

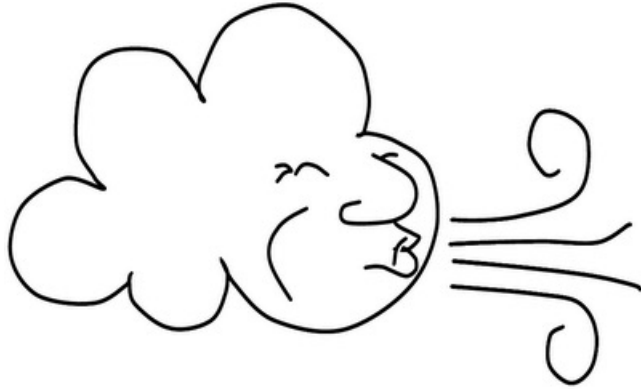
Sand and Dust Storm Warning Advisory and Assessment System (WMO SDS-WAS)

Enric Terradellas (AEMET), eterradellasj@aemet.es

Technical Coordinator of the WMO SDS-WAS Regional Center for Northern Africa, Middle East and Europe

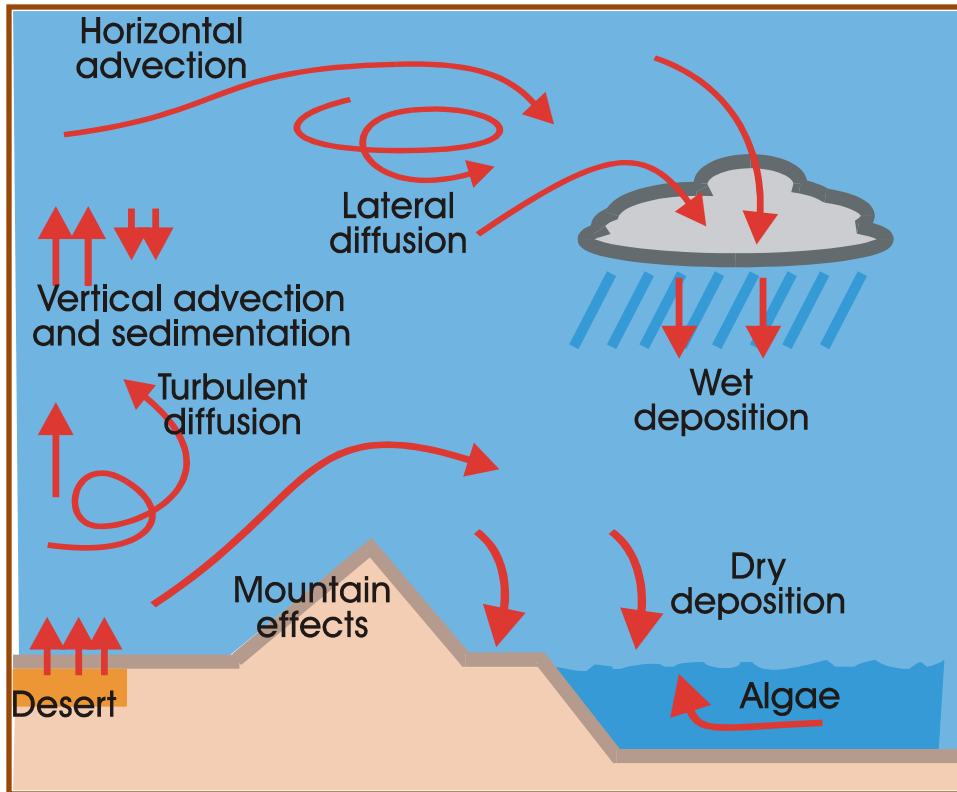


Sand and dust storm



MODIS. 3 Mar 2004

The dust cycle

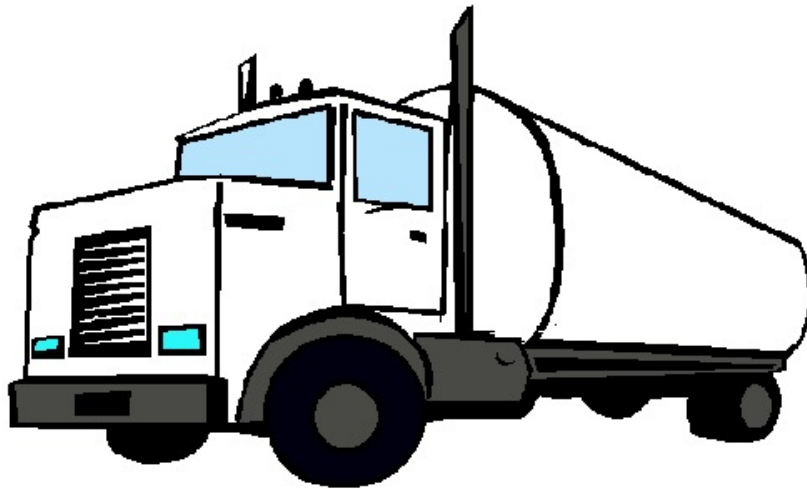


- **Emission**
- **Turbulent mixing**
- **Long-range transport**
- **Wet/dry deposition**

Modilized sand and dust

~60000 – 120000 kg / s
~2 – 4·10¹² kg / yr

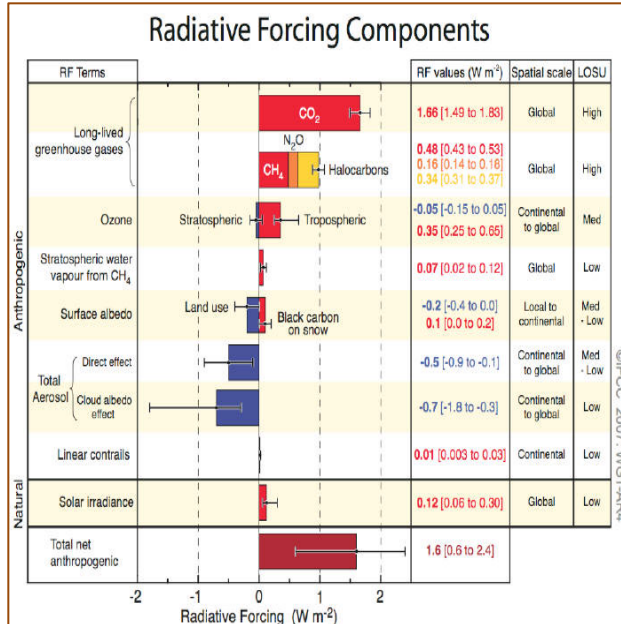
100,000,000 lorries



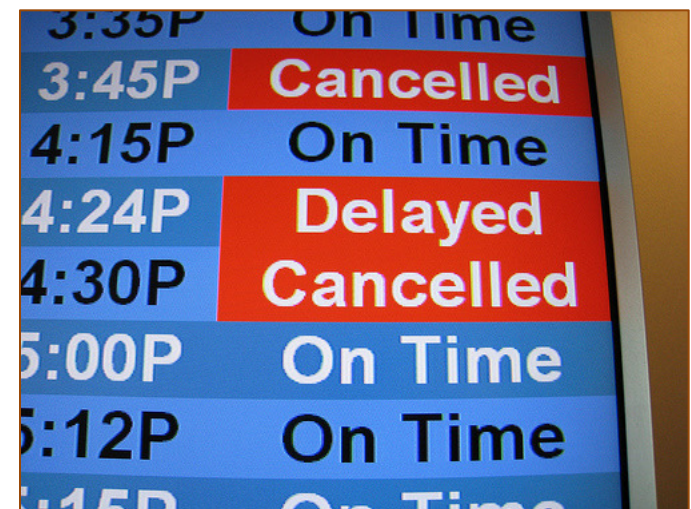
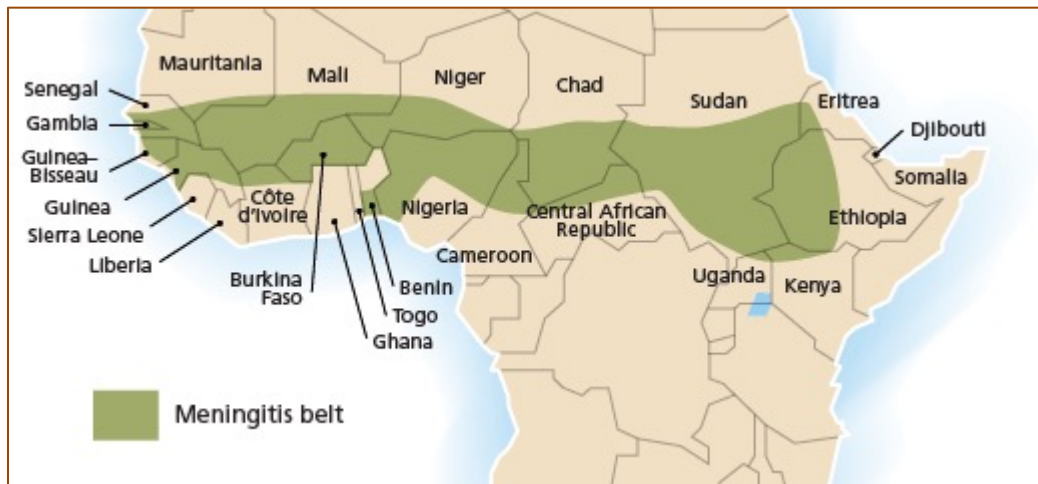
5,000 ULCC



Impacts of sand and dust



- Human health
- Weather and climate
- Economy (mainly related to reduced visibility)
- Environment (negative and positive)
- ...



WMO SDS-WAS programme

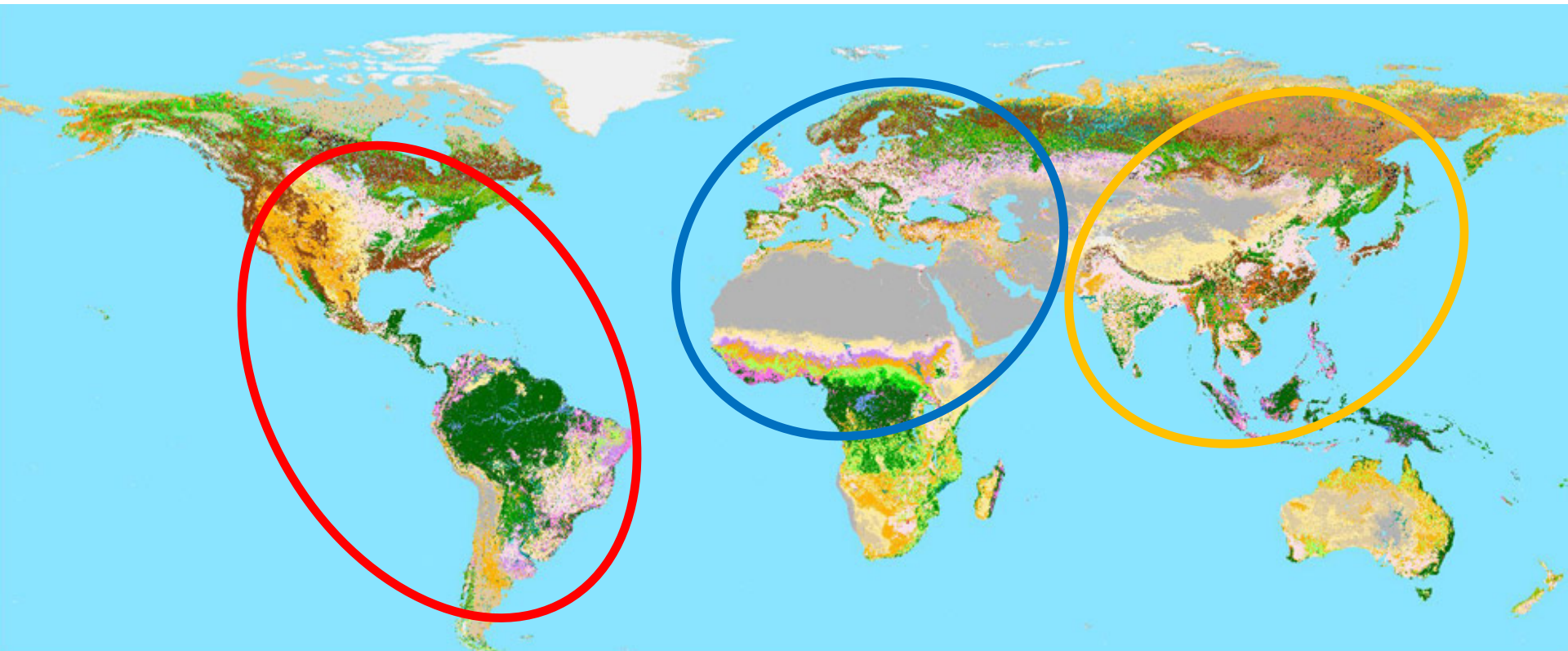
Mission:

To enhance the capacity of countries to produce and deliver to end users timely and precise sand and dust storm forecasts.

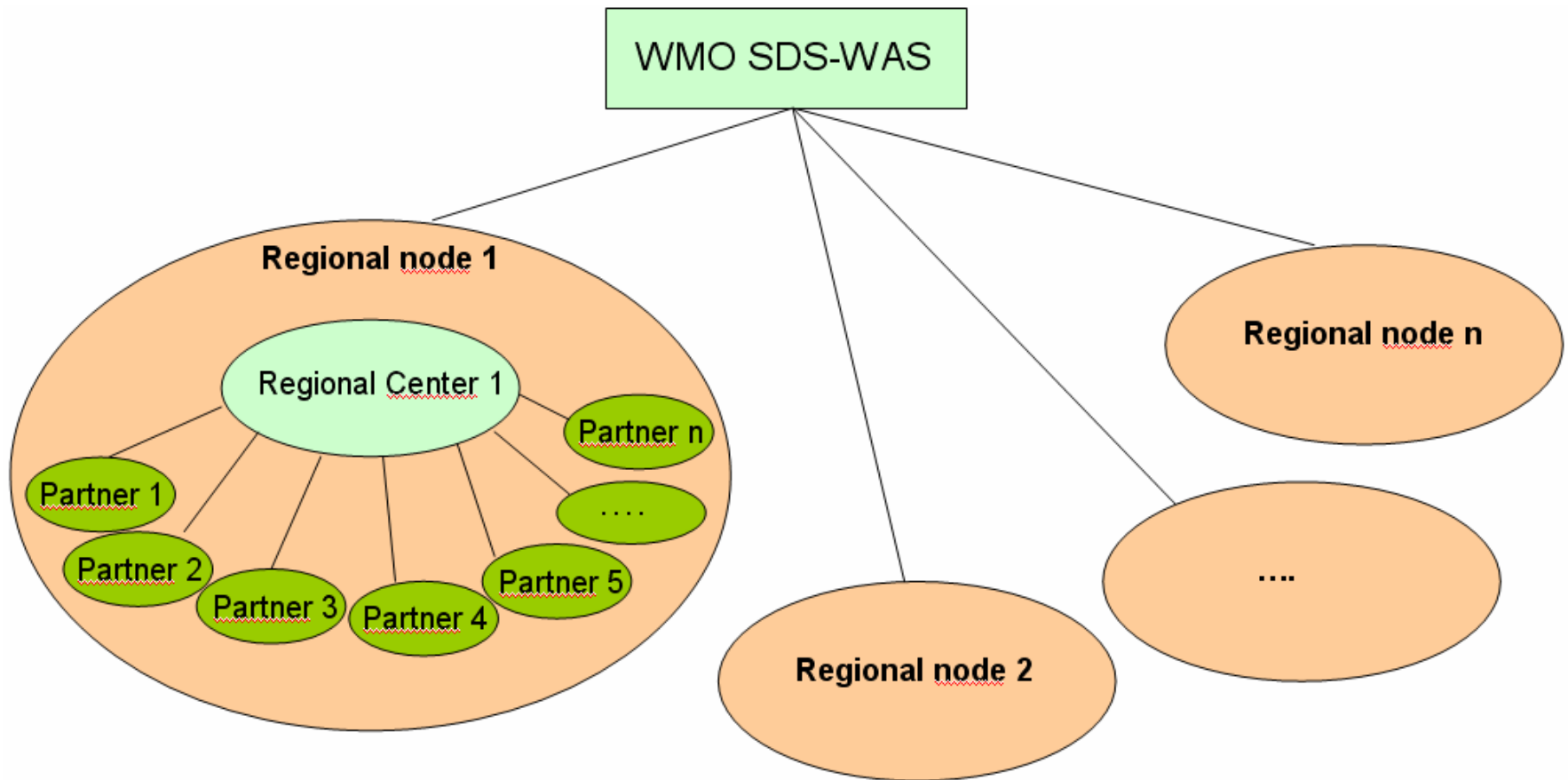


WMO SDS-WAS structure

- **Regional Center for Northern Africa, Middle East and Europe.**
Barcelona, Spain
- **Regional Center for Asia, Beijing, China**
- **Regional Center for Pan America, Orange, Ca, US**



A Federated System of Regional Nodes Bringing Modelling, Research, Observations and Users Together



The Regional Center for NA-ME-E

It is managed by a consortium of the Spanish State Met. Agency (AEMET) and the Barcelona Supercomputing Center (BSC-CNS)



Nexus II building. Campus Nord
Catalonia Technical Univ. Barcelona



MareNostrum supercomputer



A satellite image of Earth, showing a large area of white clouds over a dark ocean. A portion of a landmass, likely Africa, is visible on the right side of the frame, showing brown and green terrain. The text is overlaid on the left and center of the image.

Objectives of the Regional Center

- Identify and improve products to monitor and predict atmospheric dust by working with research and operational organizations, as well as with users
- Facilitate user access to information
- Strengthen the capacity of countries to use the observations, analysis and predictions provided by the WMO SDS-WAS programme

A satellite image of Earth, showing a large area of white clouds over a dark ocean. A portion of a landmass, likely Africa, is visible on the right side of the frame, showing brown and green terrain. The overall image has a high-contrast, slightly grainy appearance typical of satellite photography.

Objectives of the Regional Center

- **Identify and improve products to monitor and predict atmospheric dust by working with research and operational organizations, as well as with users**
- **Facilitate user access to information**
- **Strengthen the capacity of countries to use the observations, analysis and predictions provided by the WMO SDS-WAS programme**

Why do we need dust observations?

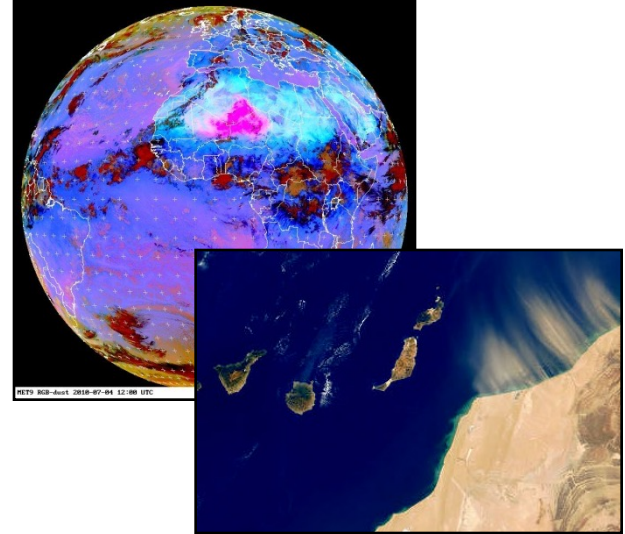
- Dust monitoring
- Model evaluation / verification
- Data assimilation by dust prediction models
- Validation of other observations (e.g. ground obs. to validate satellite obs.)

Mali, 2001

Photograph: Remi Benali/Corbis

A comprehensive observing system

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



AQ station



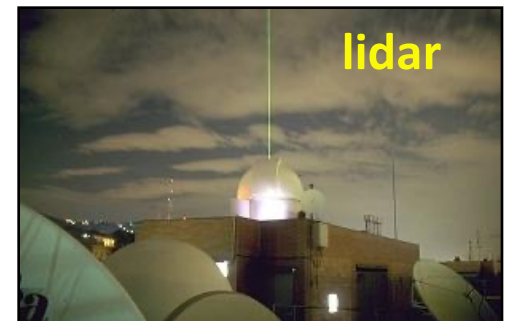
Transmissometer



Sun photometer



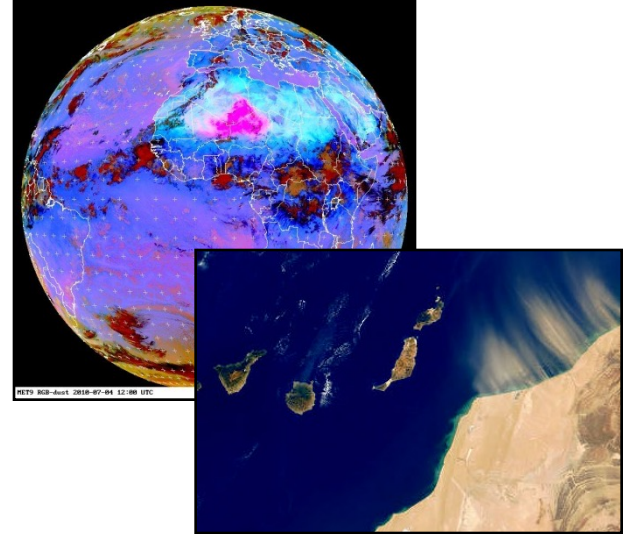
Ceilometer



lidar

A comprehensive observing system

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AQ station



Transmissometer



Sun photometer



lidar

In-situ PM10 and PM2.5 measurements from air quality monitoring stations.

a) Gravimetric (reference) method



W_1



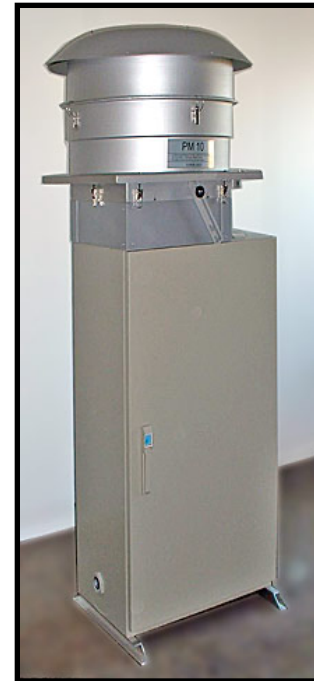
W_2

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

LVS
2.3 m³/h



HVS
68 m³/h

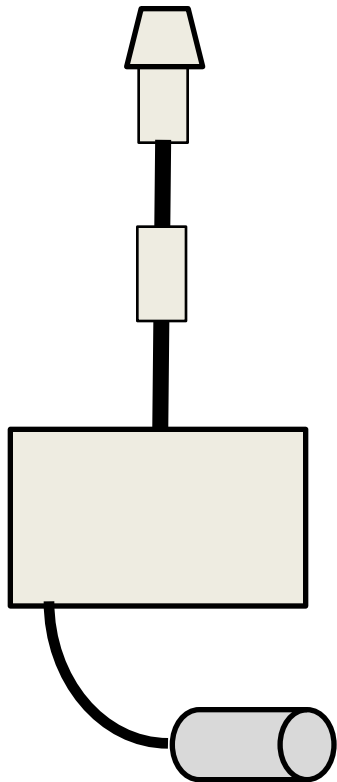


WRAC
1966
m³/h



In-situ PM10 and PM2.5 measurements from air quality monitoring stations.

b) Automatic air samplers



Beta



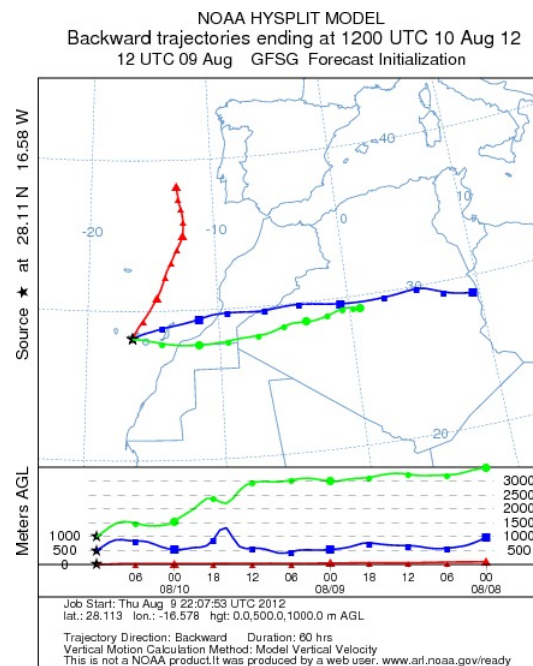
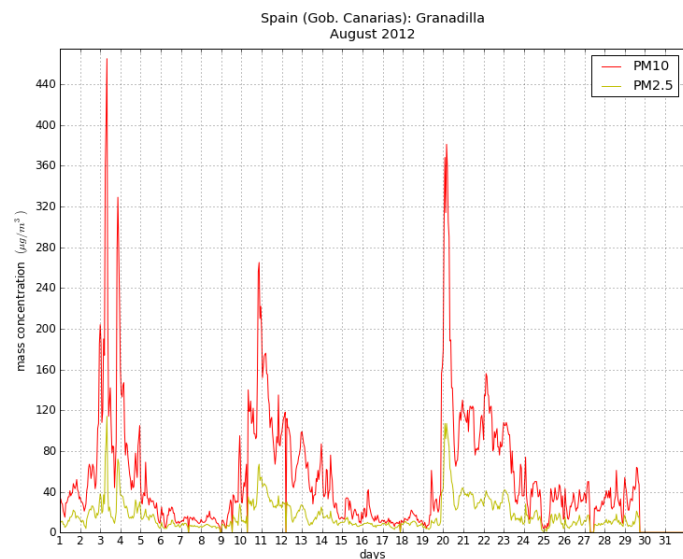
TEOM

WMO SDS-WAS Regional Center NA/ME/E

PM10, PM2.5 and back-trajectories



PM10 and PM2.5 in Granadilla (Canary Is.) in August 2012

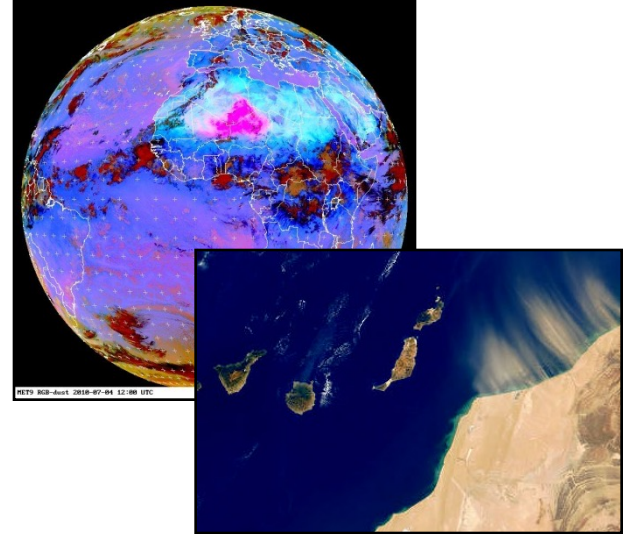


10 Aug 2012 12:00



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AQ station



Transmissometer



Sun photometer

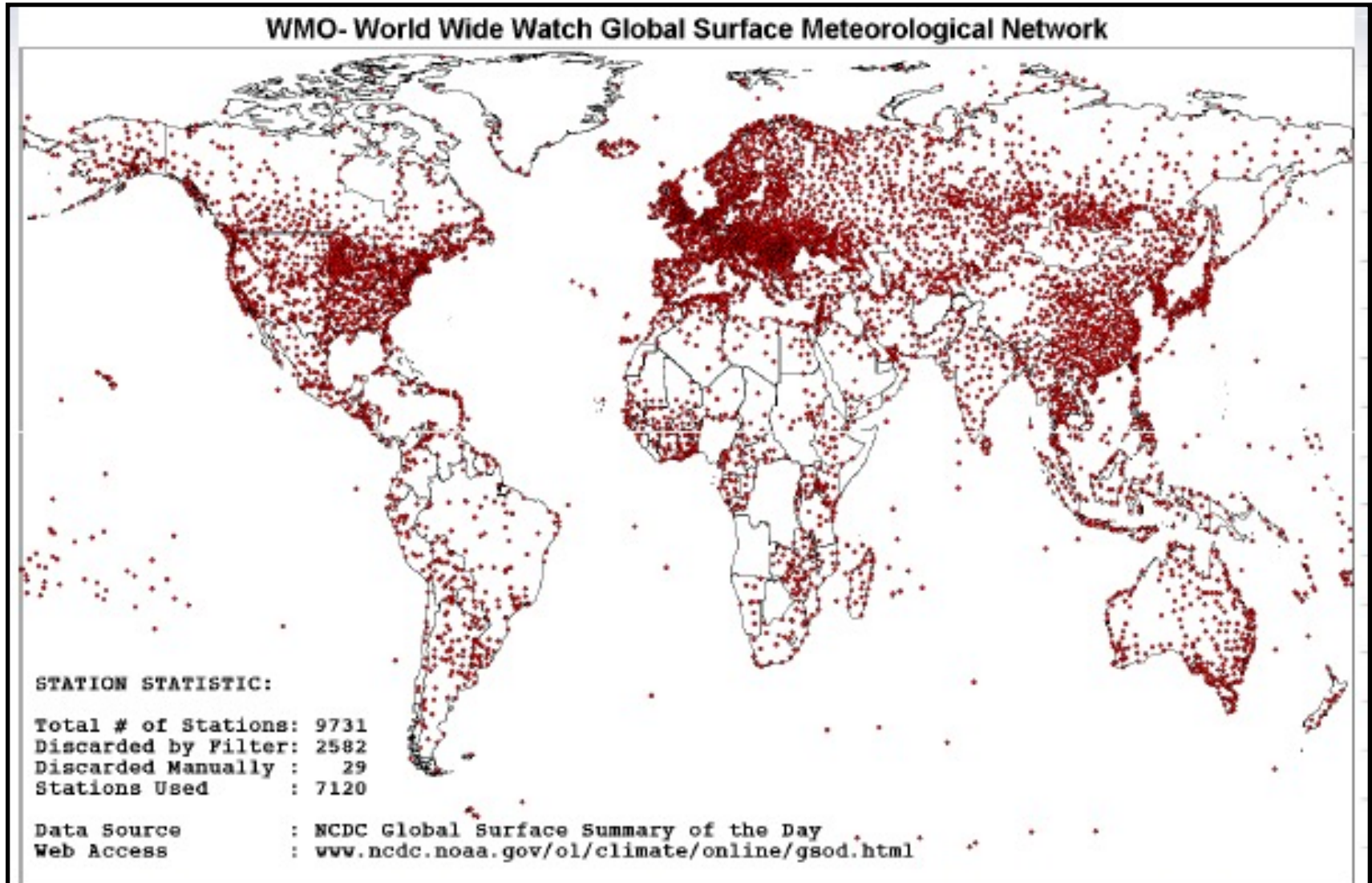


Ceilometer



lidar

Visibility measurements



Visibility measurements

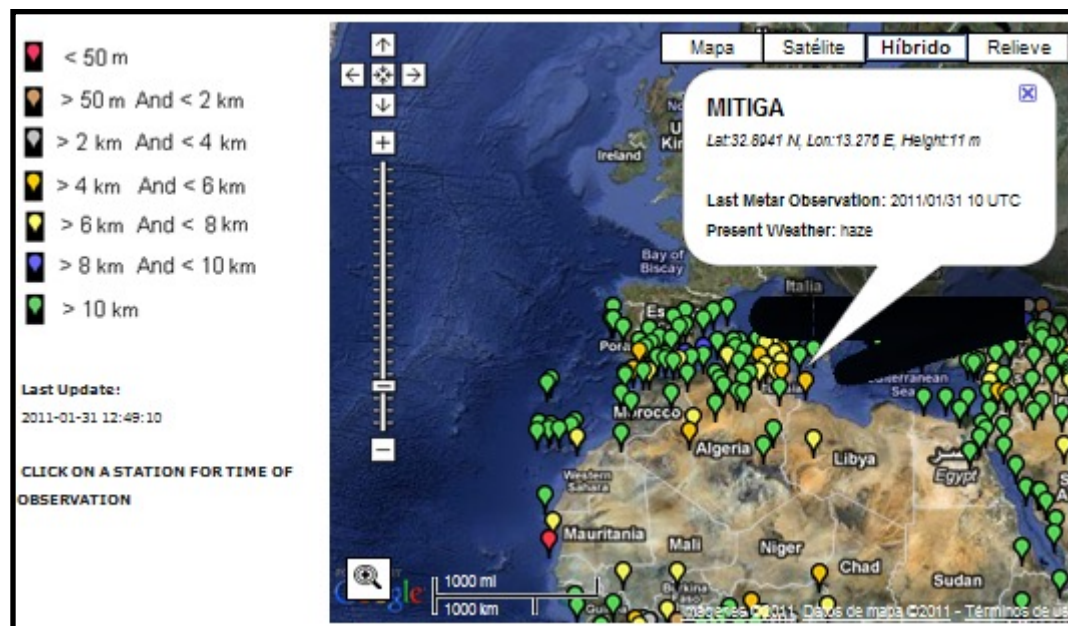
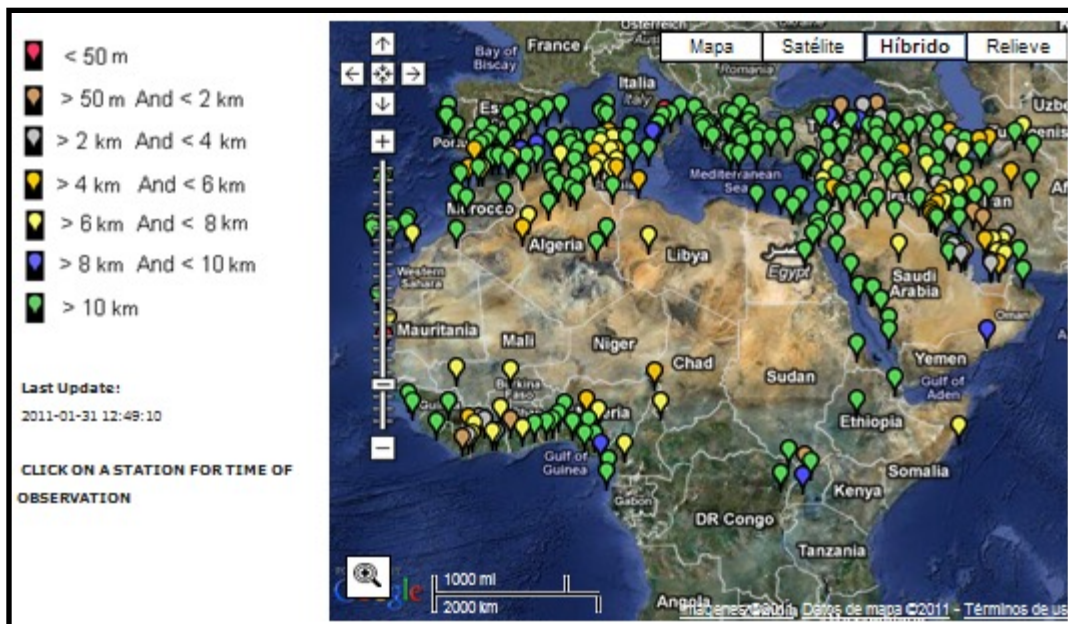
Eye

Visual estimation
using physical
references



Transmissometers

Consist of a light
source with one or
two light detectors
at fixed distance(s)



**Barcelona
Supercomputing
Center**

Centro Nacional de Supercomputación

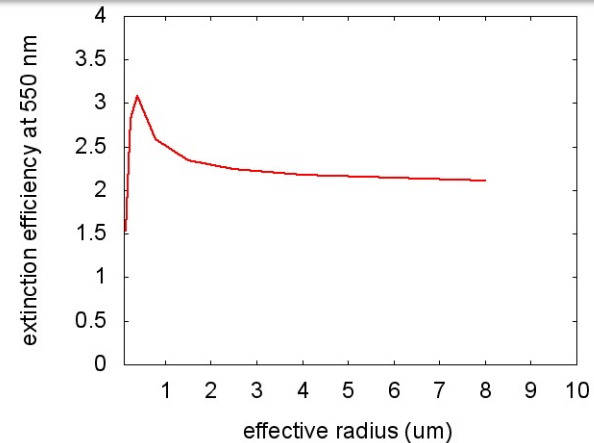
Relationship between visibility and TSP/PM10

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

Koschmieder equation

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

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



Tegen and Lacis (1996)

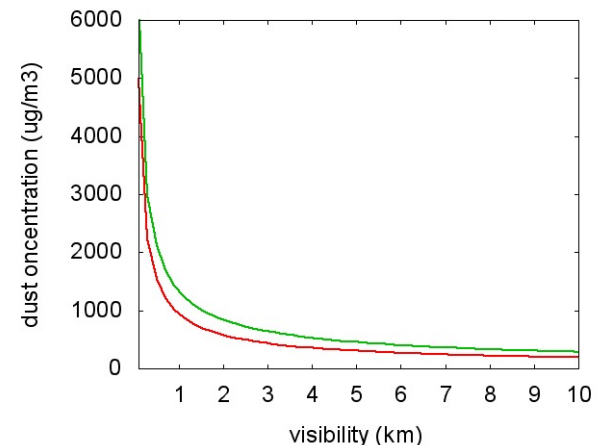
$$\text{TSP} = 1339.84V^{-0.67}$$

Ben Mohamed et al. (1992)

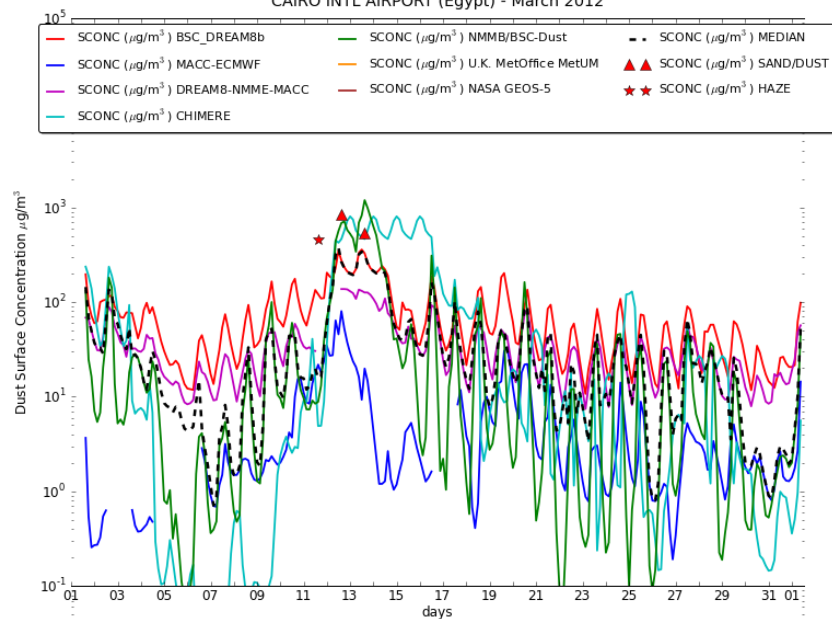
$$\text{PM}_{10} = 914.06V^{-0.73} + 19.03$$

D'Almeida (1986)

PM₁₀, TSP in $\mu\text{g}/\text{m}^3$, V in km

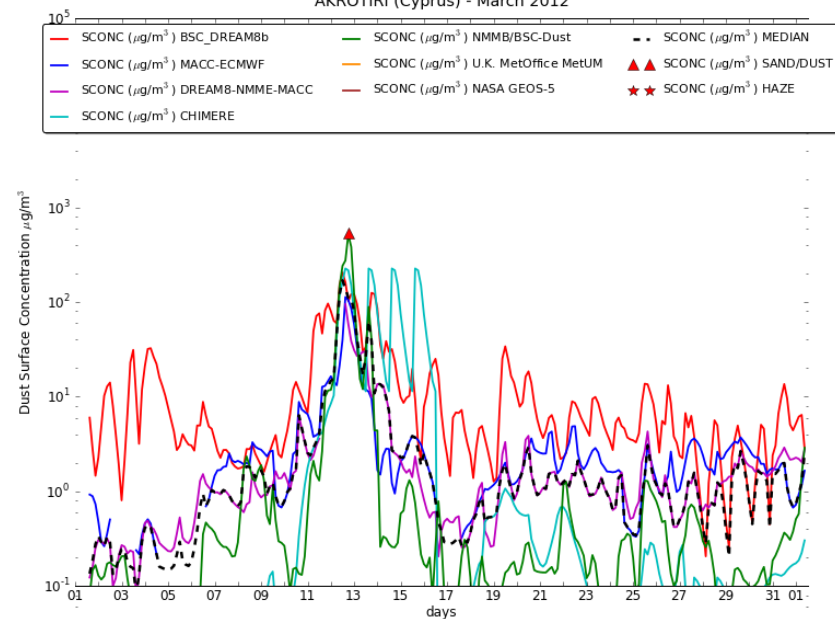


CAIRO INTL AIRPORT (Egypt) - March 2012



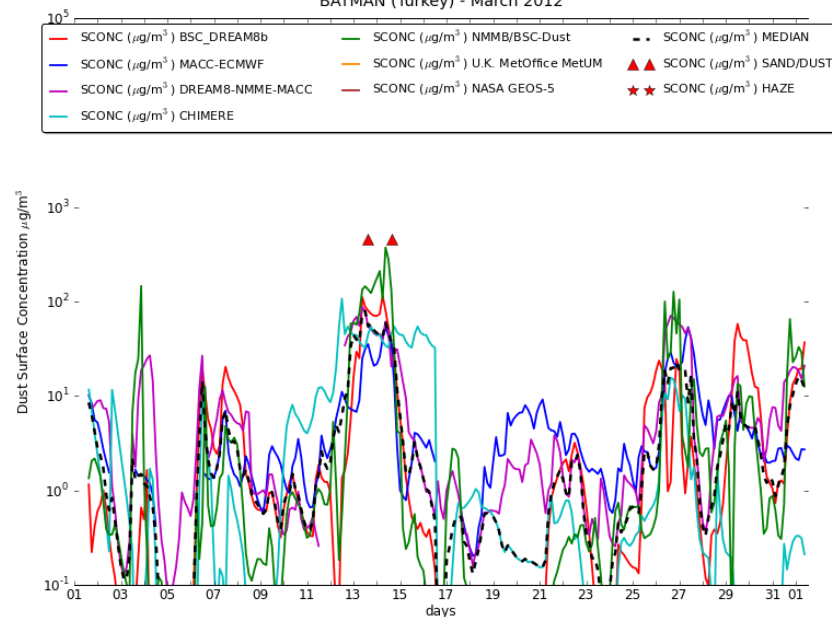
CAIRO, Egypt ★

AKROTIRI (Cyprus) - March 2012

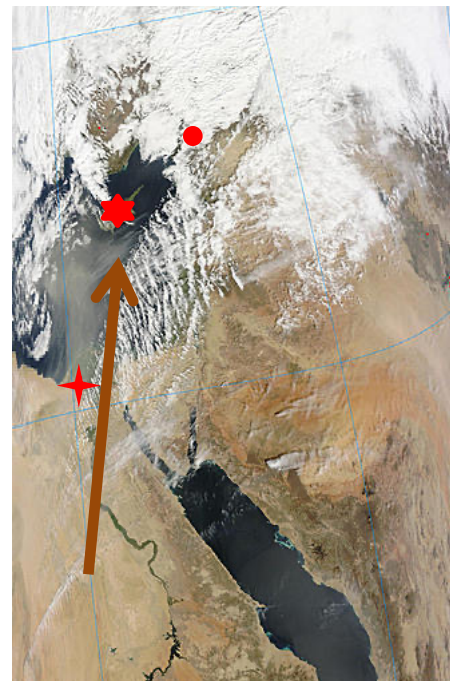


AKROTIRI, Cyprus ★

BATMAN (Turkey) - March 2012

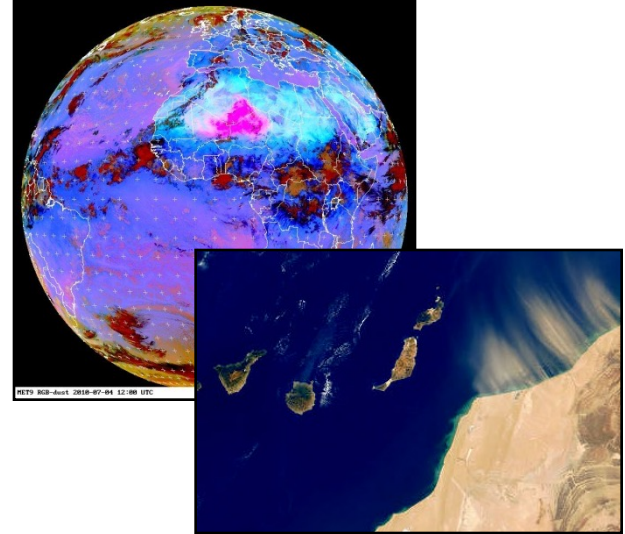


BATMAN, Turkey ●

Terra/MODIS
12 Mar 2012
08:20

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AQ station



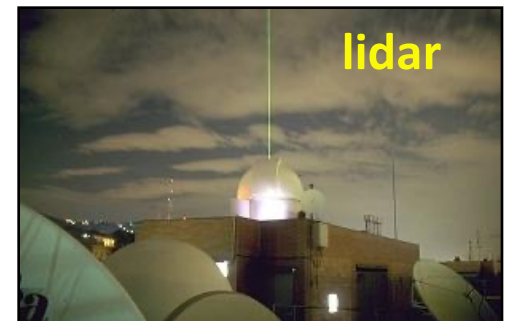
Transmissometer



Sun photometer

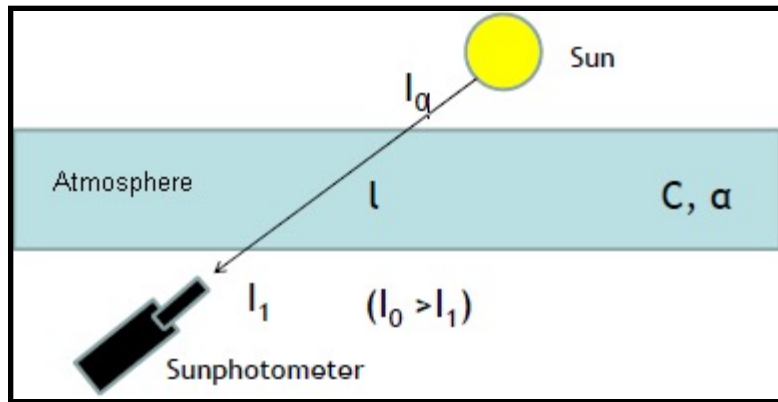


Ceilometer



lidar

Sunphotometers



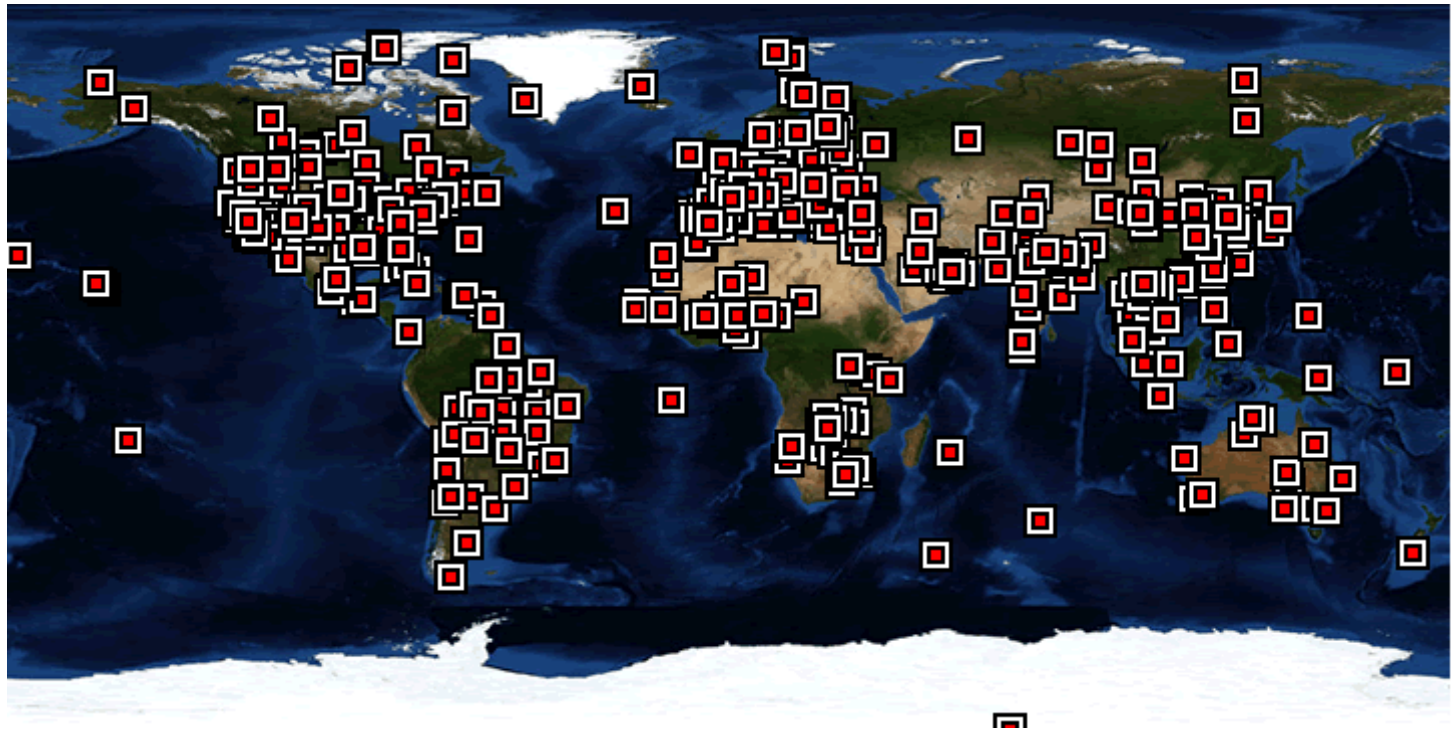
Absorption and scattering by gases should be removed

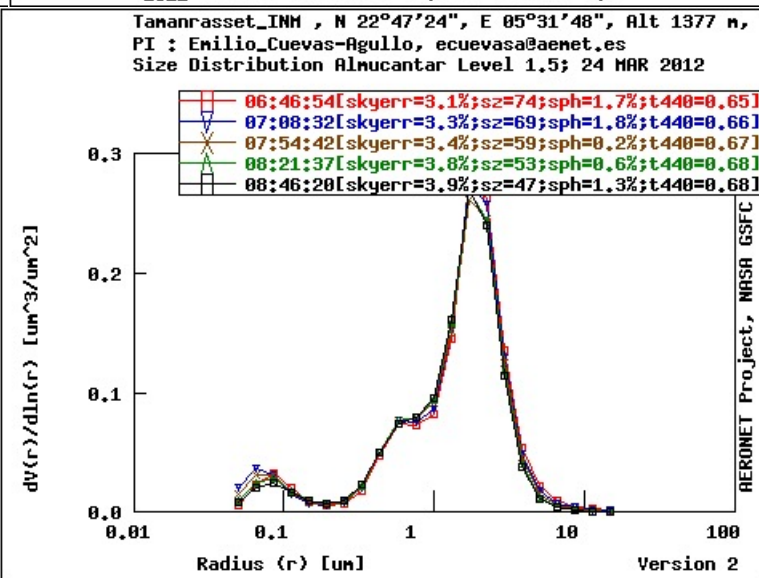
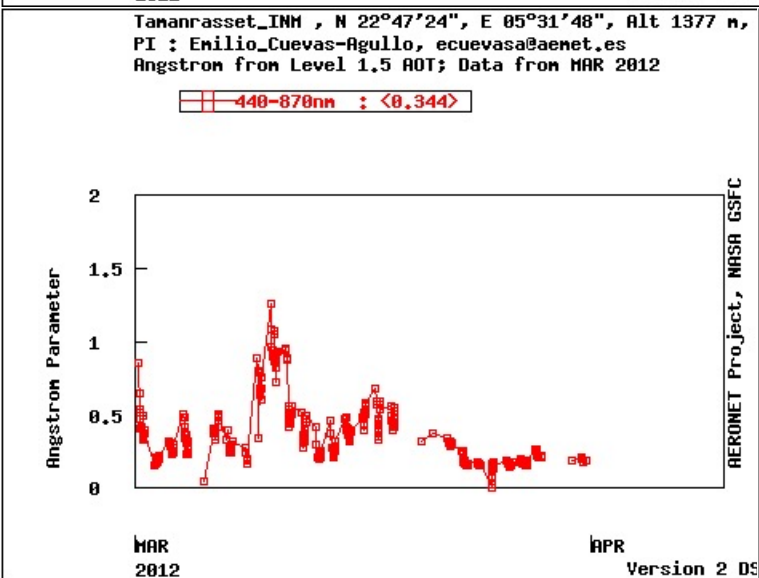
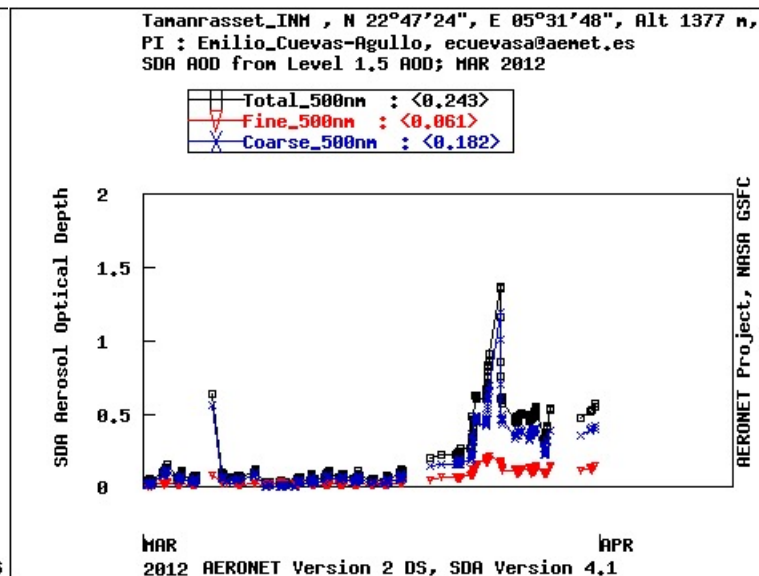
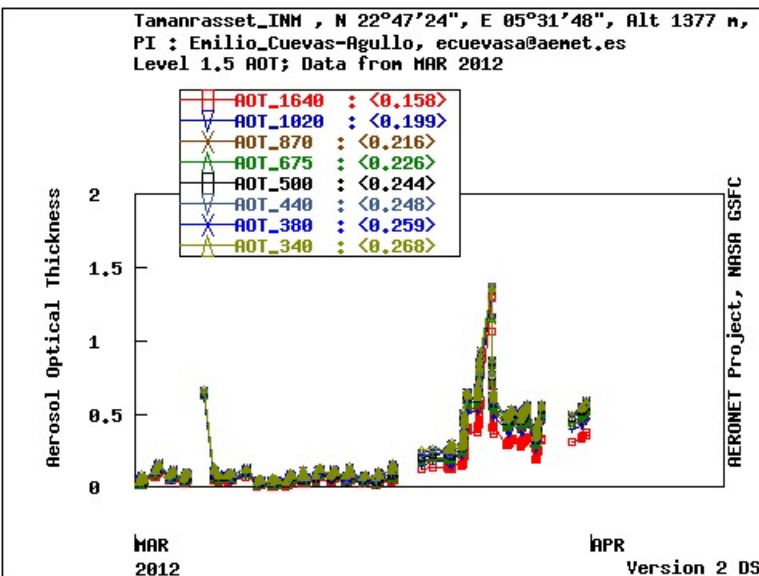
$$\tau = \ln\left(\frac{I_0}{I_1}\right) \cos(\theta)$$

$$\frac{\tau_\lambda}{\tau_{\lambda_0}} = \left(\frac{\lambda}{\lambda_0}\right)^{-\alpha}$$

- A sun photometer is a device that measures direct-sun radiance.
- The intensity of sunlight at the top of the atmosphere is constant.
- When the sunlight travels through the atmosphere, aerosols can dissipate the energy by scattering and absorbing the light.
- Knowing the amount of sunlight transmitted to the earth's surface we can determine amount of aerosols

<http://aeronet.gsfc.nasa.gov/>





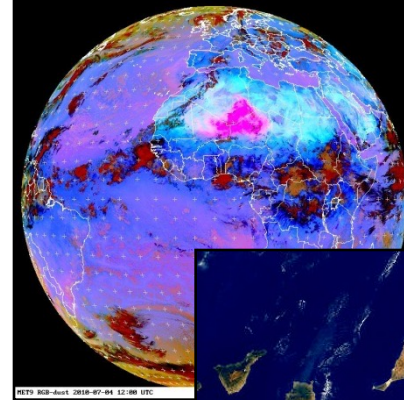
TAMANRASSET_INM
PI: E. Cuevas



$$\frac{dV}{dr} = \frac{1}{r} \frac{dV}{d\ln(r)}$$

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AQ station



Transmissometer

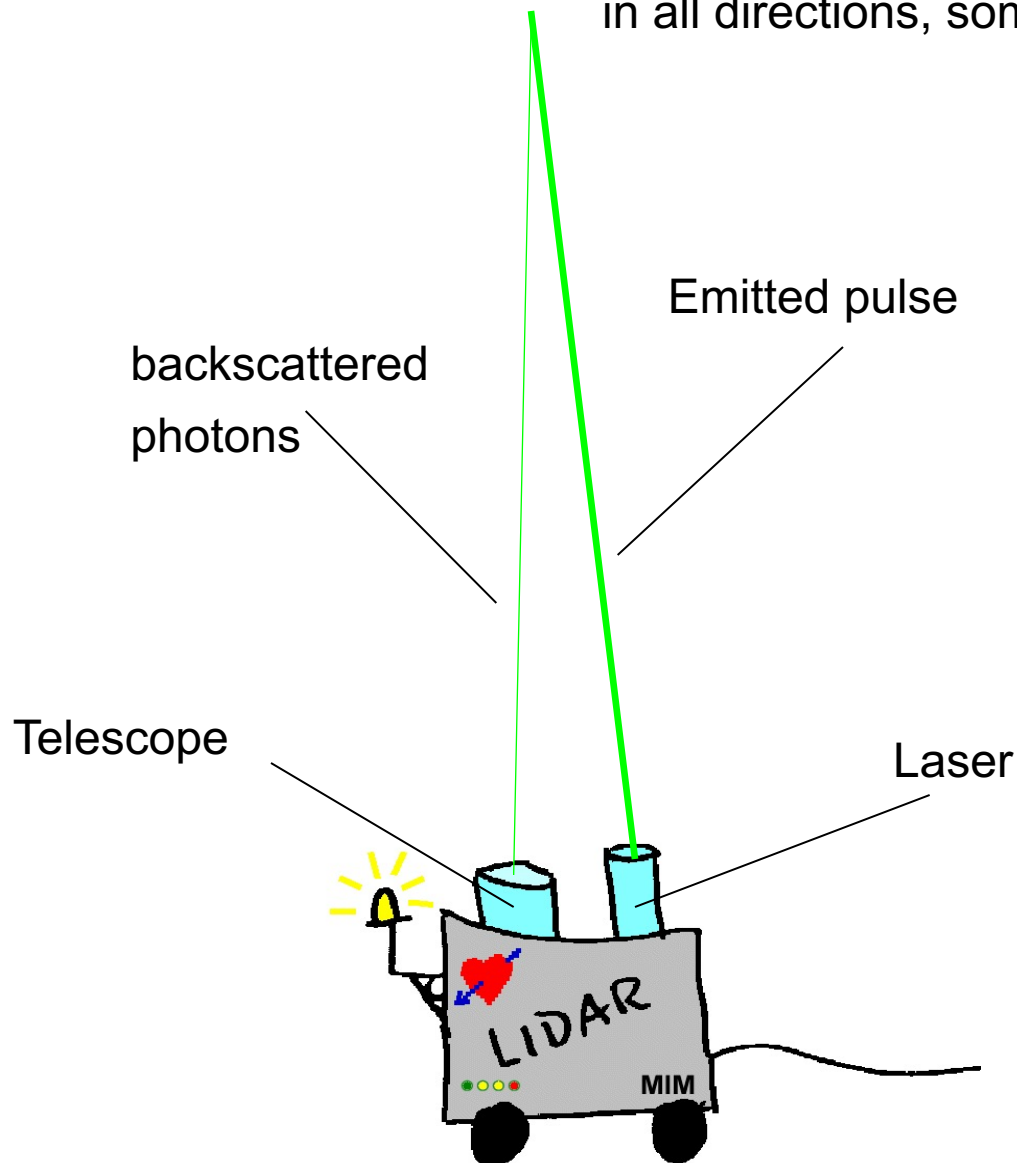


Sun photometer



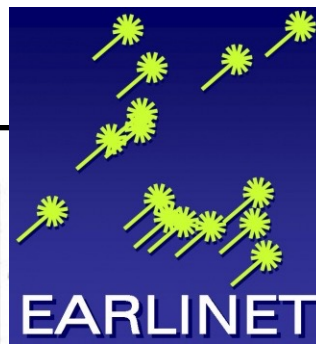
lidar

Scattering on aerosols (and molecules)
in all directions, some photons back

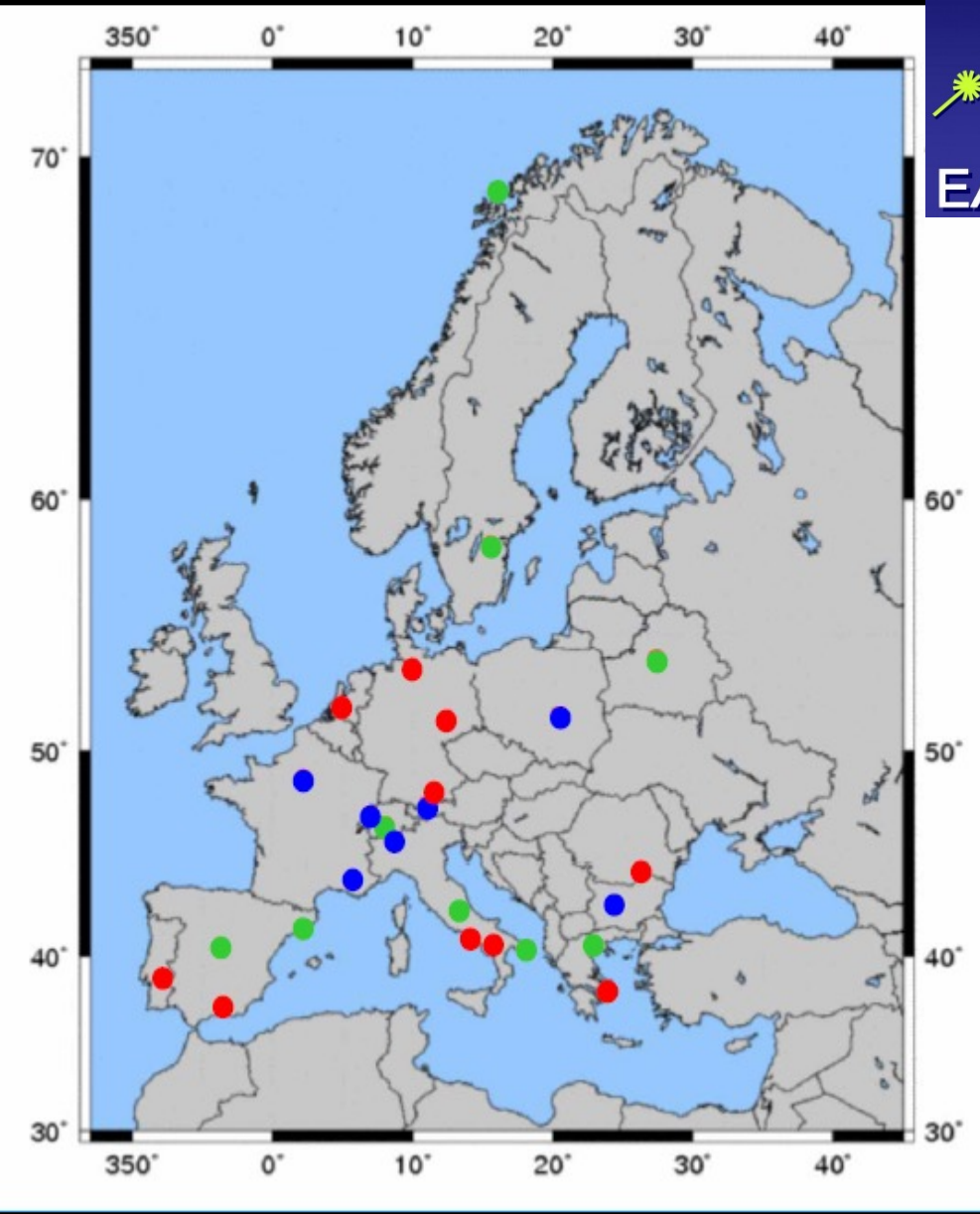


Lidar

Courtesy of Matthias Wiegner



EARLINET



EARLINET (European Aerosol Research Lidar NETwork) is a network of advanced lidar stations distributed over Europe with the main goal to provide a comprehensive, quantitative, and statistically significant data base for the aerosol distribution on a continental scale.

10 multiwavelength Raman lidars

9 Raman lidars

7 single backscatter lidars

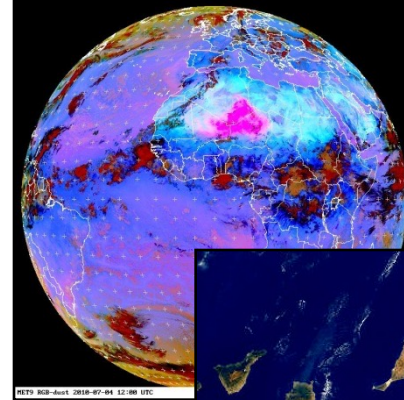
MPLNET. <http://mplnet.gsfc.nasa.gov>

The NASA Micro-Pulse Lidar Network (MPLNET) is a federated network of Micro-Pulse Lidar (MPL) systems designed to measure aerosol and cloud vertical structure continuously, day and night, over long time periods



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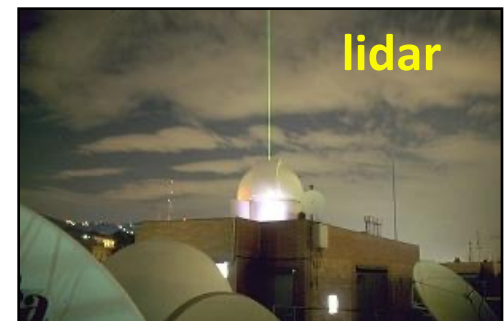
AQ station



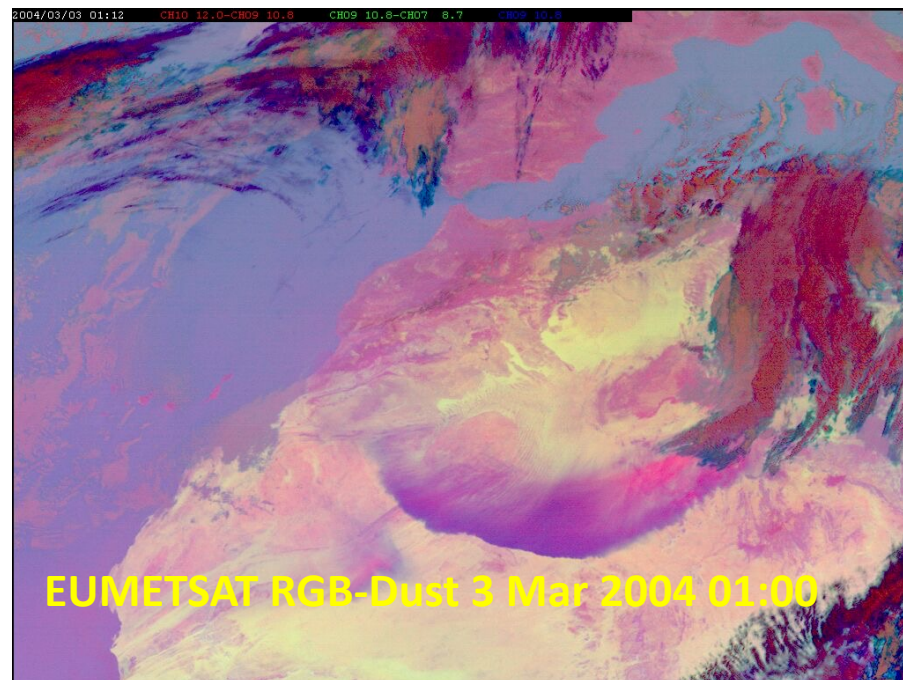
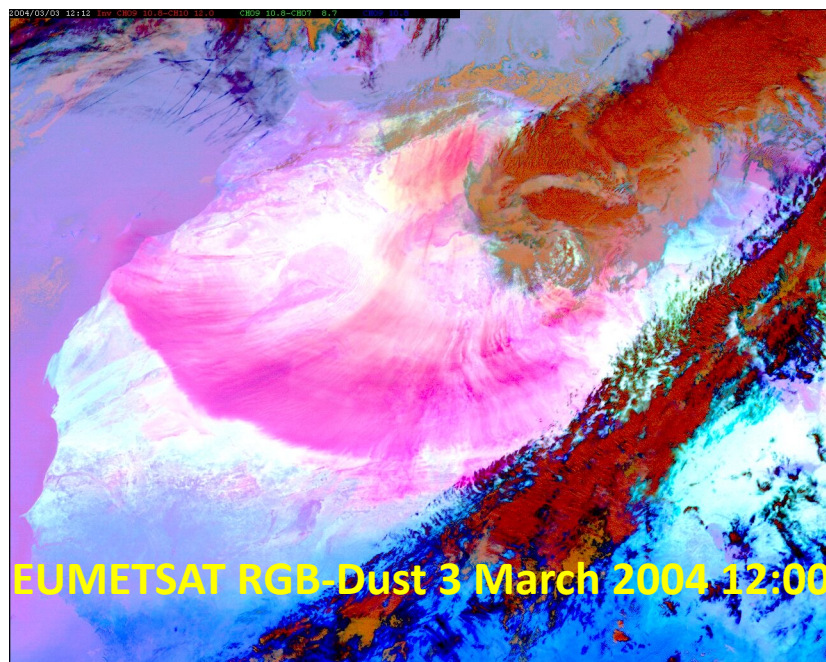
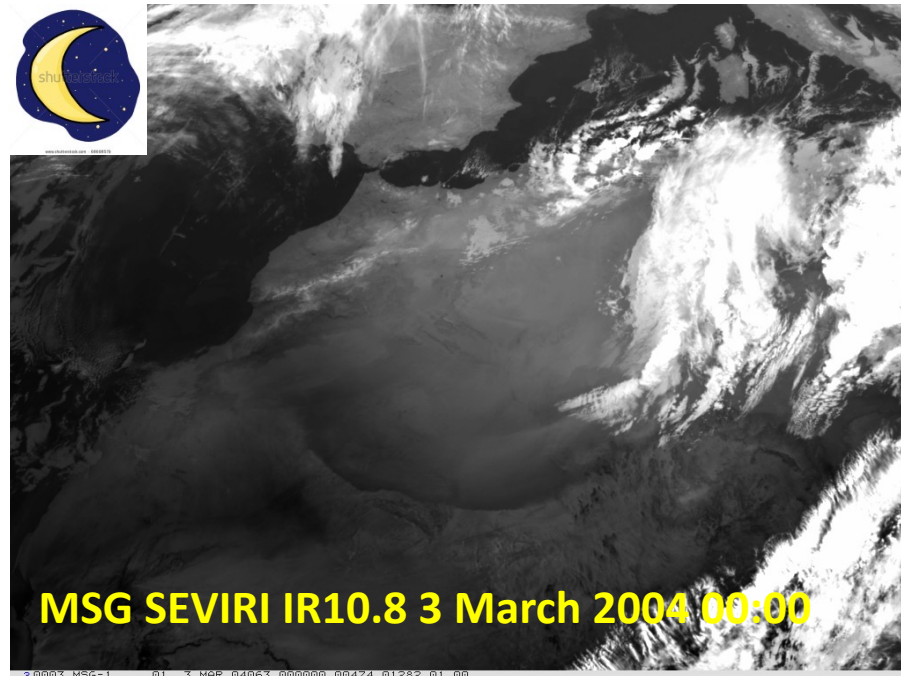
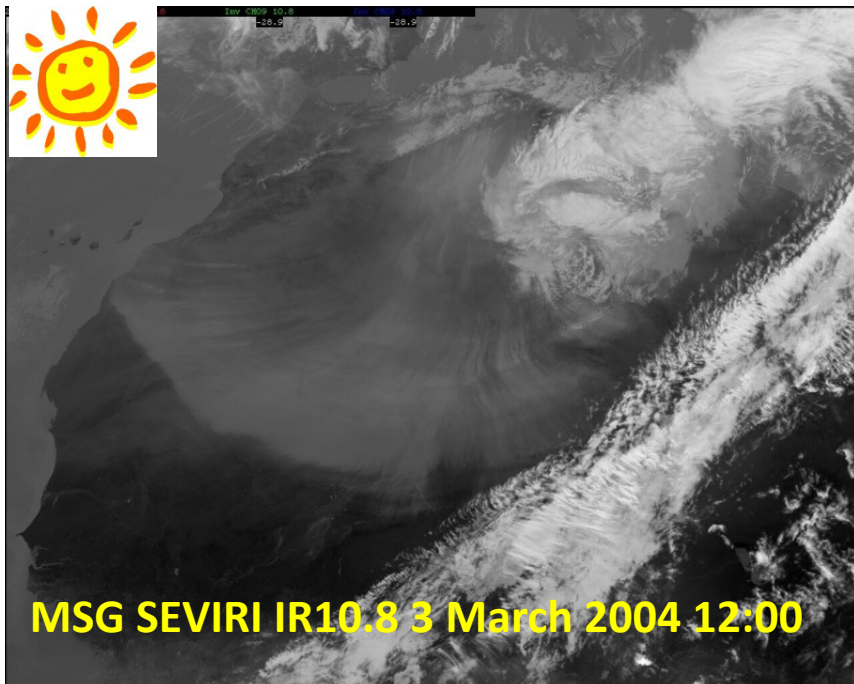
Transmissometer



Sun photometer

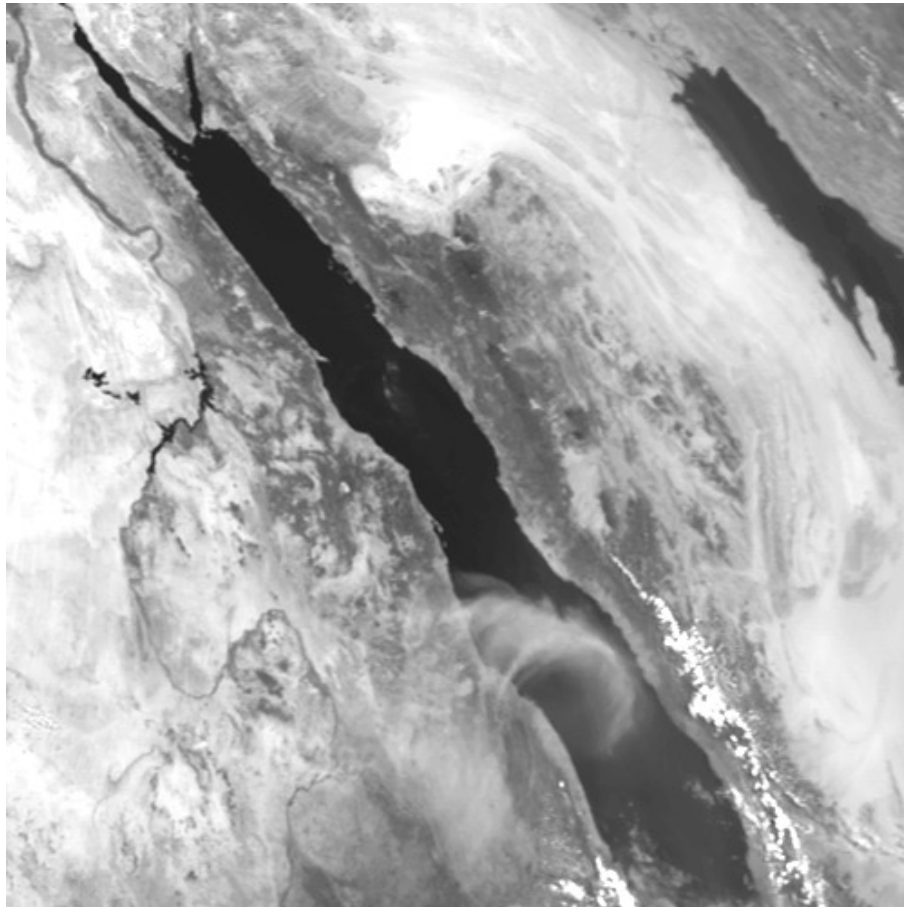


lidar

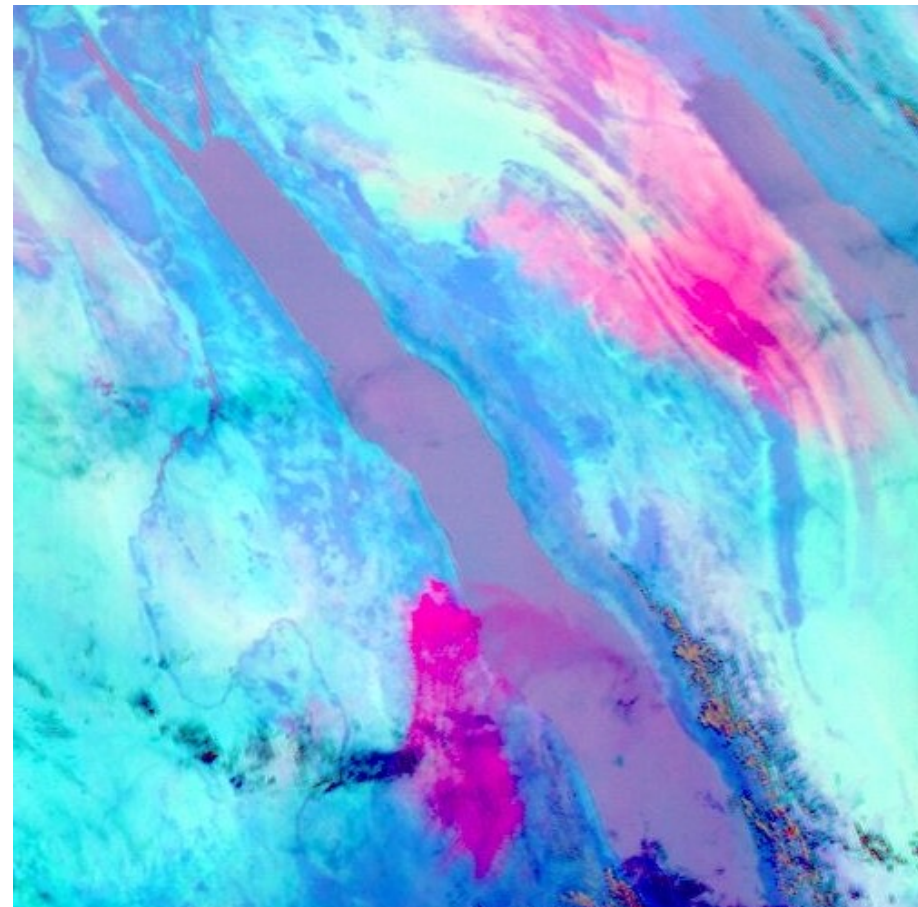


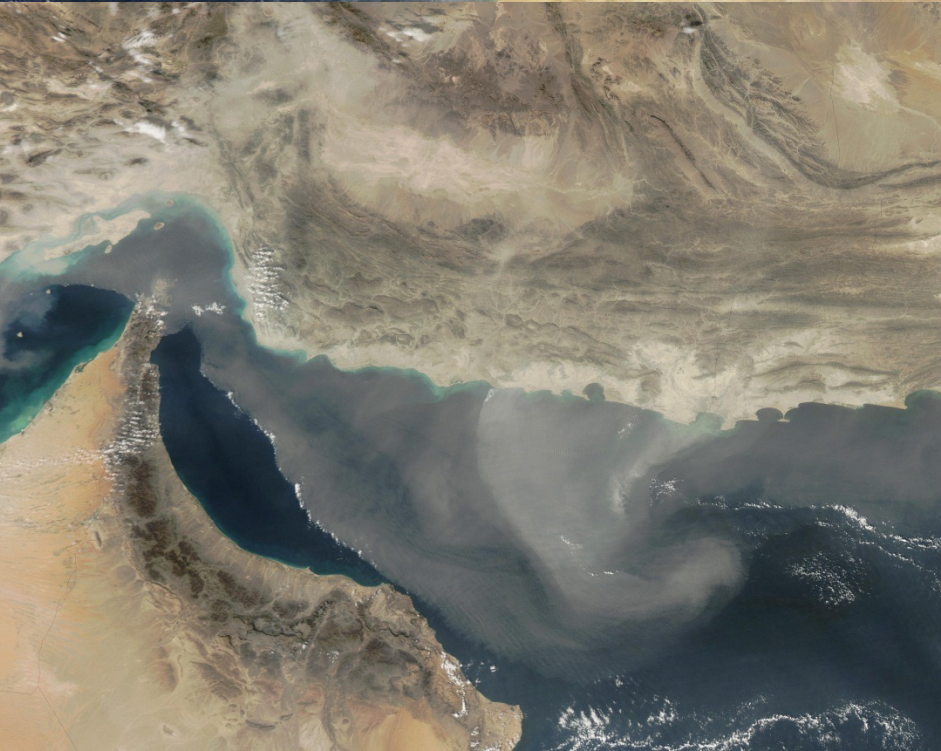
Dust detection over land and ocean

Met-8 Vis 25 Jun 2003 10:00



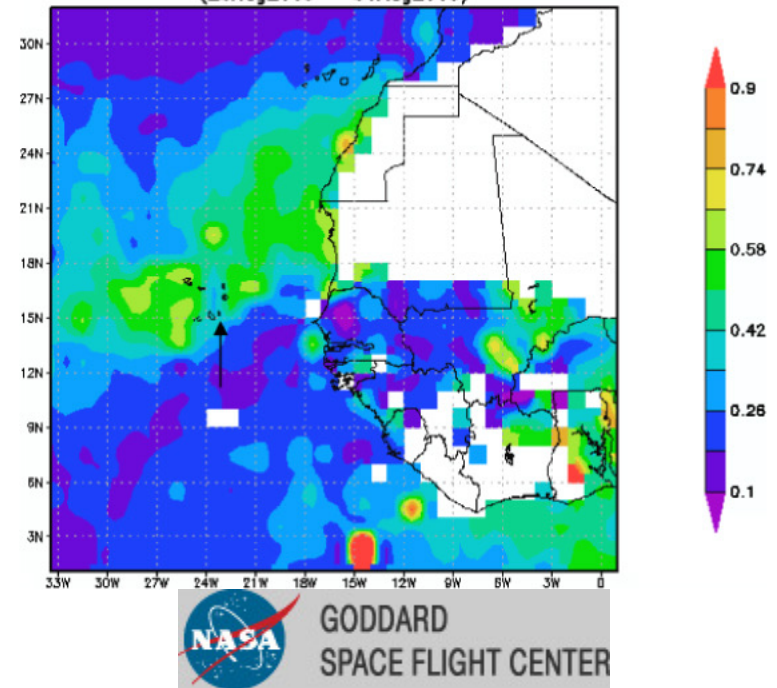
EUM RBG-Dust 25 Jun 2003 10:00



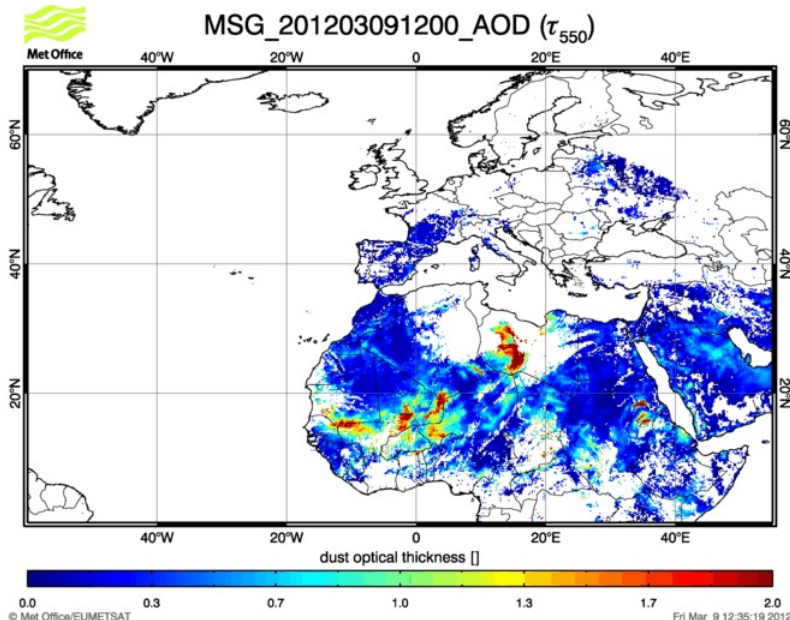


Satellite AOD retrievals

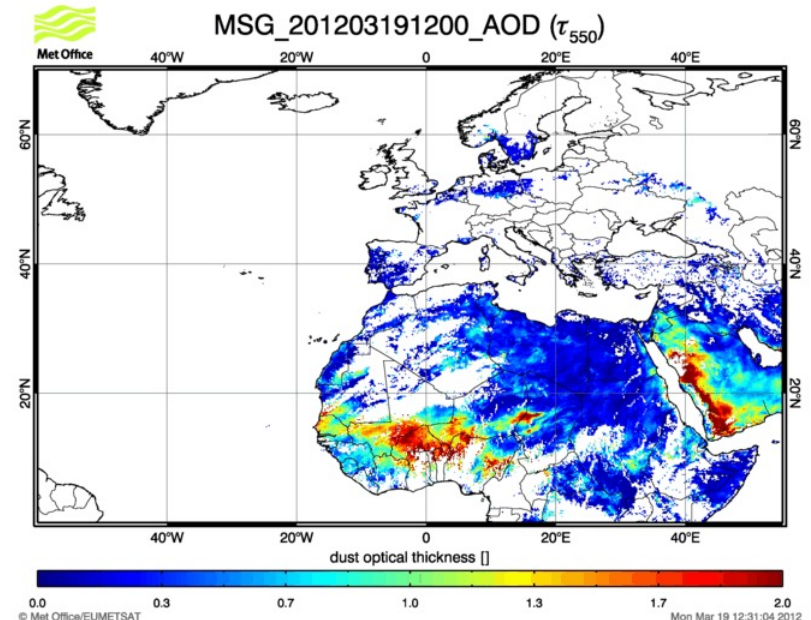
MOD08_D3.005 Aerosol Optical Depth at 550 nm [unitless]
(23Aug2009 - 30Aug2009)



MSG_201203091200_AOD (τ_{550})

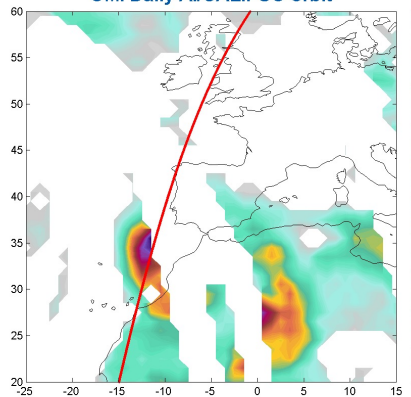


MSG_201203191200_AOD (τ_{550})

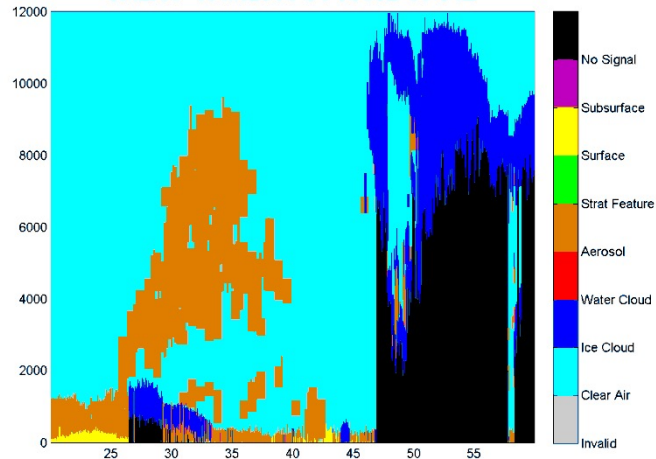


CALIOP

OMI Daily AI/CALIPSO orbit



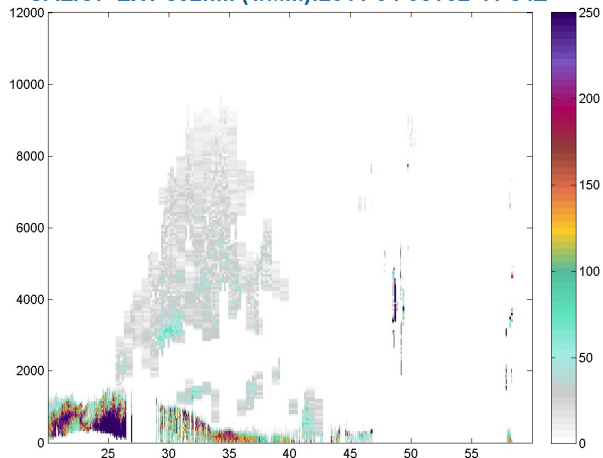
CALIOP VFM:2011-04-05T02-41-54Z



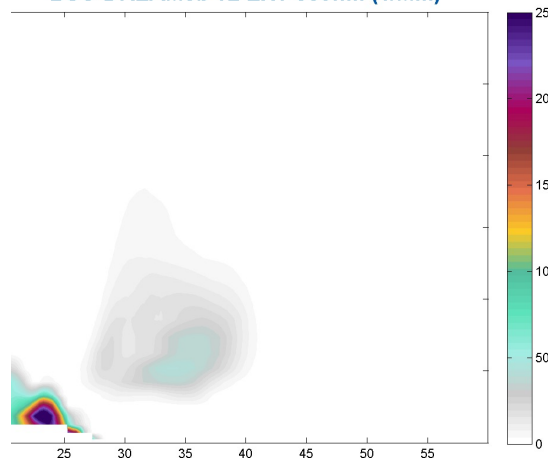
5 Apr 2011 03:00 UTC

Coartes of Sara
Basart (BSC)

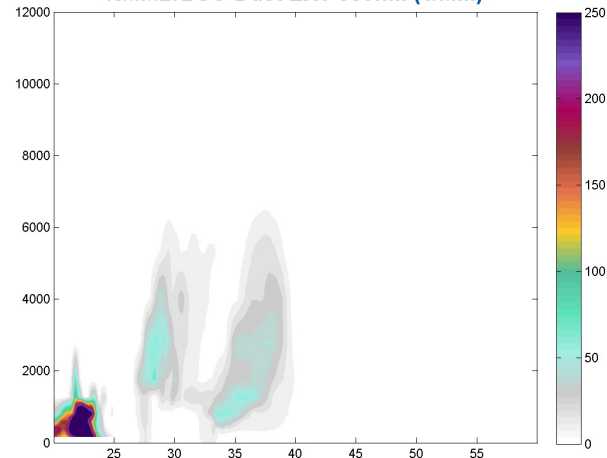
CALIOP EXT 532nm (1/Mm):2011-04-05T02-41-54Z



BSC-DREAM8b v2 EXT 550nm (1/Mm)



NMMB/BSC-Dust EXT 550nm (1/Mm)

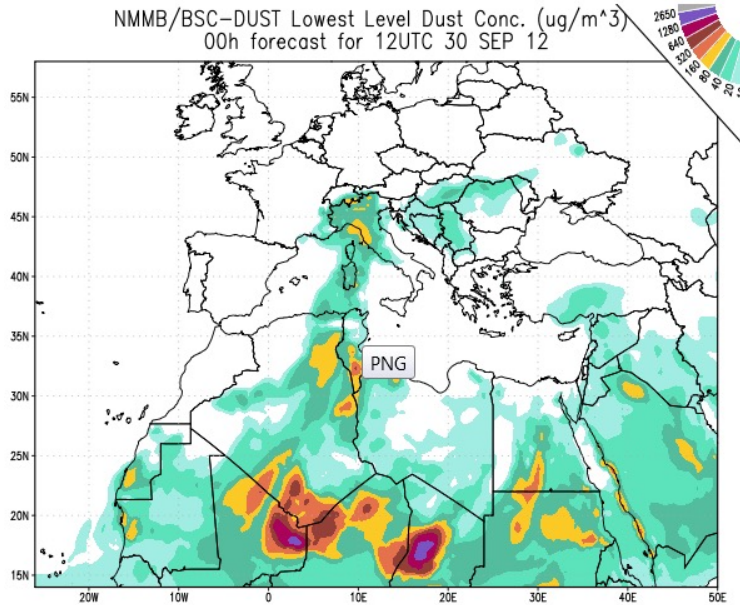


Dust forecast

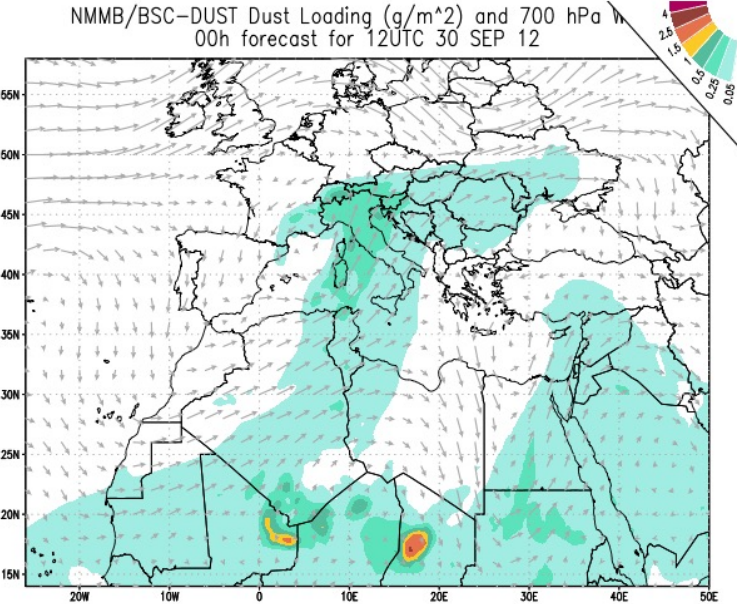


Forecast products

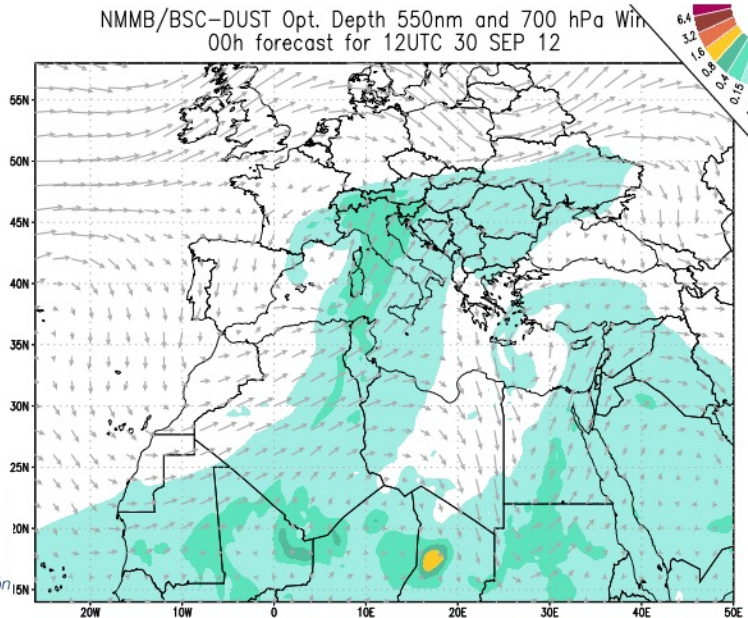
NMMB/BSC-DUST Lowest Level Dust Conc. ($\mu\text{g}/\text{m}^3$)
00h forecast for 12UTC 30 SEP 12



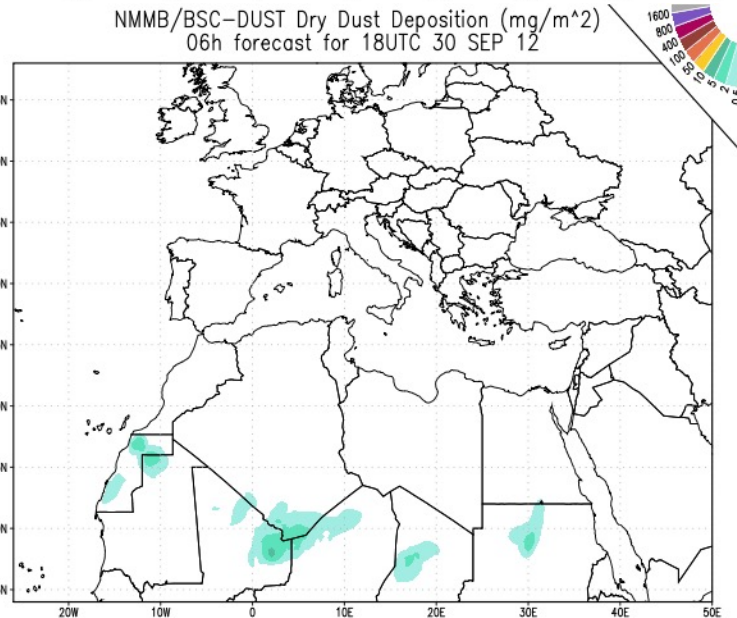
NMMB/BSC-DUST Dust Loading (g/m^2) and 700 hPa W
00h forecast for 12UTC 30 SEP 12



NMMB/BSC-DUST Opt. Depth 550nm and 700 hPa Win
00h forecast for 12UTC 30 SEP 12



NMMB/BSC-DUST Dry Dust Deposition (mg/m^2)
06h forecast for 18UTC 30 SEP 12



NMMB/BSC-
Dust model

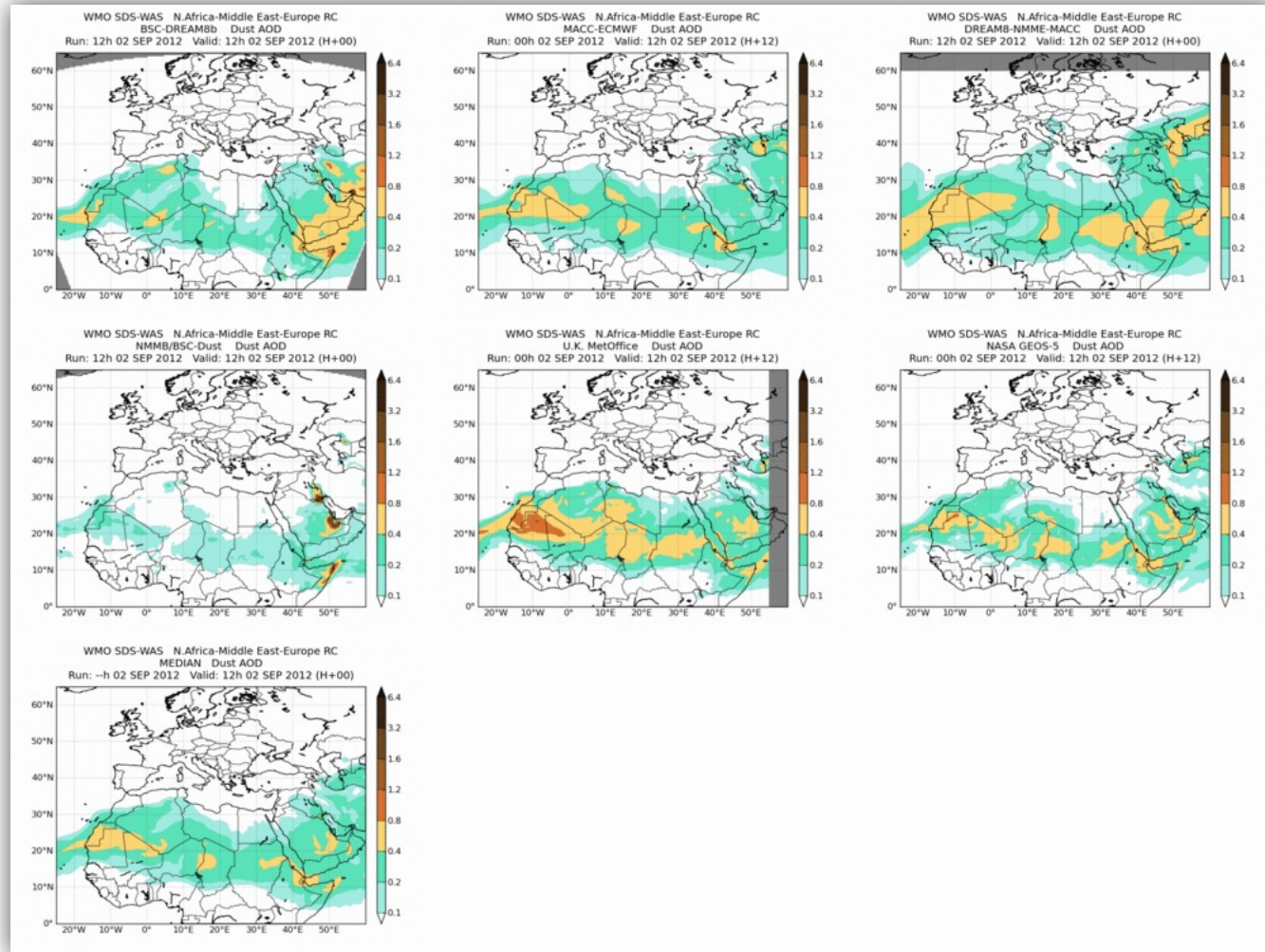
The models



MODEL	INSTITUTION	RUN TIME	DOMAIN	DATA ASSIMILATION
BSC-DREAM8b	BSC-CNS	12	Regional	No
CHIMERE	LMD	00	Regional	No
LMDzT-INCA	LSCE	00	Global	No
MACC	ECMWF	00	Global	MODIS AOD
DREAM-NMME-MACC	SEEVCCC	12	Regional	MACC analysis
NMMB/BSC-Dust	BSC-CNS	12	Regional	No
MetUM	U. K. Met Office	00	Global	No
GEOS-5	NASA	00	Global	MODIS reflectances
NGAC	NCEP	00	Global	No

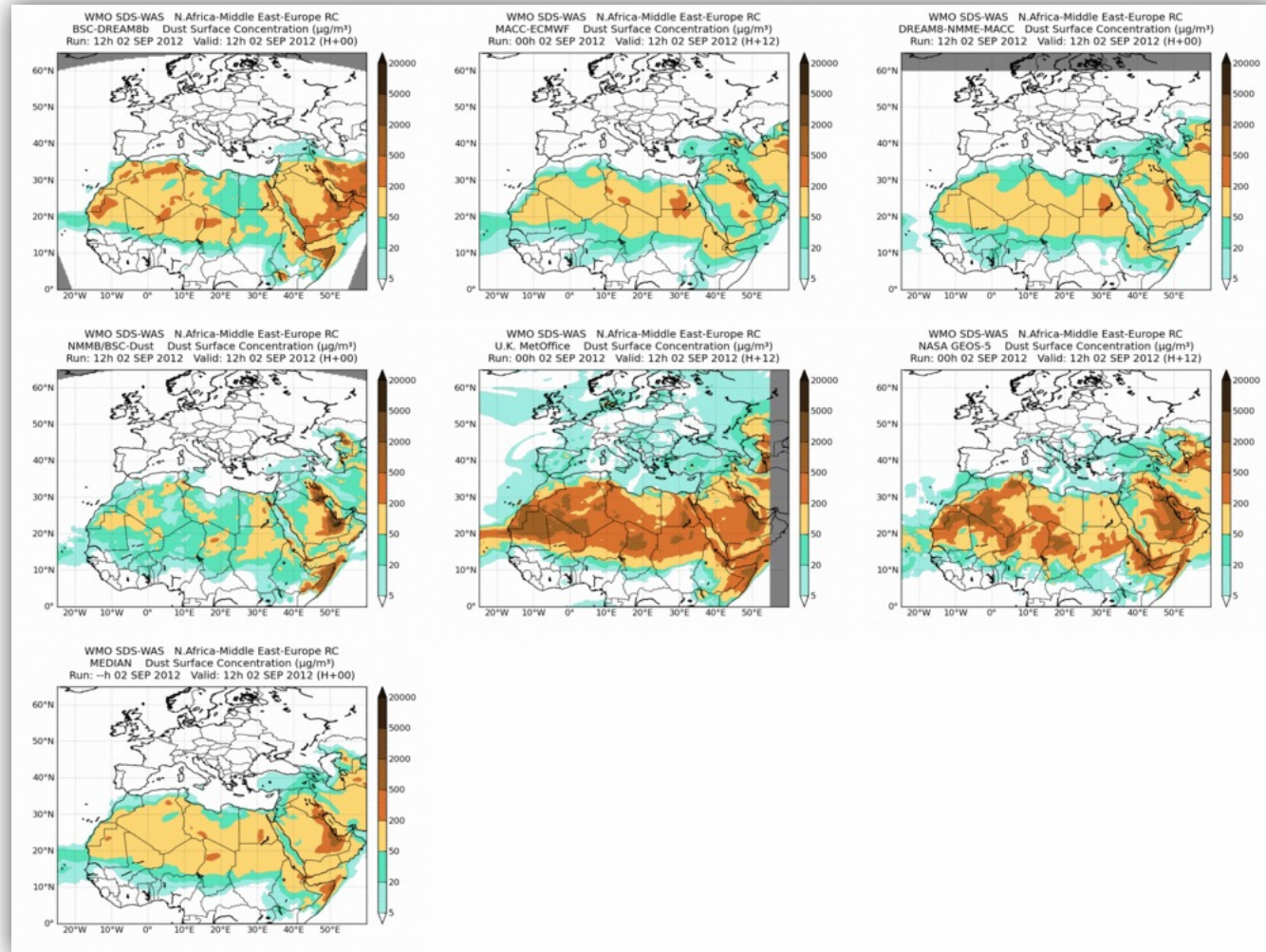
- **VARIABLES:** Dust surface concentration – Dust Optical Depth at 550 nm
- **LEAD TIME:** 0 – 72 hours, every 3 hours
- **GEOGRAPHICAL DOMAIN:** 25°W – 60°E, 0 – 65°N

Joint visualization. Dust AOD at 550 nm



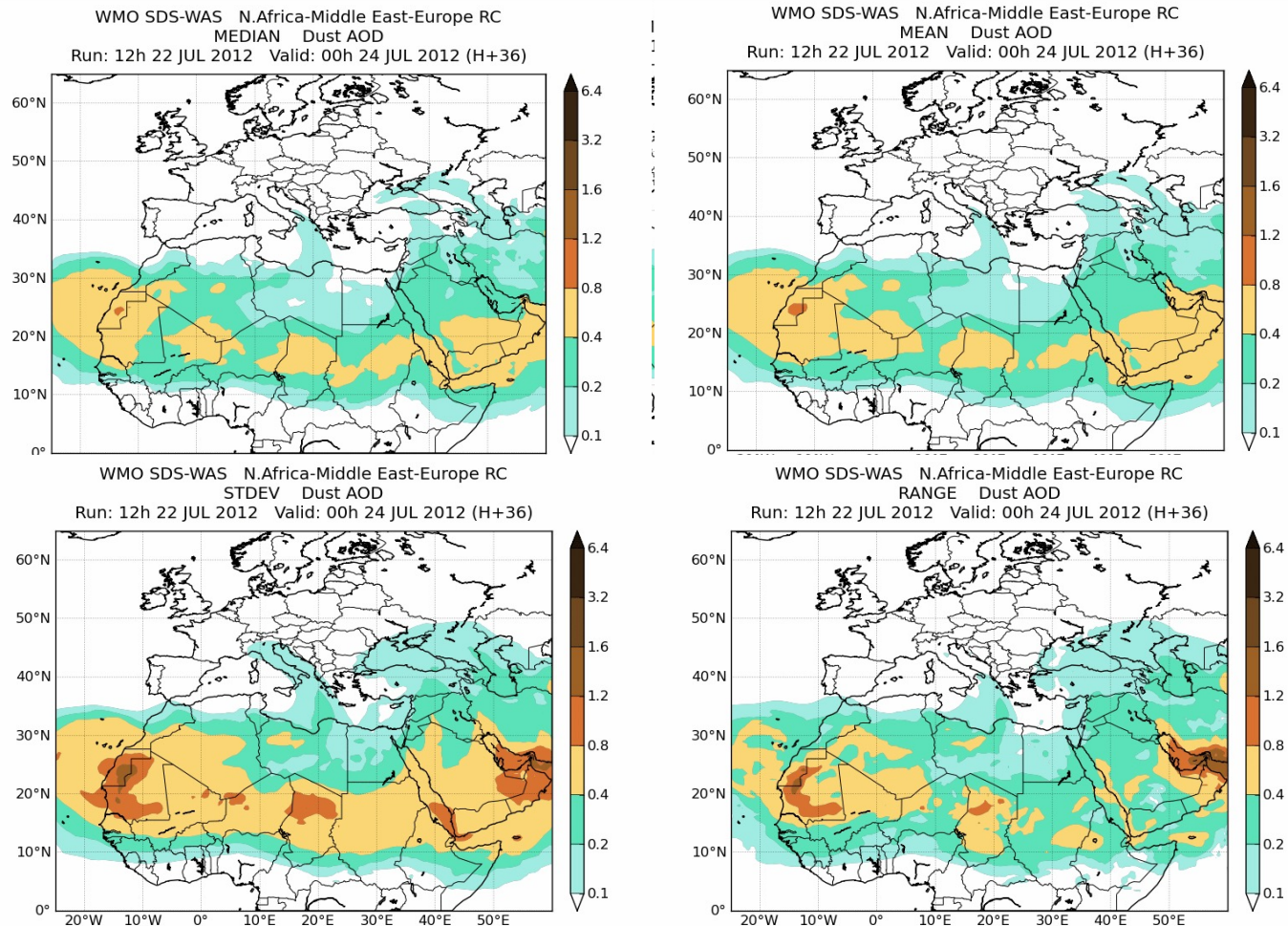
RUN: 2 Sep 2012 VALID: 2 Sep 2012 12:00 – 5 Sep 2012 00:00

Joint visualization. Surface concentration



RUN: 2 Sep 2012 VALID: 2 Sep 2012 12:00 – 5 Sep 2012 00:00

Generation of multi-model products



Model outputs are bi-linearly interpolated to a common 0.5°lon x 0.5°lat grid mesh. Then, different multi-model products are generated:

- CENTRALITY: median - mean
- SPREAD: standard deviation – range of variation

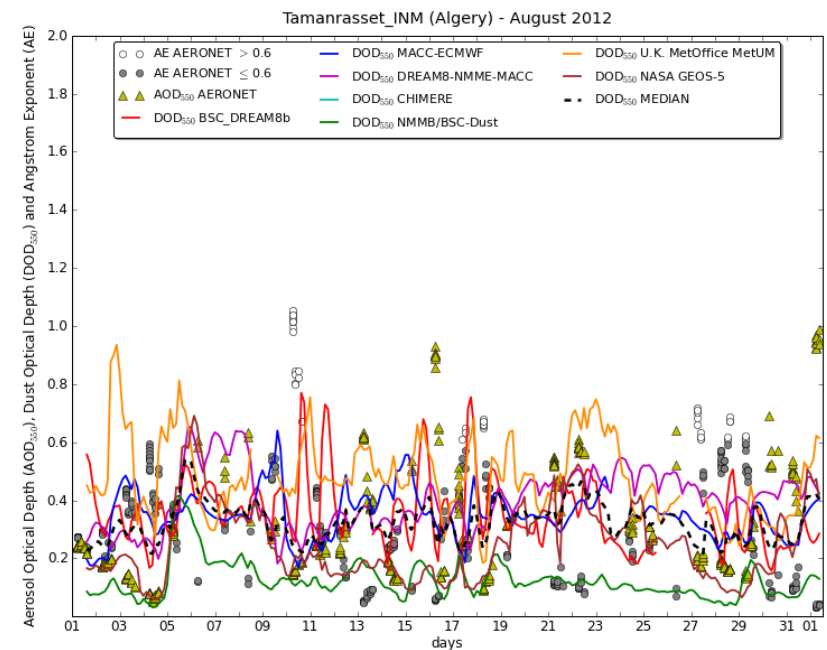
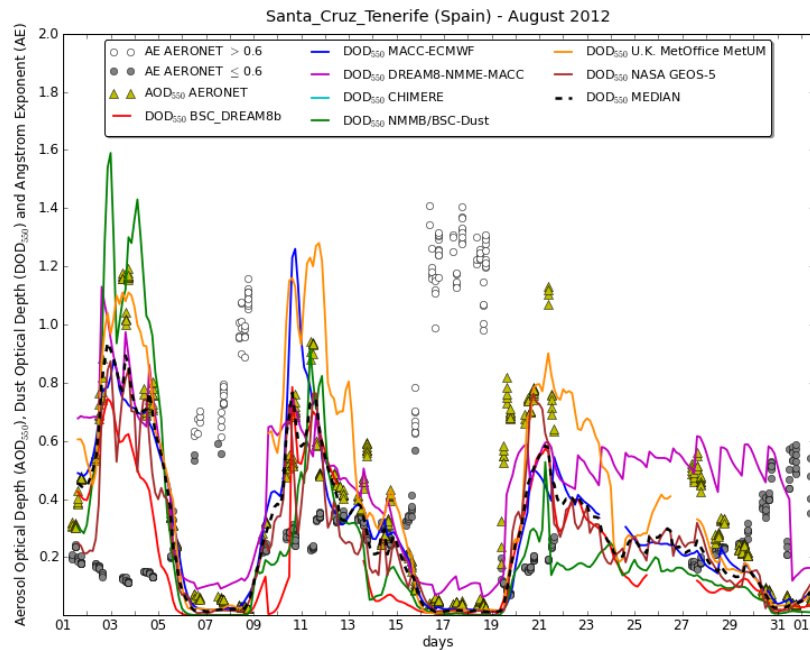
Nrt evaluation using AERONET data

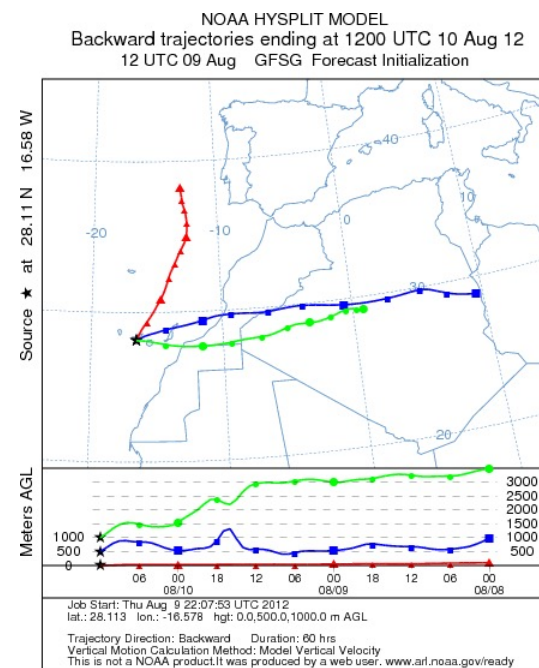
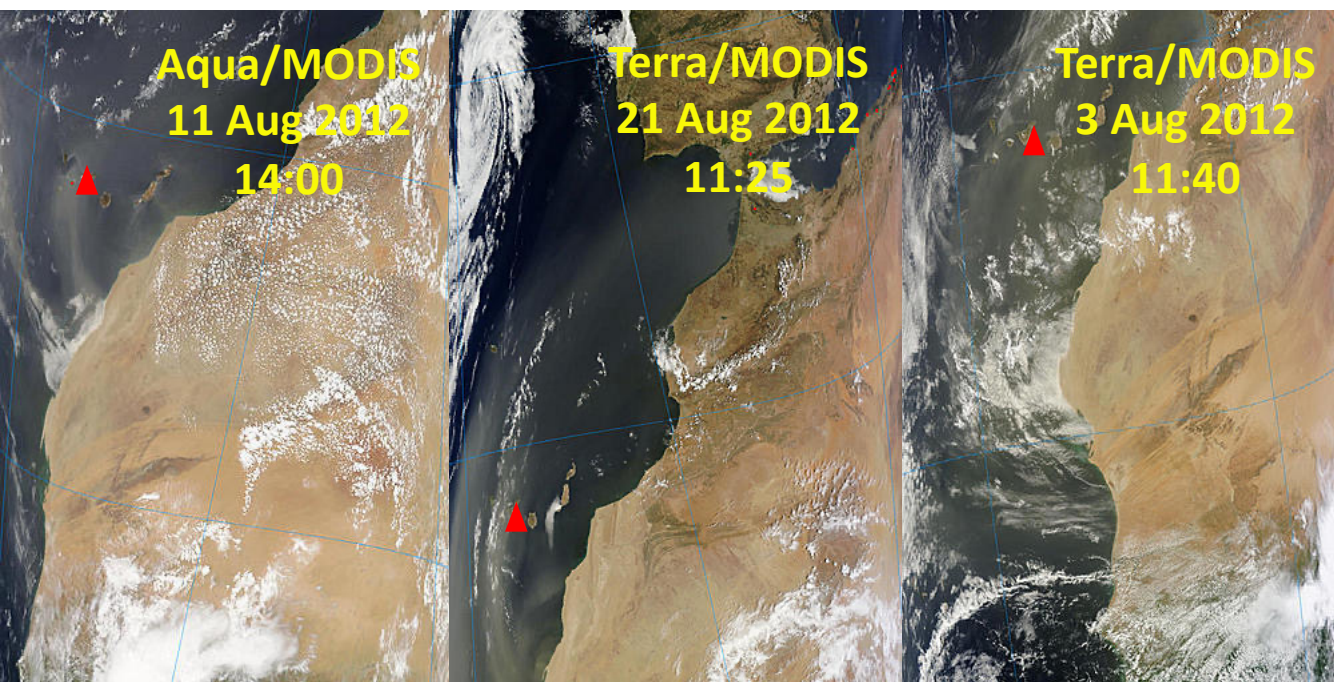
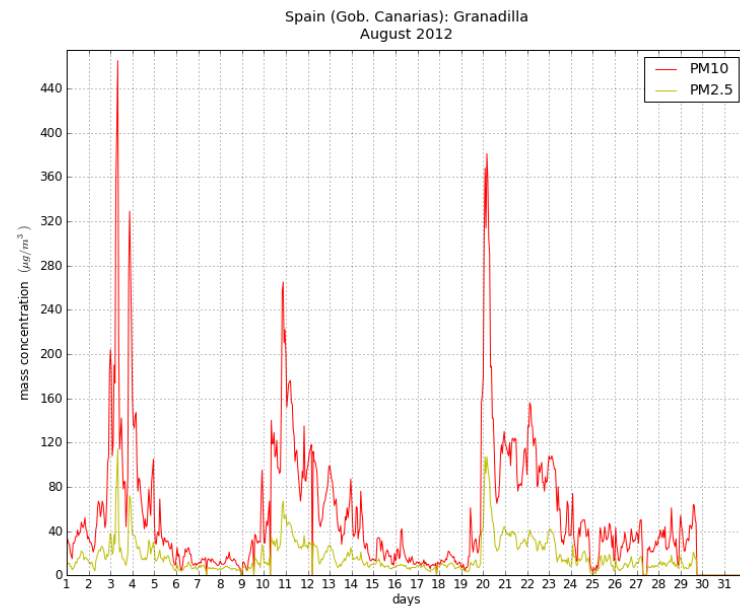
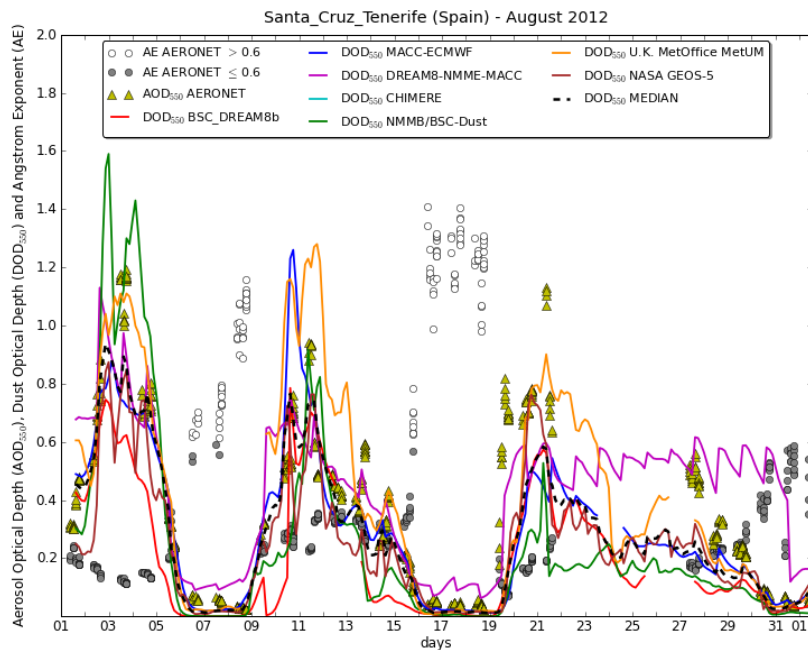


SANTA_CRUZ_TENERIFE

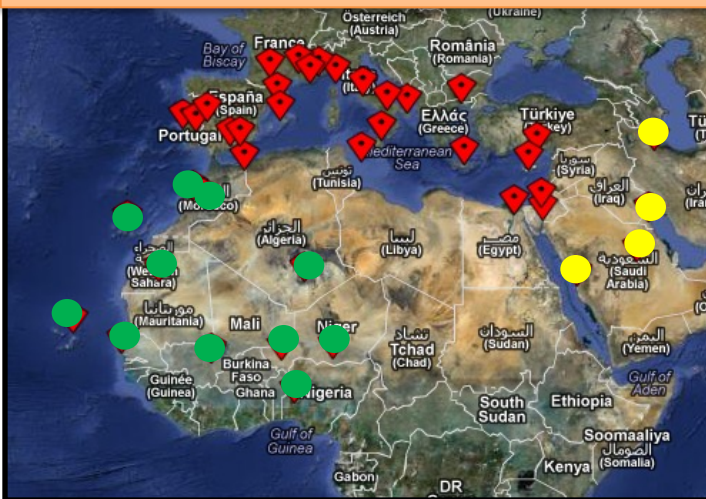


TAMANRASSET_INM





Evaluation scores using AERONET data



Jun 2012 - Aug 2012. Dust Optical Depth.
Threshold Angstrom Exponent = 0.600

BIAS

	BSC_ DREAM8b	MACC- ECMWF	DREAM8- NMME- MACC	CHIMERE	NMMB/ BSC- Dust	U.K. MetOffice	NASA GEOS-5	MEDIAN
Sahel/Sahara show stations	-0.26	-0.28	-0.13	-0.54	-0.30	-0.09	-0.18	-0.26
Middle East show stations	-0.19	-0.31	-0.12	-0.53	-0.21	-0.19	-0.20	-0.27
Mediterranean show stations	-0.16	-0.18	-0.09	-0.34	-0.23	-0.11	-0.19	-0.19
TOTAL	-0.21	-0.25	-0.11	-0.47	-0.26	-0.12	-0.19	-0.23

ROOT MEAN SQUARE ERROR

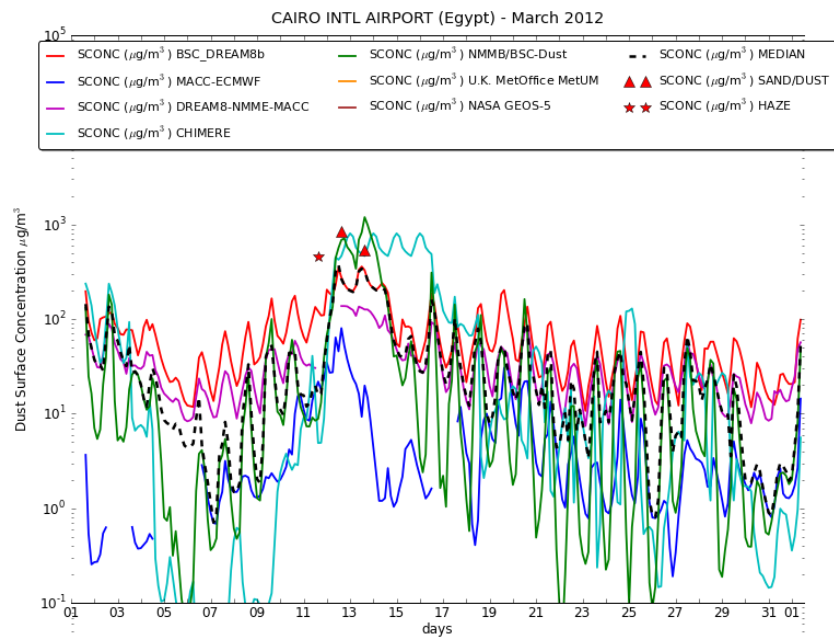
	BSC_ DREAM8b	MACC- ECMWF	DREAM8- NMME- MACC	CHIMERE	NMMB/ BSC- Dust	U.K. MetOffice	NASA GEOS-5	MEDIAN
Sahel/Sahara show stations	0.54	0.53	0.42	0.75	0.54	0.47	0.34	0.50
Middle East show stations	0.35	0.43	0.28	0.61	0.60	0.35	0.33	0.39
Mediterranean show stations	0.33	0.31	0.26	0.44	0.34	0.30	0.28	0.31
TOTAL	0.43	0.44	0.34	0.62	0.48	0.39	0.31	0.42

$$BE = \frac{1}{N} \sum_{i=1}^N (M_i - O_i)$$

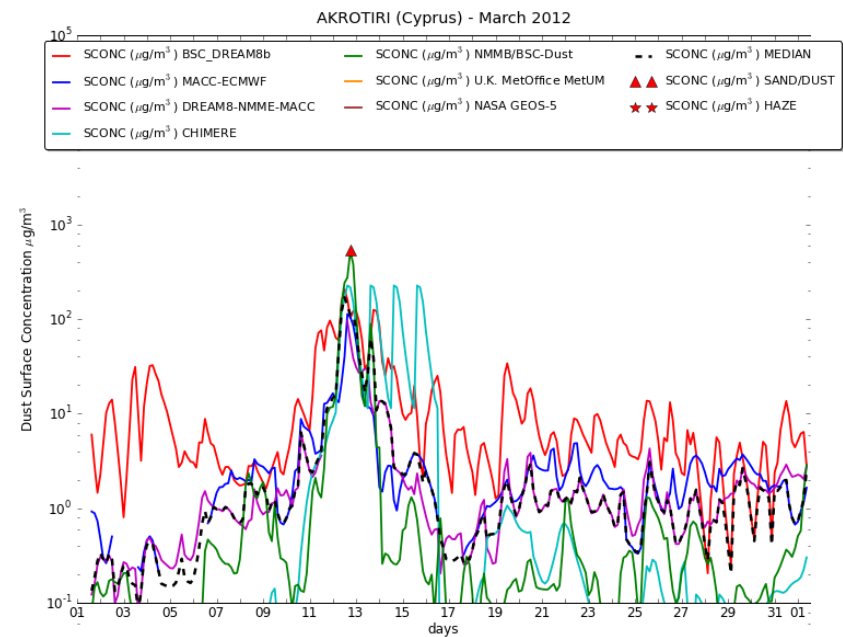
$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (M_i - O_i)^2}$$

- Monthly
- Seasonal
- Annual

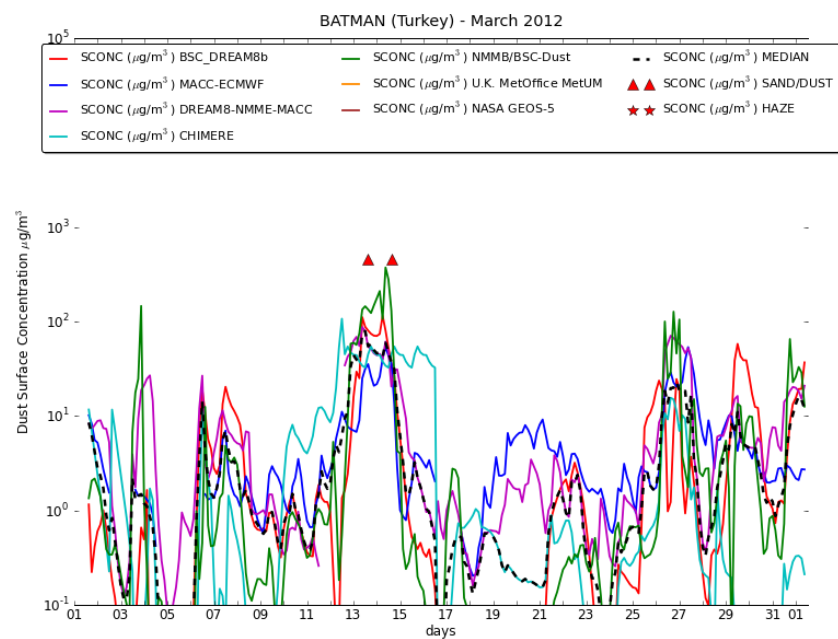
Besides dust, there might be other aerosol types. Therefore, negative BE could be expected.



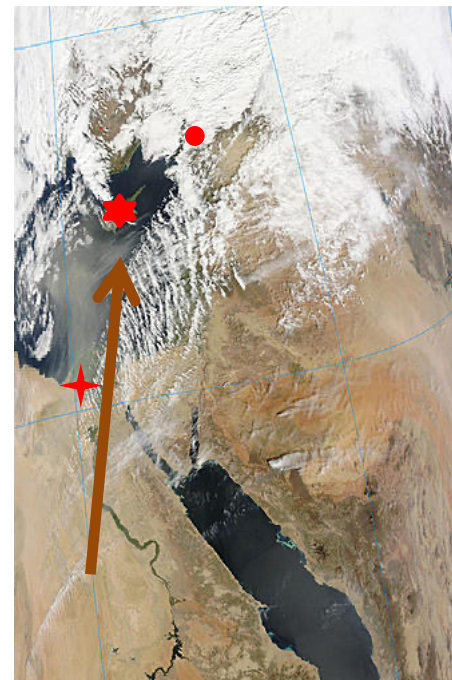
CAIRO, Egypt ★



AKROTIRI, Cyprus ★

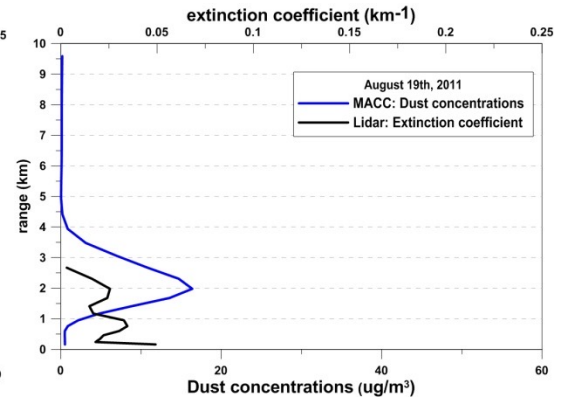
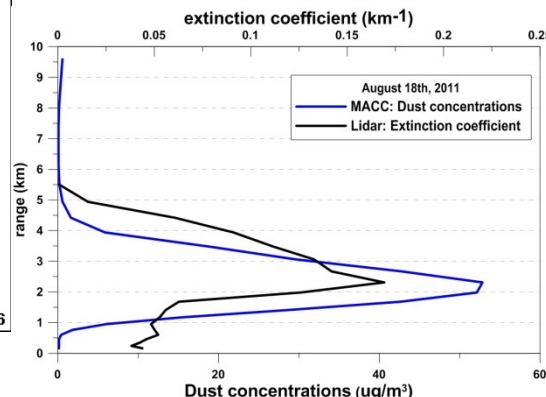
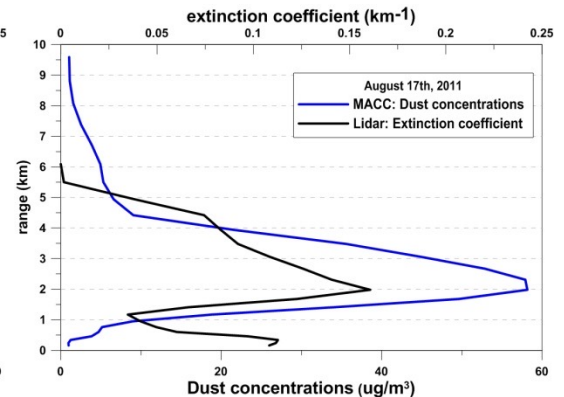
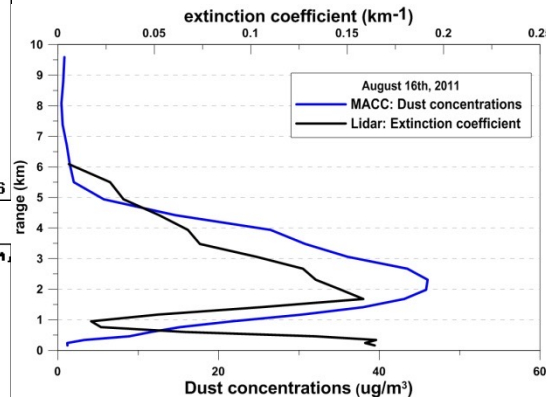
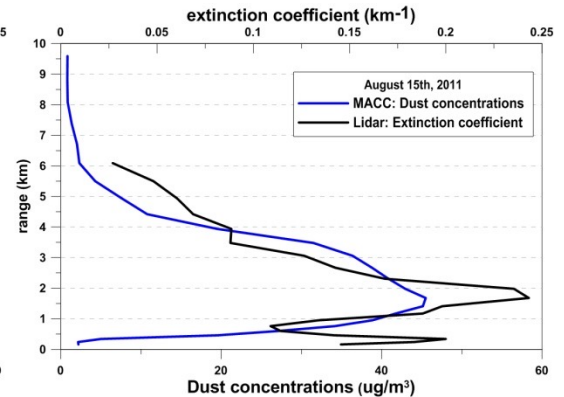
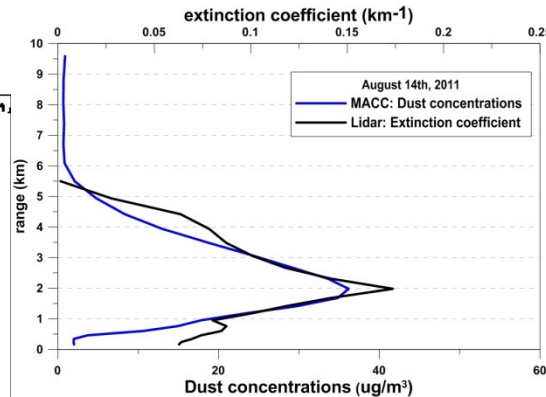
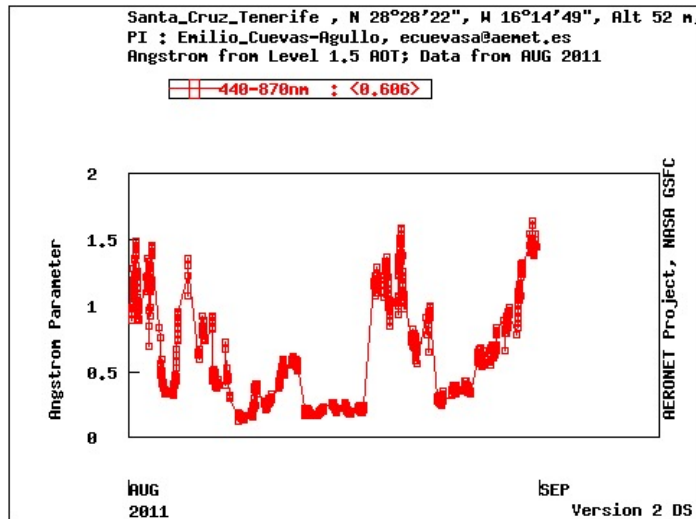
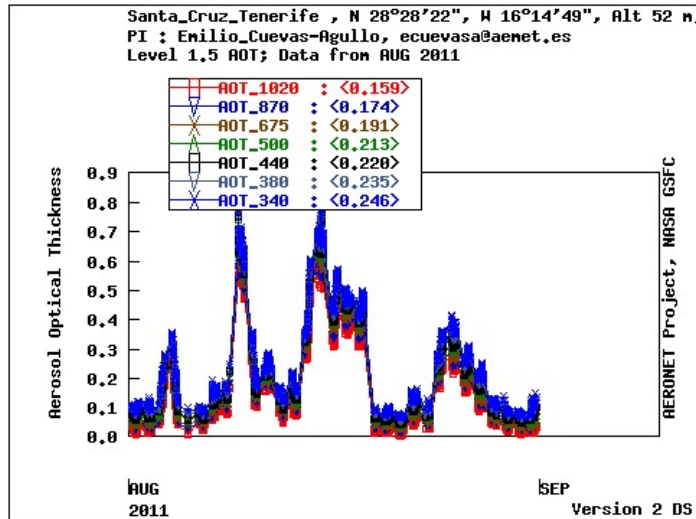


BATMAN, Turkey ●



Terra/MODIS
12 Mar 2012
08:20

Exploring the use of lidar to evaluate dust vertical profiles

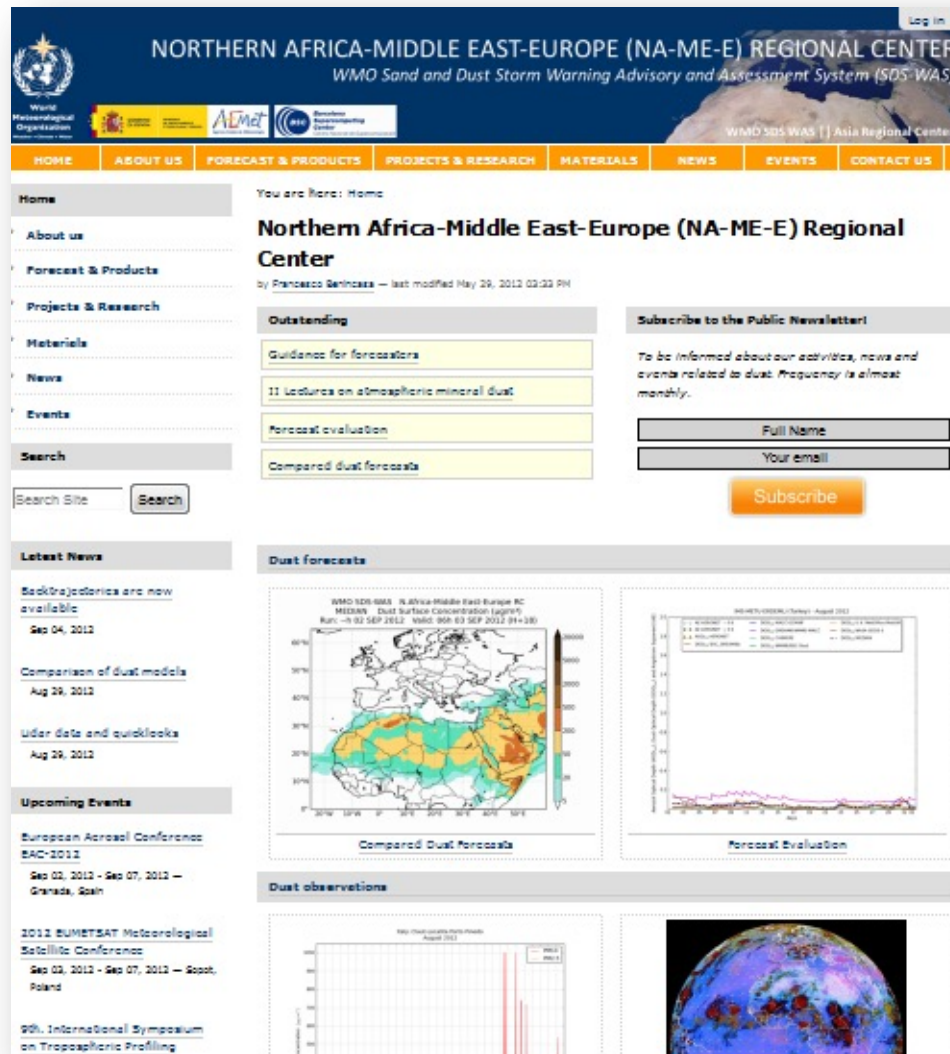


A satellite image of the Earth showing a large, dense, yellowish-brown dust plume originating from the African continent and extending over the Atlantic Ocean. The plume is composed of many smaller, swirling eddies. The surrounding ocean is dark blue, and some white clouds are visible in the upper left. The title 'Objectives of the Regional Center' is overlaid in white text on the left side of the image.

Objectives of the Regional Center

- Identify and improve products to monitor and predict atmospheric dust by working with research and operational organizations, as well as with users
- **Facilitate user access to information**
- Strengthen the capacity of countries to use the observations, analysis and predictions provided by the WMO SDS-WAS programme

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



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, the center's name, and a navigation menu with links: HOME, ABOUT US, FORECAST & PRODUCTS, PROJECTS & RESEARCH, MATERIALS, NEWS, EVENTS, and CONTACT US. A sidebar on the left contains links to Home, About us, Forecast & Products, Projects & Research, Materials, News, Events, and a Search box. The main content area features the title "Northern Africa-Middle East-Europe (NA-ME-E) Regional Center" by Francisco Sanchez, dated May 29, 2012. Below this, there are sections for "Outstanding" (Guidance for forecasters, 11 Lectures on atmospheric mineral dust, Forecast evaluation, Compared dust forecasts) and "Subscribe to the Public Newsletter!" (with fields for Full Name and Your email, and a Subscribe button). The "Dust forecasts" section displays two maps: "Compared Dust Forecasts" showing dust concentration over the region and "Forecast Evaluation" showing a time series of dust concentration. The "Dust observations" section includes a time series plot and a satellite image of the Earth showing dust storms.

sdswas@aemet.es

A satellite image of Earth showing a large, dense, yellowish-brown dust plume originating from the west coast of Africa and extending across the Atlantic Ocean. The dust is thick and billowing, partially obscuring the ocean and some landmasses. The surrounding ocean is dark blue, and some white clouds are visible in the upper left. The overall scene suggests a major atmospheric event, such as a Sahel dust storm.

Objectives of the Regional Center

- Identify and improve products to monitor and predict atmospheric dust by working with research and operational organizations, as well as with users
- Facilitate user access to information
- Strengthen the capacity of countries to use the observations, analysis and predictions provided by the WMO SDS-WAS programme

Capacity building - 2010



8-12 Nov 2010: Training Week on Satellite Meteorology. Barcelona

13 Nov 2010: Lectures on Atmospheric Mineral Dust and its Impact on Human Health, Environment and Economy. Barcelona

15-19 Nov 2010 Training Week on WMO SDS-WAS products. Barcelona



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 (satellite and ground observation and modelling of atmospheric dust). Antalya, Turkey



2011



Barcelona
Supercomputing
Center
Centro Nacional de Supercomputación

2012



5-9 Nov 2012: II Lectures on Atmospheric Mineral Dust. Barcelona

26-28 Nov 2012: Workshop on Meteorology, Sand and Dust Storm (SDS), Combating Desertification and Erosion. Ankara, Turkey



Operational forecast

Sep 2012. The WMO CBS-15 meeting recommends the designation of the Center as Regional Specialized Meteorological Center with Specialization on Atmospheric Sand and Dust Forecast(RSMC-ASDF).

Jul 2013. It is expected that the WMO Executive Council meets the recommendation and the RSMC starts working.



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