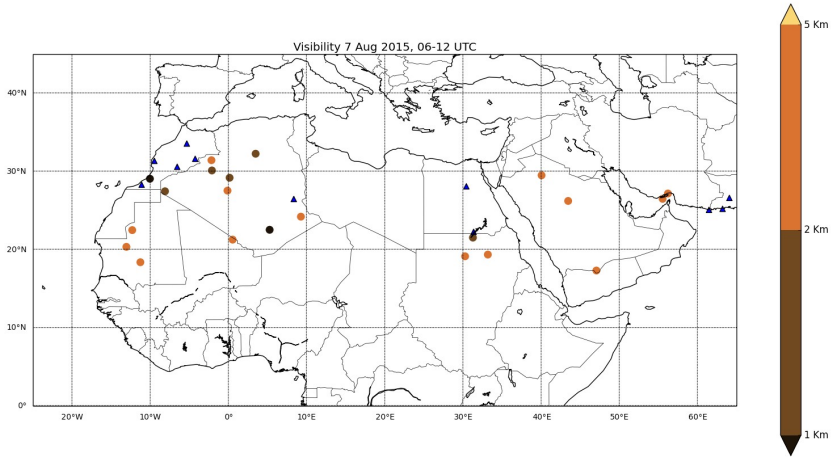
12 March 2013

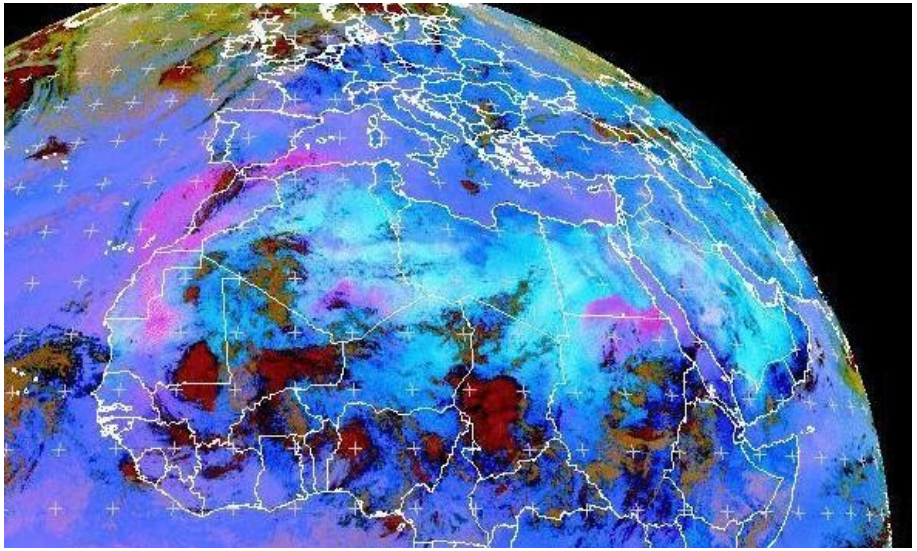


11 March 2013

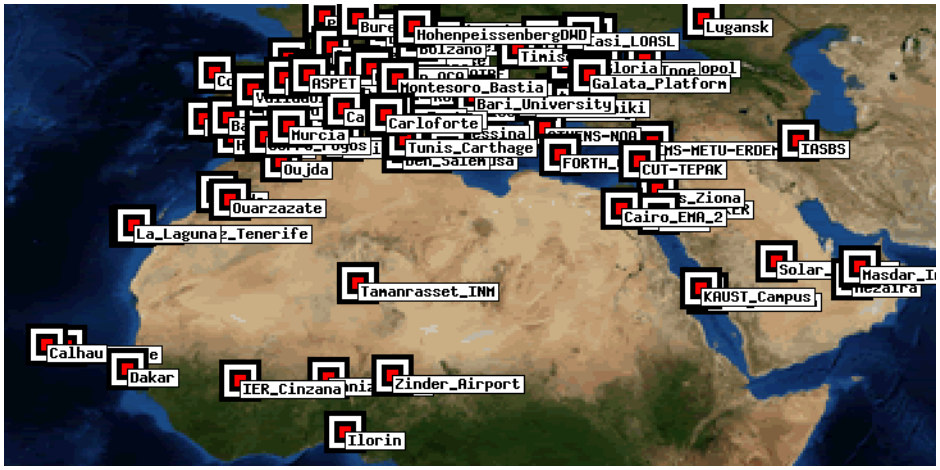
Dust observation: Visibility





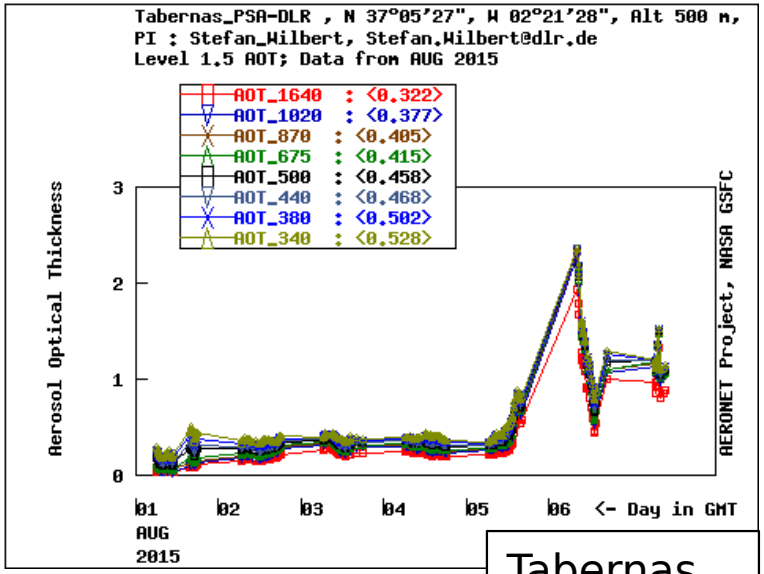


Dust observation. Sun-photometers

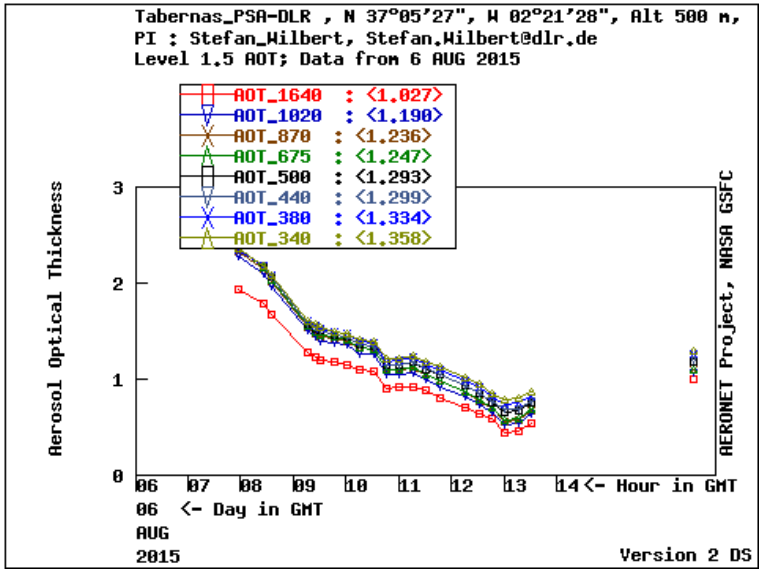


- Solar radiation at the TOA is known
- Airborne particles attenuate this radiation (absorption, scattering)
- Sun-photometers measure the direct radiation reaching the Earth's surface
- Measurement at different wavelengths allows retrieval of the aerosol contents and some of its properties (I. e. size distribution)

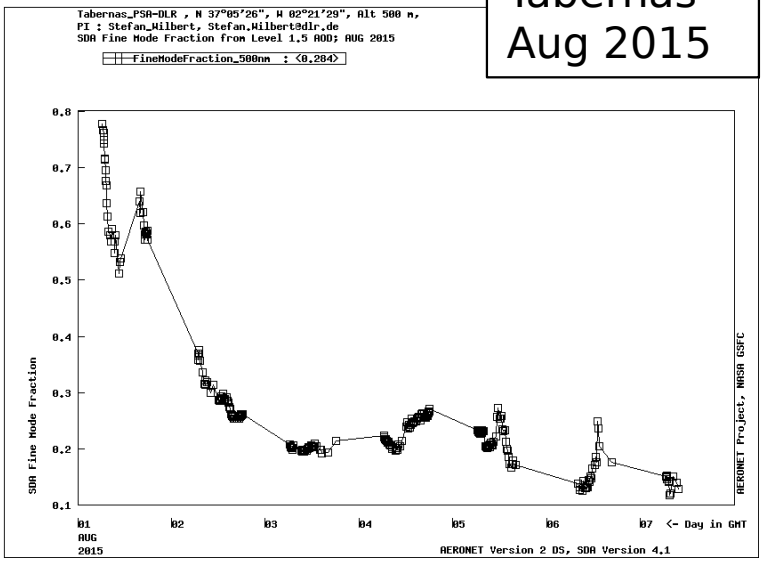
Dust observation. Sun photometers

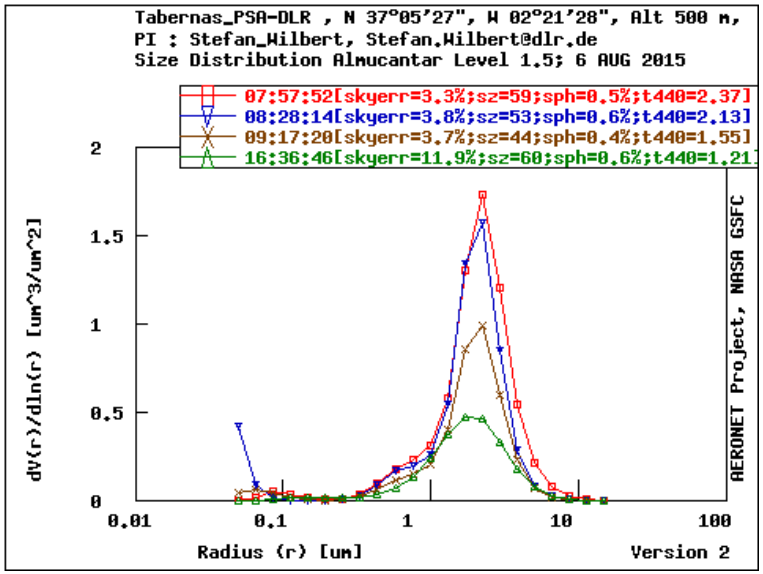


Tabernas
Aug 2015

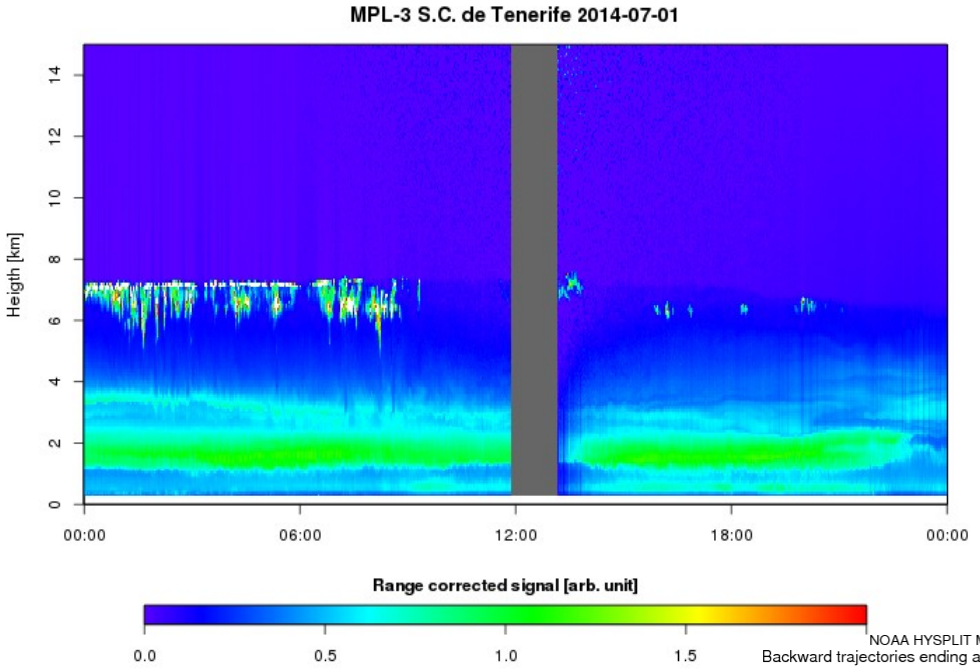


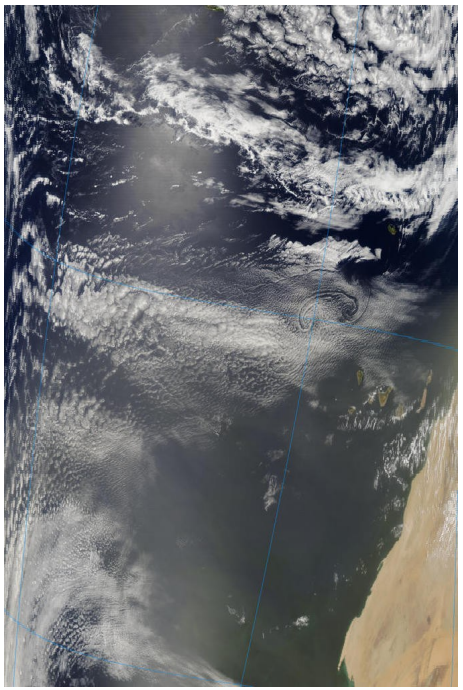
Tabernas
8 Aug 2015



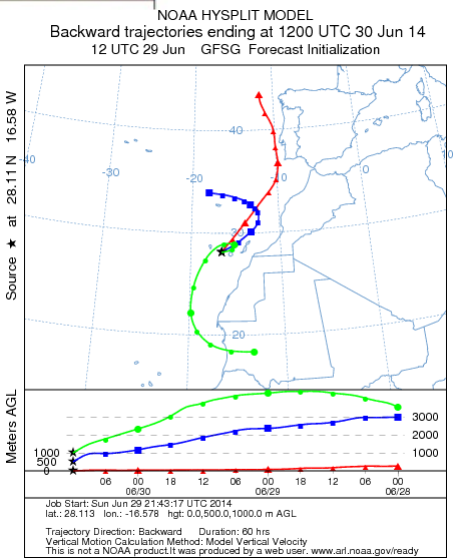


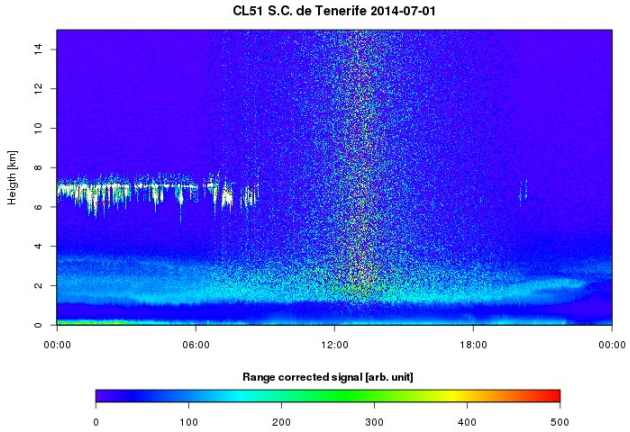
Dust observation. Lidar/ceilometers



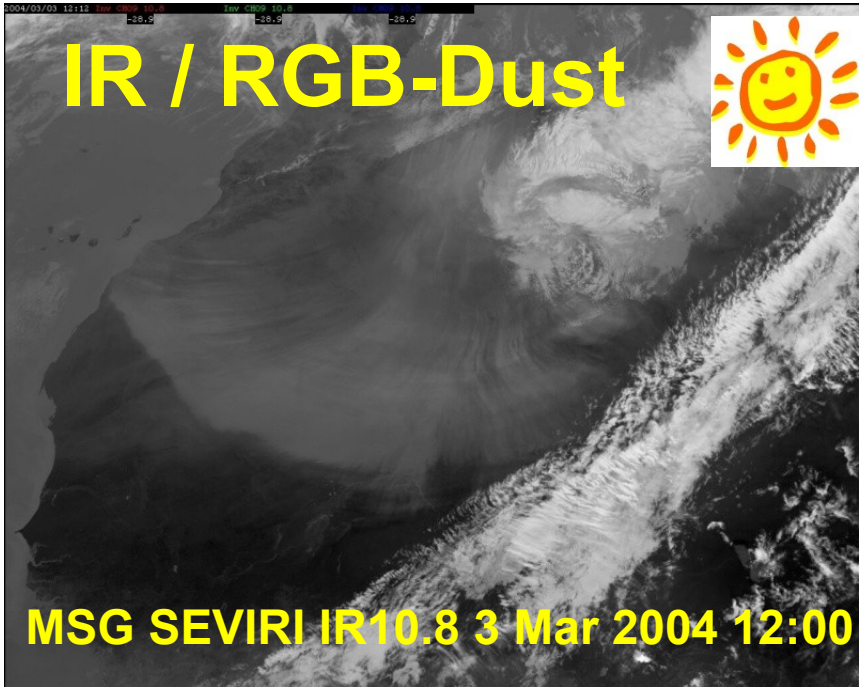


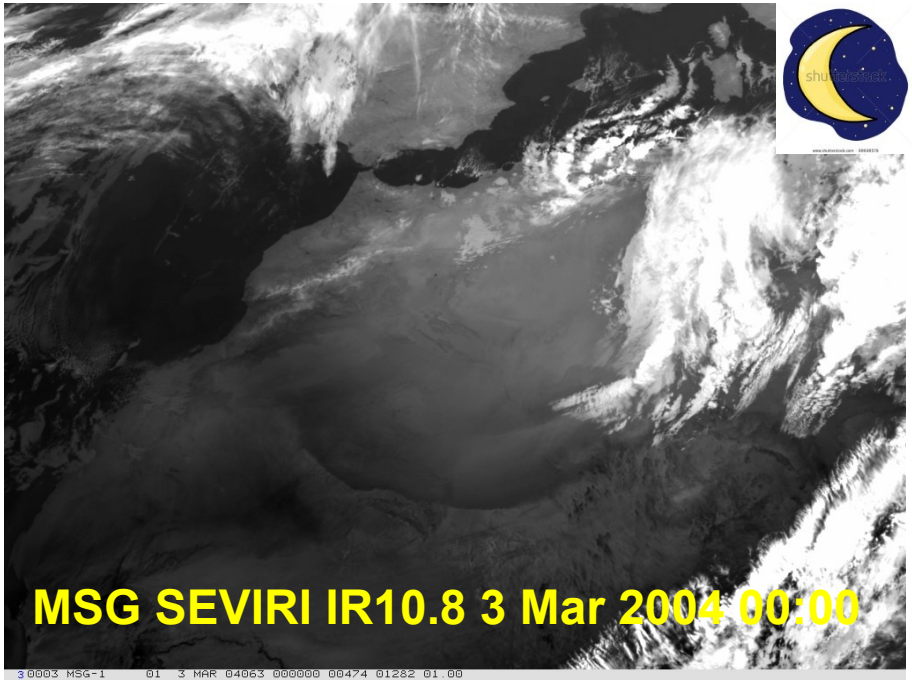
Sta. Cruz de Tenerife
1 July 2014

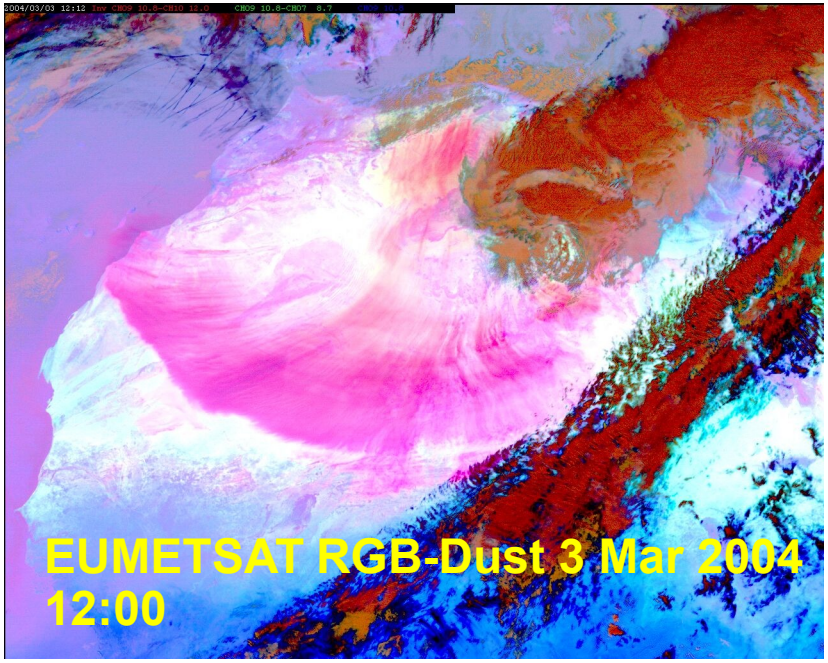


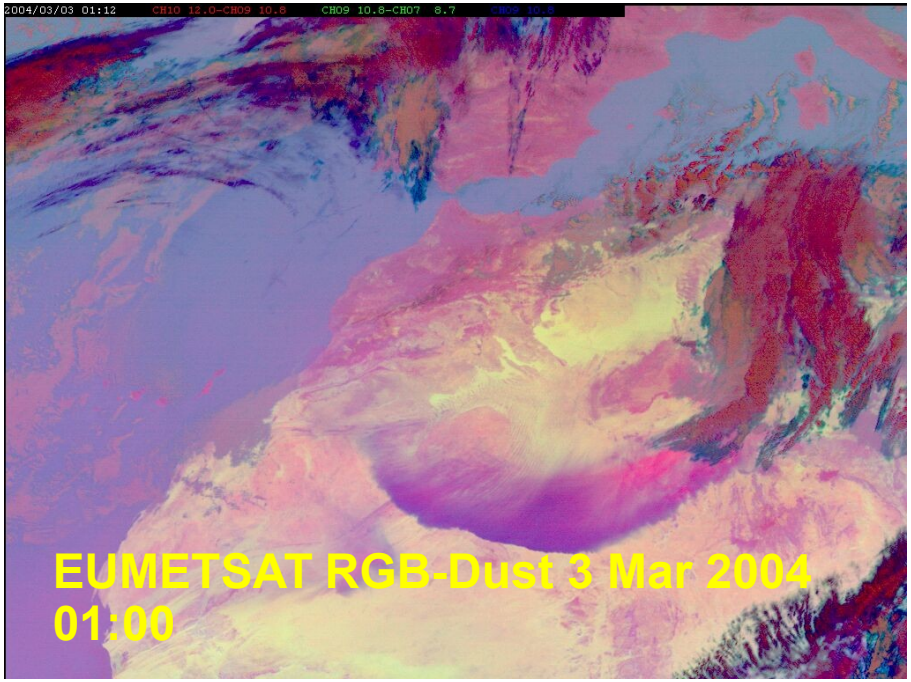


IR / RGB-Dust

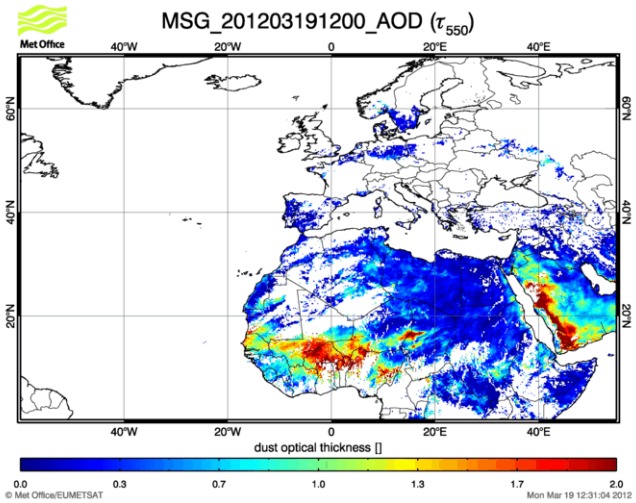

MSG SEVIRI IR10.8 3 Mar 2004 12:00

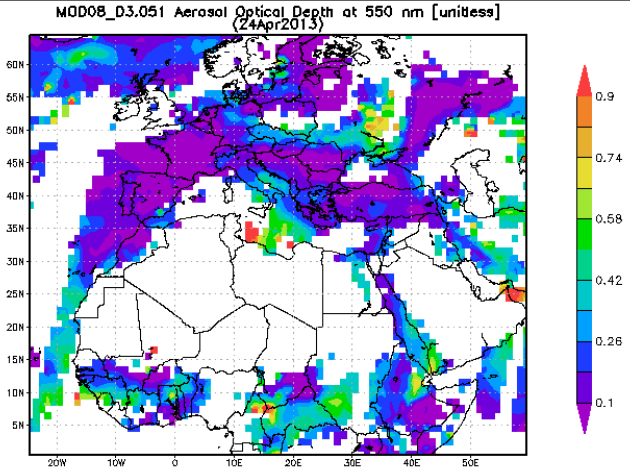

MSG SEVIRI IR10.8 3 Mar 2004 00:00

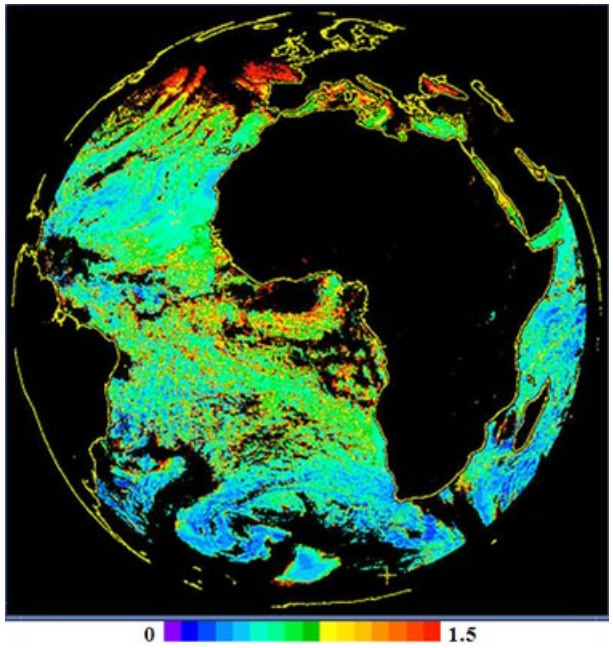

EUMETSAT RGB-Dust 3 Mar 2004 12:00

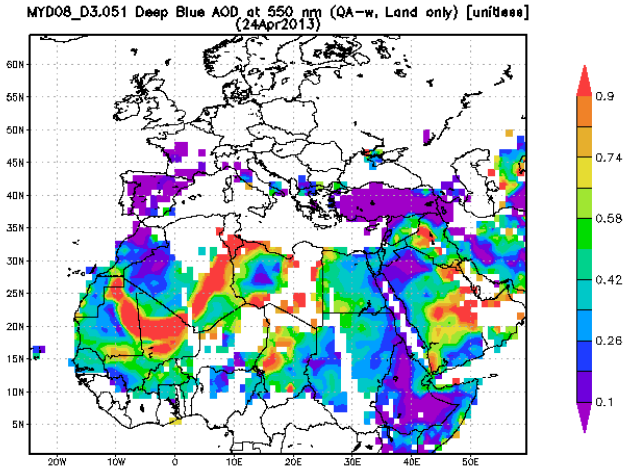

EUMETSAT RGB-Dust 3 Mar 2004 01:00

Dust observation. Quantitative retrievals









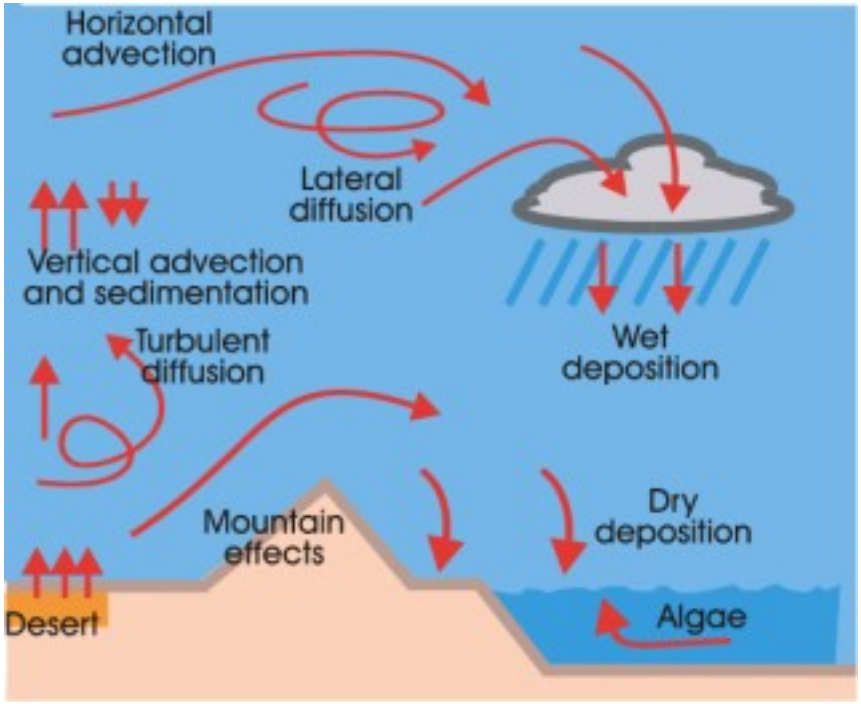
GODDARD
SPACE FLIGHT CENTER

Summary

- Atmospheric aerosol
- The cycle of mineral dust
- WMO SDS-WAS
- Barcelona Dust Forecast Center
- Dust observation
- **Dust forecast**

Dust forecast. Models

NWP model
+
Parametrization of dust cycle
=
Dust prediction model



- Emission
- Transport (diffussion, advection)
- Dry / wet deposition

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

Dust forecasts. Problems

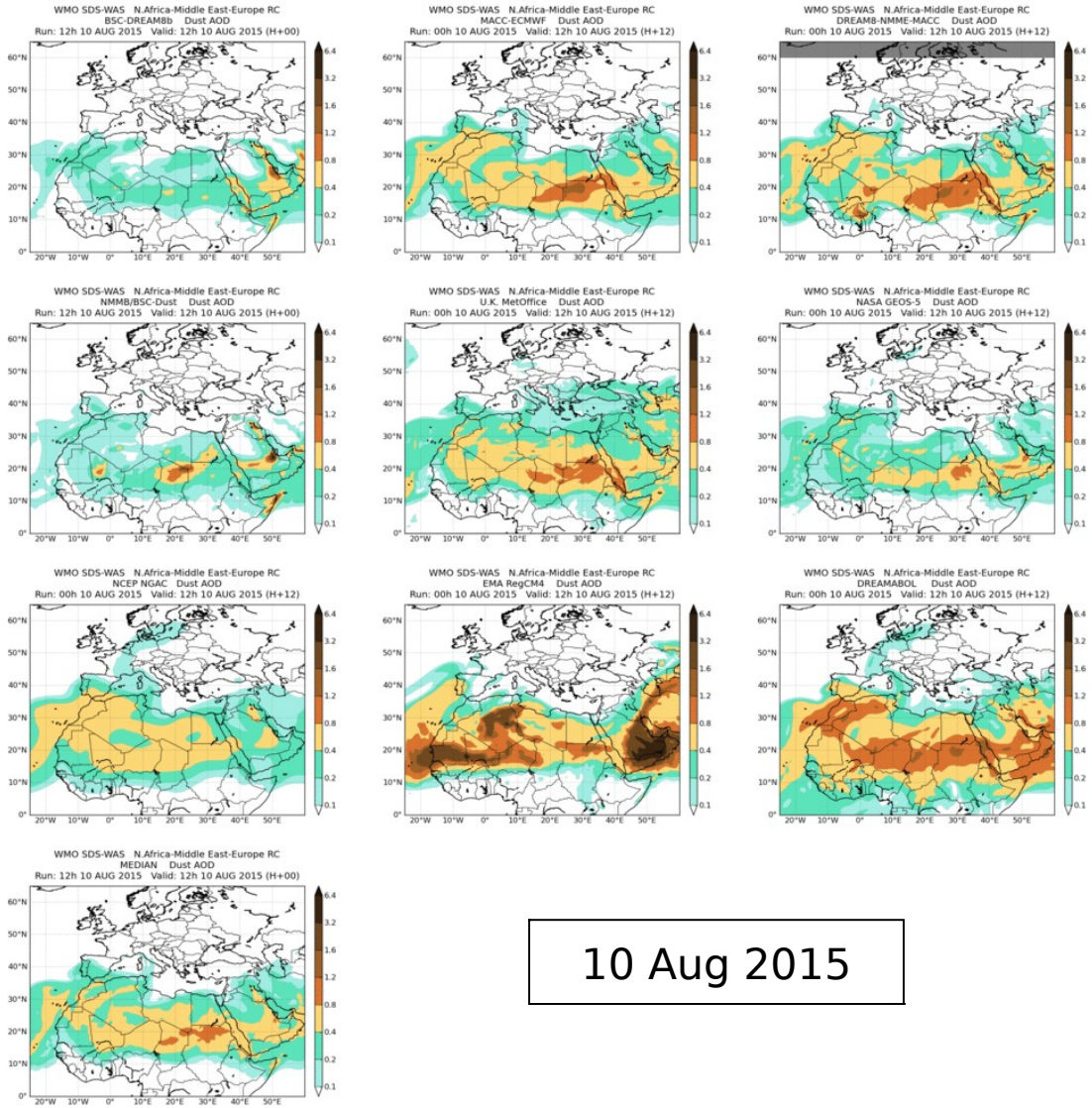
- Incomplete knowledge of the physical processes involved in the dust cycle
- Processes of very different scales
- Need of a very precise wind forecast
- Lack of suitable observations for data assimilation and forecast evaluation

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

Dust forecasts. SDS-WAS model intercomparison



10 Aug 2015

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

macc
Monitoring atmospheric composition & climate

Met Office

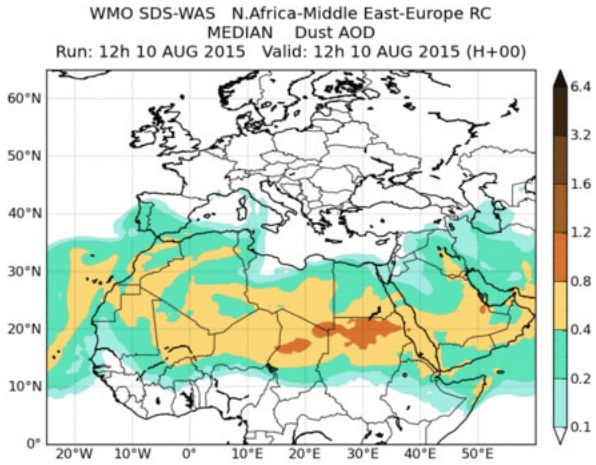
SEEVCCC

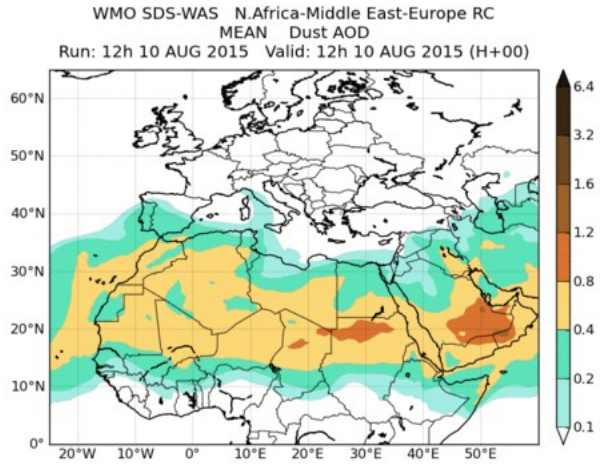
NCEP

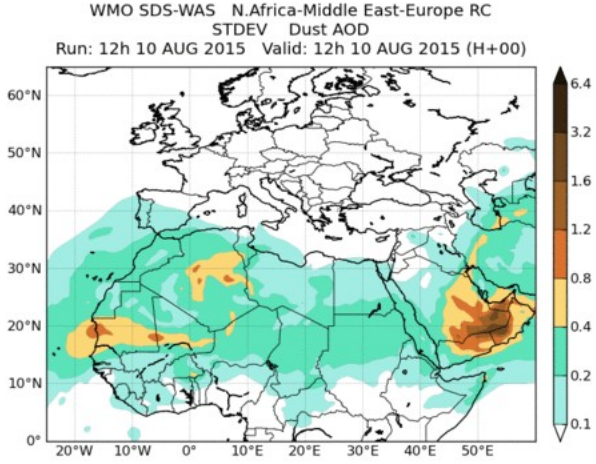
NASA

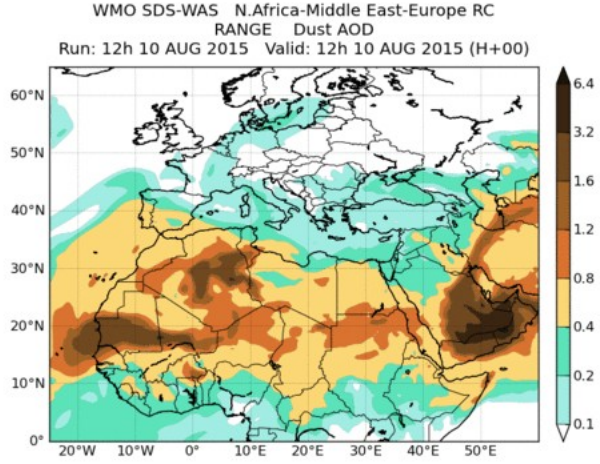
EMA

Dust forecasts. Multi-model products









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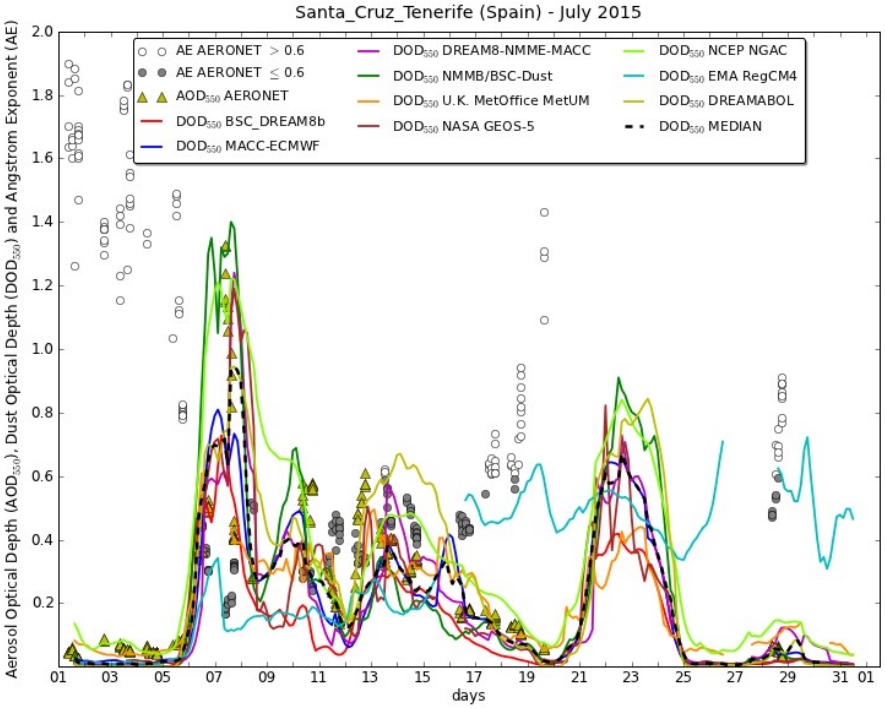
Dust forecasts. SDS-WAS forecast evaluation

AERONET

Aerosol Robotic Network



Santa Cruz de Tenerife (Spain)
July 2015

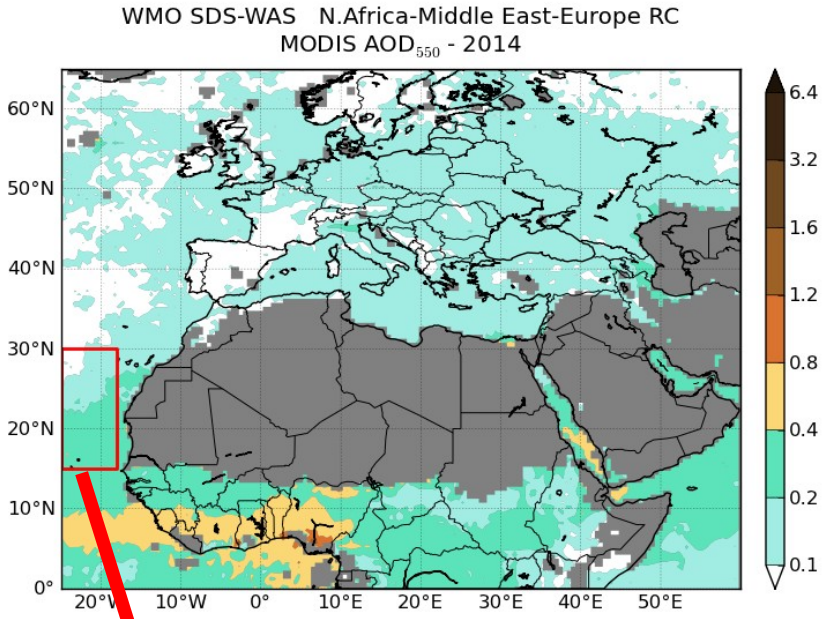
Dust forecasts. SDS-WAS forecast evaluation

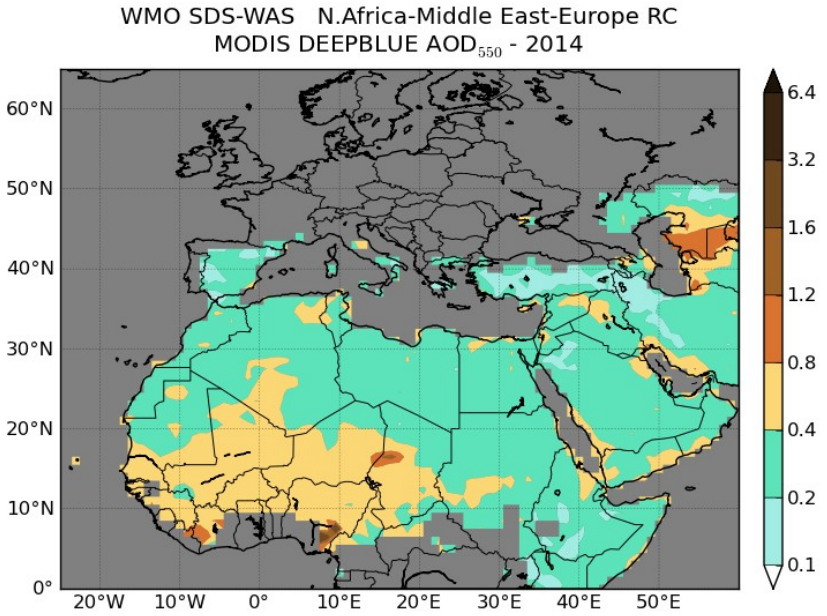
CORRELATION COEFFICIENT

	BSC_ DREAM8b	MACC-ECMWF	DREAM8-NMME-MACC	NMMB/ BSC-Dust	U.K. Met Office	NASA GEOS-5	NCEP NGAC	EMA RegCM4	DREAM ABOL	MEDIAN
Sahel/Sahara show stations	**0.53**	**0.56**	**0.47**	**0.53**	**0.57**	**0.58**	**0.60**	**0.25**	**0.30**	**0.62**
Middle East show stations	**0.36**	**0.36**	**0.44**	**0.42**	**0.36**	**0.37**	**0.32**	**0.29**	**0.20**	**0.35**
Mediterranean show stations	**0.38**	**0.51**	**0.40**	**0.48**	**0.47**	**0.49**	**0.46**	**0.20**	**0.34**	**0.51**
TOTAL	**0.51**	**0.56**	**0.47**	**0.54**	**0.56**	**0.58**	**0.58**	**0.28**	**0.35**	**0.61**

2014

Dust forecasts. SDS-WAS forecast evaluation





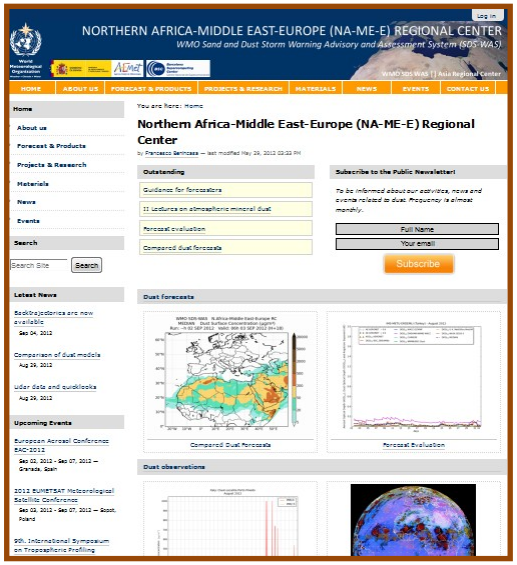
	BIAS	ROOT MEAN SQUARE ERROR	CORRELATION COEFFICIENT	FRACTIONAL GROSS ERROR	NUMBER OF CASES
BSC_ DREAM8b	-0.14	0.20	0.72	1.07	22154
NMMB/BSC-Dust	-0.13	0.18	0.79	1.09	22154
NCEP NGAC	0.04	0.15	0.81	0.59	21608
EMA RegCM4	-0.04	0.37	0.26	1.09	13300
DREAMABOL	-0.04	0.17	0.69	0.92	13611

MODIS

2014

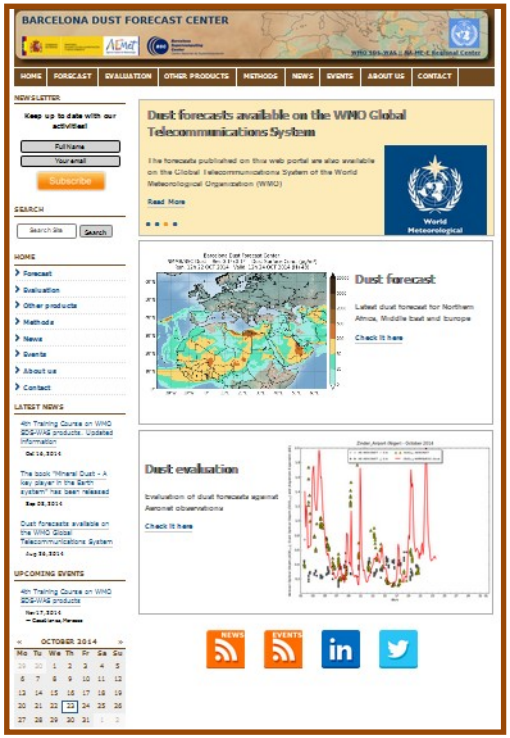
Thanks for your attention

R&D



http://sds-was.aemet.es

Operational Forecast



http://dust.aemet.es