

The dust cycle and impacts

Observation and prediction of airborne dust

Enric Terradellas, AEMET, Barcelona

WMO SDS-WAS. Regional Center for N. Africa, Middle East and Europe
Barcelona Dust Forecast Center



**World
Meteorological
Organization**
Weather • Climate • Water

4t Training Course on WMO SDS-WAS Products
Casablanca, Morocco, 17-20 Nov 2014

- Atmospheric aerosol
- The dust cycle
- Observation of atmospheric dust
- Prediction of atmospheric dust

**WMO SDS-WAS Regional Center for
Northern Africa, Middle East and
Europe**

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

Barcelona Dust Forecast Center

<http://dust.aemet.es>
dust@aemet.es



- **Atmospheric aerosol**
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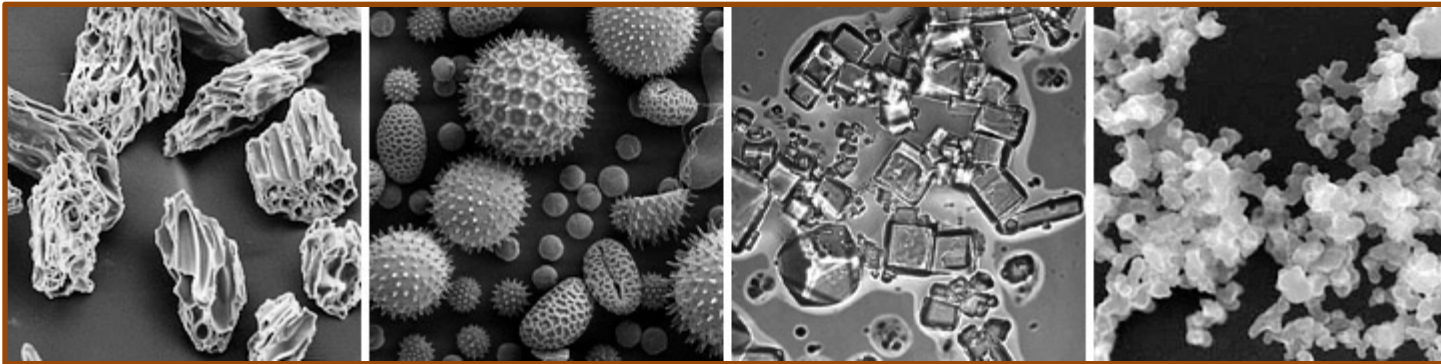
Atmospheric aerosol

Atmospheric aerosol

Solid or liquid particles suspended in the air

Particle size

Diameter $\sim 0.002 - 100 \mu\text{m}$

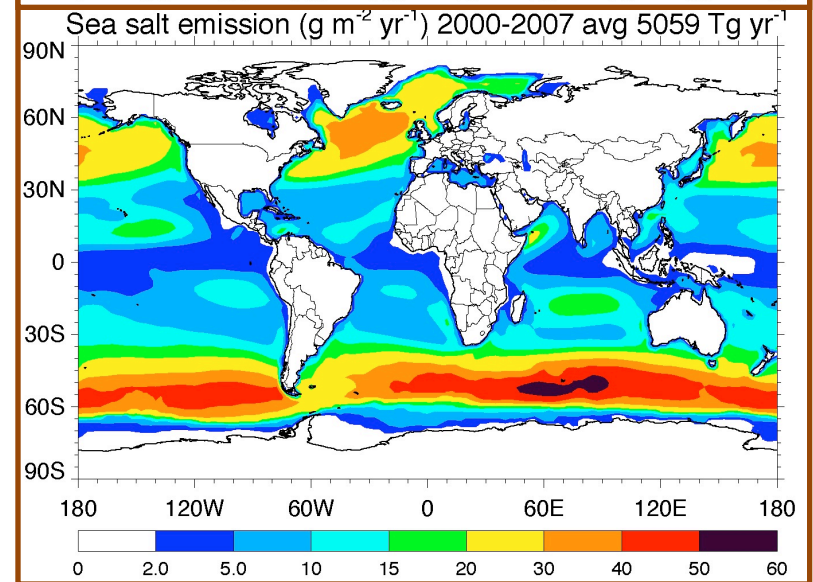
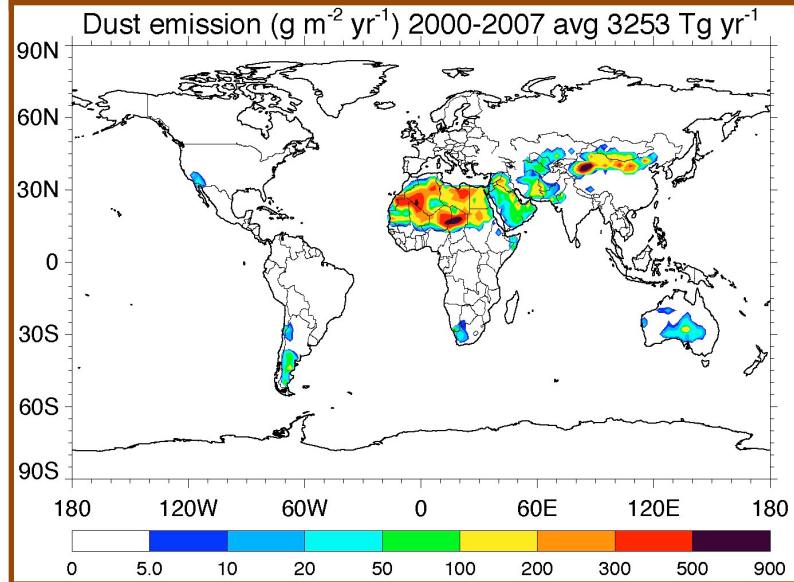
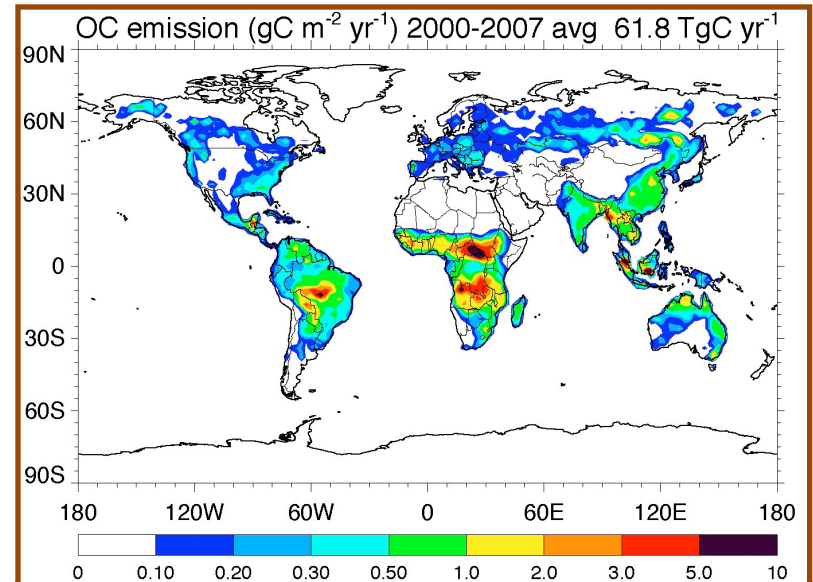
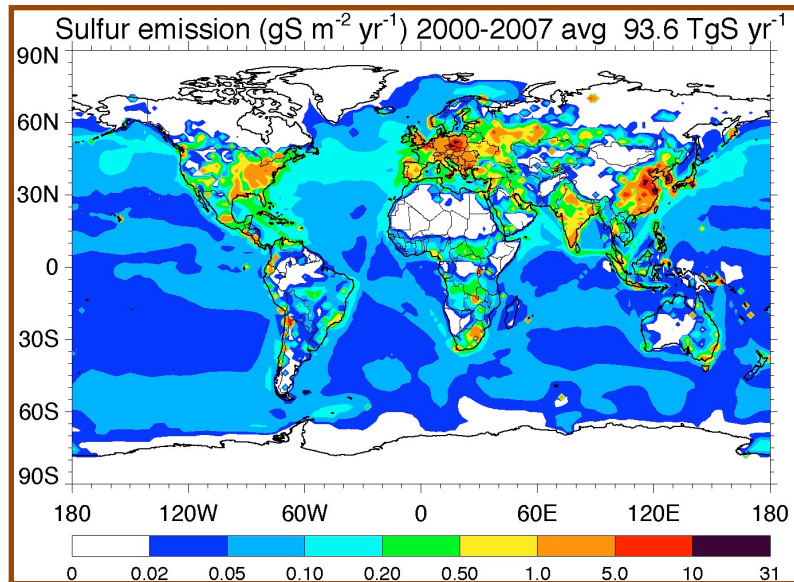


Aerosol sources



Volcanoes, botanical debris, sea salt, biomass burning, mineral dust, anthropic pollution, ...

Emissions 2000-2007



- Atmospheric aerosol
- **The dust cycle**
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WMO SDS-WAS Regional Center for
Northern Africa, Middle East and
Europe

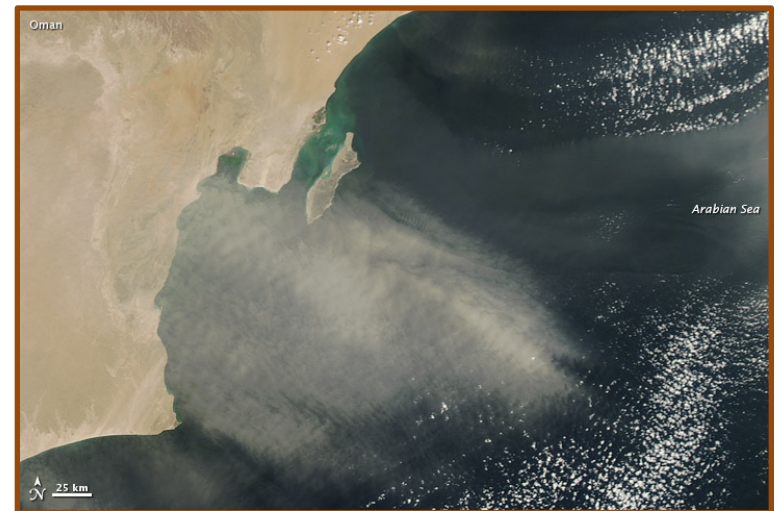
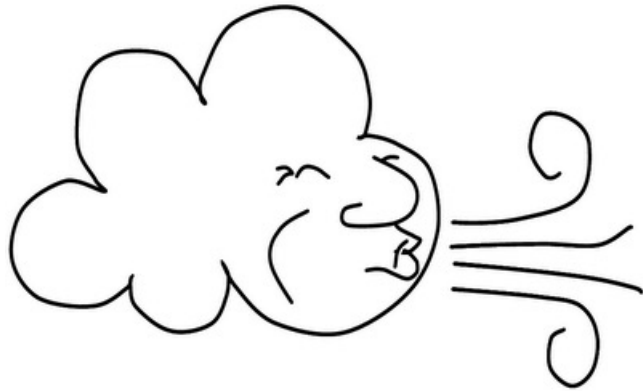
<http://sds-was.aemet.es>
sdswas@aemet.es

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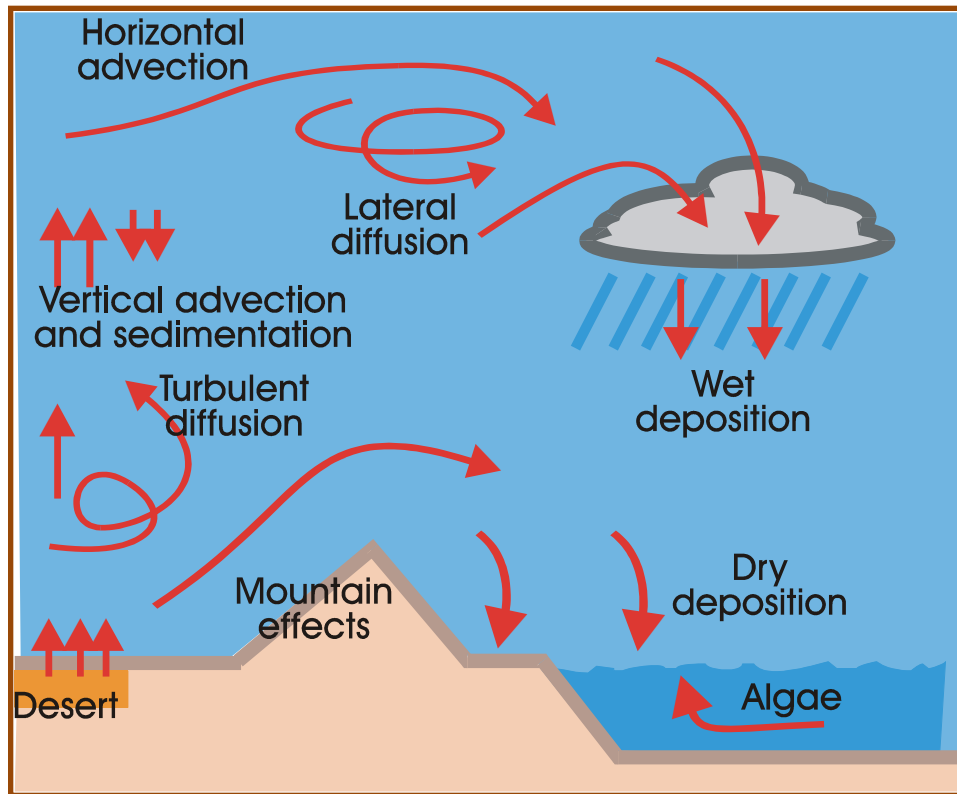


The dust cycle



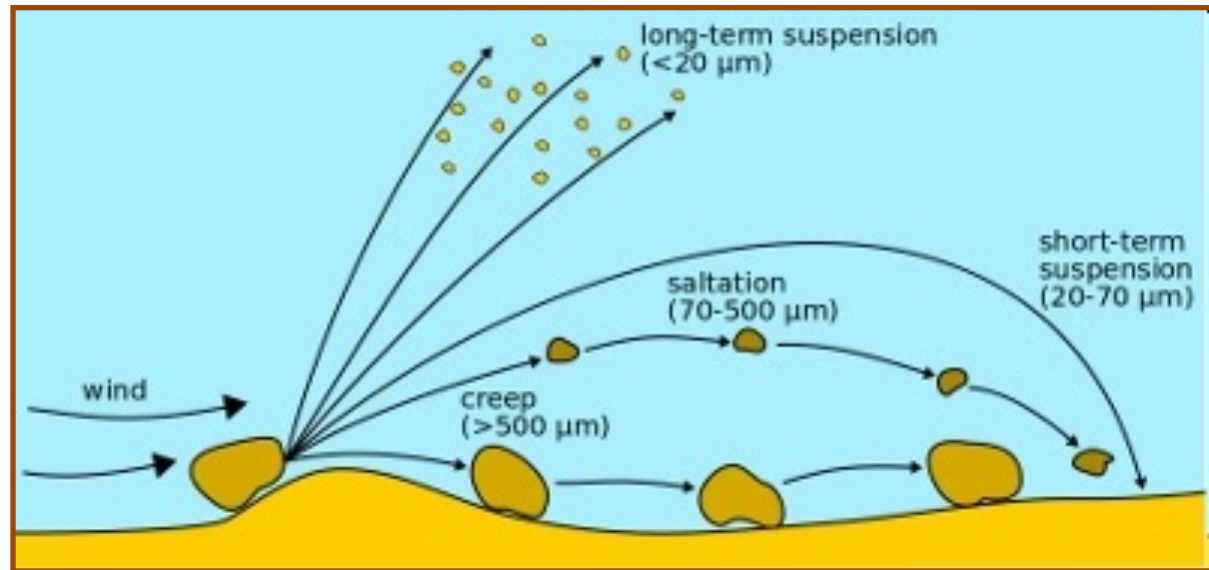
MODIS. 4 Feb 2013

The dust cycle



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

Emission



Land factors

- Soil texture
- Soil humidity
- Vegetation

Meteorological factors

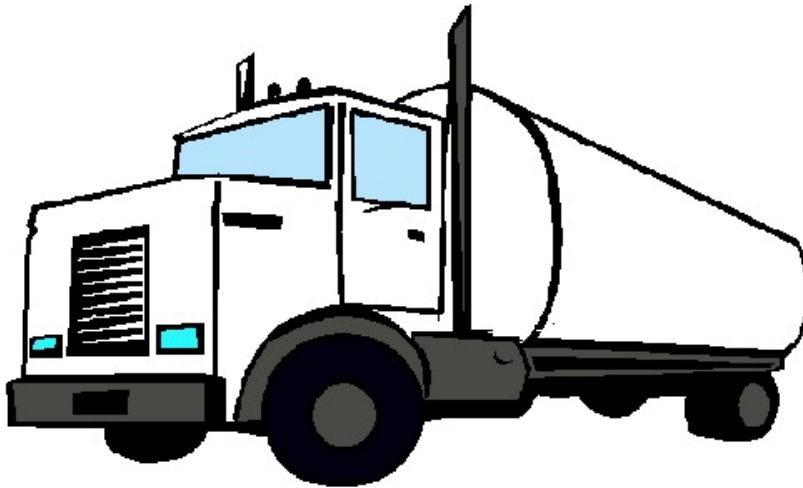
- Wind
- Near-surface turbulence

Mobilized dust

$\sim 30,000 - 60,000 \text{ kg / s}$

$\sim 1 - 3 \cdot 10^{12} \text{ kg / yr}$

50,000,000 trucks



3,000 ULCC

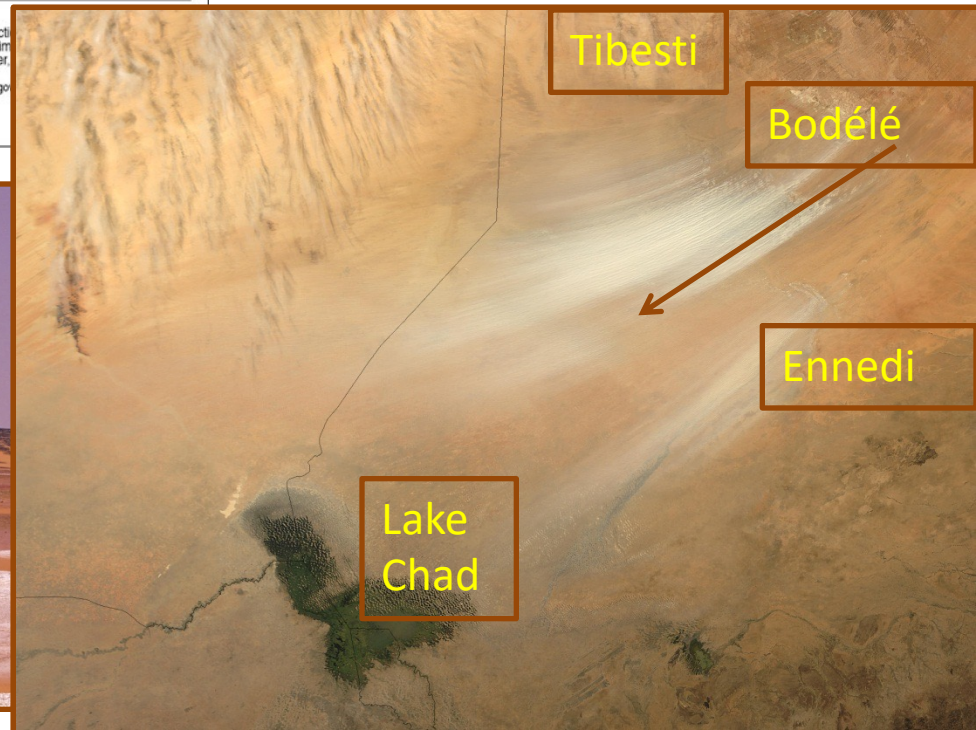
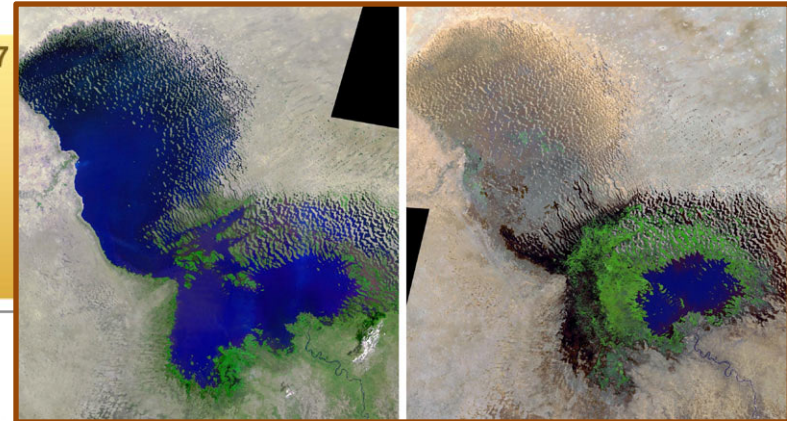
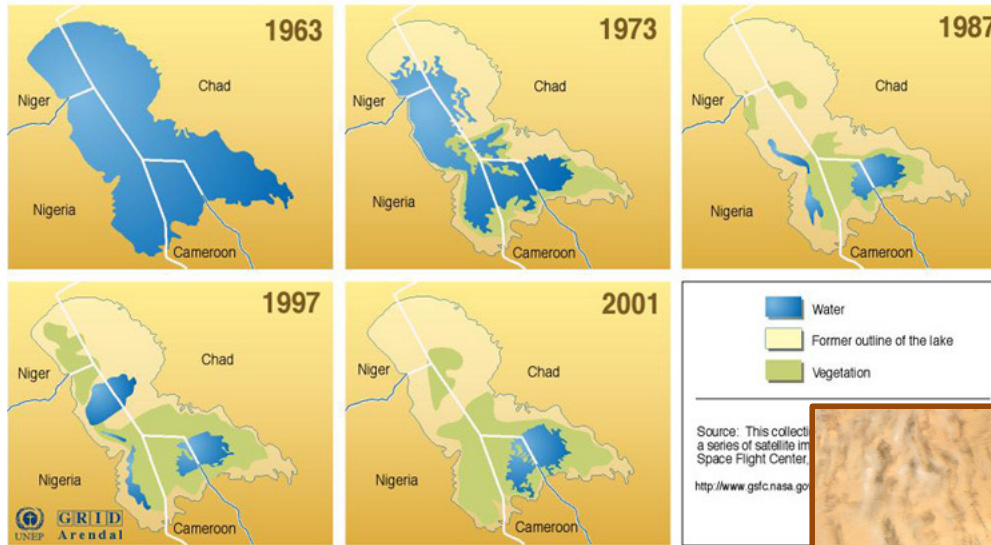


Dust sources

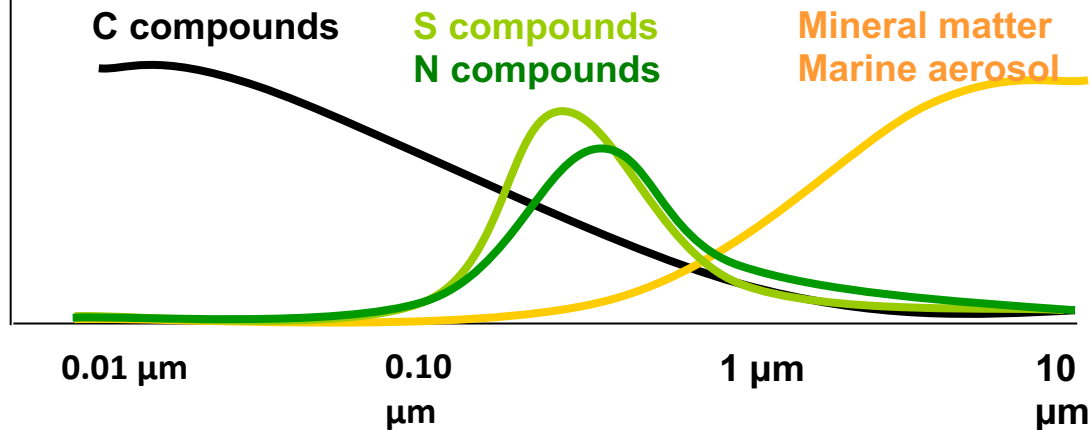


The Bodélé depression

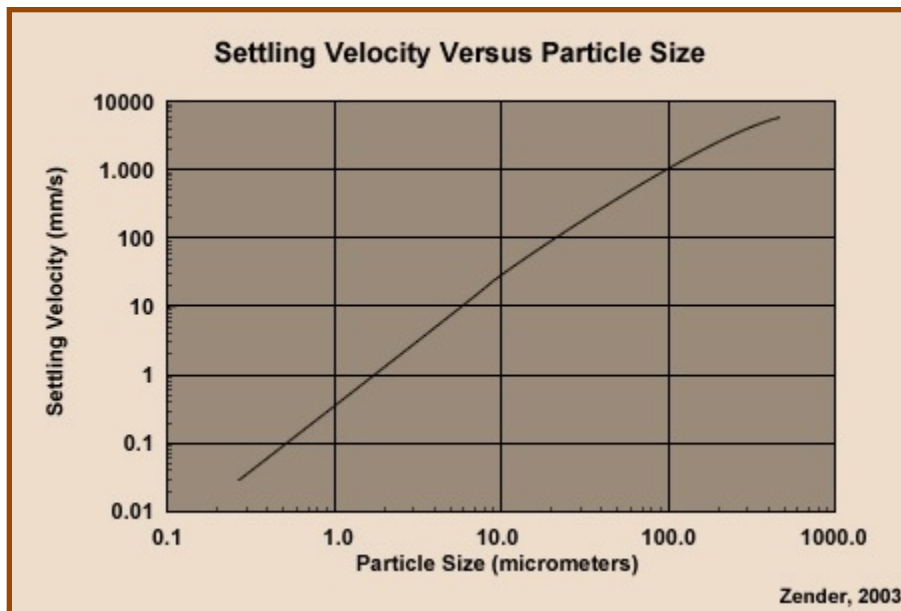
The Disappearance of Lake Chad in Africa



Dry deposition



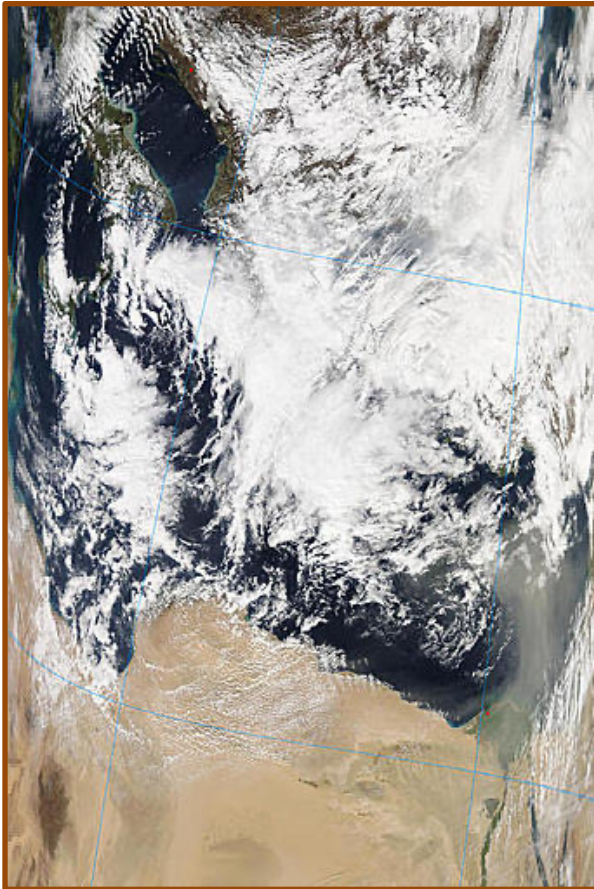
Warneck (1988), Harrison and Van Grieken (1998)



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

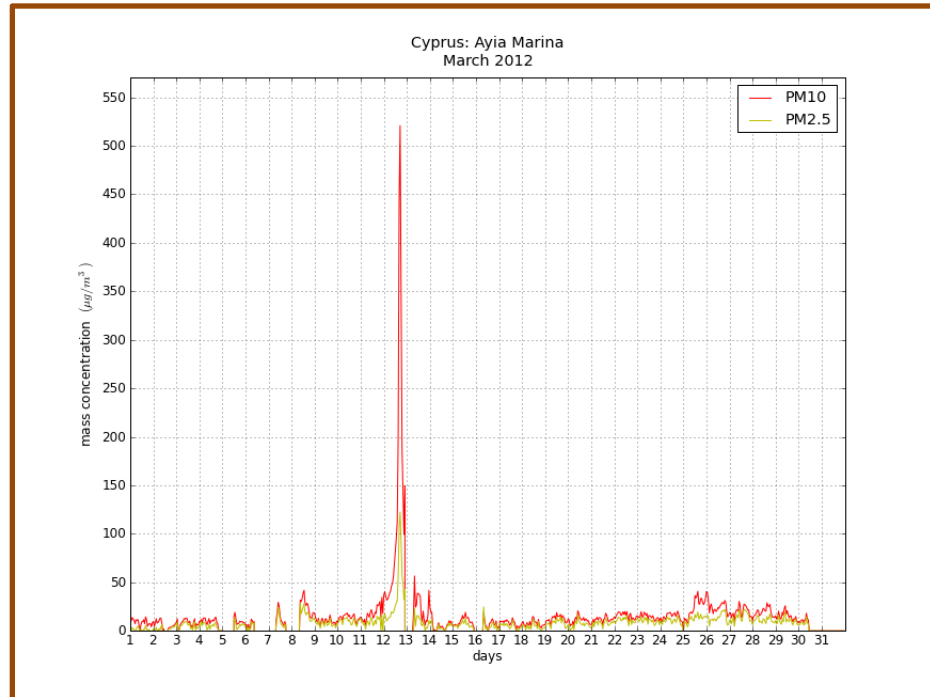
Tegen and Lacis (1996)

Wet deposition

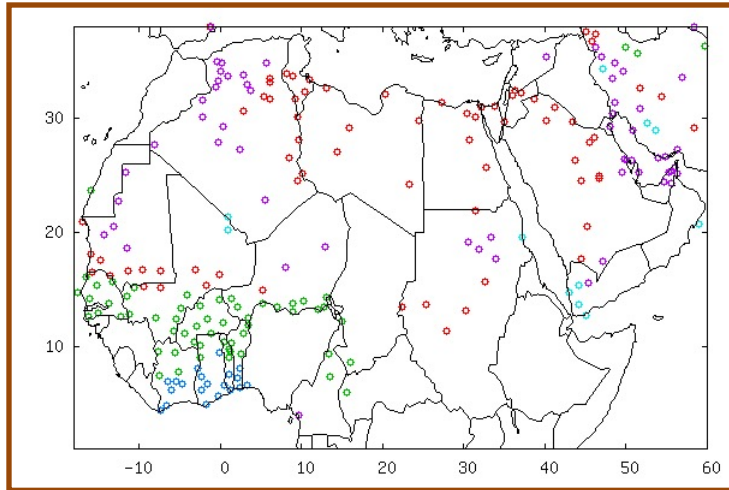


MODIS 12 Mar 2012

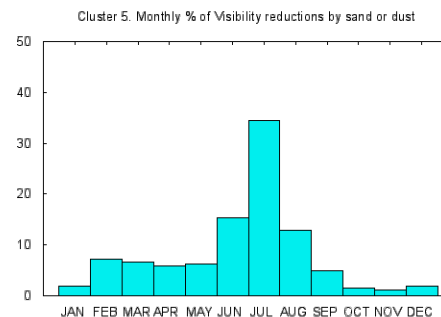
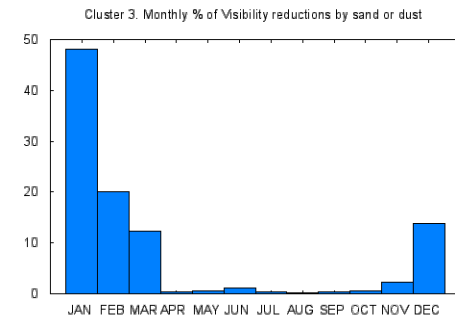
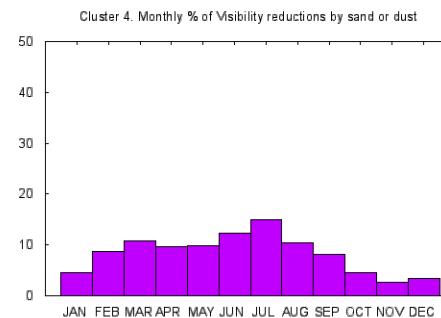
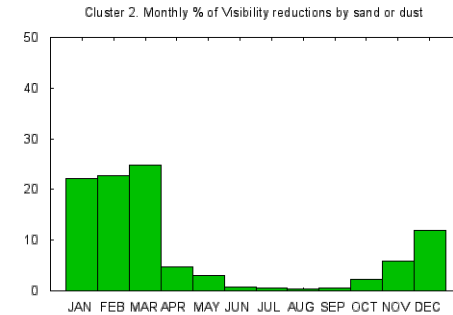
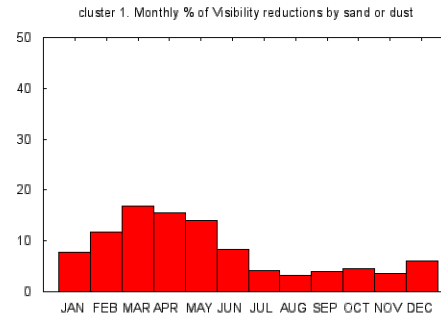
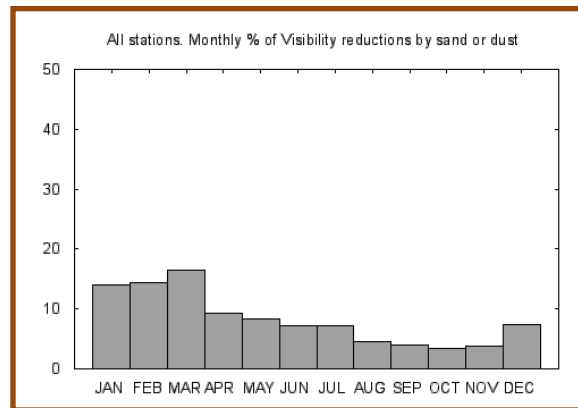
Ayia Marina (Cyprus)
March 2012



Seasonal variability



1996-2010



Terradellas et al. (2012)

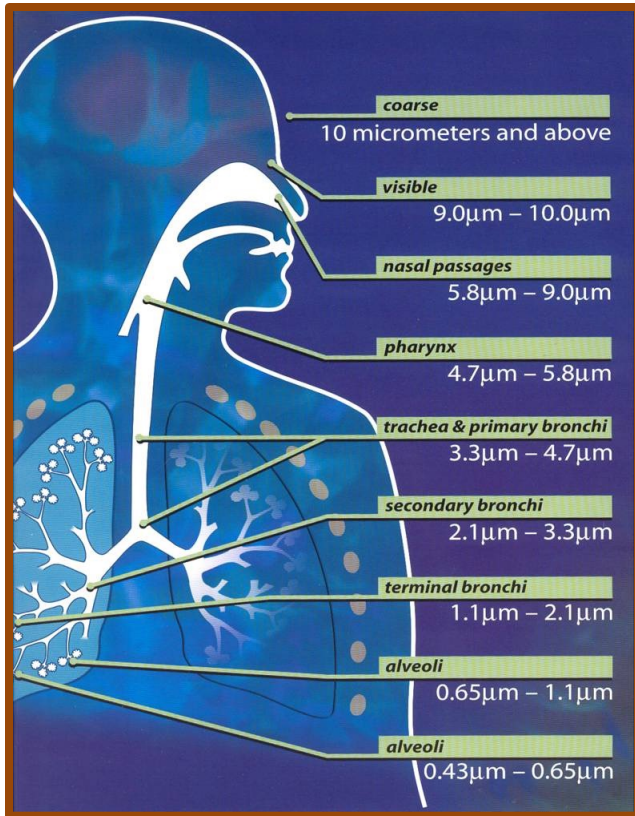
Impacts of atmospheric dust

- Health
- Weather and climate
- Transport (visibility reduction)
- Energy generation
- Agriculture, forestry, fishing
- ...

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



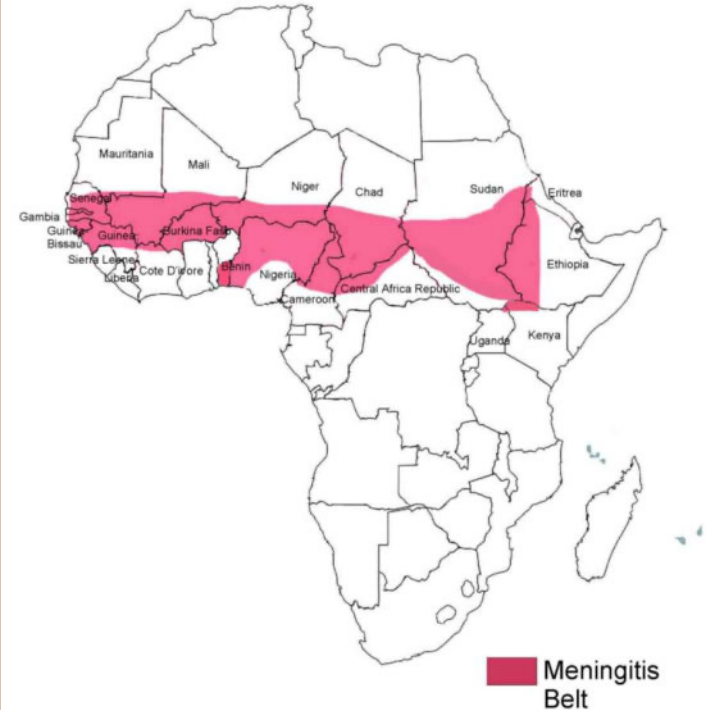
Health



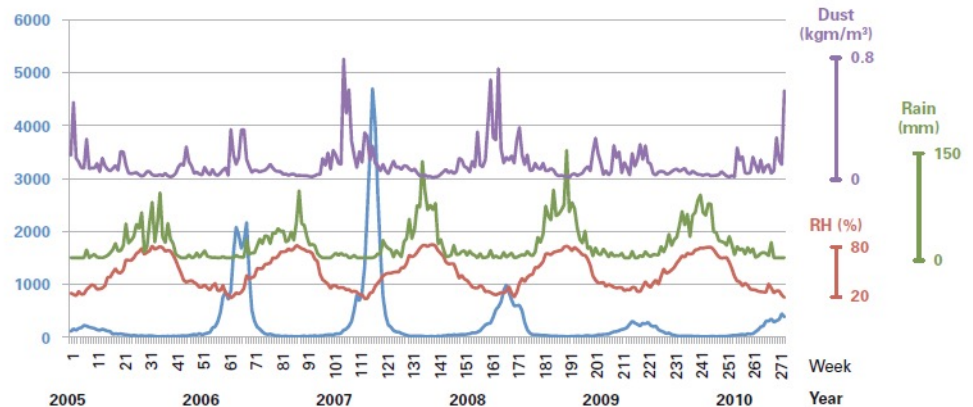
Burkina Faso



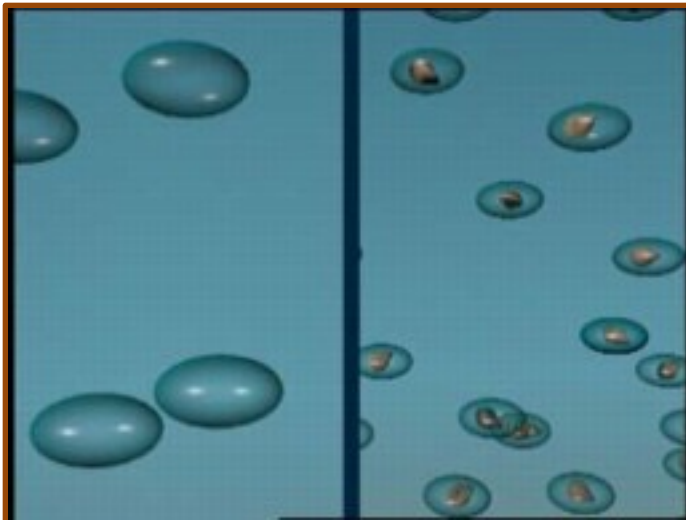
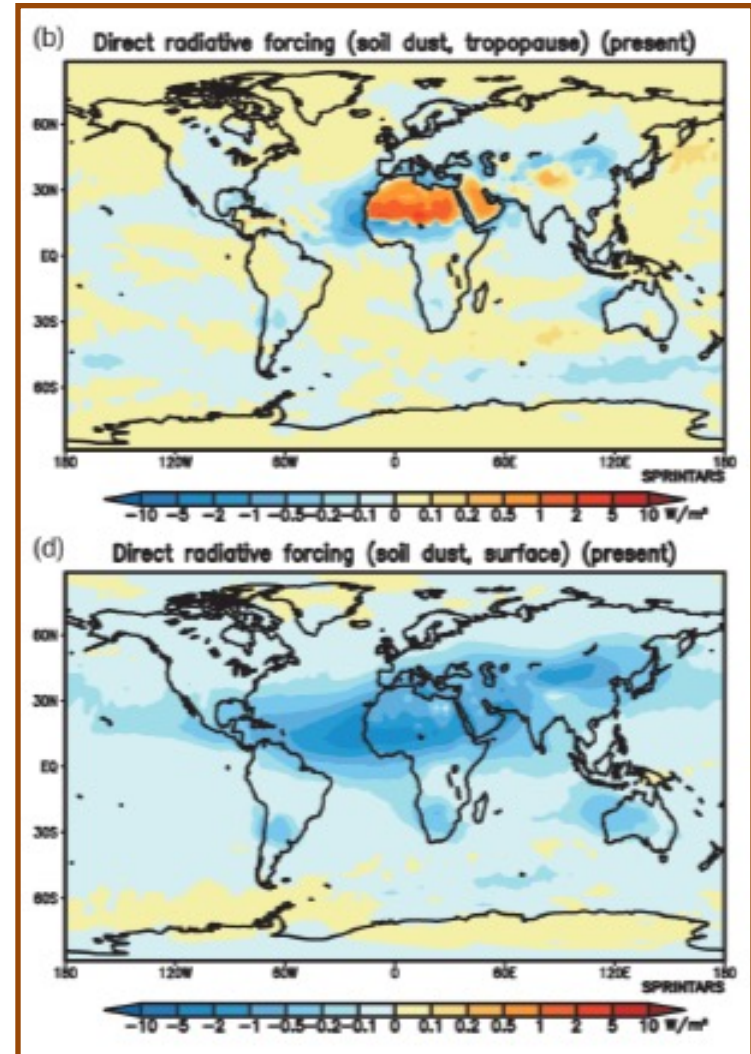
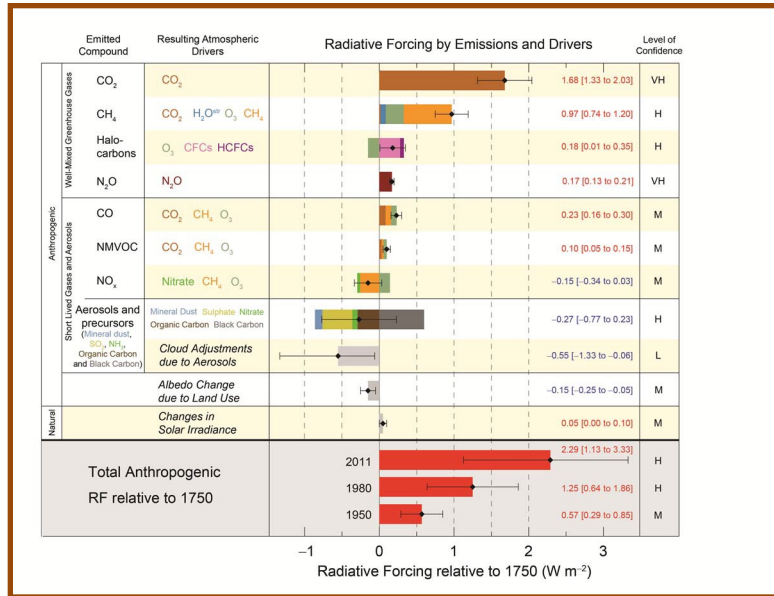
African Meningitis Belt



Meningitis cases per week

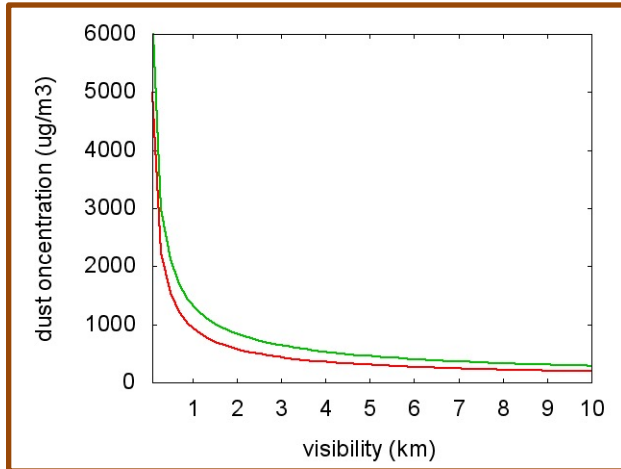


Weather and climate



Takemura et al. (2009)

Transport



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



Tunisia - 7 May 2002

Generation of solar energy

- Reduction of the available energy
- Reduction of the efficiency



Agriculture – Forestry - Fishing



WMO SDS-WAS

Mission:

Improve the capacity of countries to produce and distribute to end users accurate forecasts of the mineral dust content in the atmosphere

Structure:

- Regional Center for Northern Africa, Middle East and Europe. Barcelona, Spain
- Regional Center for Asia, Beijing, China
- Regional Center for Pan America, Univ. Arizona, U.S.A.
- Regional Center for West Asia (??)

Regional Center NA-ME-E

The Center is managed by a consortium of AEMET and the Barcelona Supercomputing Center (BSC-CNS)



MINISTERIO
DE MEDIO AMBIENTE
Y MEDIO RURAL Y MARINO

AEMET
Agencia Estatal de Meteorología



**Barcelona
Supercomputing
Center**

Centro Nacional de Supercomputación

Nexus II Building. Barcelona

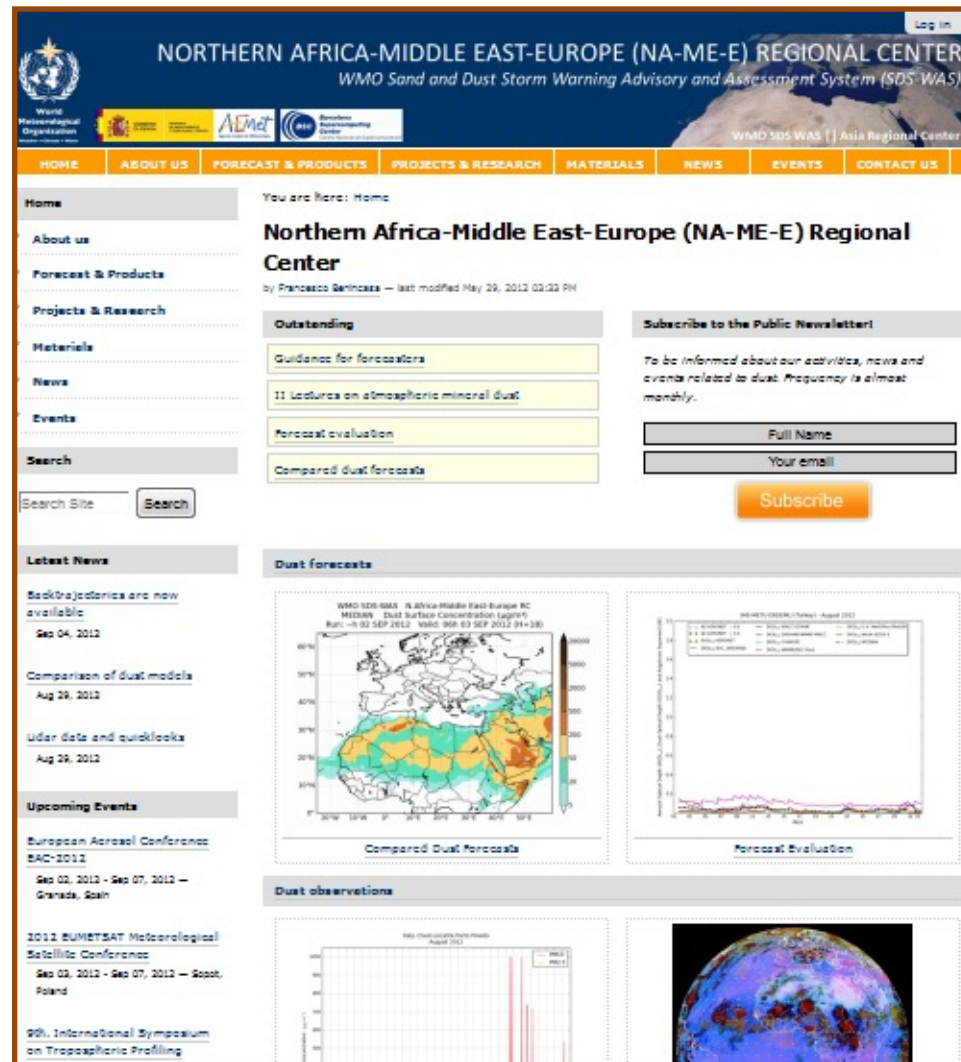


MareNostrum – 3 supercomputer



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

The dust cycle



The screenshot shows the homepage of the Northern Africa-Middle East-Europe (NA-ME-E) Regional Center for the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS). The header includes the WMO logo and the center's name. A navigation bar contains links: HOME, ABOUT US, FORECAST & PRODUCTS, PROJECTS & RESEARCH, MATERIALS, NEWS, EVENTS, and CONTACT US. A sidebar on the left lists categories: Home, About us, Forecast & Products, Projects & Research, Materials, News, Events, and a Search box. The main content area features a title 'Northern Africa-Middle East-Europe (NA-ME-E) Regional Center' and a list of 'Outstanding' items: 'Guidance for forecasters', '11 lectures on atmospheric mineral dust', 'Forecast evaluation', and 'Compared dust forecasts'. A 'Subscribe to the Public Newsletter!' section is on the right. Below, there are sections for 'Latest News' (listing articles like 'Sedimentation and now available' and 'Comparison of dust models'), 'Upcoming Events' (listing conferences like 'European Aerosol Conference EAC-2012'), 'Dust forecasts' (showing a map of dust concentration and a line graph of forecast evaluation), and 'Dust observations' (showing a line graph of dust observations and a satellite image of dust over the Middle East).

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Operational forecasts



**Barcelona
Supercomputing
Center**
Centro Nacional de Supercomputación

May 2013. The WMO designates the consortium of AEMET and the BSC to host the first Regional Specialized Meteorological Center with activity specialization on Atmospheric Sand and Dust Forecast (RSMC-ASDF). The Center shall operationally generate and distribute dust predictions for Northern Africa, Middle East and Europe.

Feb 2014. The Barcelona Dust Forecast Center (BDFC) is created to be this RSMC-ASDF




Jun 2014. The BDFC is publicly presented

<http://dust.aemet.es>



The dust cycle

Log in Register

BARCELONA DUST FORECAST CENTER



Barcelona
Supercomputing
Center
Centro Nacional de Supercomputación



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LATEST NEWS

Establishing a WMO SDS-WAS Regional Node for West Asia

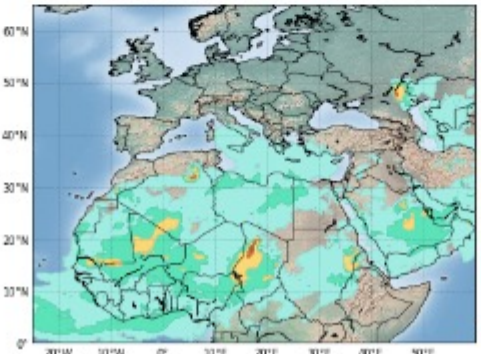
Training events in Muscat, Oman

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
NMMS/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](#)

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- Atmospheric aerosol
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- **Observation of atmospheric dust**
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Why do we need dust observations?

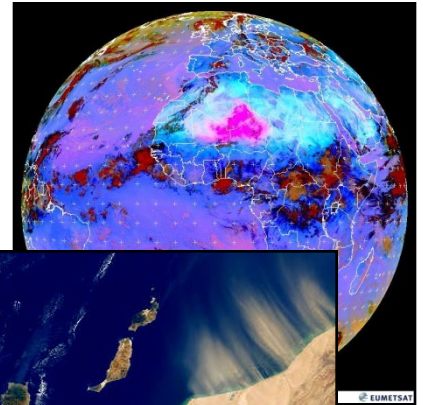
- **Dust monitoring**
- **Evaluation of numerical dust forecasts**
- **Data assimilation into dust models**
- **Validation of other observations (i. e. ground observations to validate satellite products)**

Mali, 2001

Photo: Remi Benali/Corbis

A comprehensive observing system

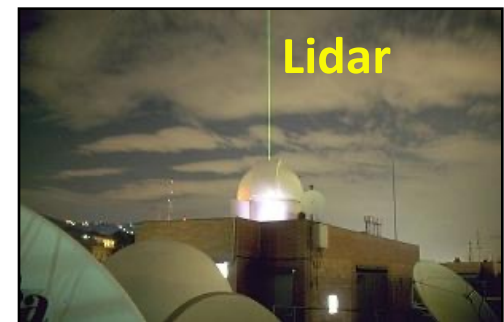
- Ground observations
 - In-situ
 - Indirect obs.: visibility
 - Sun photometers
 - Lidar – ceilometers
- Satellite observations



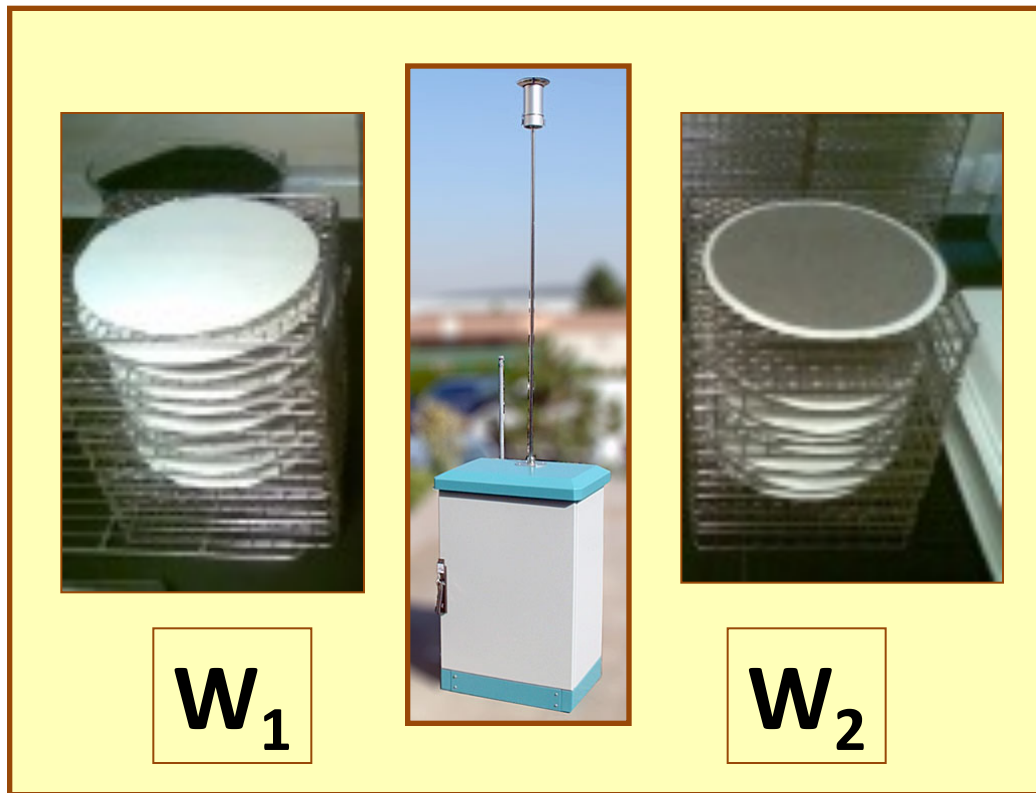
AQ station



Transmissometer



In-situ measurements of PM10 and PM2.5 in AQ monitoring stations



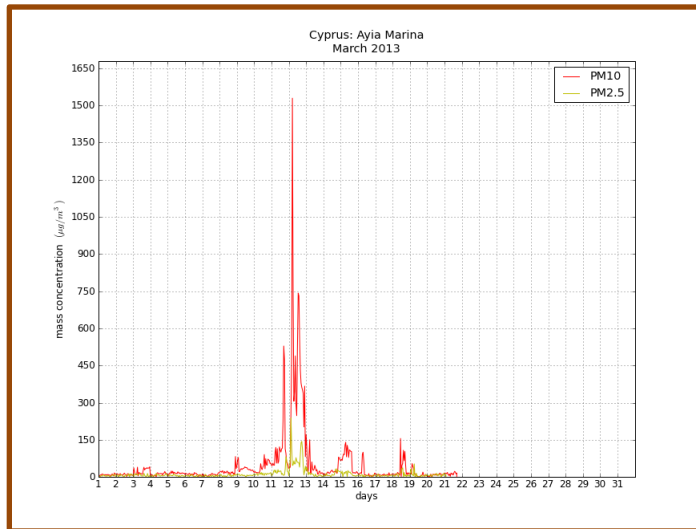
$$PM = \frac{(W_2 - W_1)}{\text{Volumen}} \mu\text{g}/\text{m}^3$$



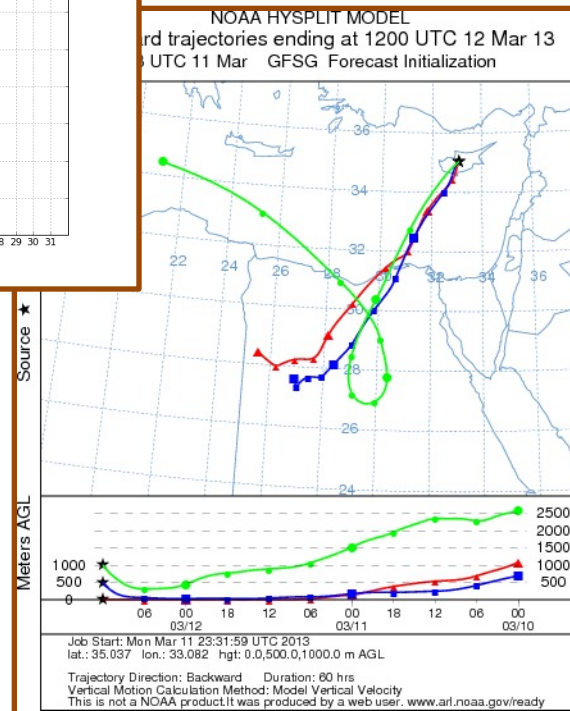
Monitoring dust events with in-situ observations



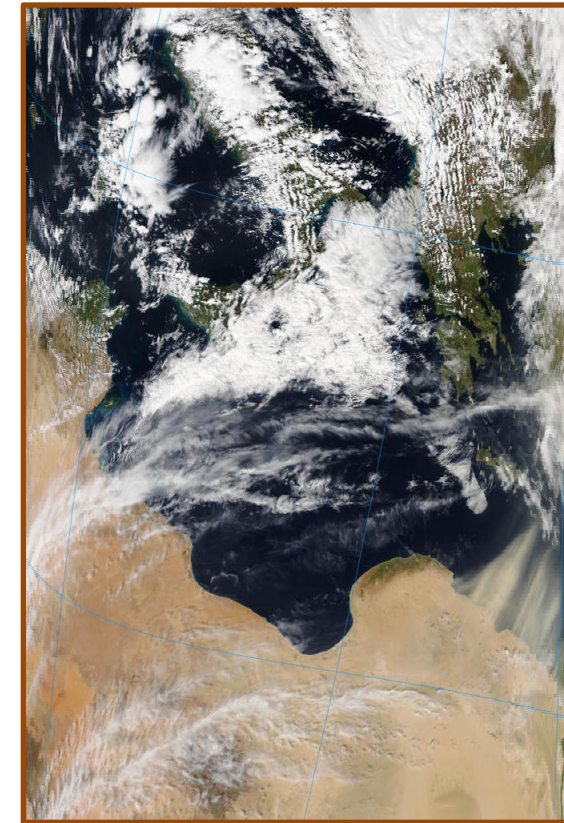
Monitoring dust events with in-situ observations



Mar 2013

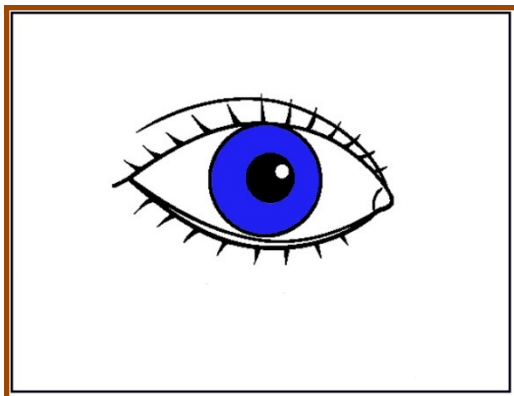


12 Mar 2013

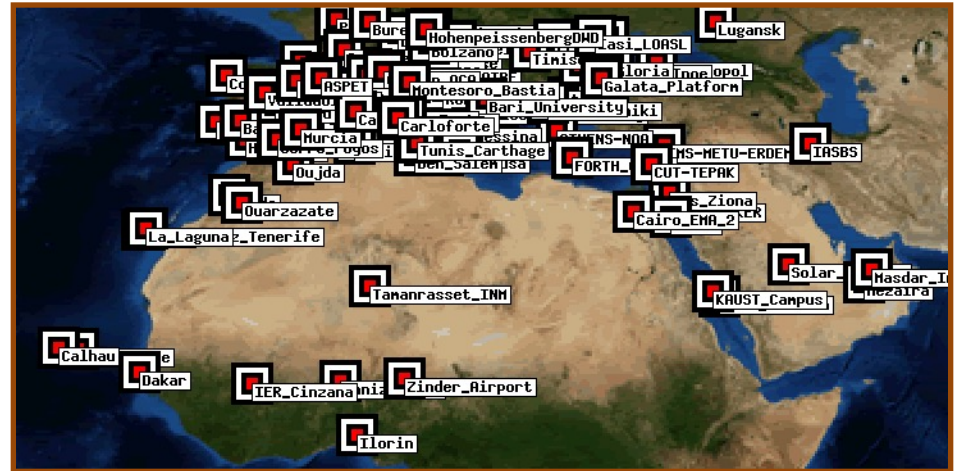


11 Mar 2013

Visibility and present weather from meteorological reports



Sun photometers

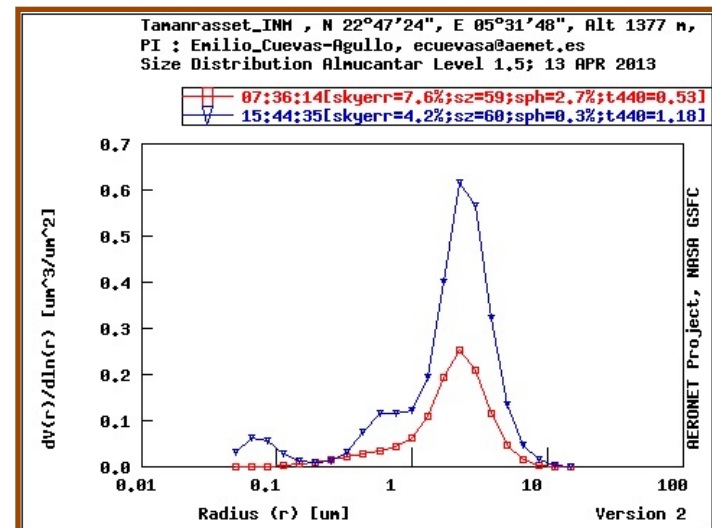
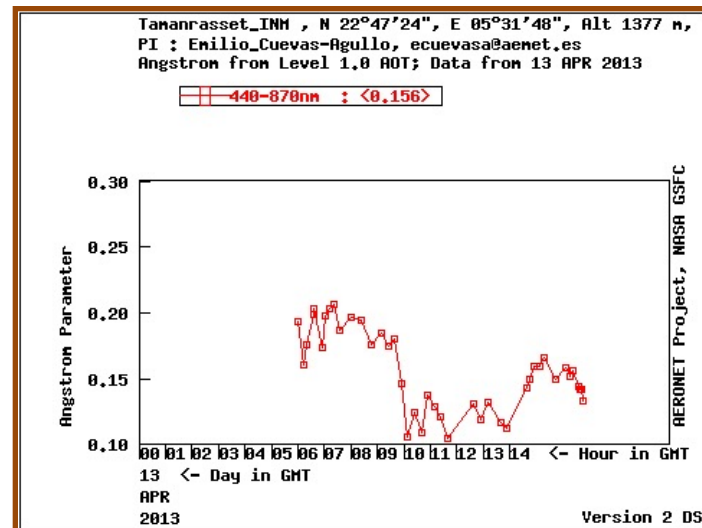
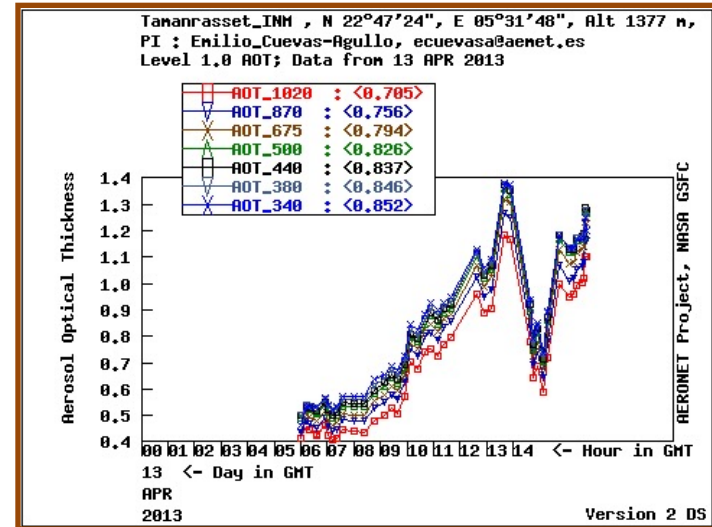
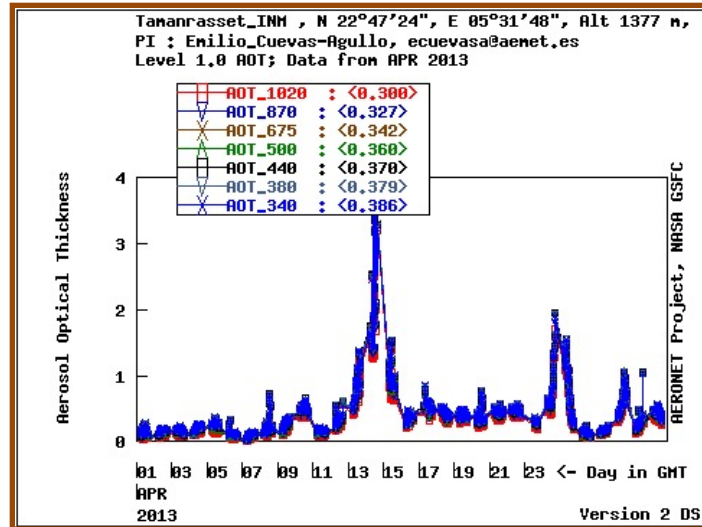


- Sun photometers measure direct solar radiation
- Radiation at the top of the atmosphere is known
- Particles dissipate energy due to absorption and scattering
- Information on the aerosol concentration can be derived from the radiation that reaches the Earth surface

SDS-Africa

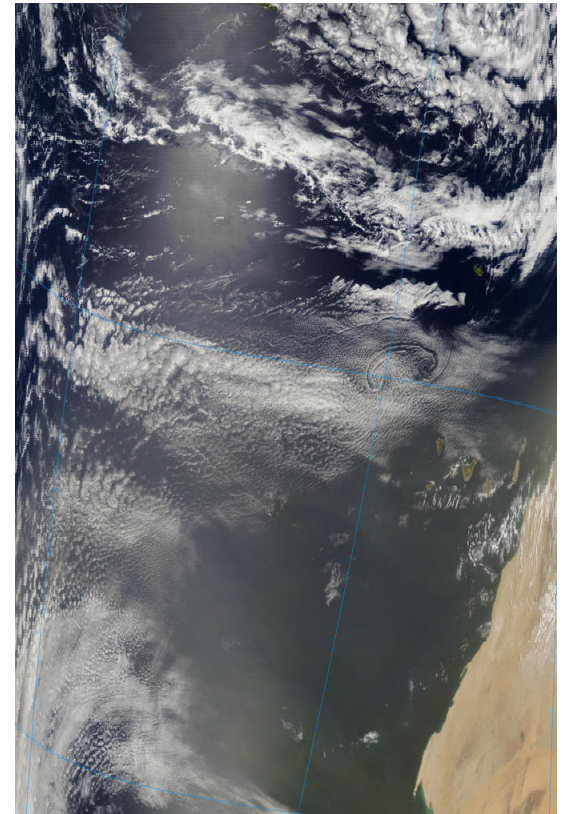
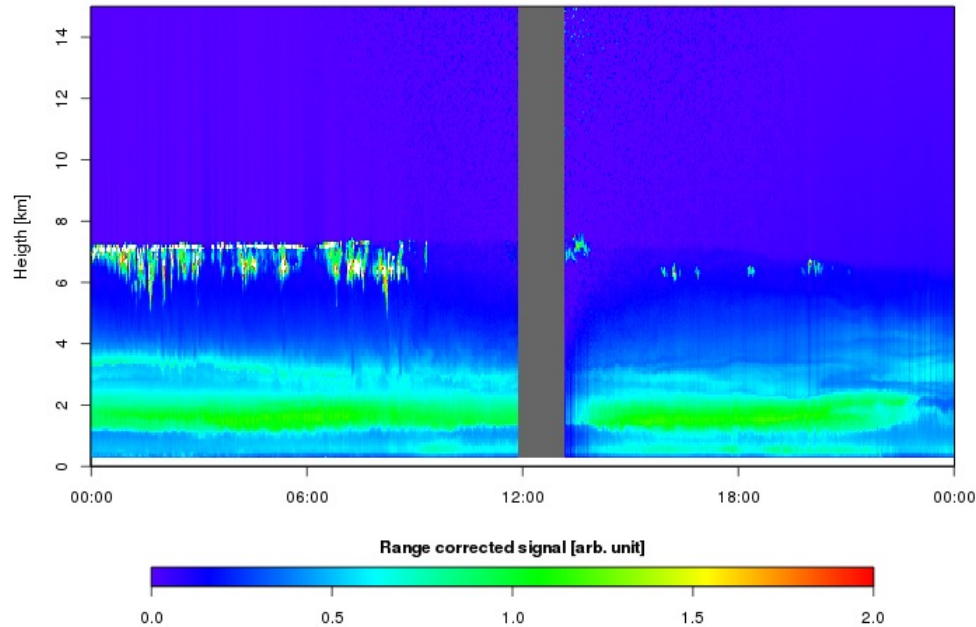


Monitoring dust events with AERONET data



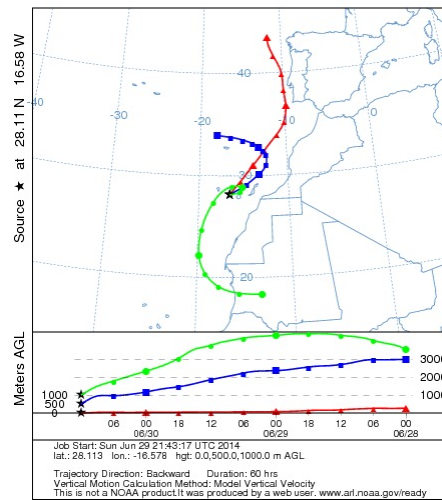
Lidar

MPL-3 S.C. de Tenerife 2014-07-01

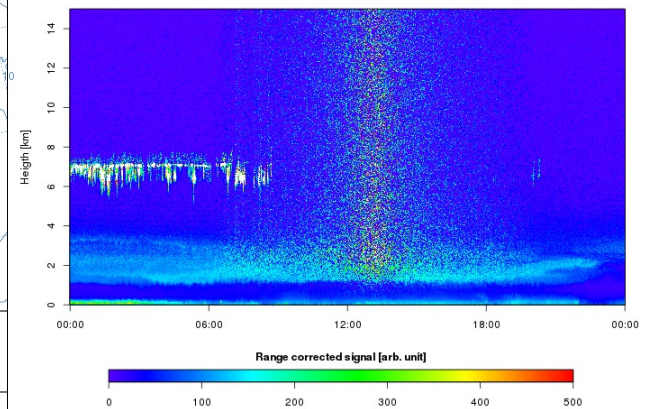


Santa Cruz de Tenerife, 1 Jul 2014

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 30 Jun 14
12 UTC 29 Jun GFS Forecast Initialization



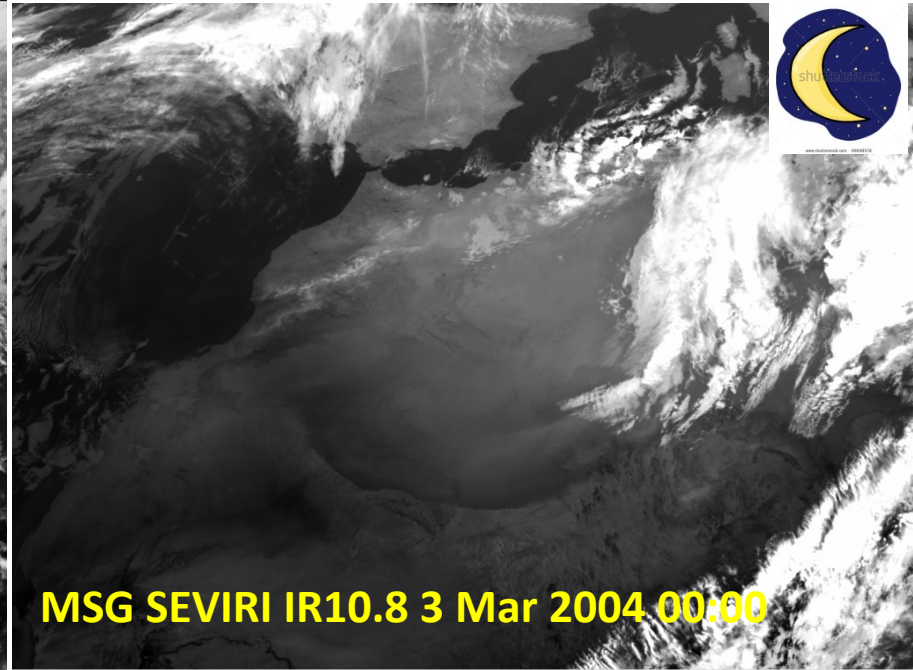
CL51 S.C. de Tenerife 2014-07-01



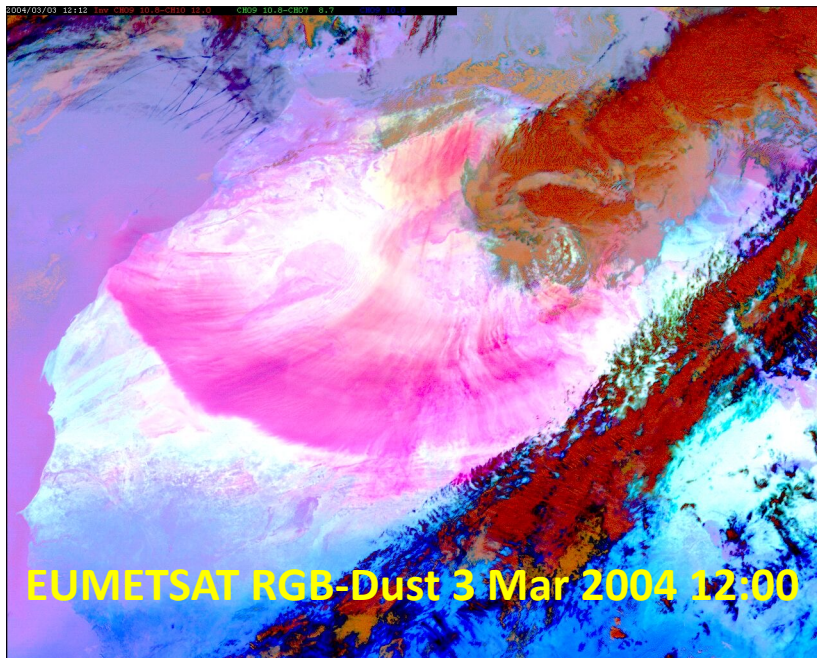
IR / RGB-Dust



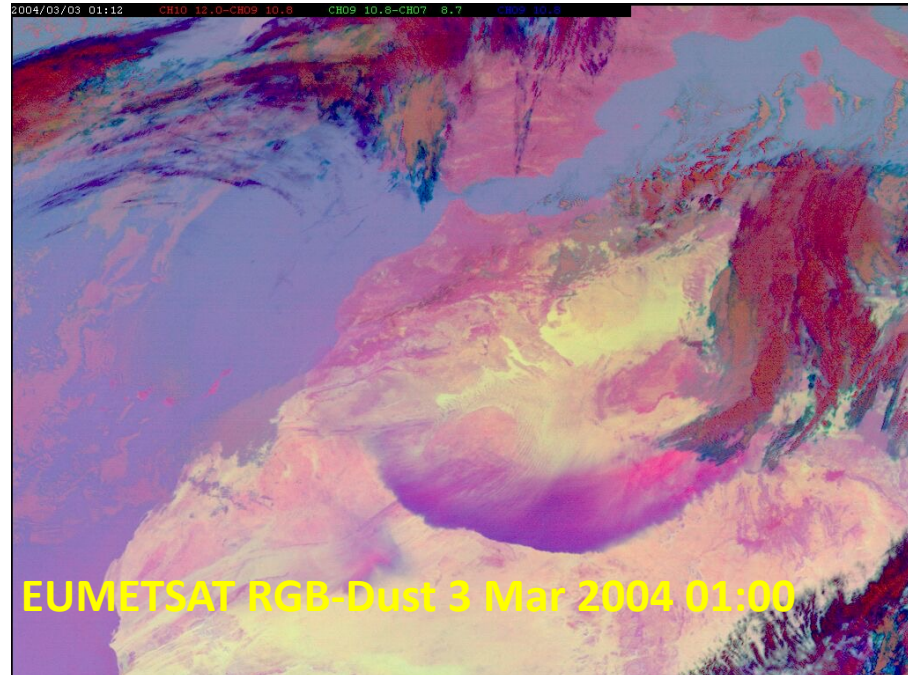
MSG SEVIRI IR10.8 3 Mar 2004 12:00



MSG SEVIRI IR10.8 3 Mar 2004 00:00

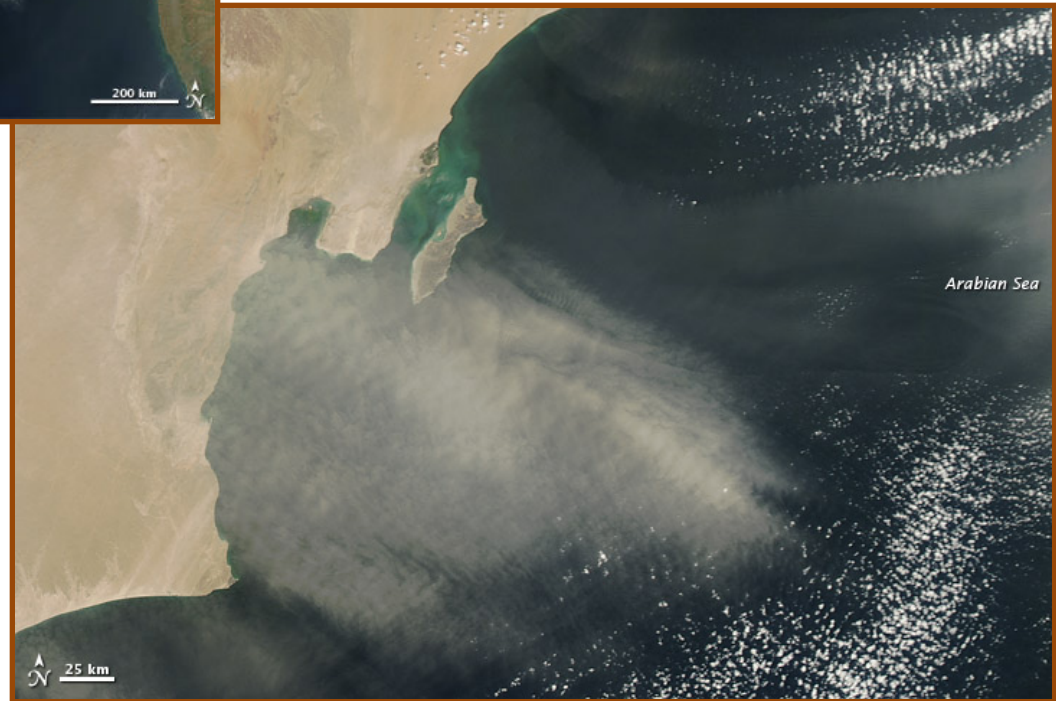
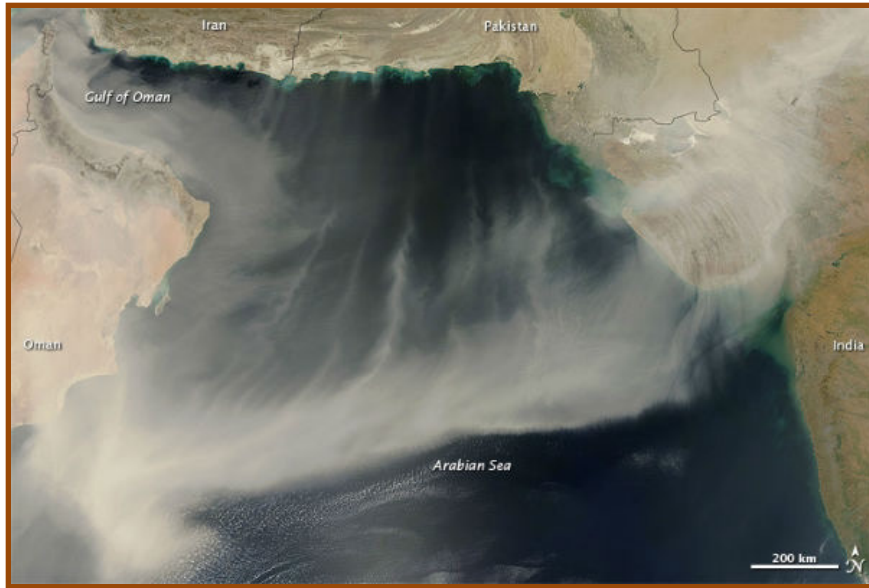


EUMETSAT RGB-Dust 3 Mar 2004 12:00

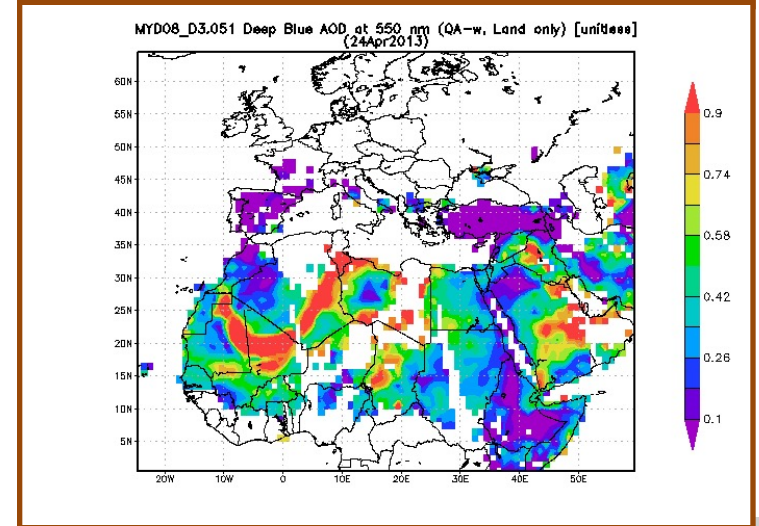
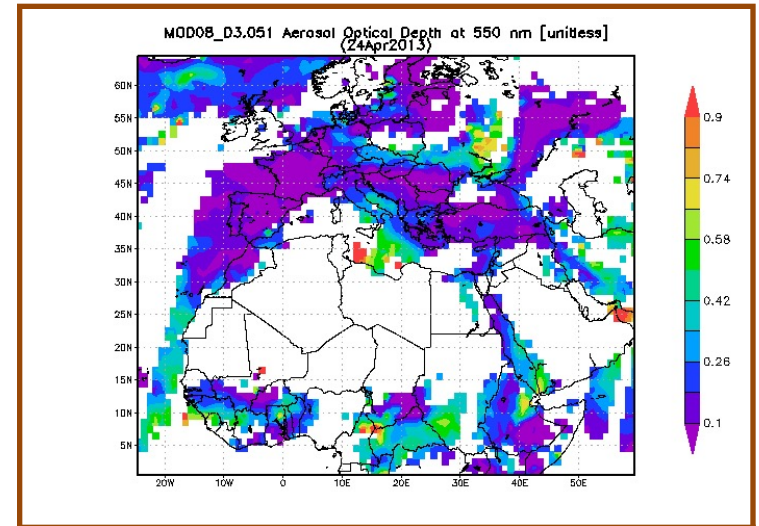
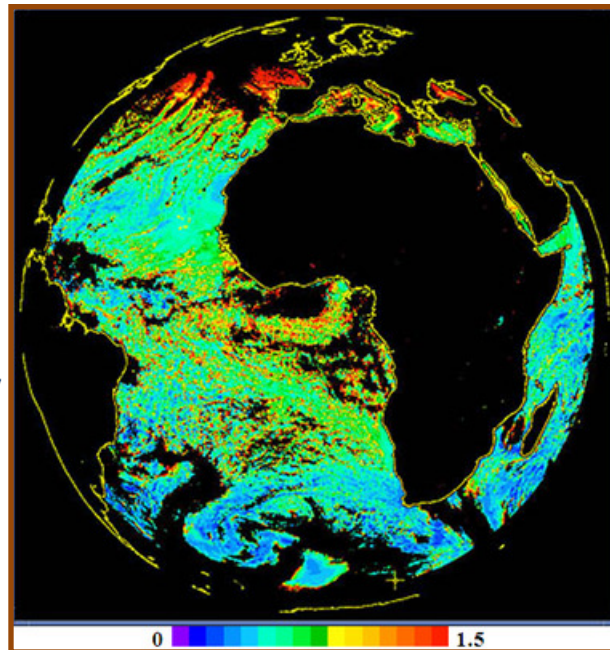
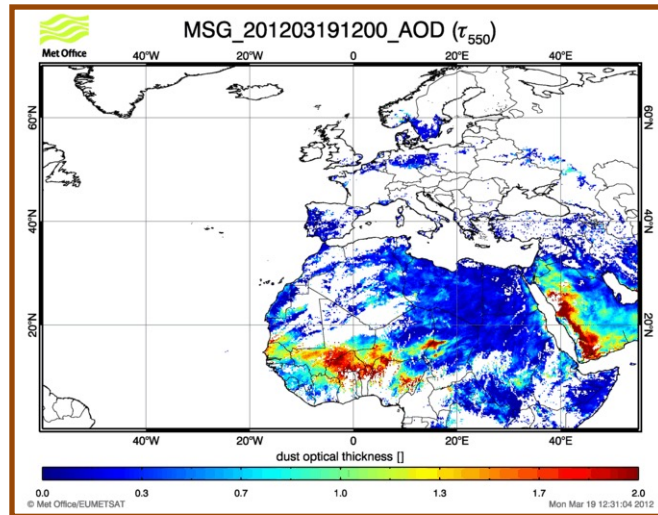


EUMETSAT RGB-Dust 3 Mar 2004 01:00

Other composites: MODIS



Quantitative estimations of AOD



GODDARD
SPACE FLIGHT CENTER

- Atmospheric aerosol
- The dust cycle
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- **Prediction of atmospheric dust**

WMO SDS-WAS Regional Center for
Northern Africa, Middle East and
Europe

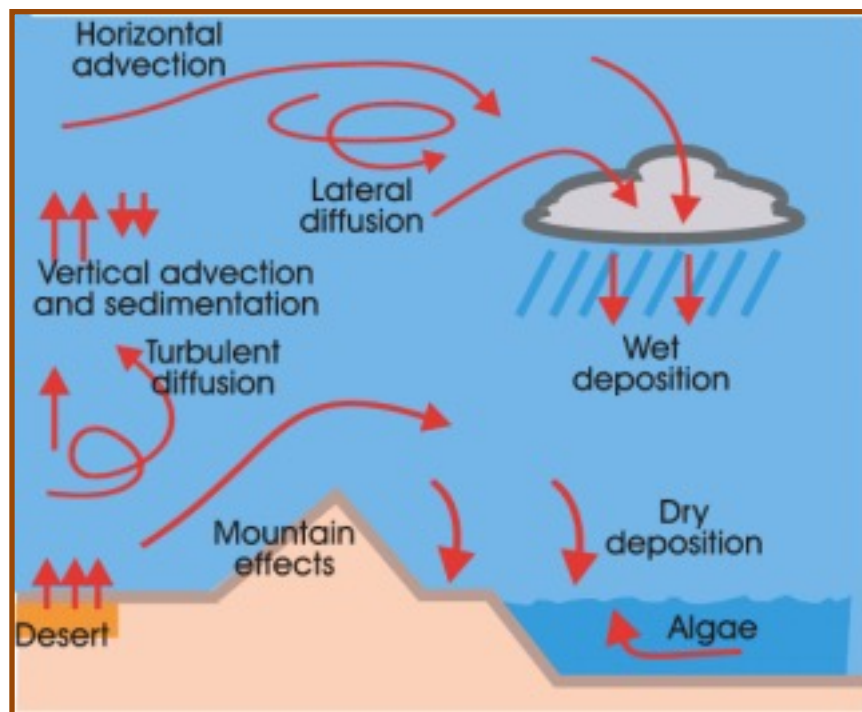
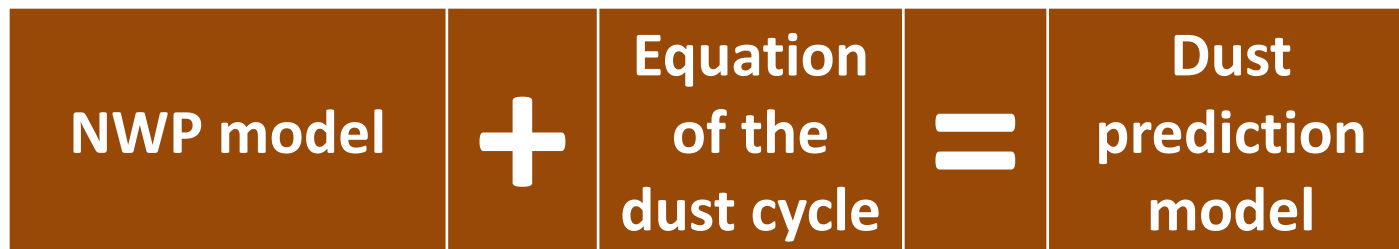
<http://sds-was.aemet.es>
sdswas@aemet.es

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Dust prediction models



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

- Interaction with radiation
- Interaction with cloud particles
- Atmospheric chemistry
- ...

Dust prediction: main problems

- Processes of very different scales
- Need for very precise wind prediction
- Lack of suitable observations for forecast evaluation and data assimilation

Tegen et al. (1994)

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

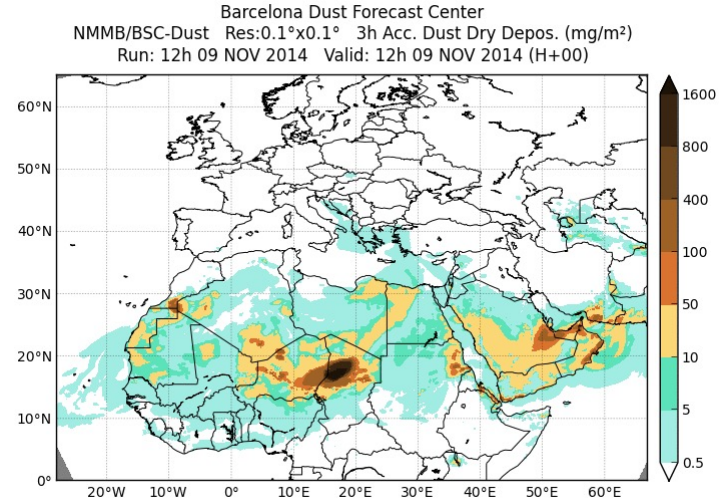
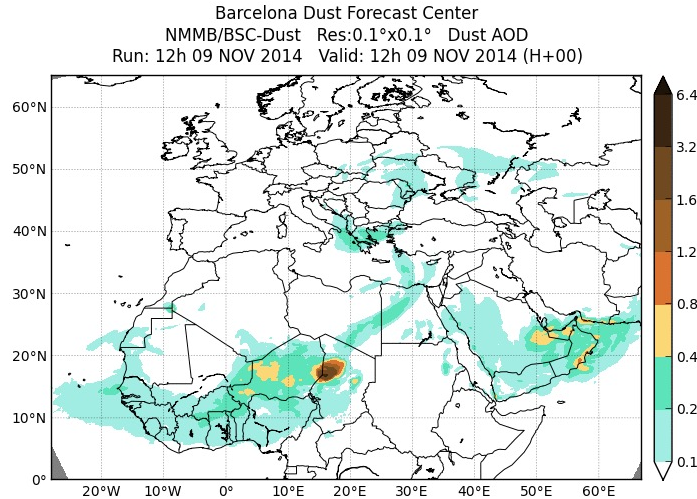
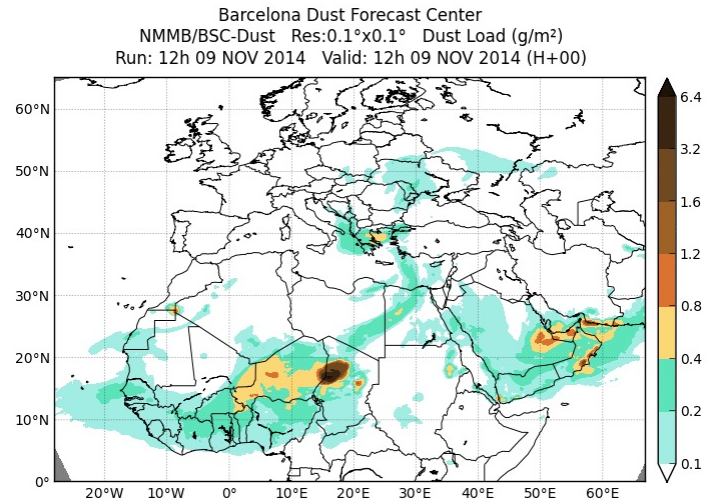
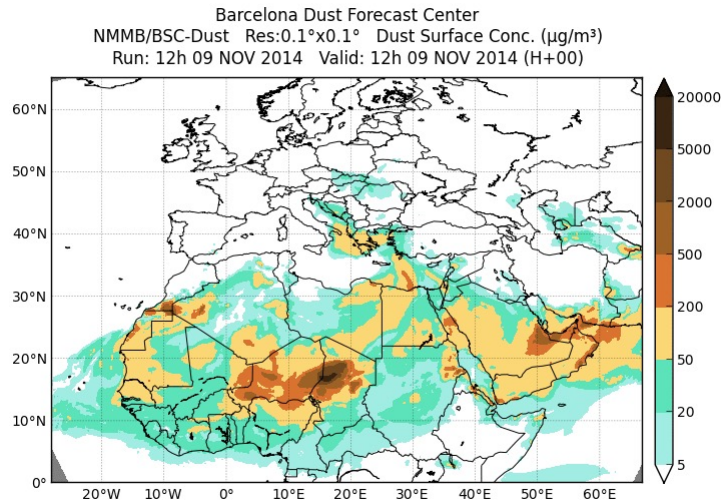
Marticorena et al. (1997)

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

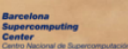
Ginoux et al. (2001)

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

Forecast products

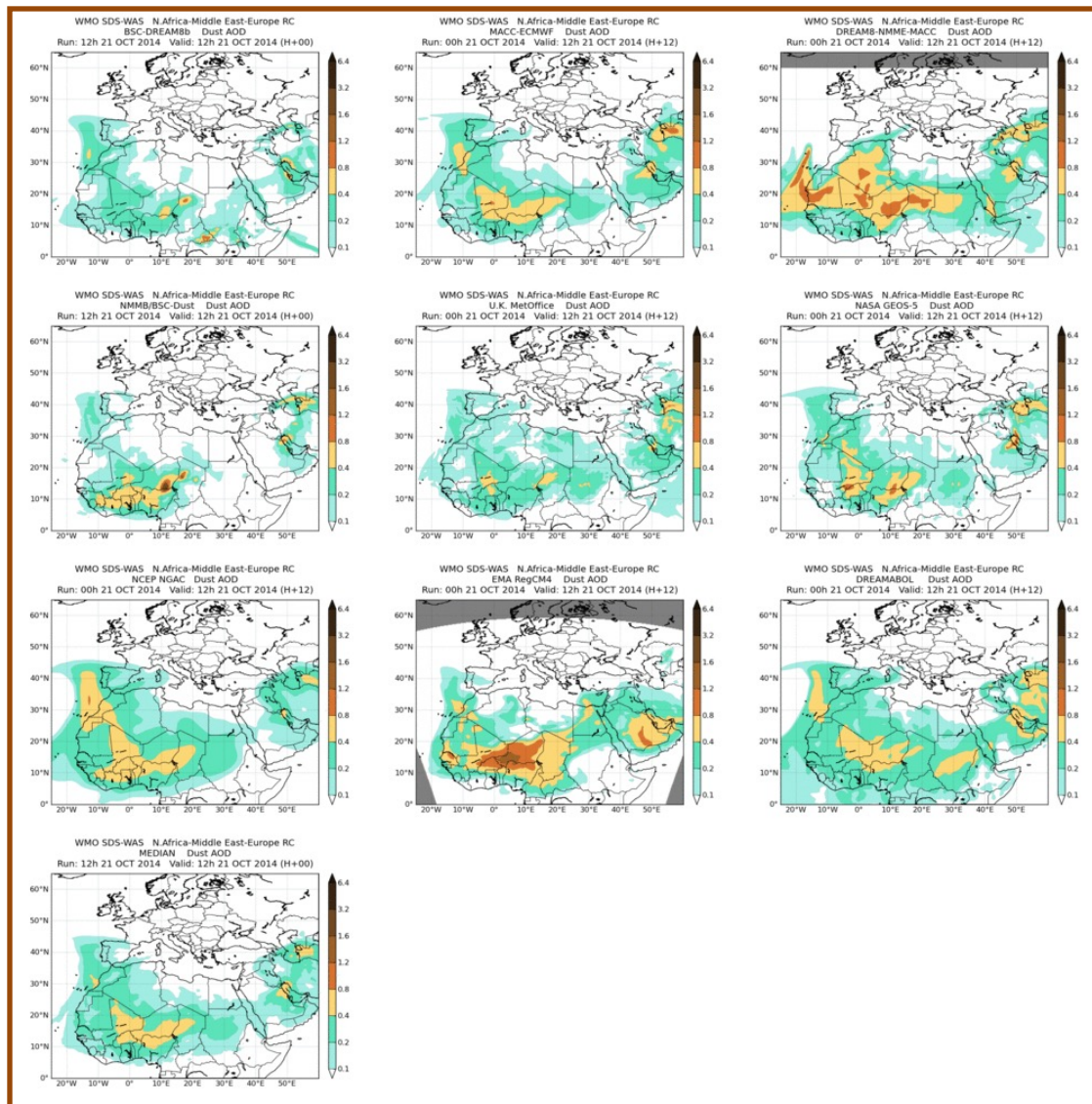


BARCELONA DUST FORECAST CENTER



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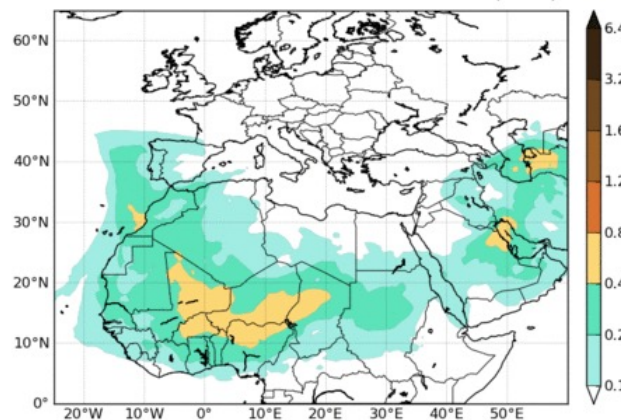
Dust optical depth at 550 nm



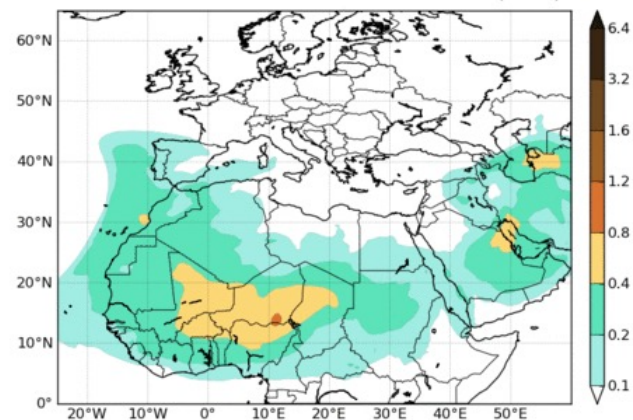
Dust optical Depth 550 nm. Models runtime: 21 Oct 2014

Multi-model products

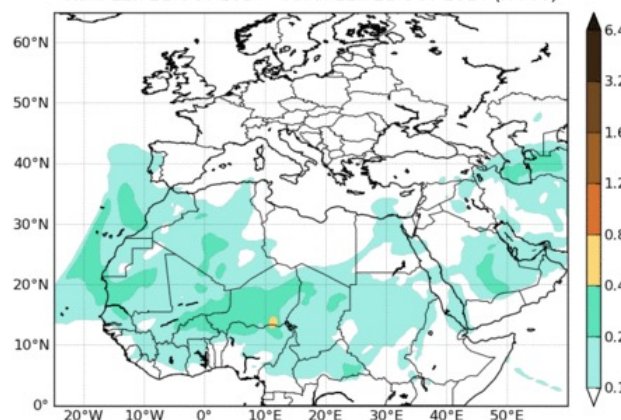
WMO SDS-WAS N.Africa-Middle East-Europe RC
MEDIAN Dust AOD
Run: 12h 21 OCT 2014 Valid: 12h 21 OCT 2014 (H+00)



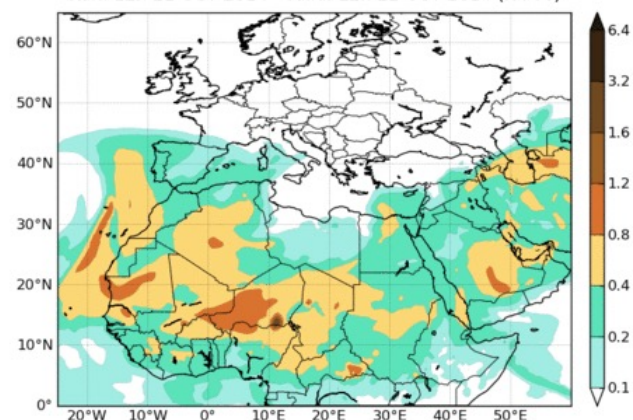
WMO SDS-WAS N.Africa-Middle East-Europe RC
MEAN Dust AOD
Run: 12h 21 OCT 2014 Valid: 12h 21 OCT 2014 (H+00)



WMO SDS-WAS N.Africa-Middle East-Europe RC
STDEV Dust AOD
Run: 12h 21 OCT 2014 Valid: 12h 21 OCT 2014 (H+00)

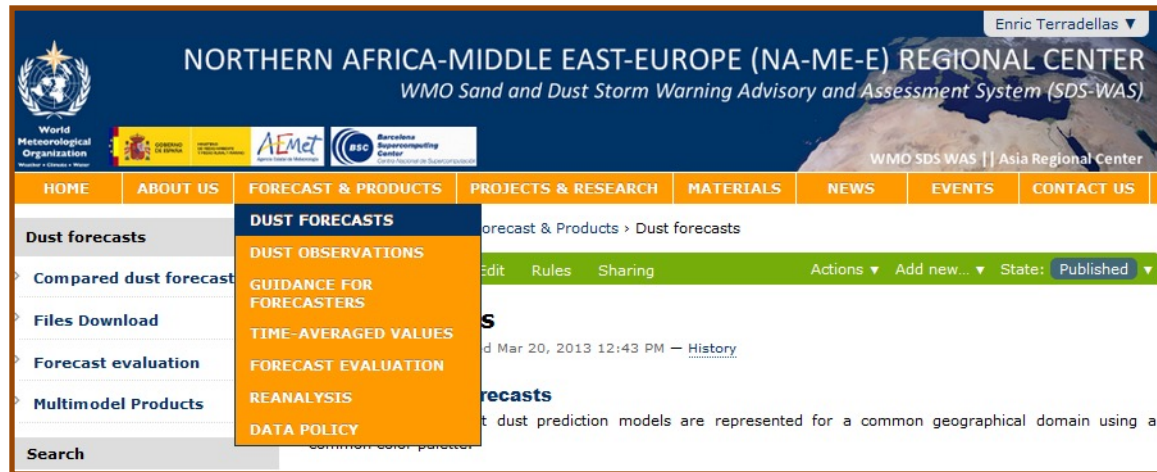


WMO SDS-WAS N.Africa-Middle East-Europe RC
RANGE Dust AOD
Run: 12h 21 OCT 2014 Valid: 12h 21 OCT 2014 (H+00)










Dust optical Depth 550 nm. Models runtime: 21 Oct 2014

Download of numerical forecasts



Sfc. Concentración
Dust AOD 550 μm

BSC-DREAMb v2.0	DOWNLOAD FILES	Model website	 Barcelona Supercomputing Center Centro Nacional de Supercomputación
MACC-ECMWF	DOWNLOAD FILES	Model website	 MACC Monitoring atmospheric composition & climate
DREAM-NMME-MACC	DOWNLOAD FILES	Model website	 SEEVCCC
NMMB/BSC-Dust	DOWNLOAD FILES	Model website	 Barcelona Supercomputing Center Centro Nacional de Supercomputación
NASA-GEOS-5	DOWNLOAD FILES	Model website	 NASA
NCEP-NGAC	DOWNLOAD FILES	Model website	 NCEP NATIONAL CENTER FOR ENVIRONMENTAL PREDICTION
Multimodel MEDIAN	DOWNLOAD FILES	Model website	 WMO World Meteorological Organization

netCDF format



Title	Size	Modified
latest - <i>(download all)</i>	4.0 kB	Apr 18, 2013 09:00 PM
2013 - <i>(download all)</i>	4.0 kB	Apr 01, 2013 09:00 PM
2012 - <i>(download all)</i>	4.0 kB	Apr 08, 2013 04:30 PM

Forecast evaluation with AERONET data



Model evaluation metrics. Seasonal scores

by Francesco Benincasa — last modified Mar 25, 2013 05:26 PM — History

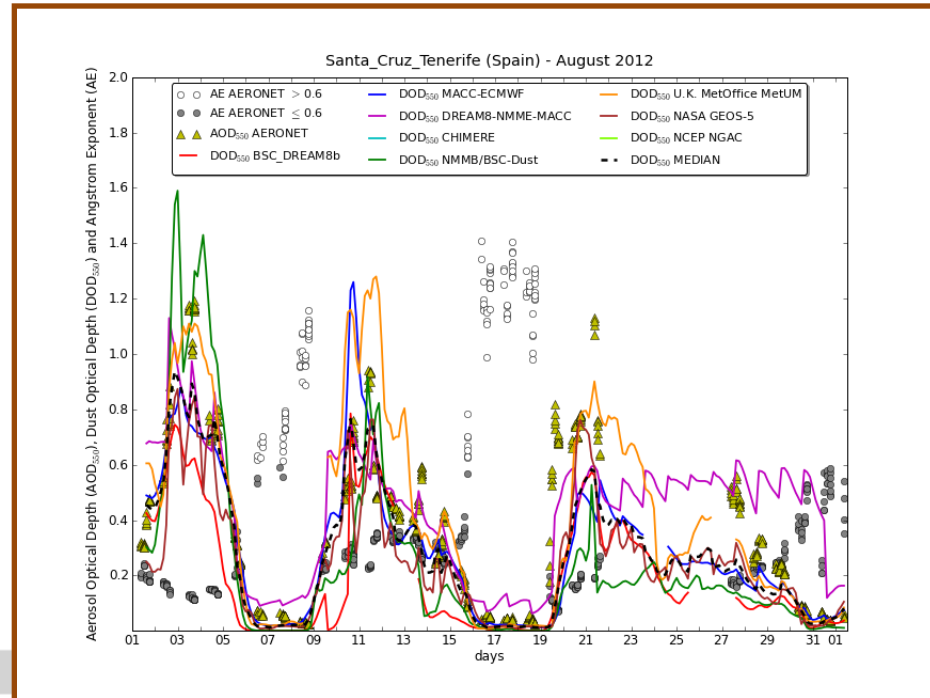
Date: - Select Year - - Select Season -

Dec 2012 - Feb 2013. Dust Optical Depth.

Threshold Angstrom Exponent = 0.600

BIAS

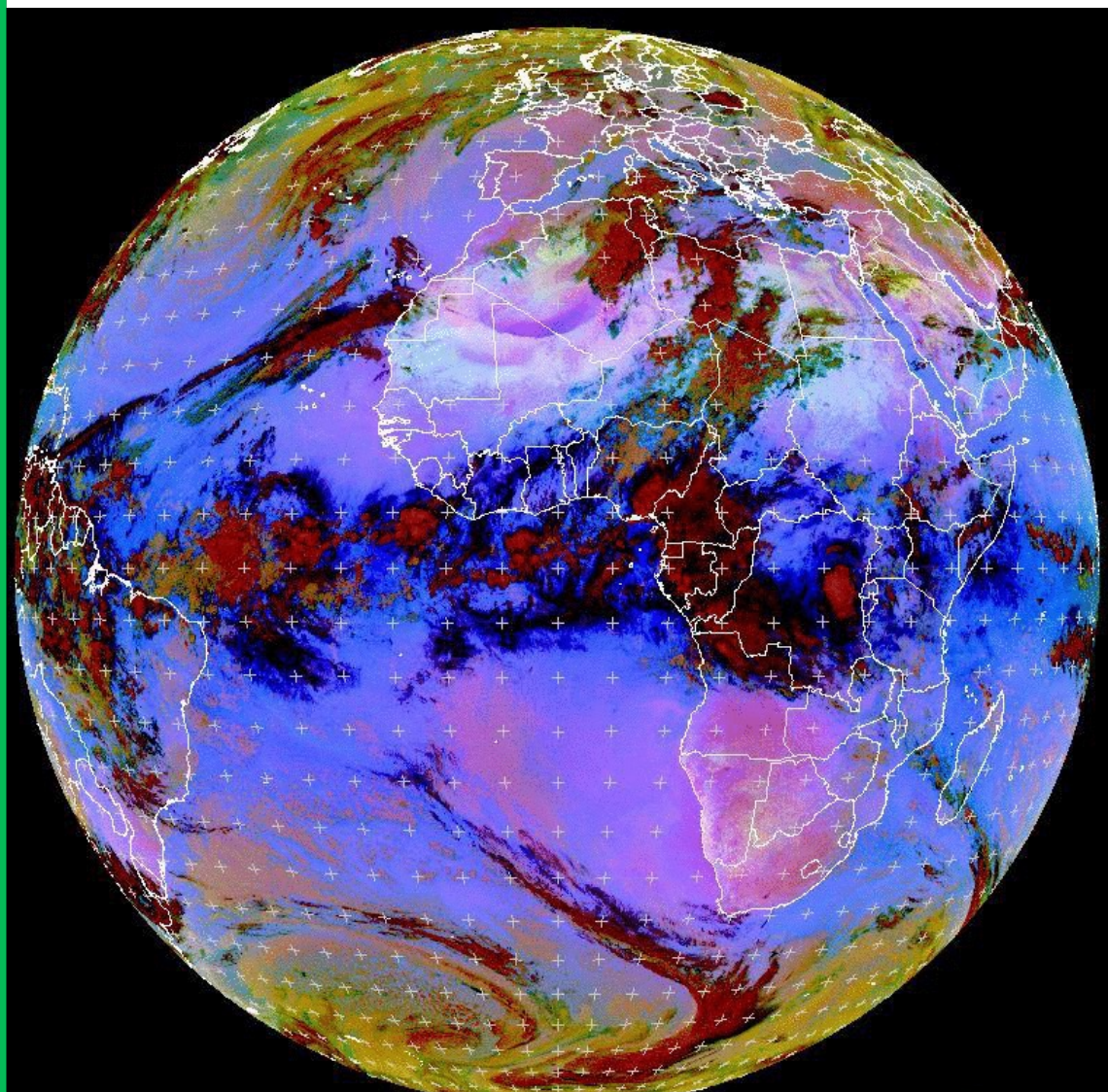
	BSC_ DREAM8b	MACC- ECMWF	DREAM8- NMME- MACC	NMMB/ BSC- Dust	U.K. Met Office	NASA GEOS-5	NCEP NGAC	MEDIAN
Sahel/Sahara show stations	-0.18	-0.14	-0.14	-0.09	0.00	-0.08	-0.03	-0.11
Middle East show stations	-0.12	-0.13	-0.04	-0.22	-0.00	-0.15	-0.14	-0.13
Mediterranean show stations	-0.13	-0.14	-0.12	-0.15	-0.09	-0.14	-0.11	-0.13
TOTAL	-0.16	-0.14	-0.13	-0.12	-0.03	-0.11	-0.07	-0.12



- Bias
- RMSE
- Correlation coefficient
- FGE

Monthly
Seasonal
Yearly

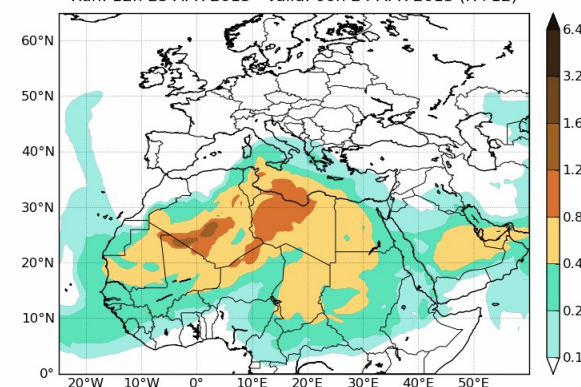
Forecast evaluation with satellite prods.



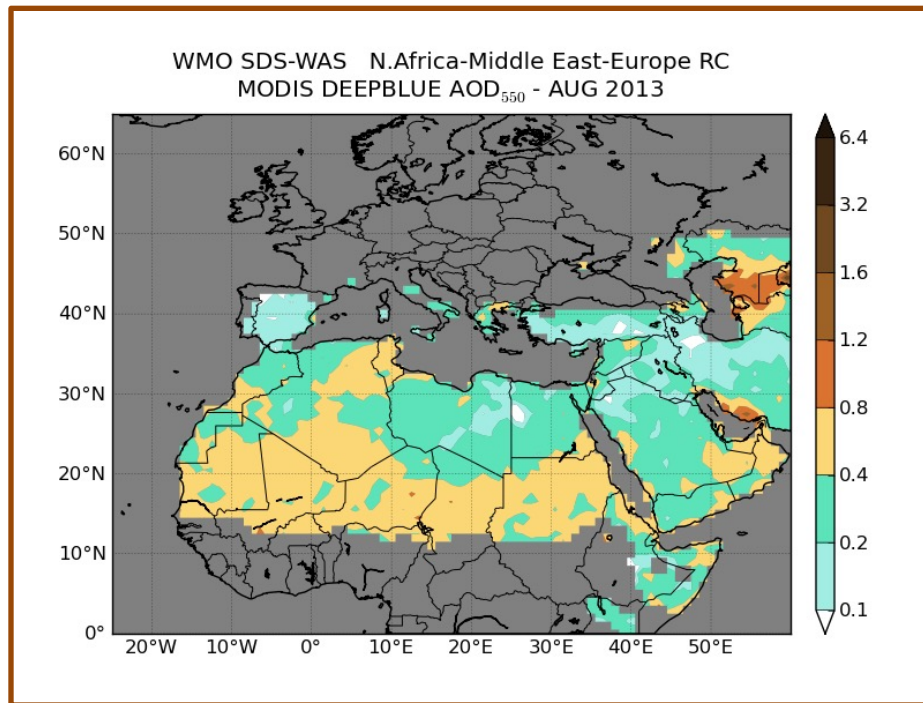
MET10 RGB-Dust 2013-04-24 00:00 UTC

24 April 2013

WMO SDS-WAS N.Africa-Middle East-Europe RC
MEDIAN Dust AOD
Run: 12h 23 APR 2013 Valid: 00h 24 APR 2013 (H+12)



Evaluation with MODIS Deep Blue



	BIAS	ROOT MEAN SQUARE ERROR	CORRELATION COEFFICIENT	FRACTIONAL GROSS ERROR	NUMBER OF CASES
BSC_ DREAM8b	-0.17	0.31	0.28	0.96	42618
NMMB/BSC- Dust	-0.20	0.33	0.29	1.05	41049
NCEP NGAC	-0.06	0.29	0.32	0.64	42664

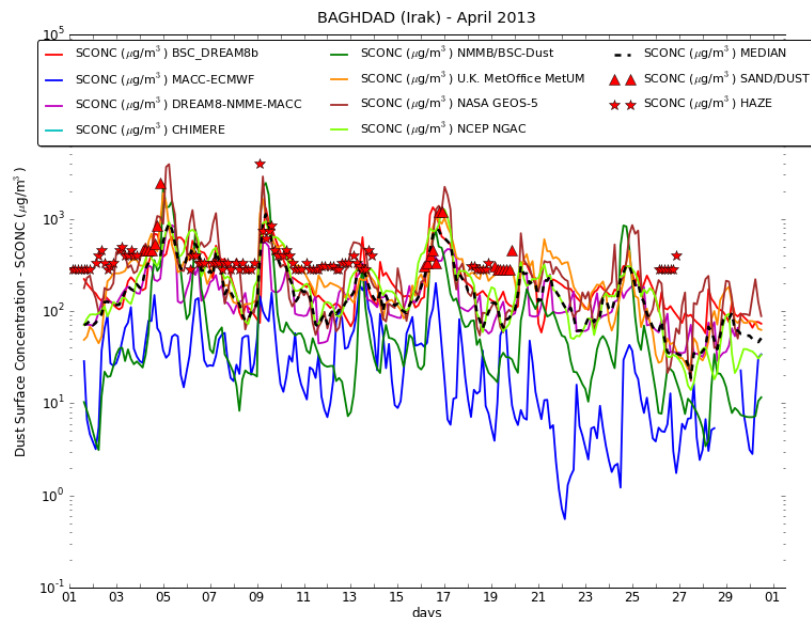
Evaluation with visibility



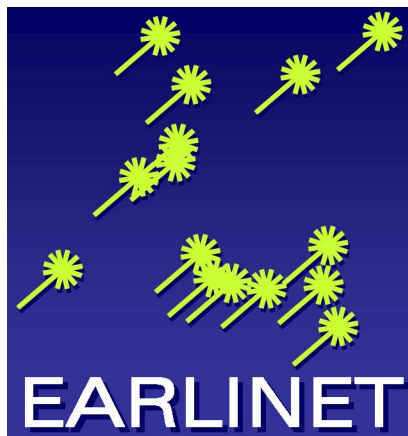
$$PM_{10} = 1339.84 V^{-0.67}$$

Ben Mohamed et al. (1992)

BAGHDAD, Iraq
April 2013



LIDAR – models comparison



BSC-DREAM8B_v2

NMMB-BSC/Dust



DREAM8-NMME-MACC



BOLCHEM

60 – 80 dust cases for the period Jan 2011 – Jun 2013

Capacity building

- 8-12 Nov 2010: Training Week on Satellite Meteorology. Barcelona, Spain
- 13 Nov 2010: Lectures on Atmospheric Mineral Dust and its Impact on Human Health, Environment and Economy. Barcelona, Spain
- 15-19 Nov 2010 Training Week on WMO SDS-WAS products. Barcelona, Spain
- 22-26 Feb 2011: Training on Meteorological Services, SDS Forecast and Early Warning System. Istanbul, Turkey
- 21-25 Nov 2011: 2nd Training Course on WMO SDS-WAS products (satellite and ground observation and modelling of atmospheric dust). Antalya, Turkey
- 5-9 Nov 2012: II Lectures on Atmospheric Mineral Dust. Barcelona, Spain
- 19-23 Nov 2012: Cours sur l'utilisation des produits satellitaires aux applications agrometeorologiques, Niamey, Niger
- 26-28 Nov 2012: Workshop on Meteorology, Sand and Dust Storm (SDS), Combating Desertification and Erosion. Ankara, Turkey
- *10-14 Jun 2013*: Training Course on the Use of Satellite Products for Agrometeorological Applications, Accra, Ghana
- 28-31 Oct 2013: Workshop on Meteorology, Sand and Dust Storm (SDS), Combating Desertification and Erosion, Istanbul, Turkey
- 8-12 Dec 2013: 3rd Training Course on WMO SDS-WAS products (satellite and ground observation and modelling of atmospheric dust), Muscat, Oman
- 15-16 Dec 2013: McIDAS-V Tutorial with focus on atmospheric dust cases, Muscat, Oman
- 5-9 May 2014: Cours sur l'utilisation des produits satellitaires aux applications agrométéorologiques , Ouagadougou, burkina Faso
- 17-20 Nov 2014: 4th Training Course on WMO SDS-WAS products (satellite and ground observation and modelling of atmospheric dust). Casablanca, Morocco

Thanks for your attention

NORTHERN AFRICA-MIDDLE EAST-EUROPE (NA-ME-E) REGIONAL CENTER
WMO SDS-WAS Regional Center for Northern Africa, Middle East and Europe

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