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

Enric Terradellas, AEMET, Barcelona
WMO SDS-WAS. Regional Center for Northern Africa, Middle East and Europe

3rd Training Course on WMO SDS-WAS Products
Sultan Qaboos University, Muscat, Oman, 8-12 Dec 2013

Outline

- 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

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
World Meteorological Organization
Weather • Climate • Water

Outline

- **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

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
World Meteorological Organization
Weather • Climate • Water

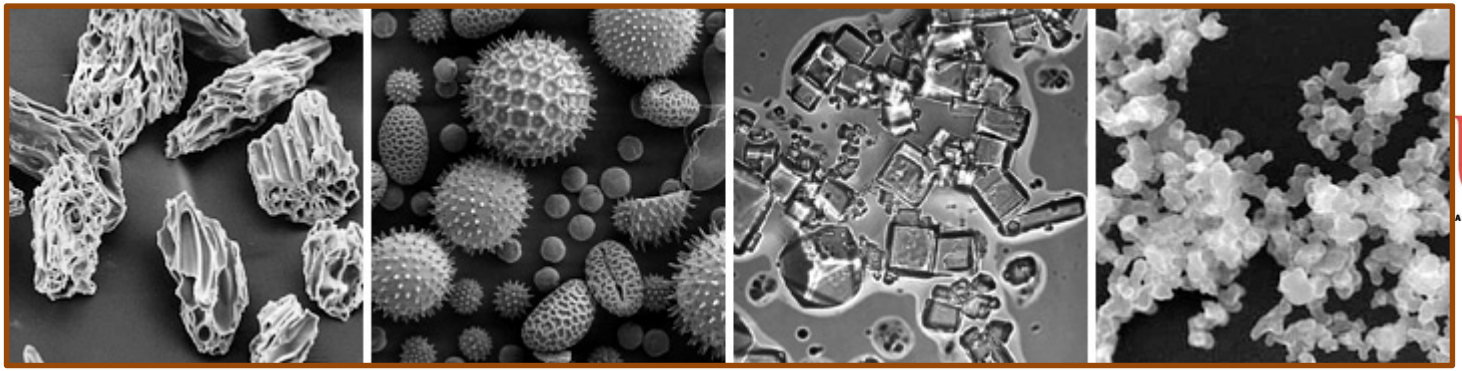
Atmospheric aerosol

Atmospheric aerosol

Solid or liquid particles suspended in the air

Particle size

Diameter ~ 0.002 – 100 µm



USGS science for a changing world

UMBC AN HONORS UNIVERSITY IN MARYLAND

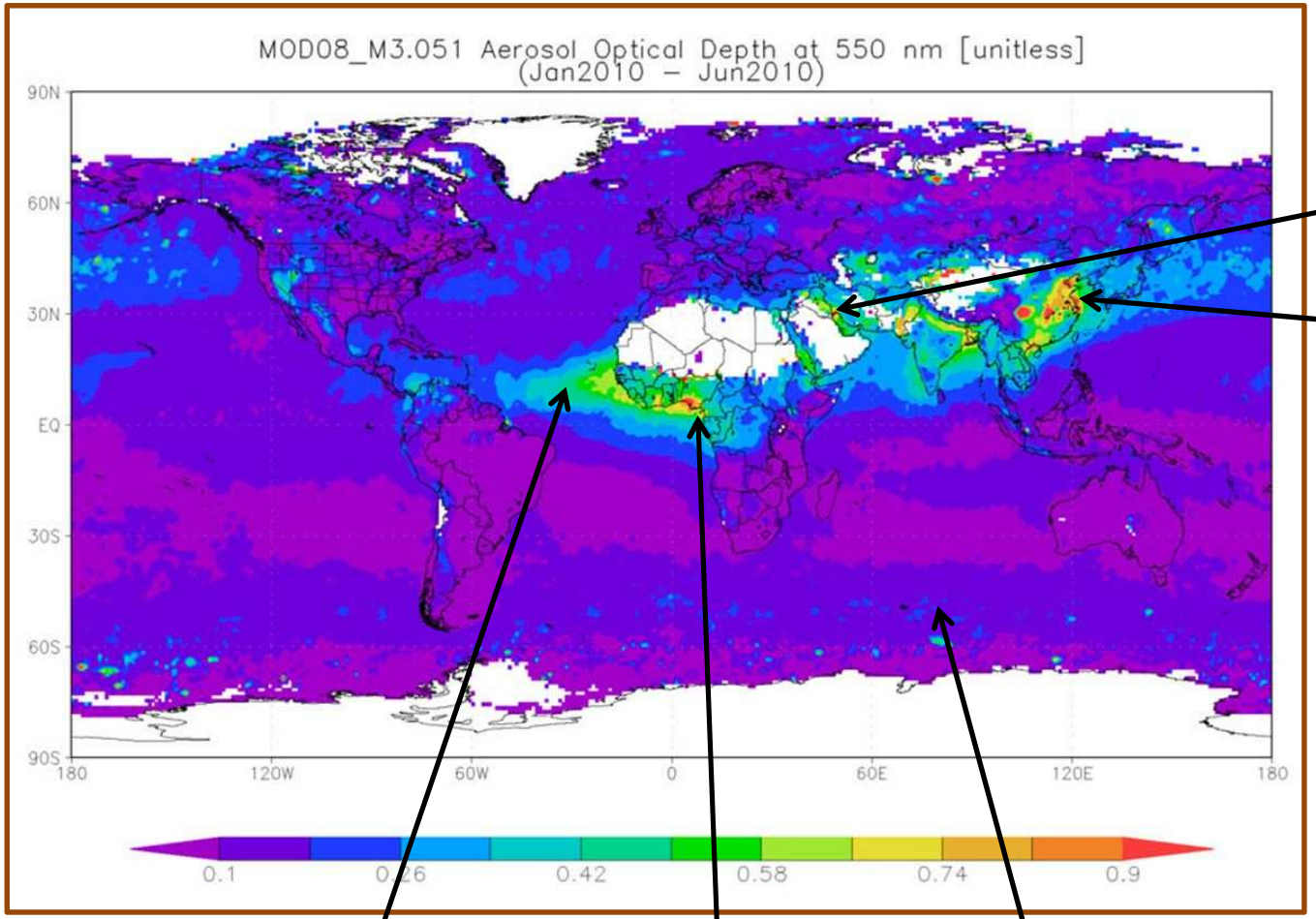
ASU Arizona State University

Atmospheric aerosol

Aerosol sources

Atmospheric aerosol

Gobal AOD



Mineral dust

pollution

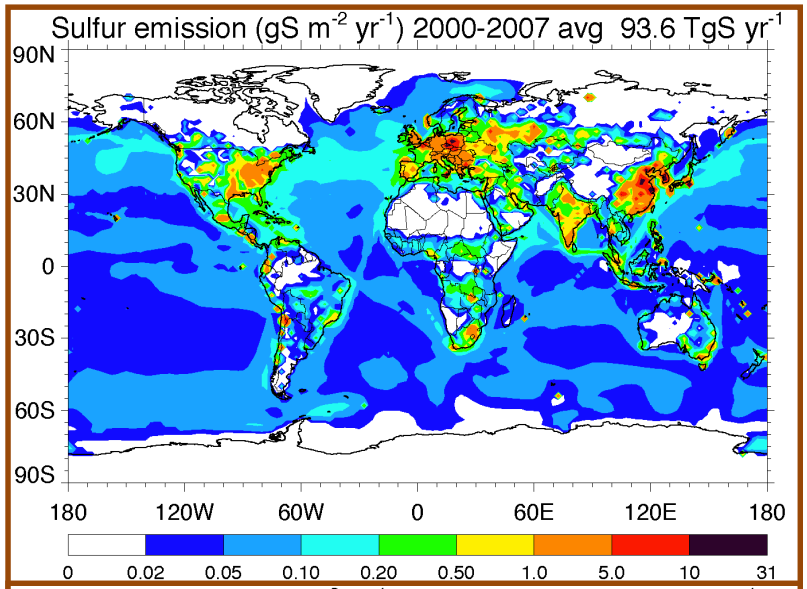
Mineral dust

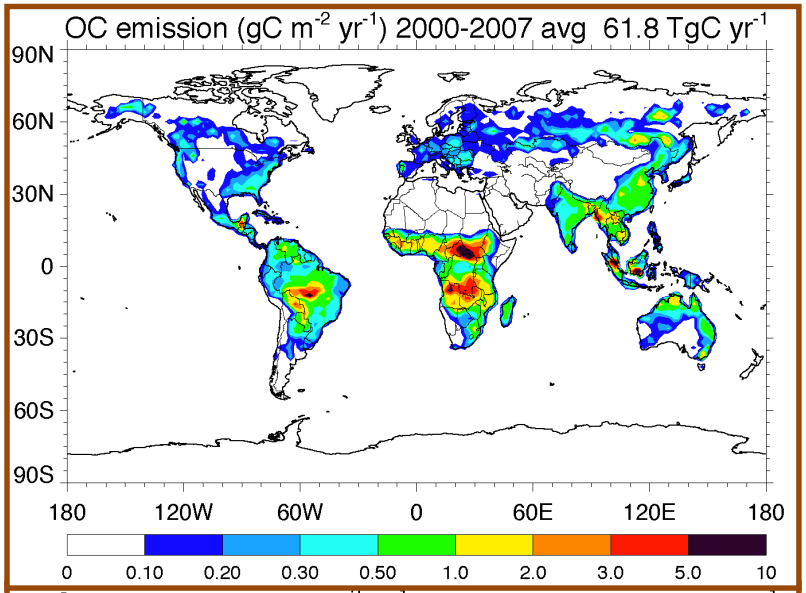
Biomass burning

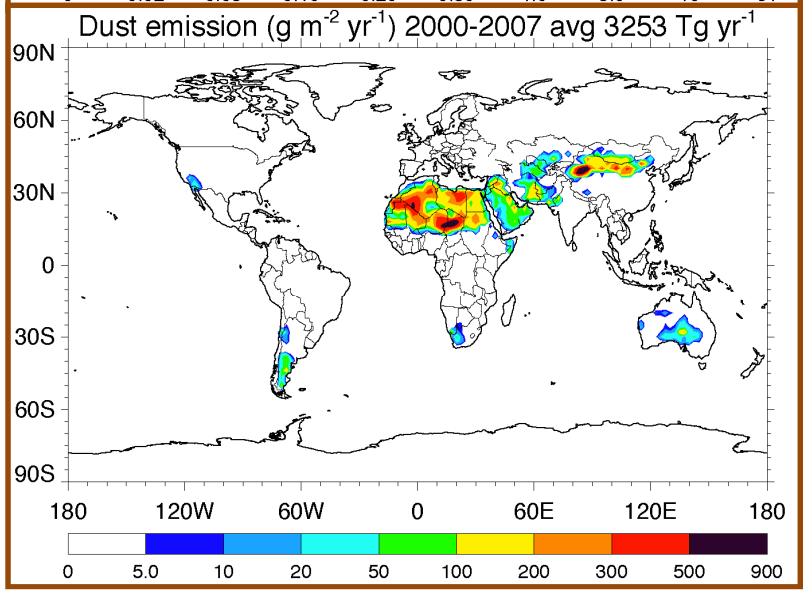
Sea salt

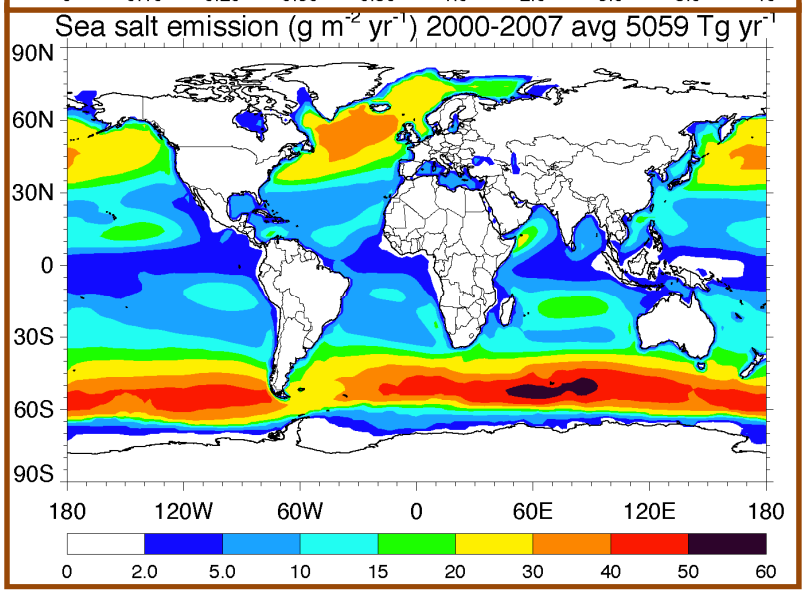
Atmospheric aerosol

Emissions 2000-2007









Chin et al. (2009)

The dust cycle

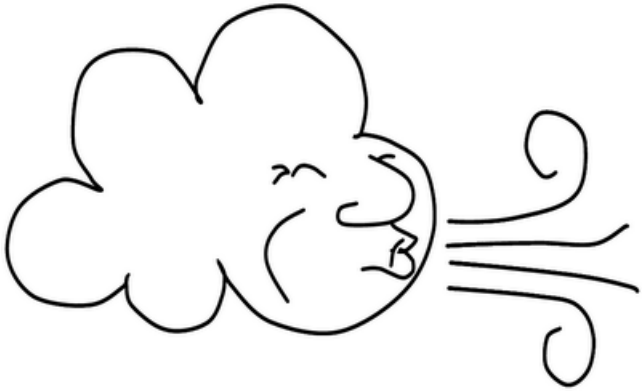
- Atmospheric aerosol
- **The dust cycle**
- Observation of atmospheric dust
- Prediction of atmospheric dust

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

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

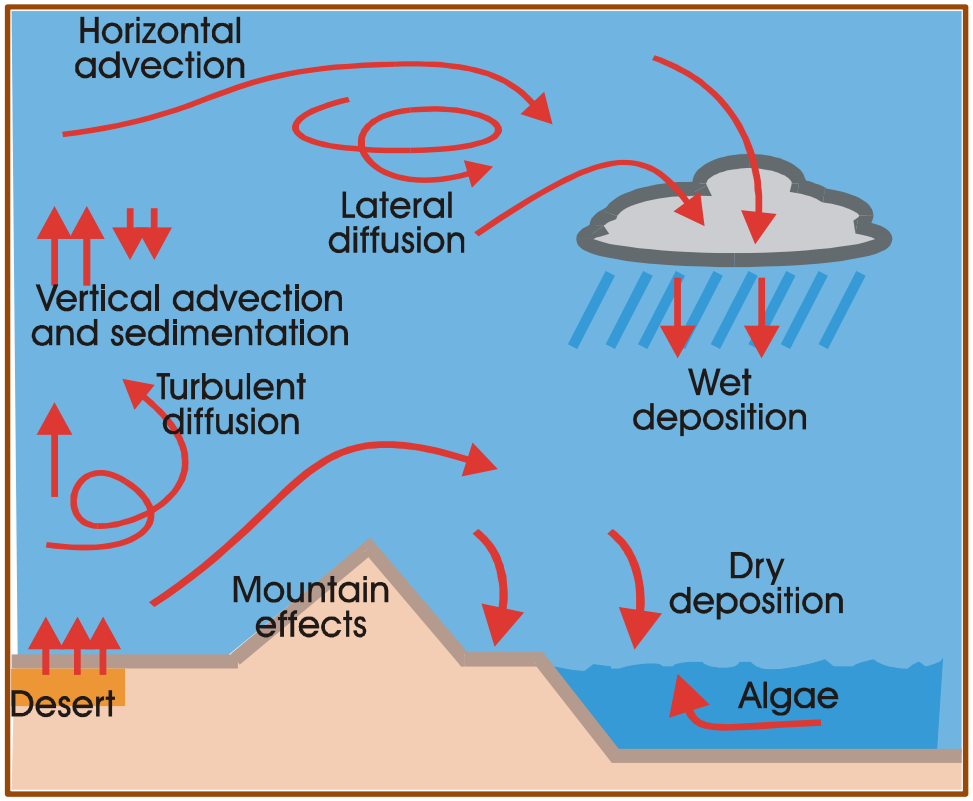
GOBIERNO DE ESPAÑA
MINISTERIO DE MEDIO AMBIENTE Y MEDIO RURAL Y MARINO
AEMet Agencia Estatal de Meteorología
BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación
World Meteorological Organization
Weather • Climate • Water

The dust cycle



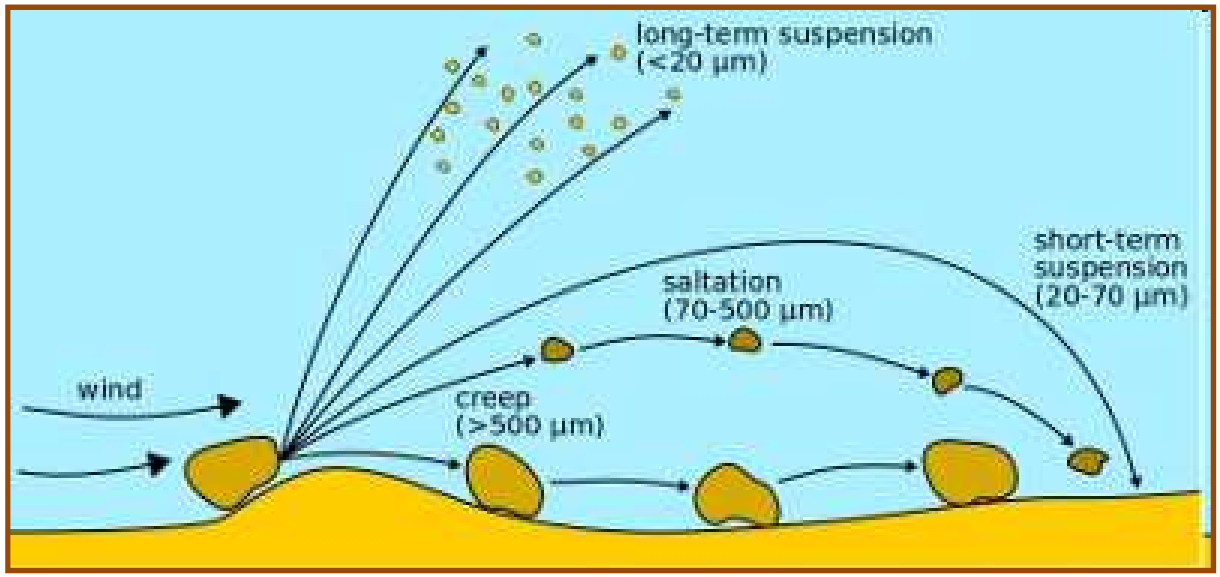
MODIS. 4 Feb 2013

The dust cycle



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

Emission



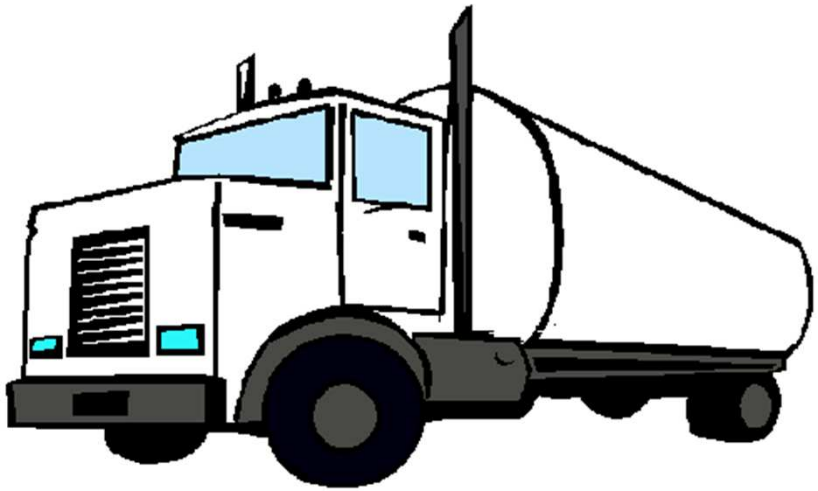
- **Soil texture**
- **Soil humidity**
- **Vegetation**

- **Wind**
- **Near-surface turbulence**

Mobilized dust

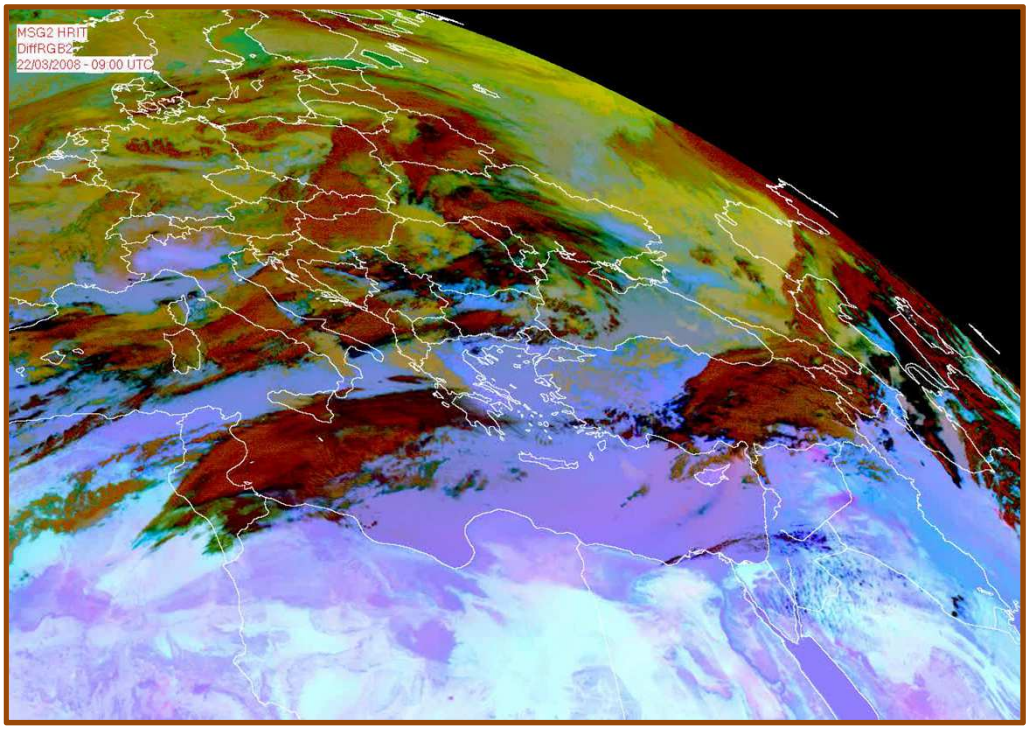
~ 60,000 – 120,000 kg / s
~ 2 – 4·10^{12} kg / yr

100,000,000 trucks



5,000 ULCC

Meteorological conditions

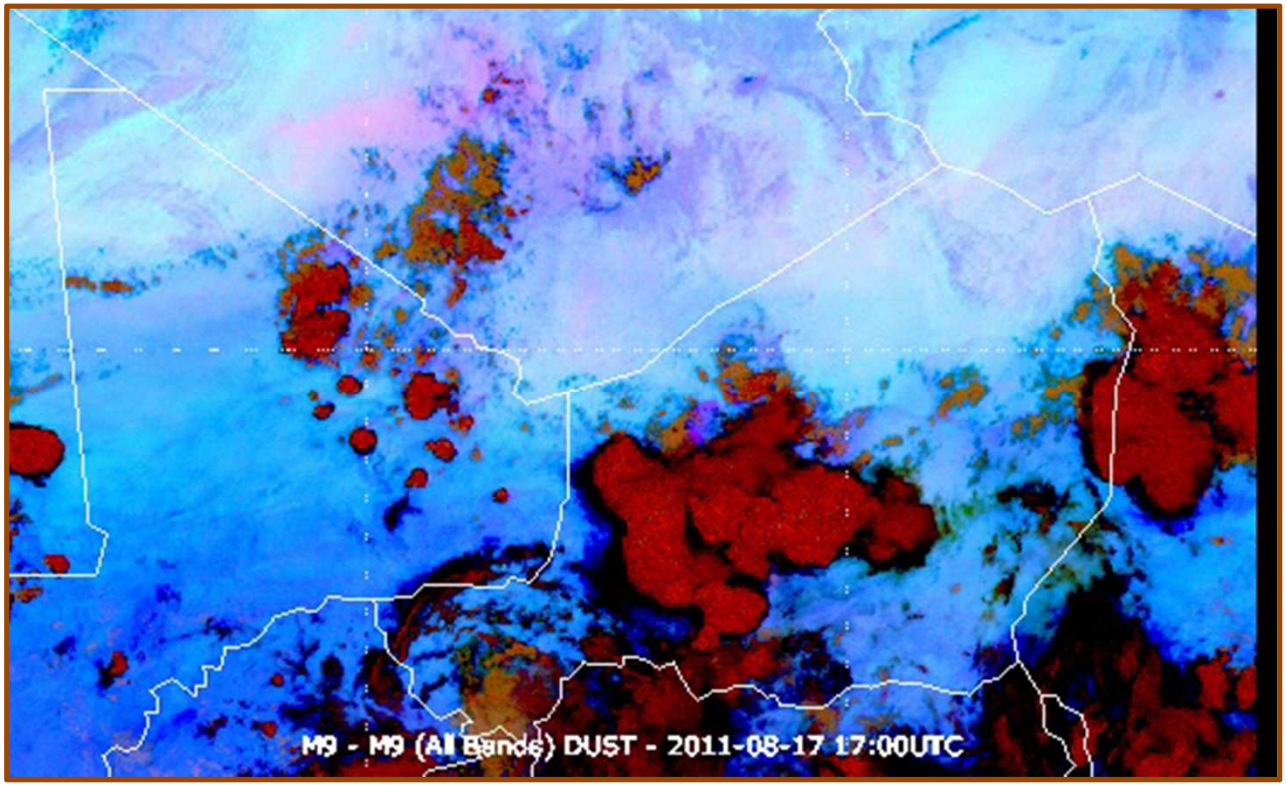


EUMETSAT

SYNOPTIC SCALE

- **Frontal systems**
- **Reinforced trade winds**

Meteorological conditions

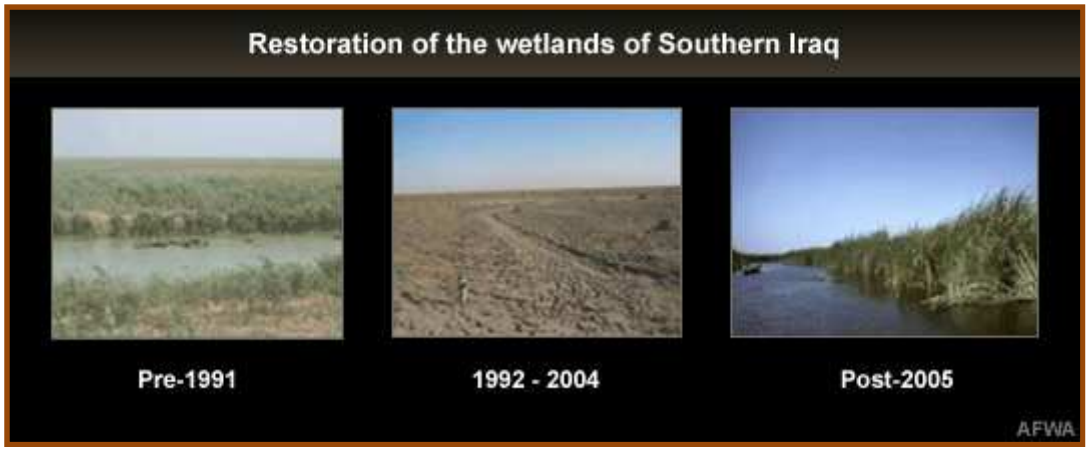


EUMETSAT

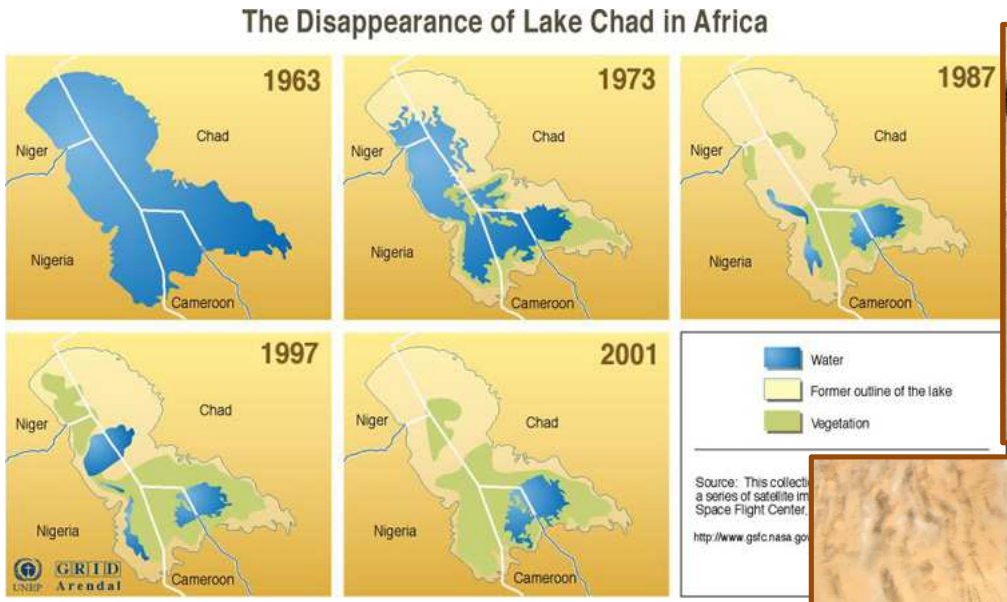
MESOSCALE-MICROSCALE

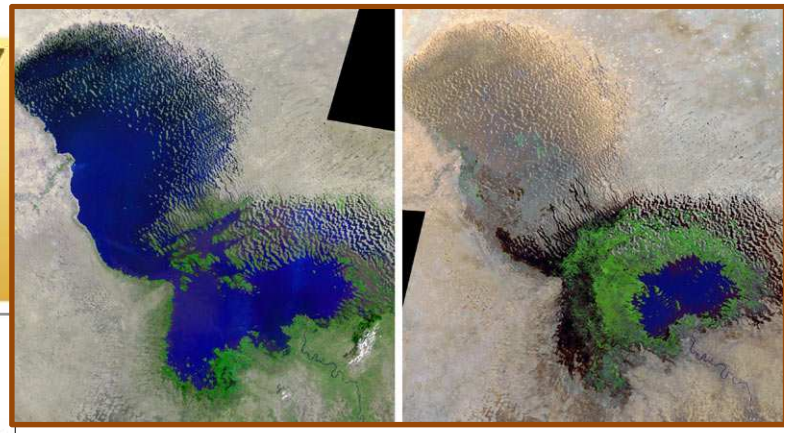
Convection	**Drainage winds**
Low-level jets	**Gap winds**

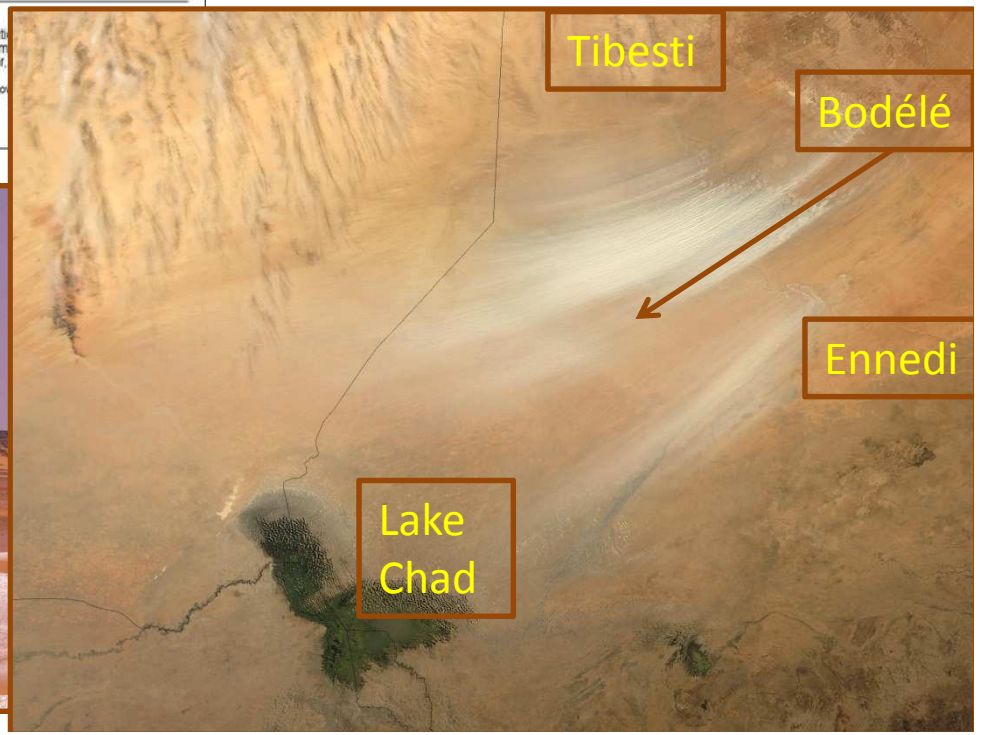
Dust sources



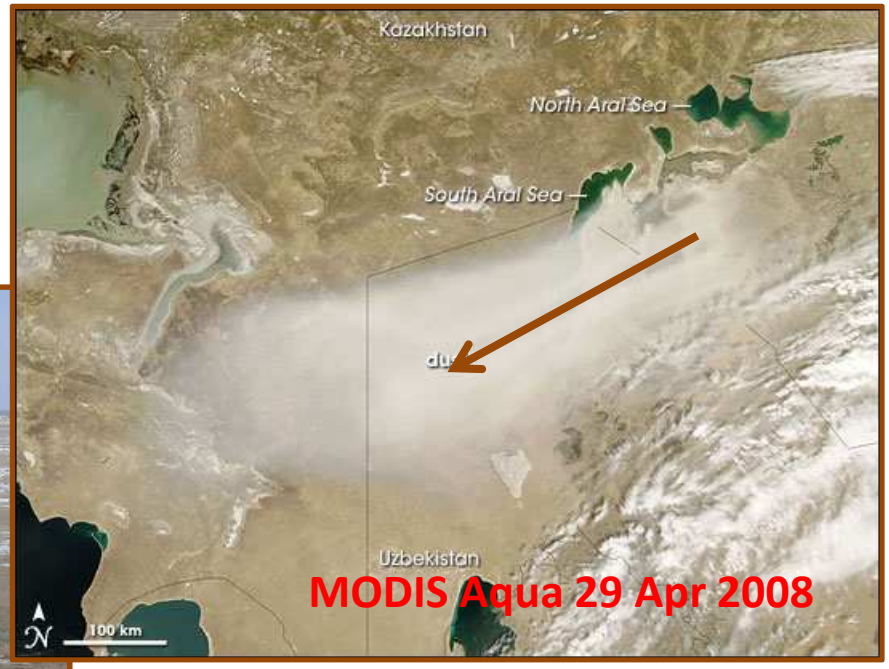
The Bodélé depression



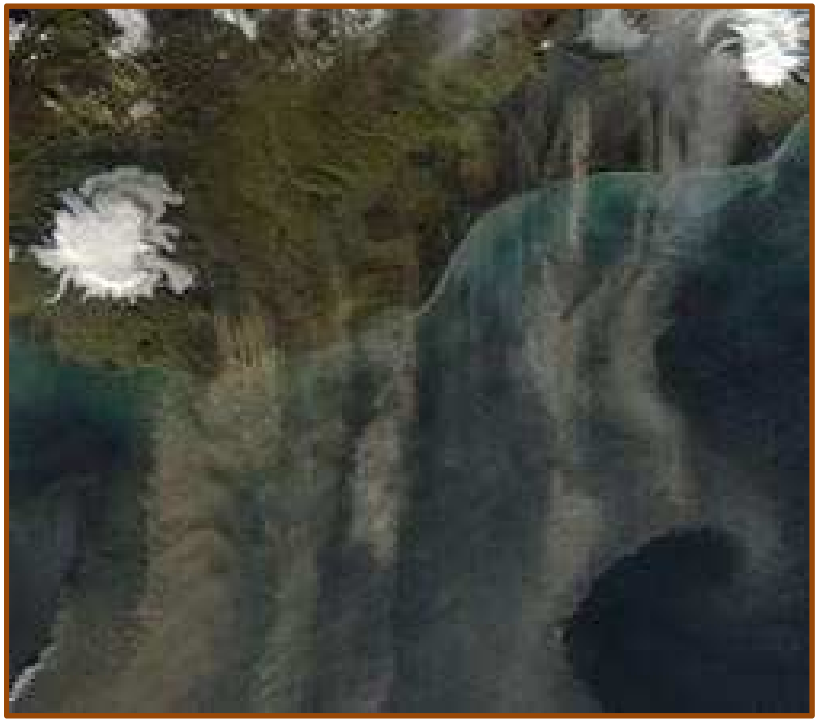




The Aral sea


Kazakhstan
North Aral Sea
South Aral Sea
Uzbekistan
100 km
MODIS Aqua 29 Apr 2008

Dust at high latitude

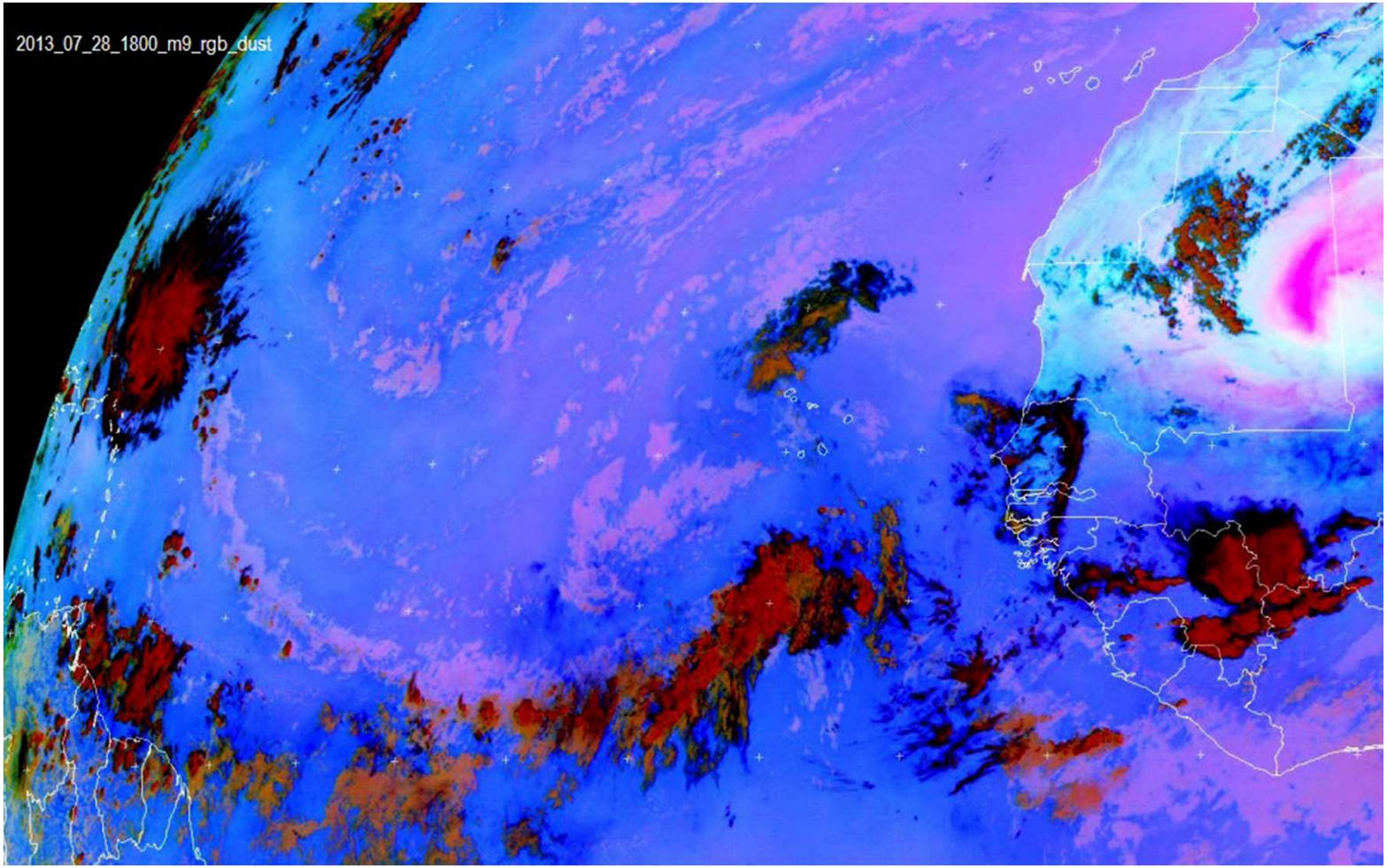


South Iceland
MODIS. 4 Oct 2004

South Alaska
MODIS. 5 Nov 2005

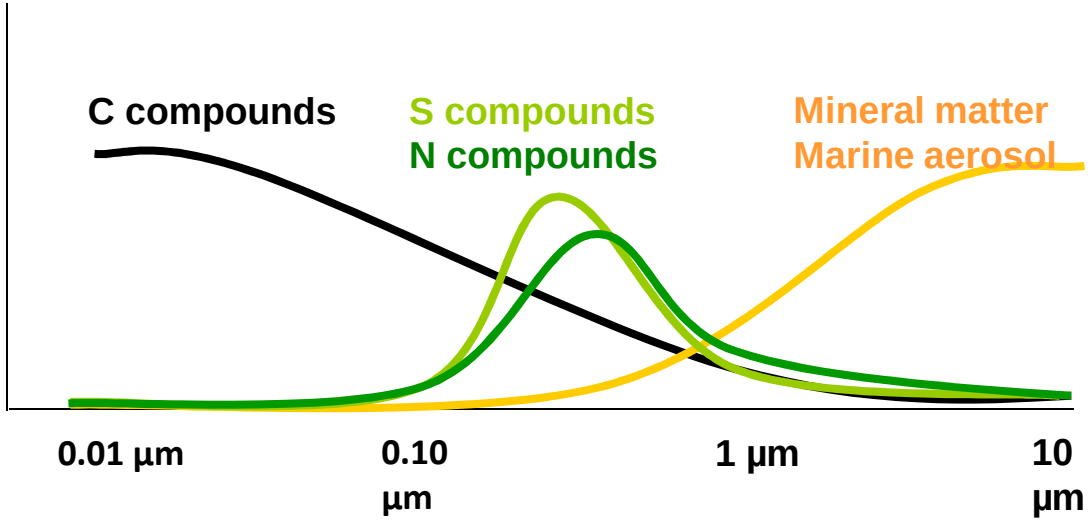
Common in autumn, when the level of rivers fall and sediments are exposed to wind. Not to be confused with volcanic ash or products from biomass burning (tundra fires)

Transport

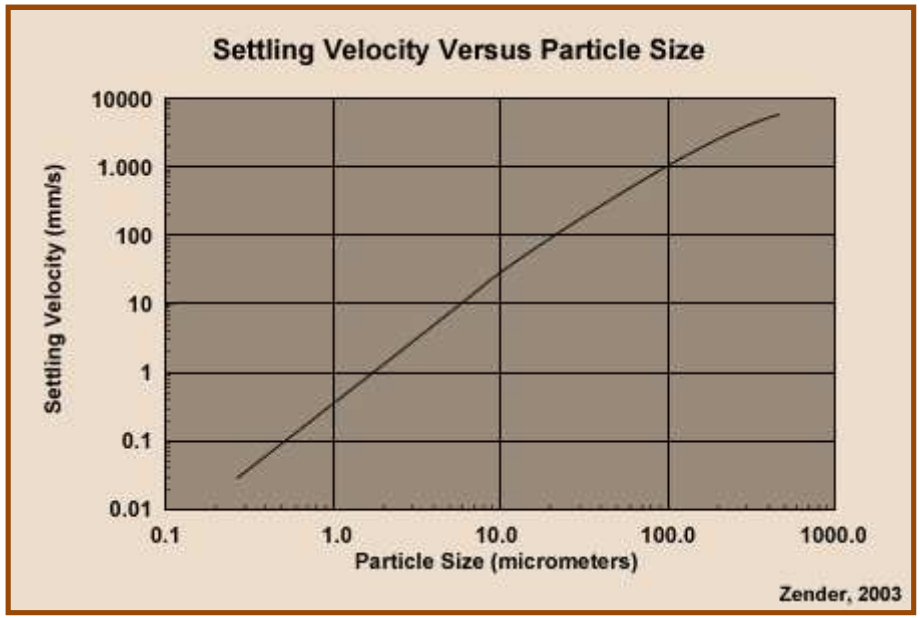


Thunderstorms over W Africa arise large amounts of dust. On 30 July 2013, dust starts crossing the Atlantic and reaches the Antiles on 2 August

Dry deposition



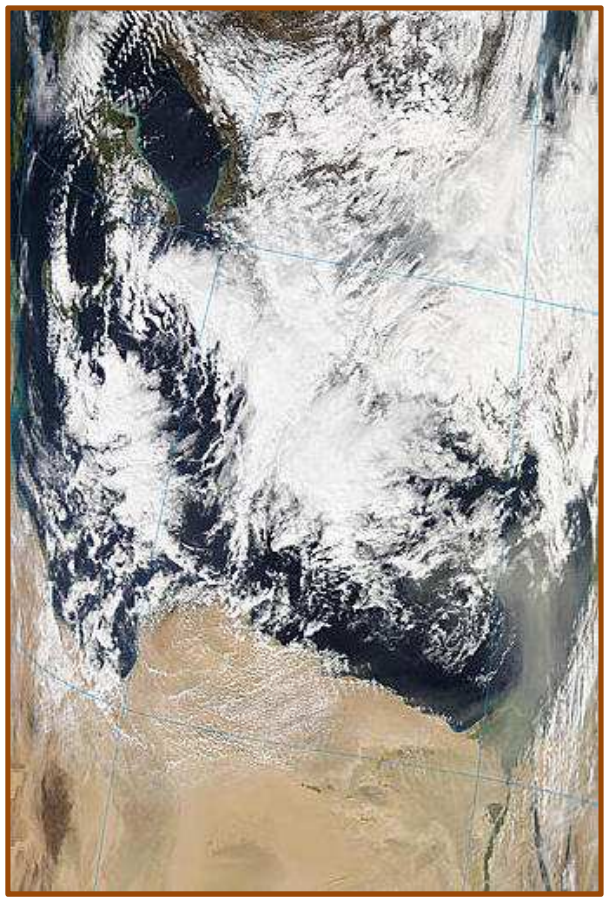
Warneck (1988), Harrison and Van Grieken (1998)



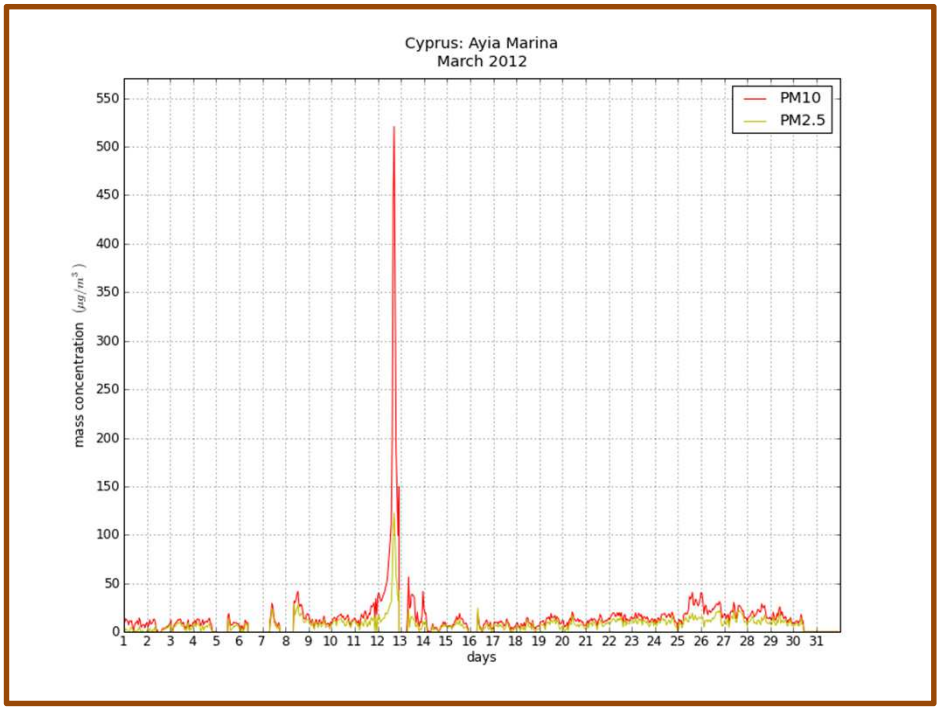
SIZE (µm)	AVERAGE LIFETIME (h)
0.1 - 0.18	231
0.18 - 0.3	229
0.3 - 0.6	225
0.6 – 1	219
1 - 1.8	179
1.8 – 3	126
3 – 6	67
6 - 10	28

Tegen and Lacis (1996)

Wet deposition



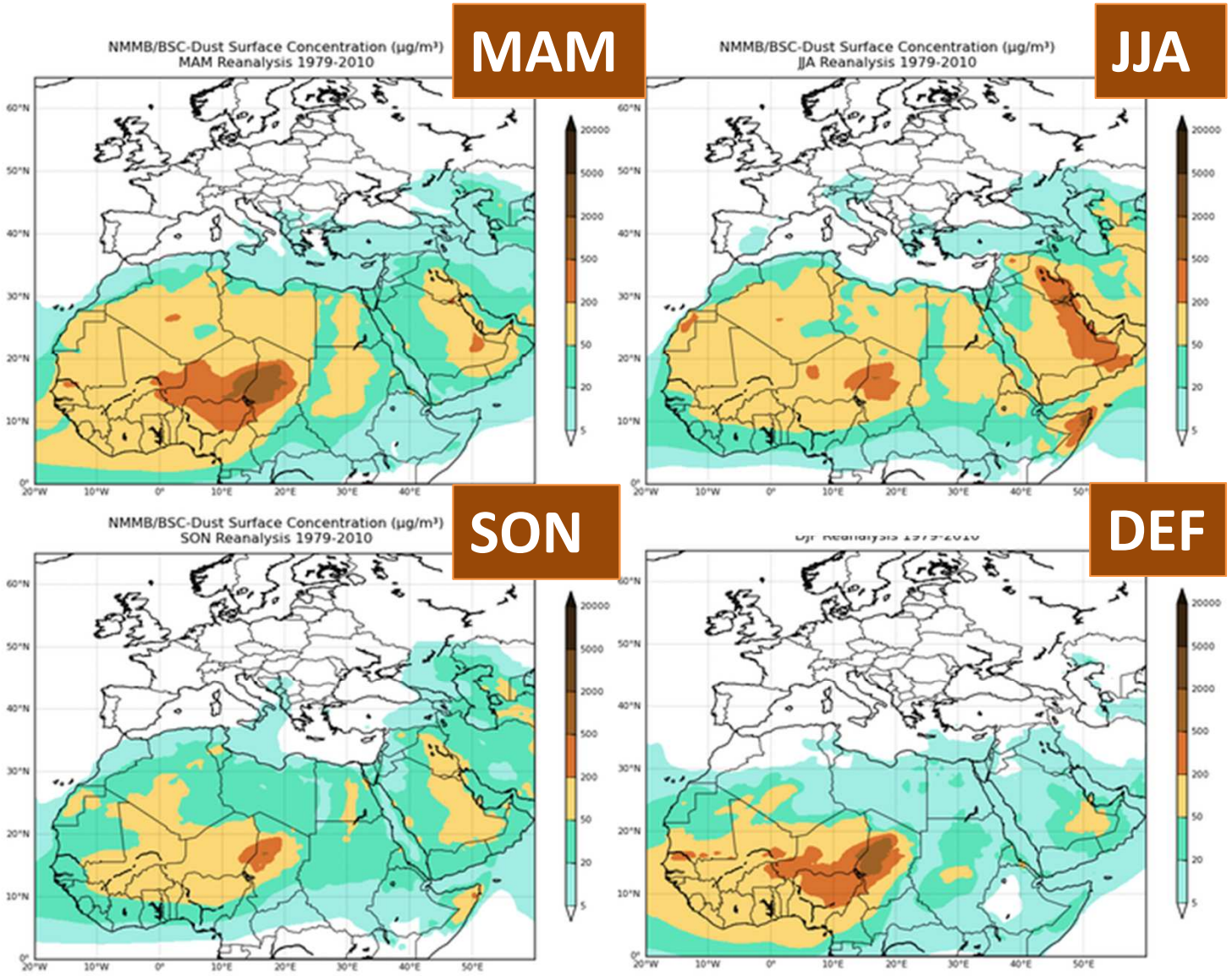
MODIS 12 Mar 2012



Ayia Marina (Cyprus)
March 2012

The dust cycle

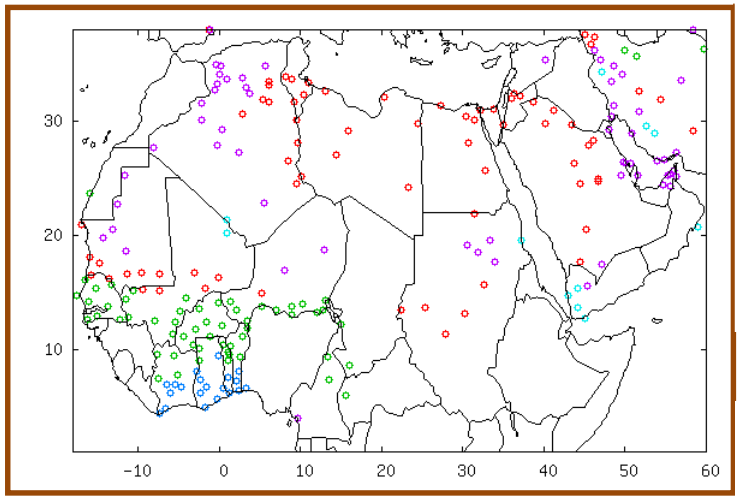
Seasonal variability



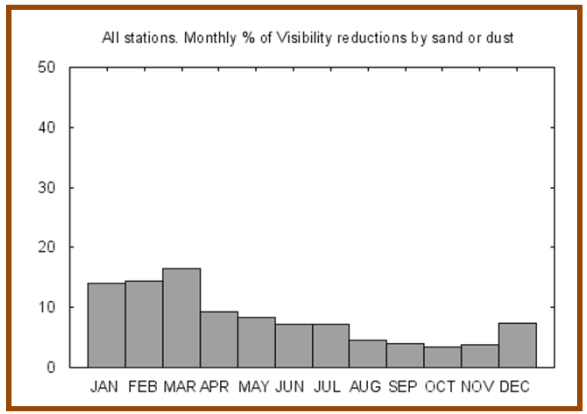
- Seasonal meteorology
- Phenology

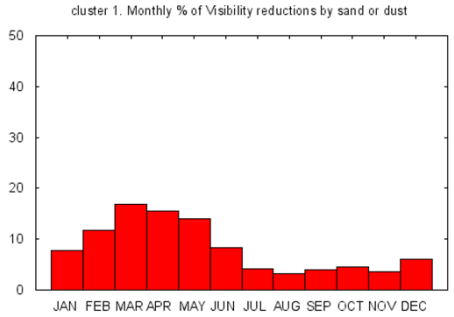
The dust cycle

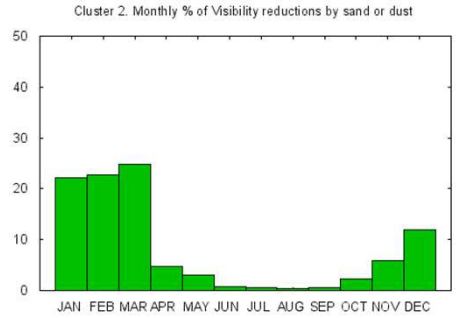
Seasonal variability

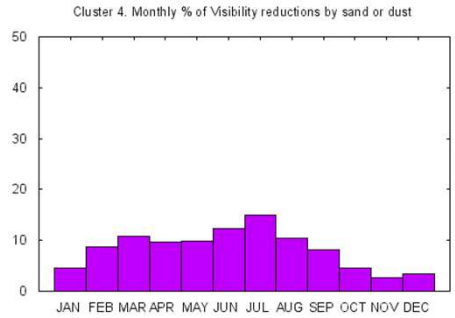


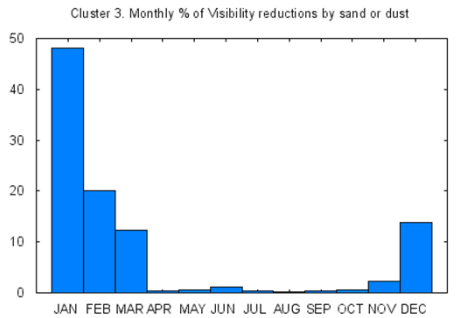
1996-2010

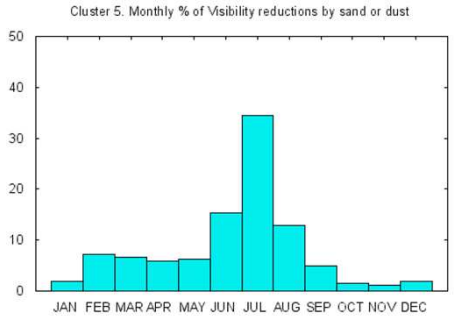












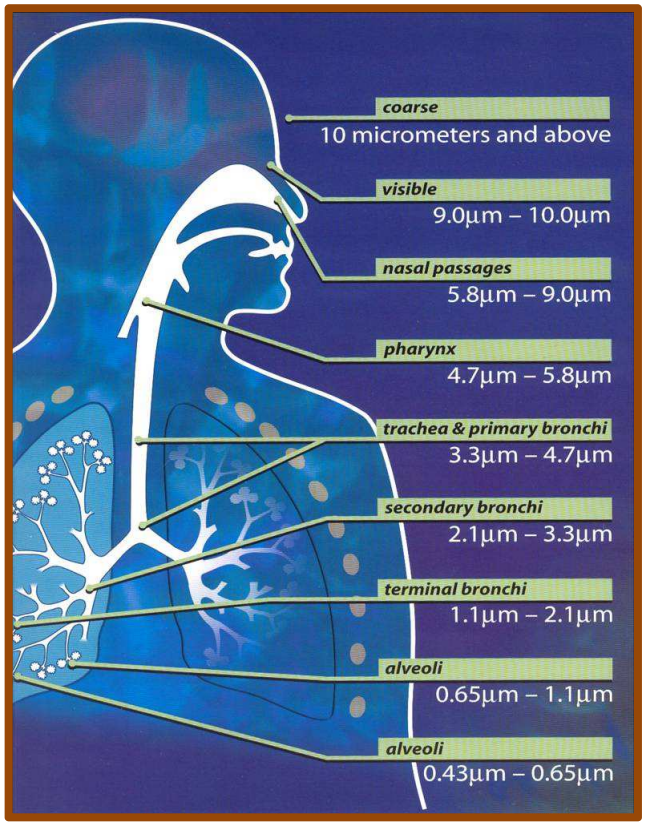
Terradellas et al. (2012)

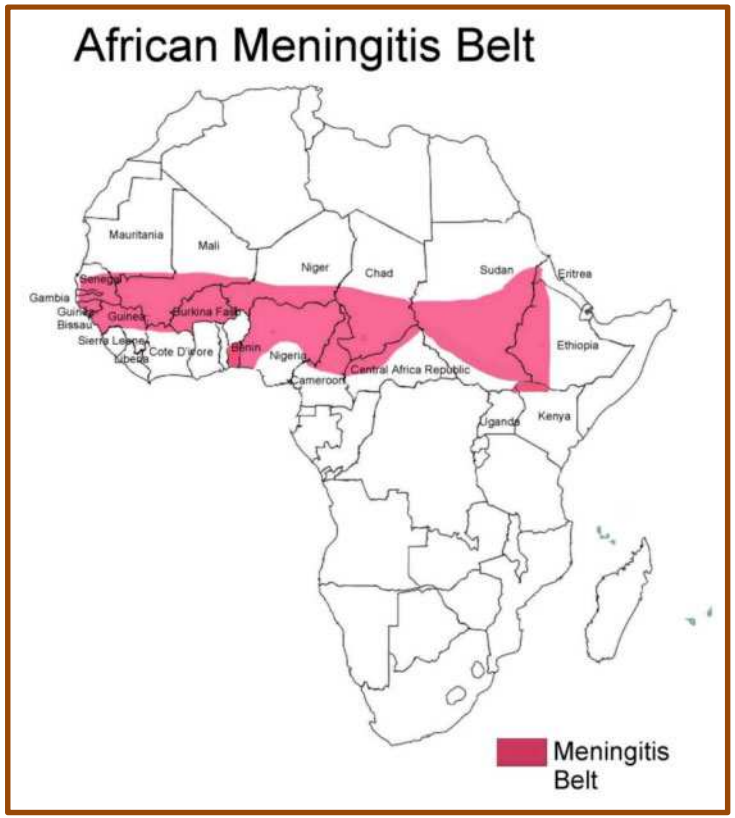
Impacts of atmospheric dust

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

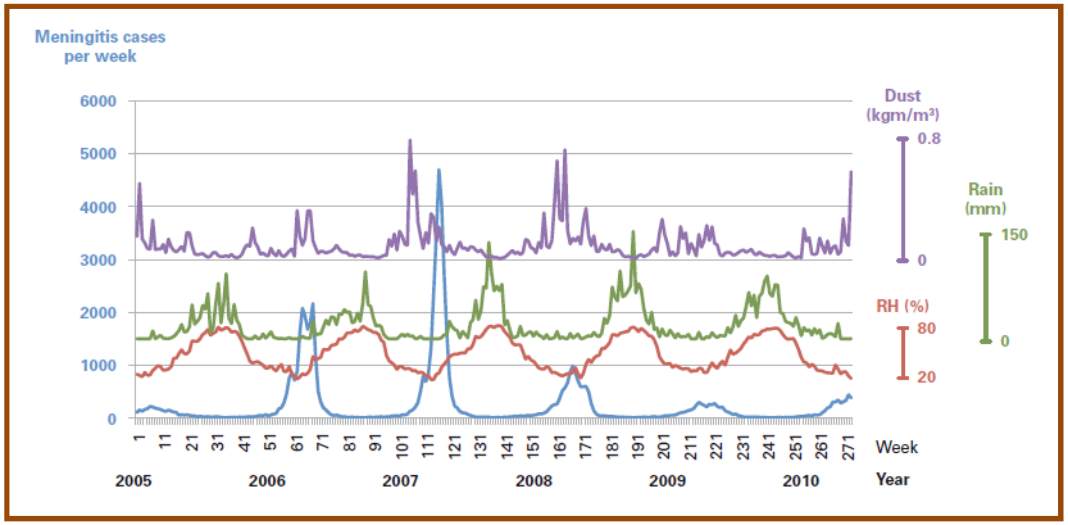
The dust cycle

Health



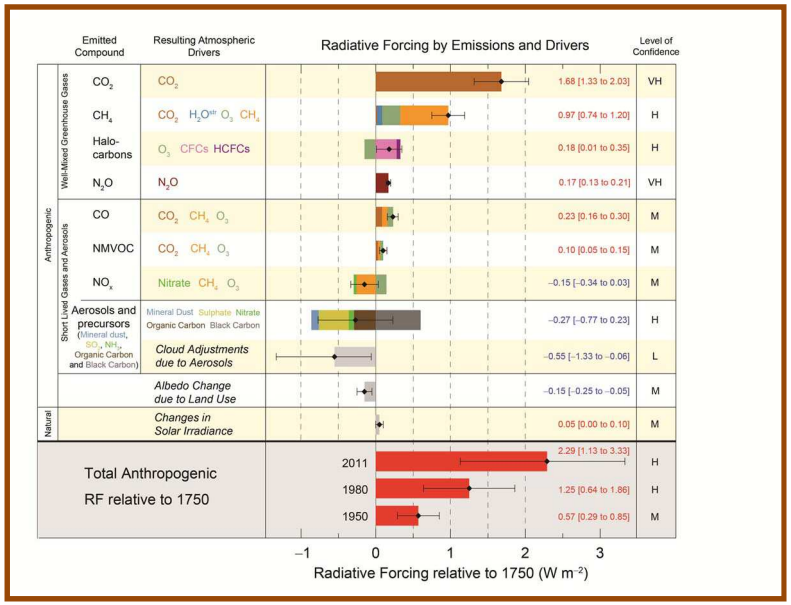


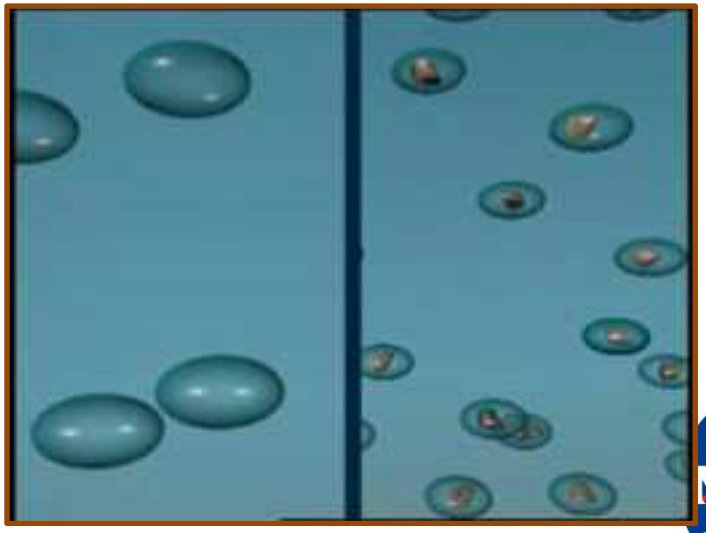
Burkina Faso

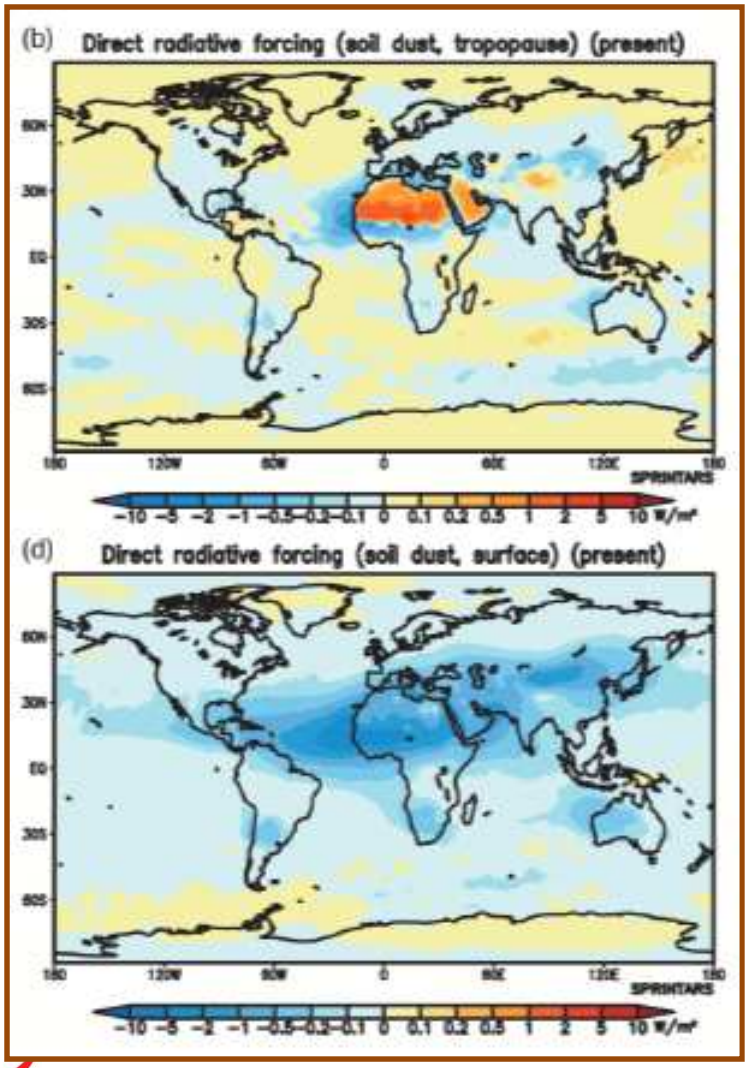


The dust cycle

Weather and climate

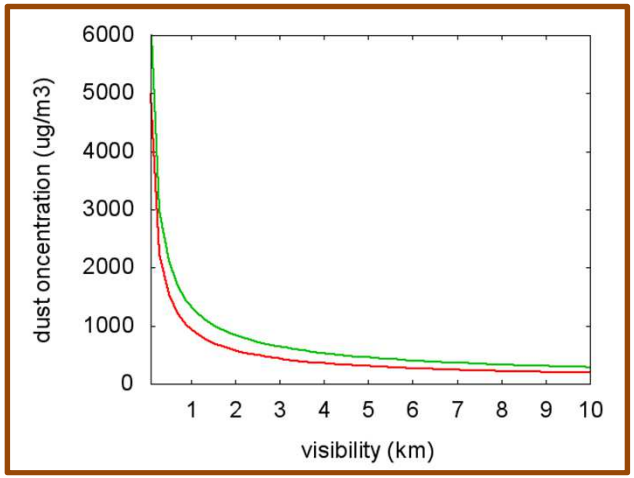






Takemura et al. (2009)

Transport



D'Almeida (1986)

Ben Mohamed et al. (1992)

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, Orange, Ca, 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)

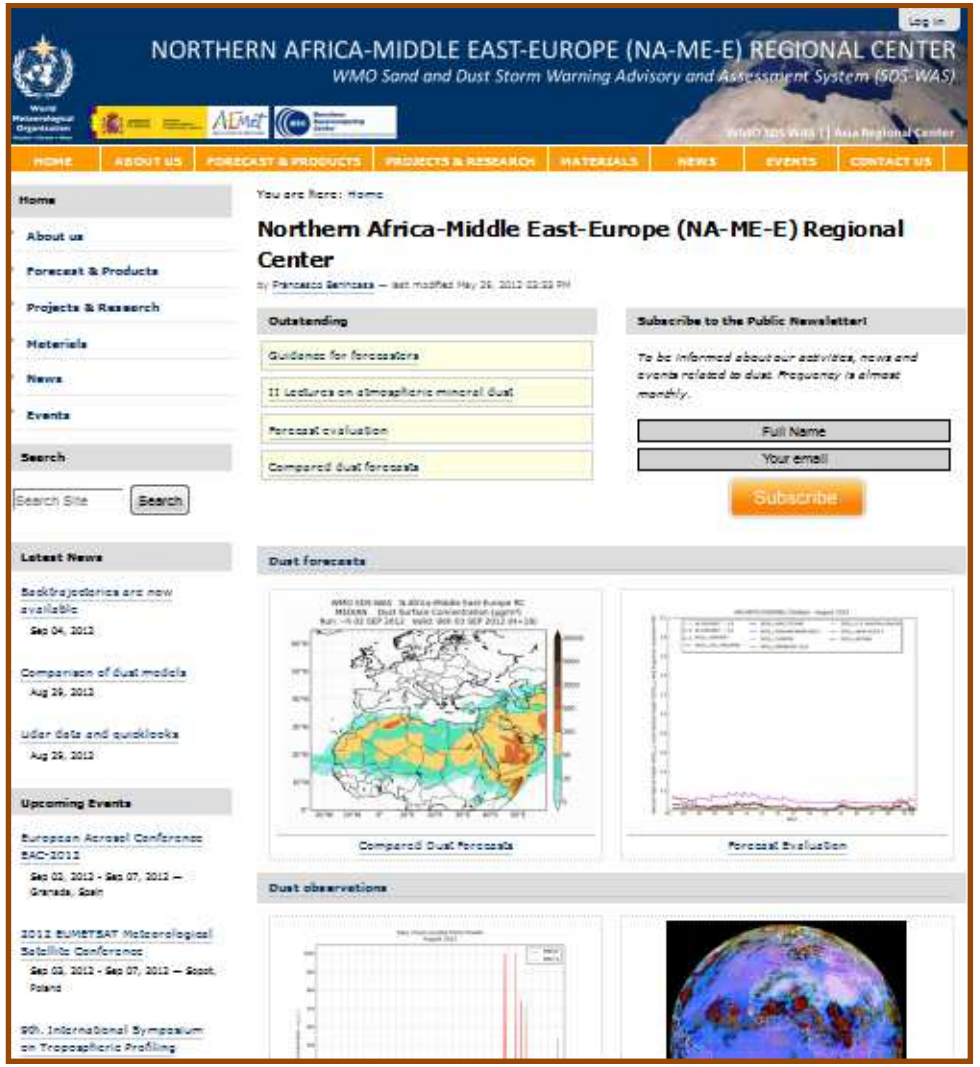
GOBIERNO DE ESPAÑA
MINISTERIO DE MEDIO AMBIENTE Y MEDIO RURAL Y MARINO
AEMet Agencia Estatal de Meteorología
BSC Barcelona Supercomputing Center Centro Nacional de Supercomputación

Nexus II Building. Barcelona

MareNostrum – 3 supercomputer

The dust cycle

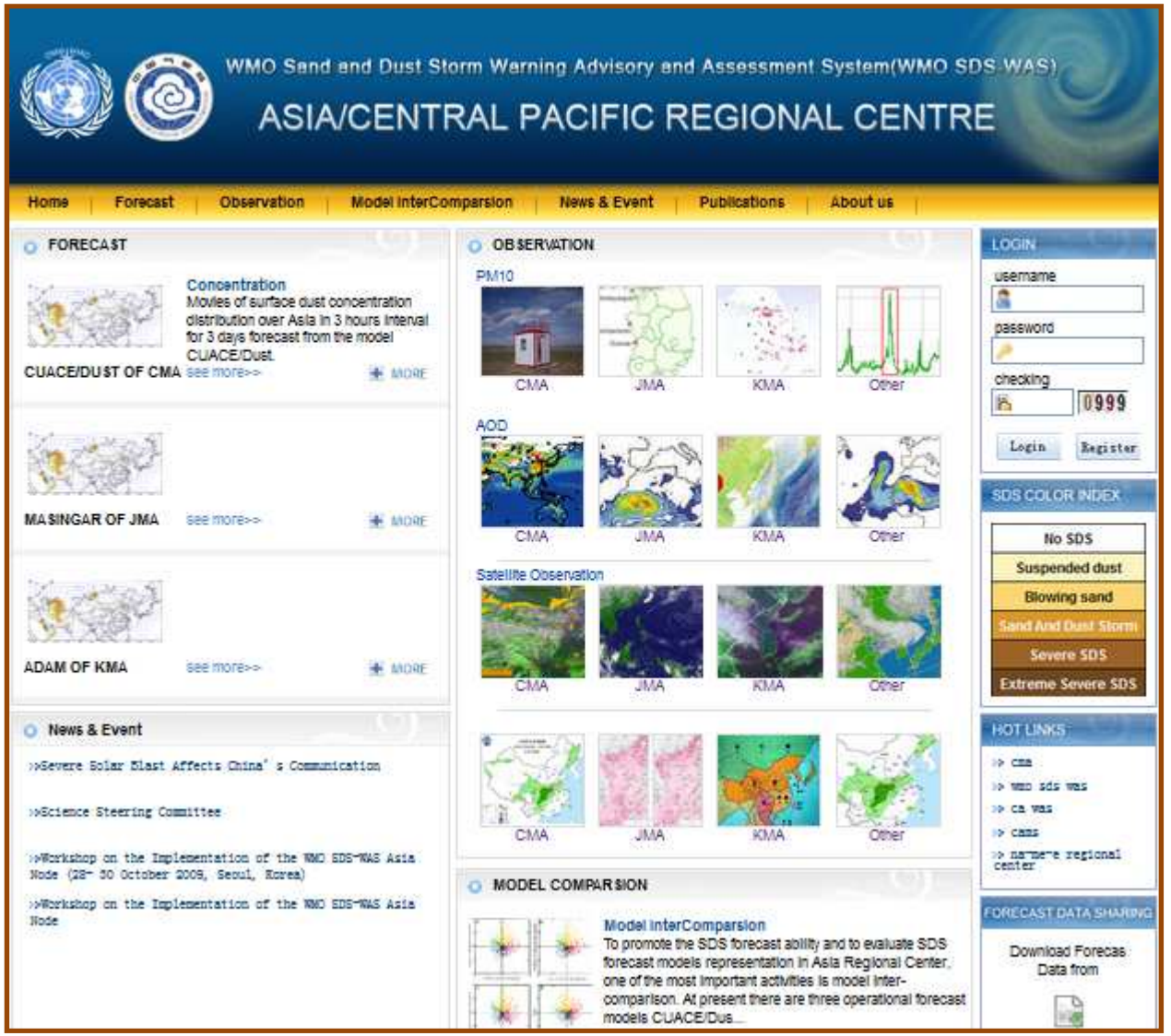
http://sds-was.aemet.es



sdswas@aemet.es eterradellasj@aemet.es

The dust cycle

http://www.sds.cma.gov.cn



Operational forecasts

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

In May 2013, the WMO Executive Council appoints the consortium AEMET / BSC-CNS to create in Barcelona the first Regional Specialized Meteorological Center for Atmospheric Sand and Dust Forecast.

The Center will operationally generate and distribute predictions for Northern Africa, Middle East and Europe

The dust cycle

http://dust.aemet.es

To be released in January 2014

Observation of atmospheric dust

- 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

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
World Meteorological Organization
Weather • Climate • Water

Why do we need dust observations?

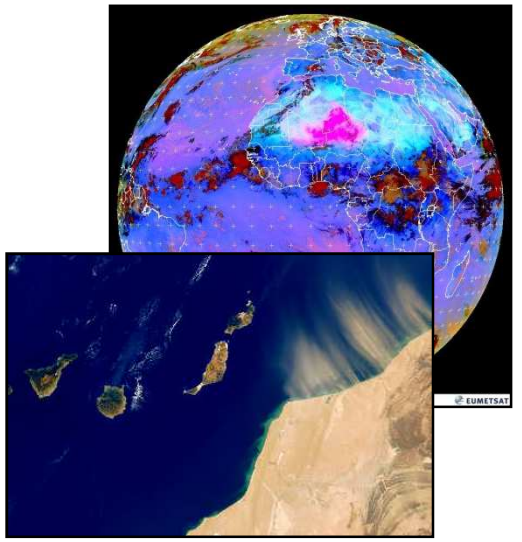
- **Dust monitoring**
- **Evaluation of numerical dust forecasts**
- **Data assimilation into dust models**
- **Validation of other observations (i. e. ground observations to validate satellite products)**

Mali, 2001
Photo: Remi Benali/Corbis

Observation of atmospheric dust

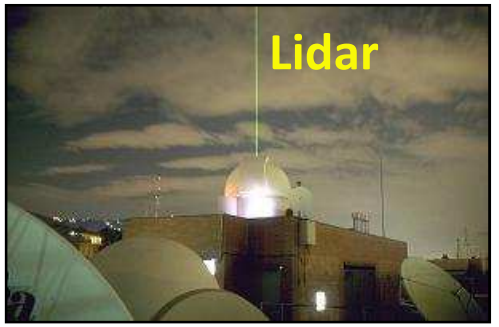
A comprehensive observing system

- **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

W_1 W_2

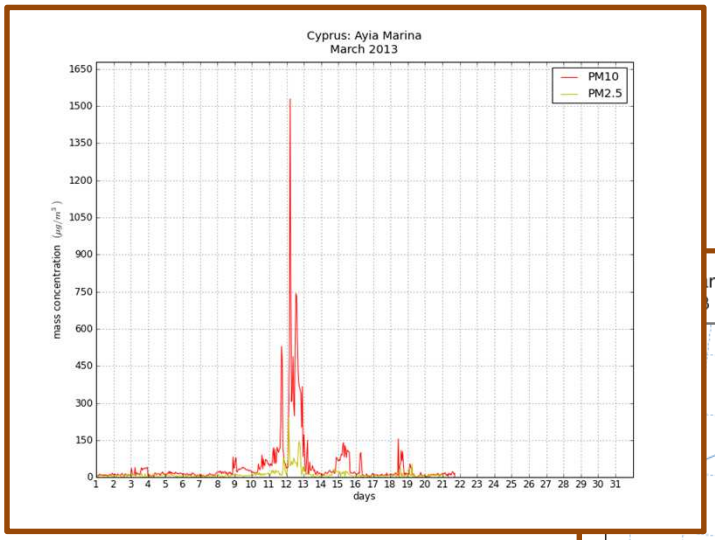
$$PM = \frac{(W2-W1)}{Volumen} \quad \mu g/m^3$$

Observation of atmospheric dust

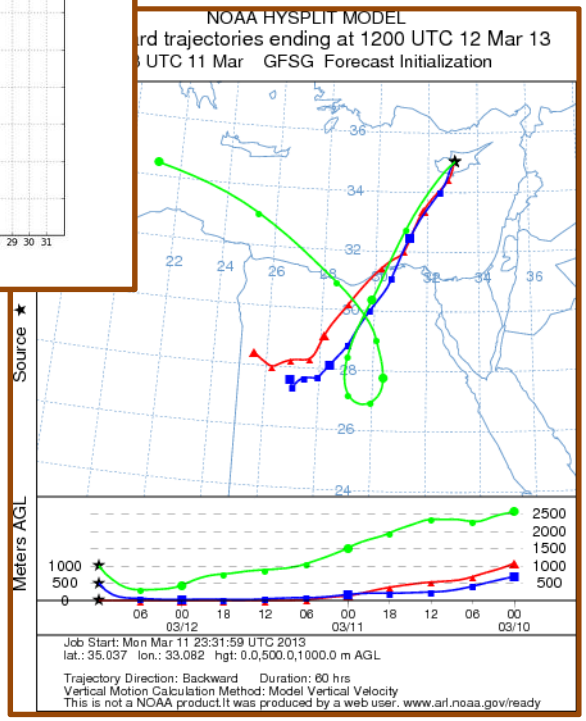
Monitoring dust events with in-situ observations

Observation of atmospheric dust

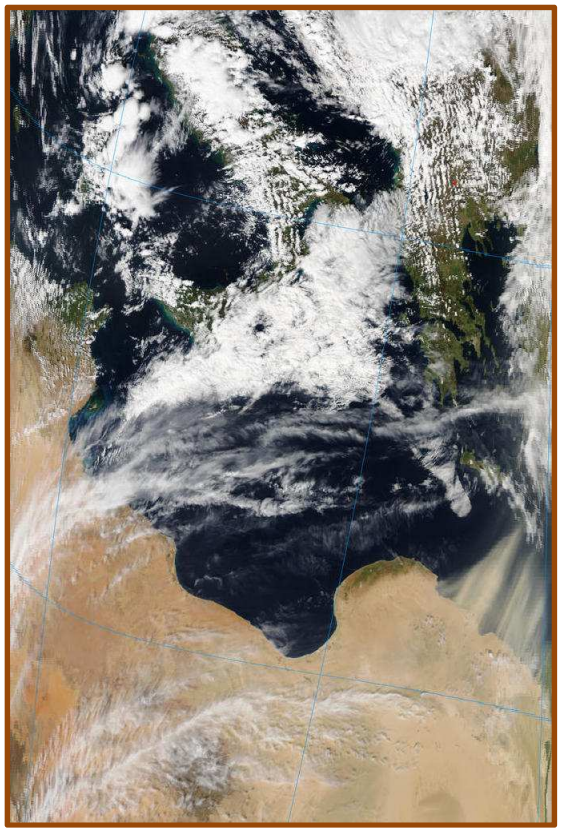
Monitoring dust events with in-situ observations



Mar 2013



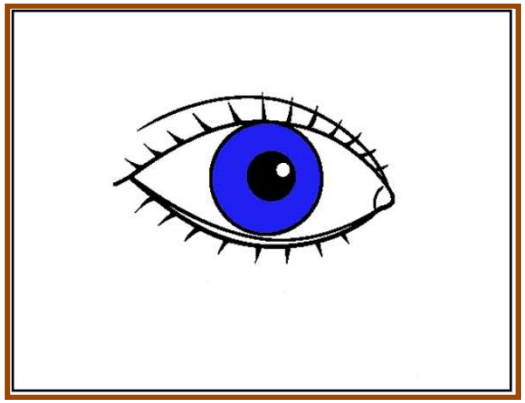
12 Mar 2013



11 Mar 2013

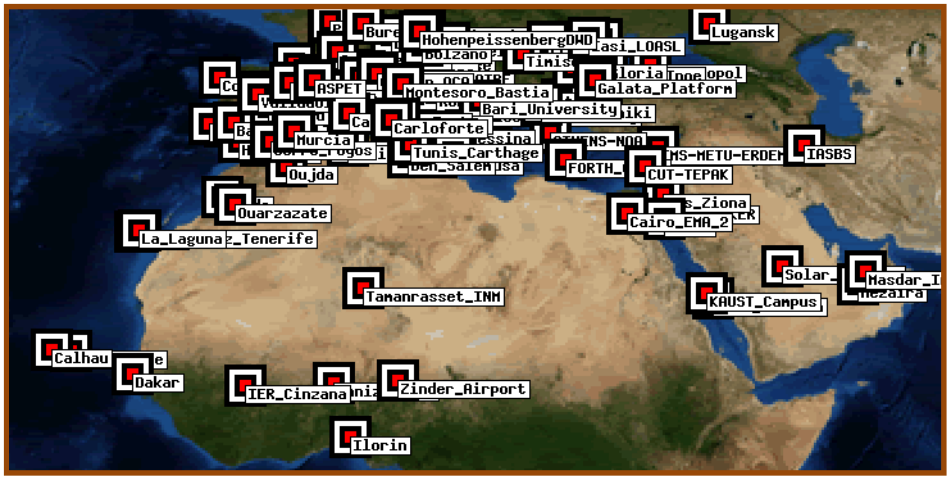
Observation of atmospheric dust

Visibility and present weather from meteorological reports



Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Sun photometers



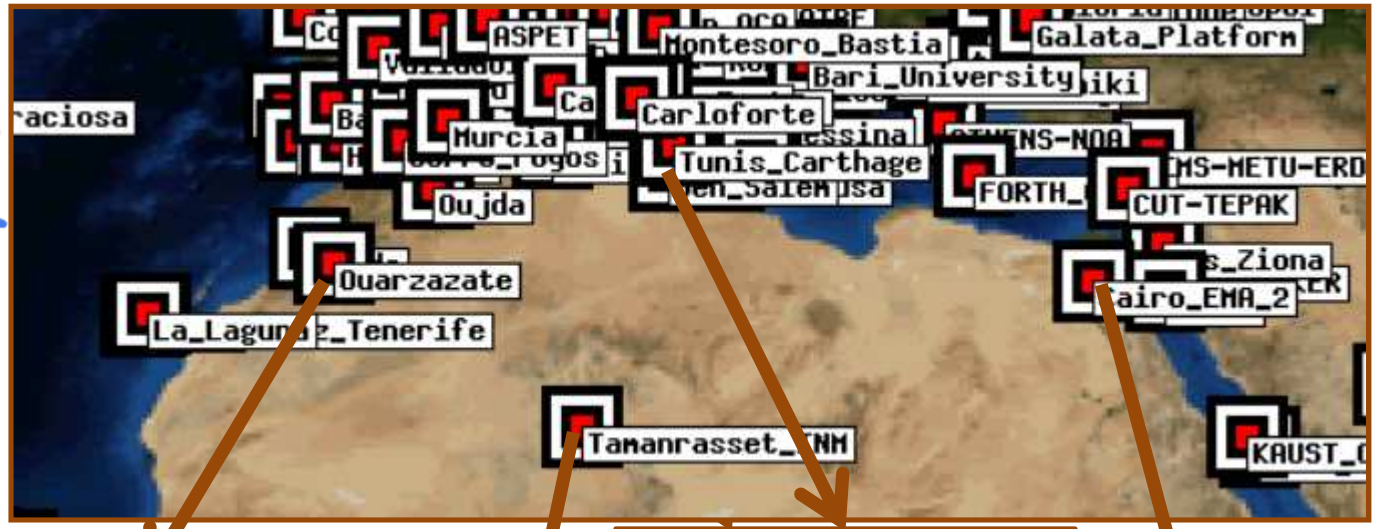
- **Sun photometers measure direct solar radiation**
- **Radiation at the top of the atmosphere is known**
- **Particles dissipate energy due to absorption and scattering**
- **Information on the aerosol concentration can be derived from the radiation that reaches the Earth surface**

Observation of atmospheric dust

SDS-Africa

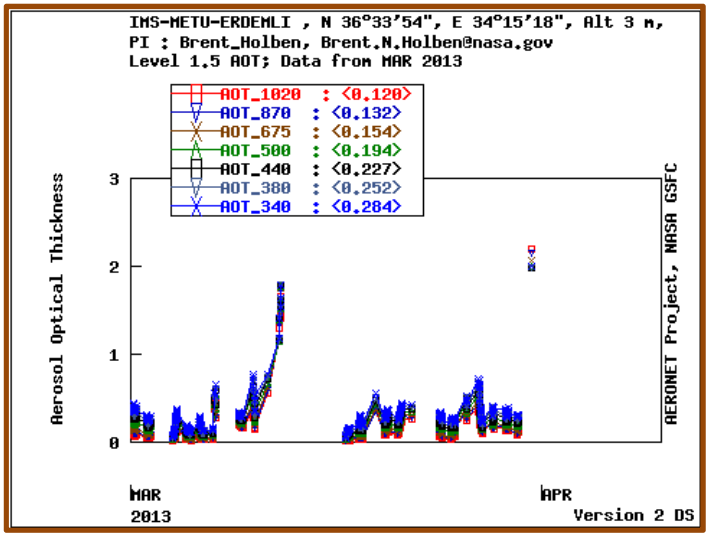
AGENCIA ESPAÑOLA DE COOPERACIÓN INTERNACIONAL

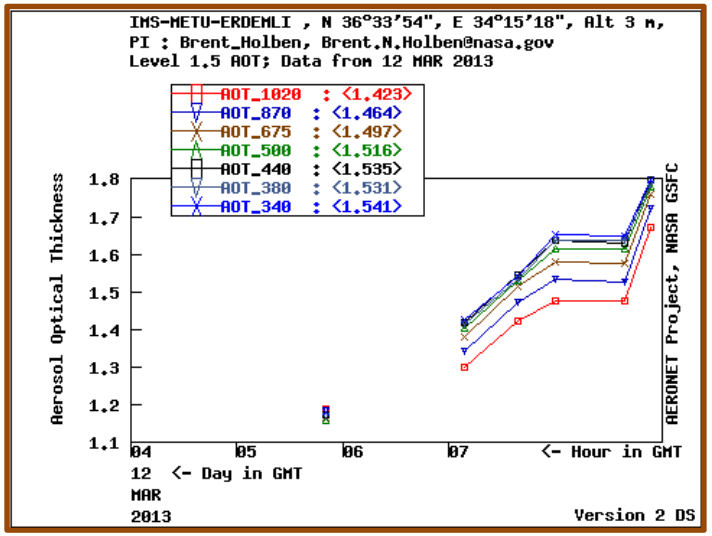
AEMet Agencia Estatal de Meteorología

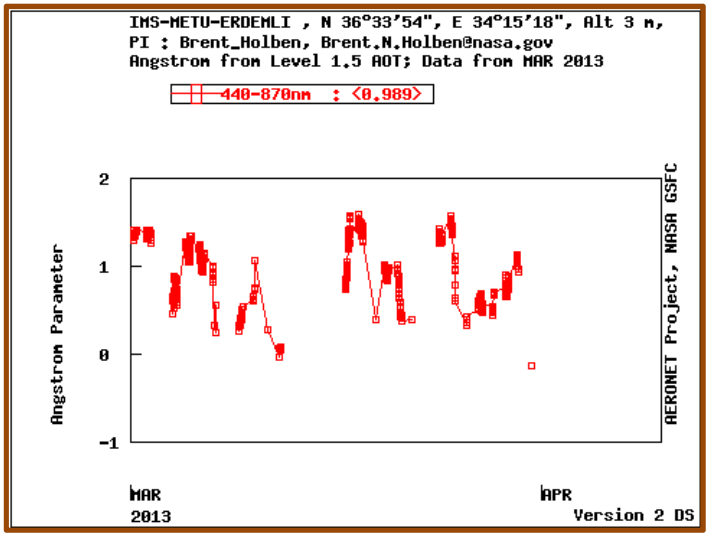


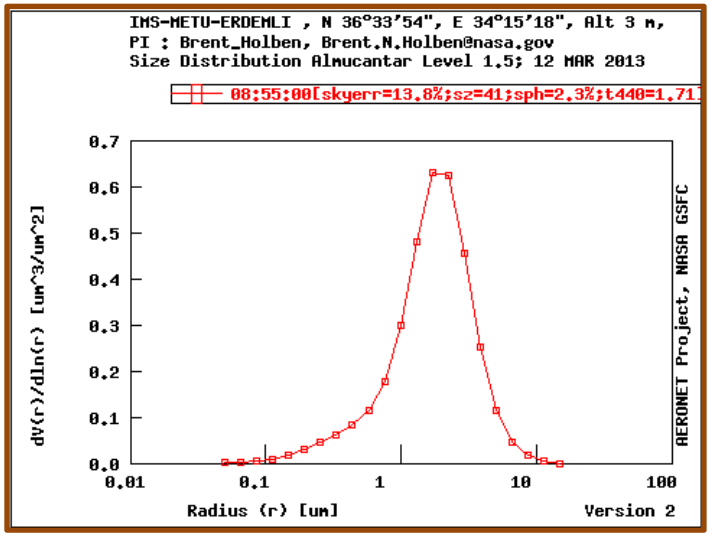
Observation of atmospheric dust

Monitoring dust events with AERONET data





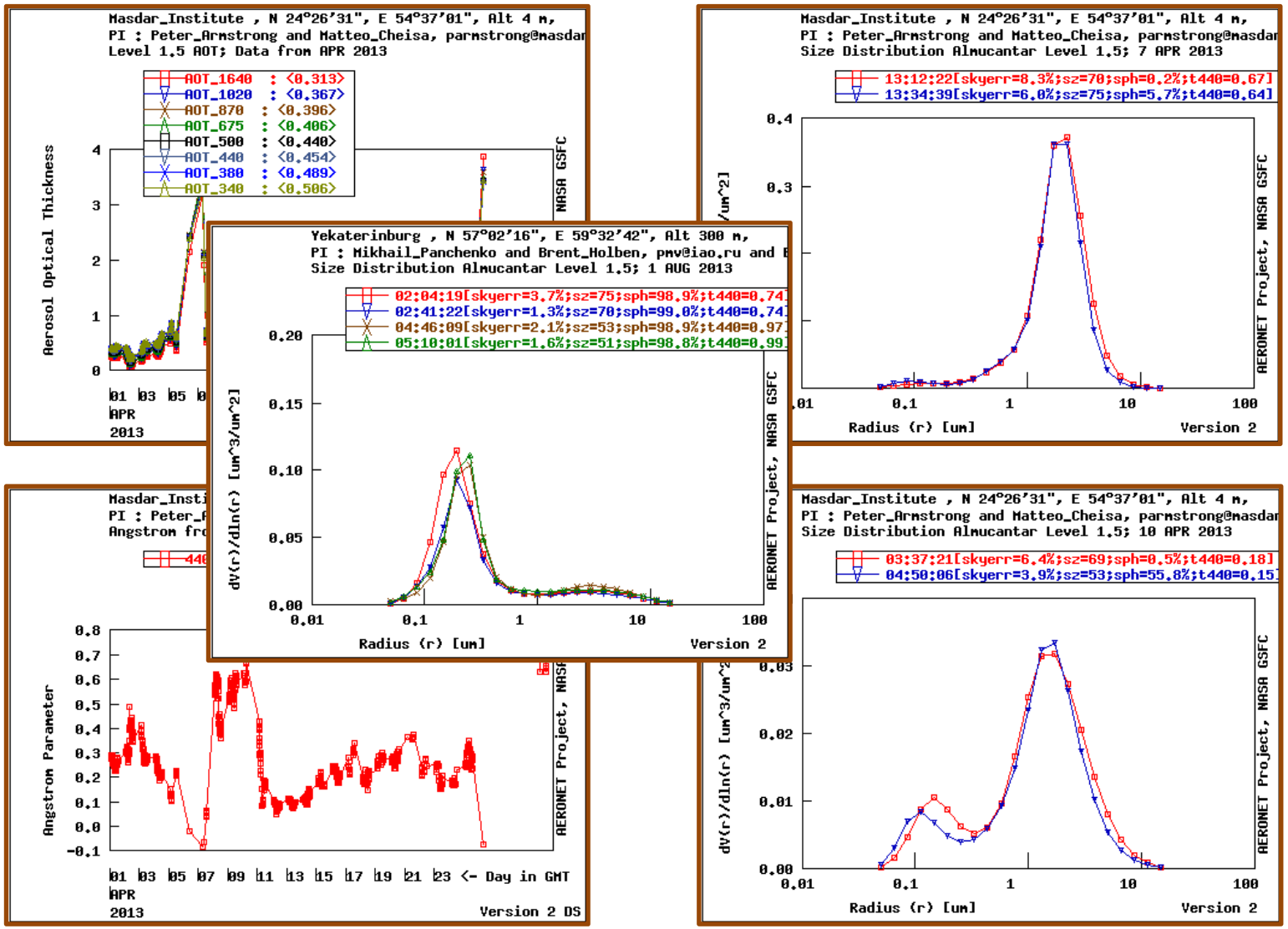




IMS-METU-ERDEMLI, Turkey, 12 Mar 2013

Observation of atmospheric dust

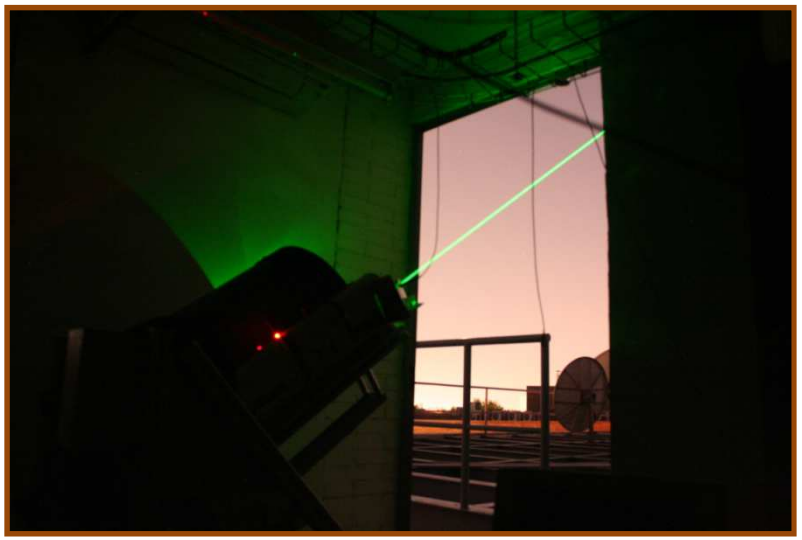
Monitoring dust events with AERONET data



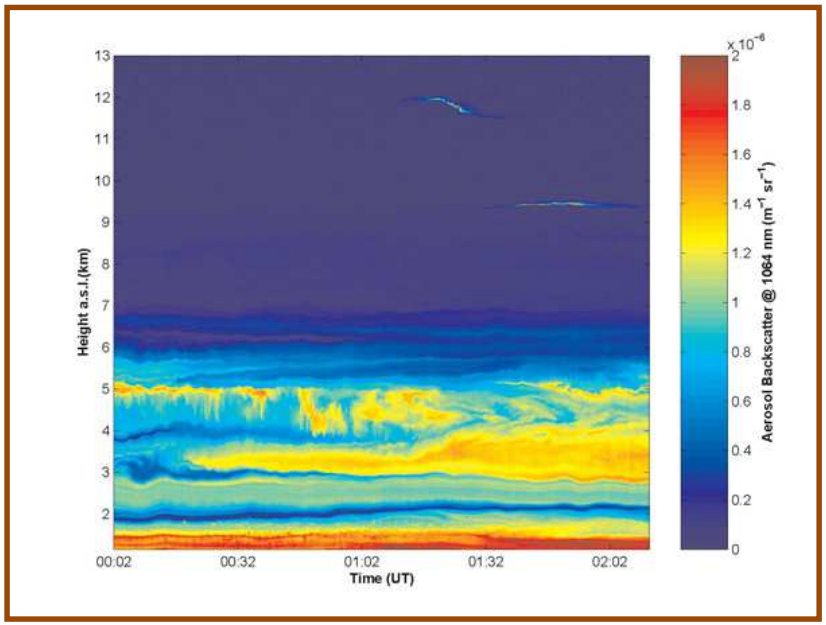
Masdar Institute, UAE, 10 Apr, 7 Apr 2013

Observation of atmospheric dust

Lidar



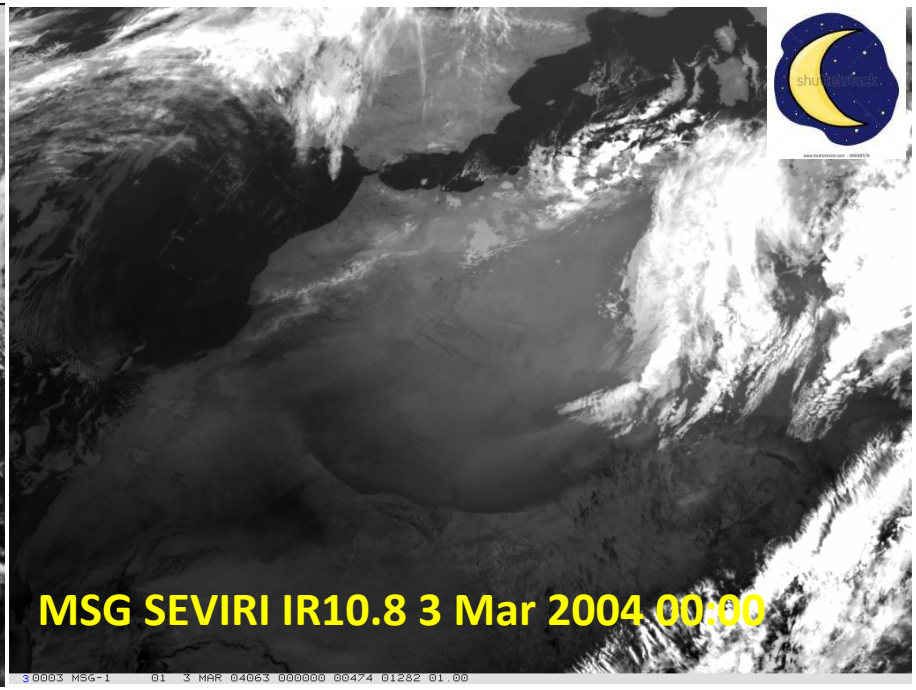
UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

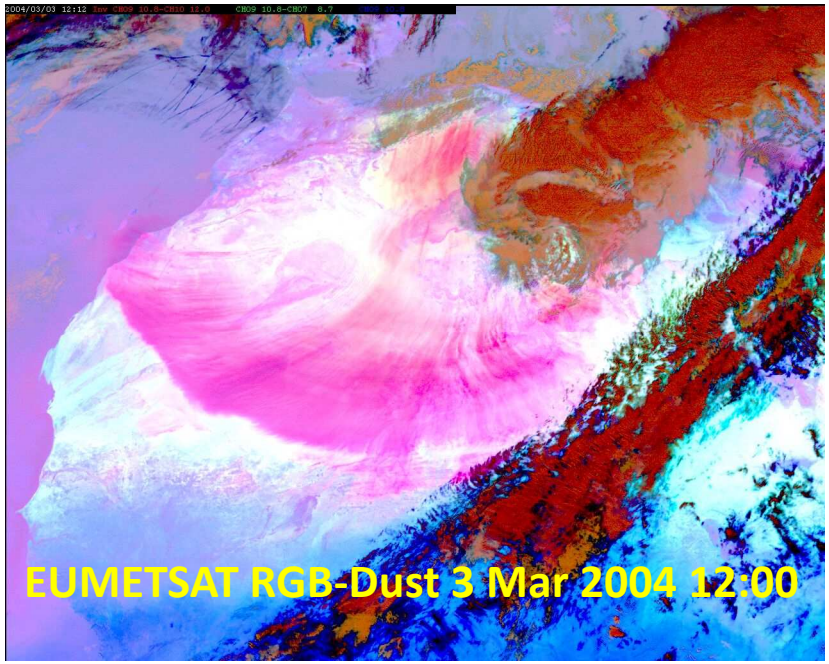


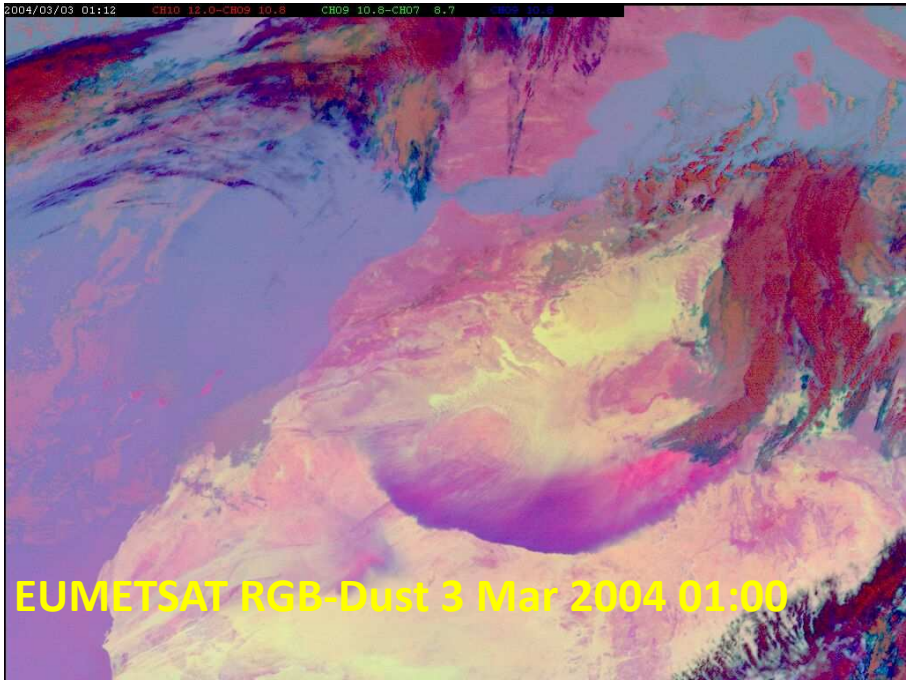
Potenza, Italia
26 Jun 2006

Observation of atmospheric dust

IR / RGB-Dust

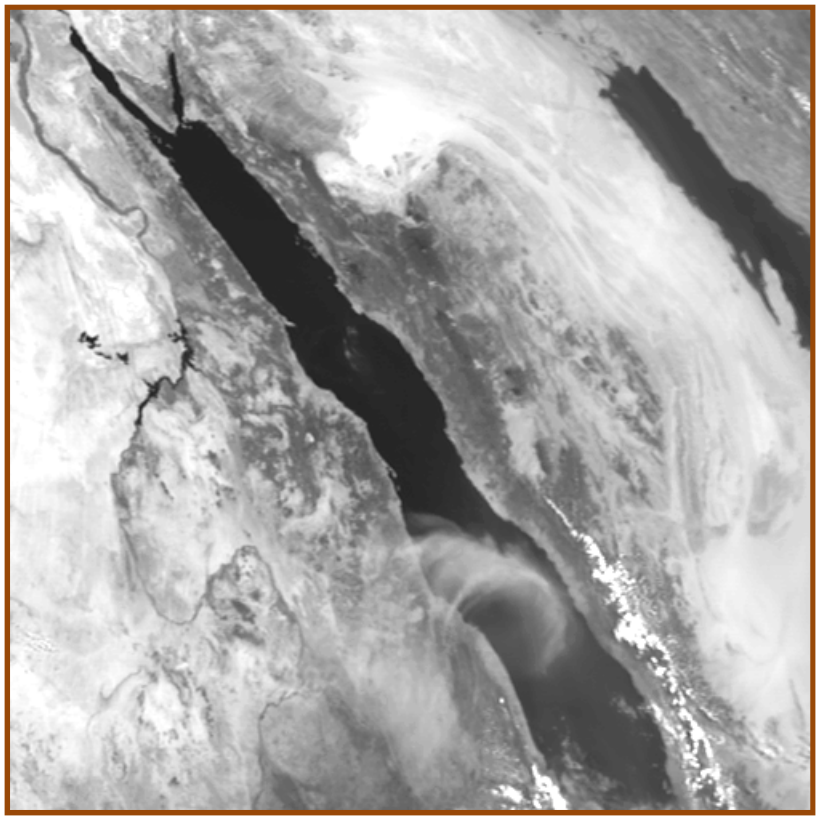




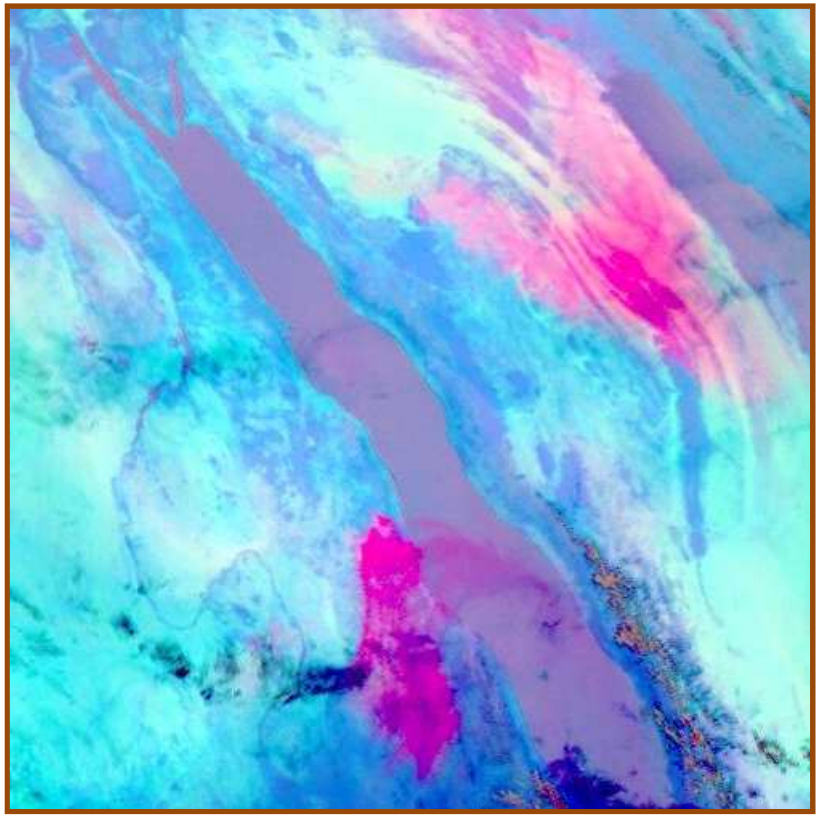


Visible / RGB-Dust

Met-8 Vis
25 Jun 2003 10:00

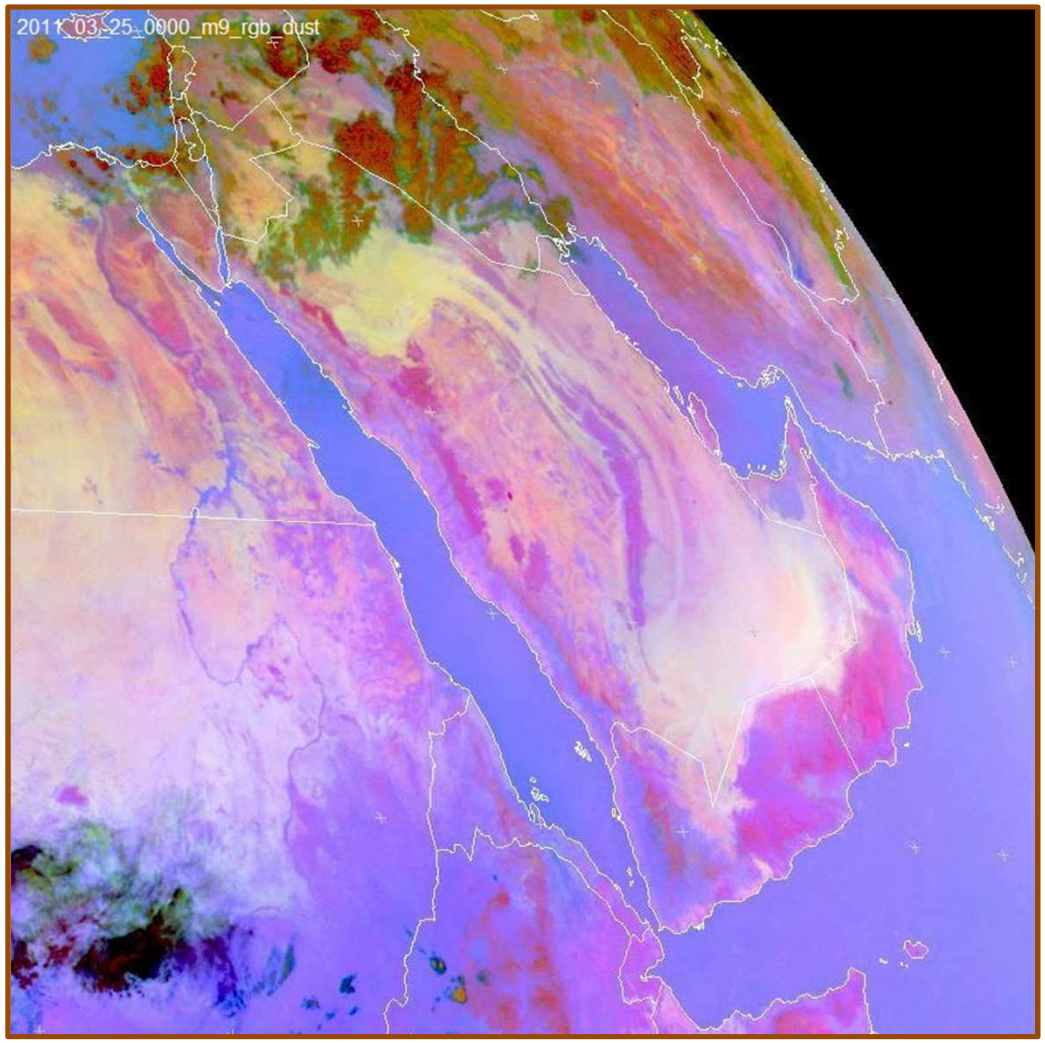


EUM RBG-Dust
25 Jun 2003 10:00



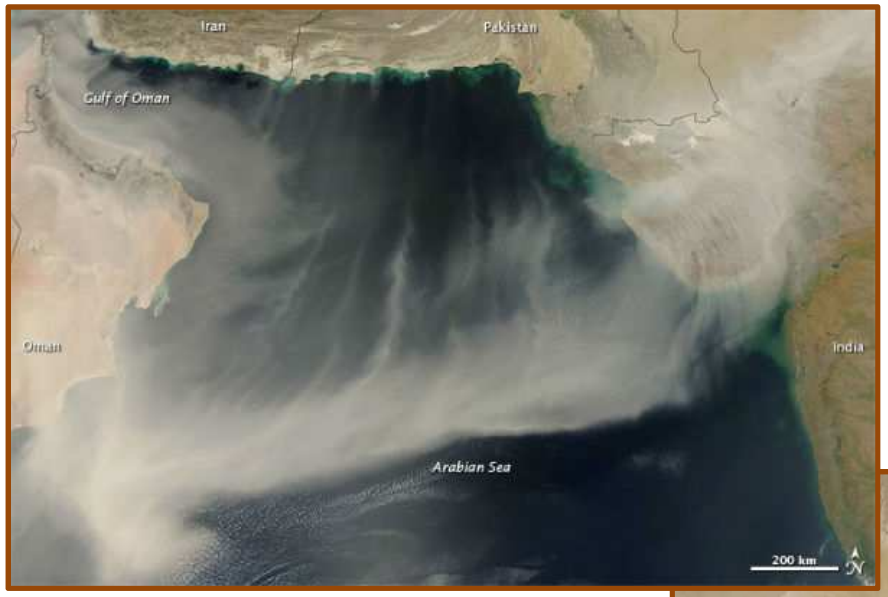
Observation of atmospheric dust

EUMETSAT RRG-Dust



26 Mar 2011

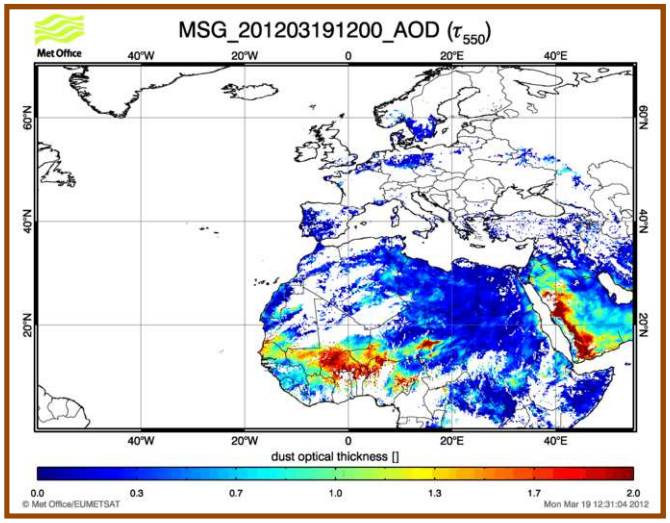
Other composites: MODIS

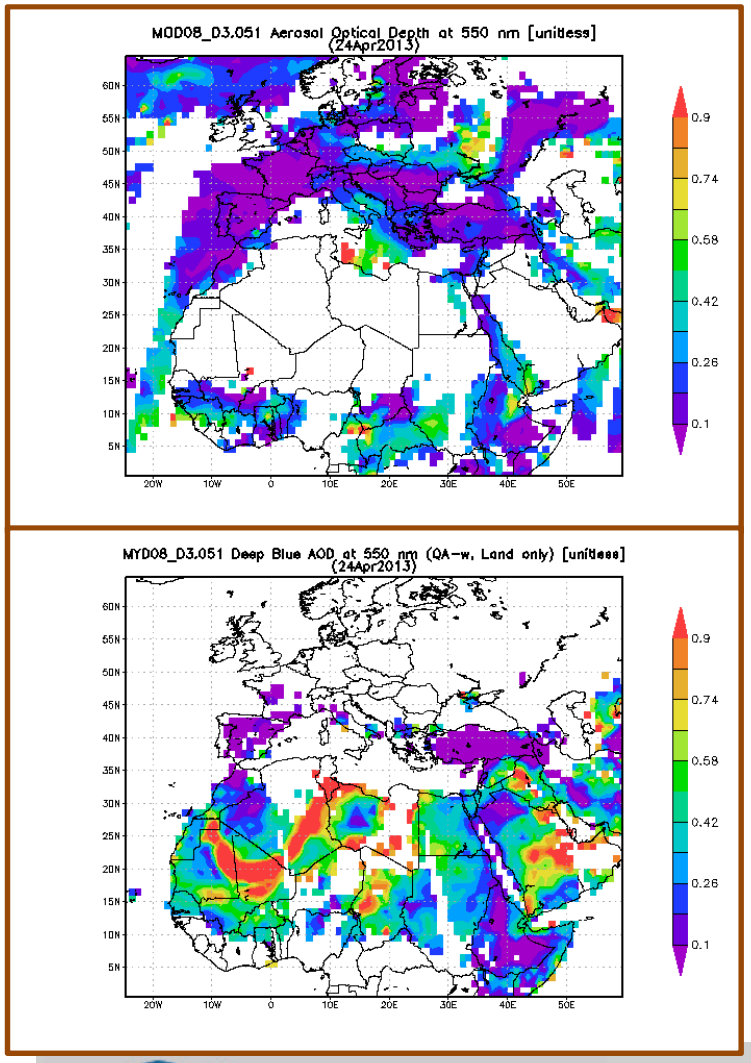


Observation of atmospheric dust

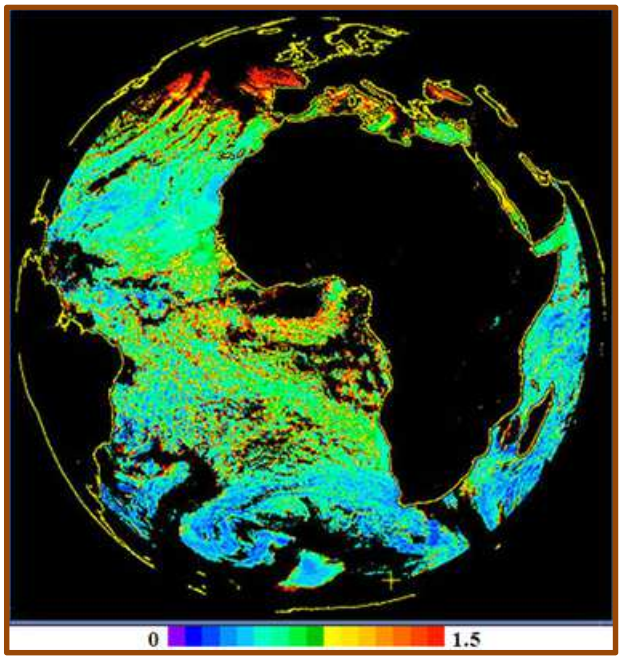
Quantitative estimations of AOD

Met Office





EUMETSAT



NASA GODDARD SPACE FLIGHT CENTER

Prediction of atmospheric dust

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

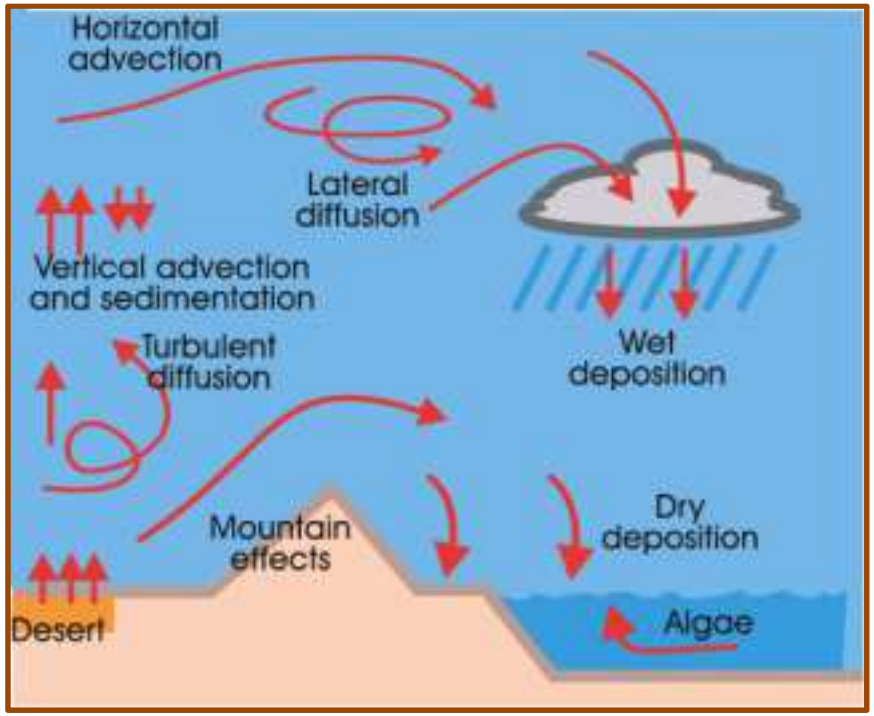
WMO SDS-WAS Regional Center for Northern Africa, Middle East and Europe

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

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
World Meteorological Organization
Weather • Climate • Water

Dust prediction models

NWP model	+	Equation of the dust cycle	=	Dust prediction model



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

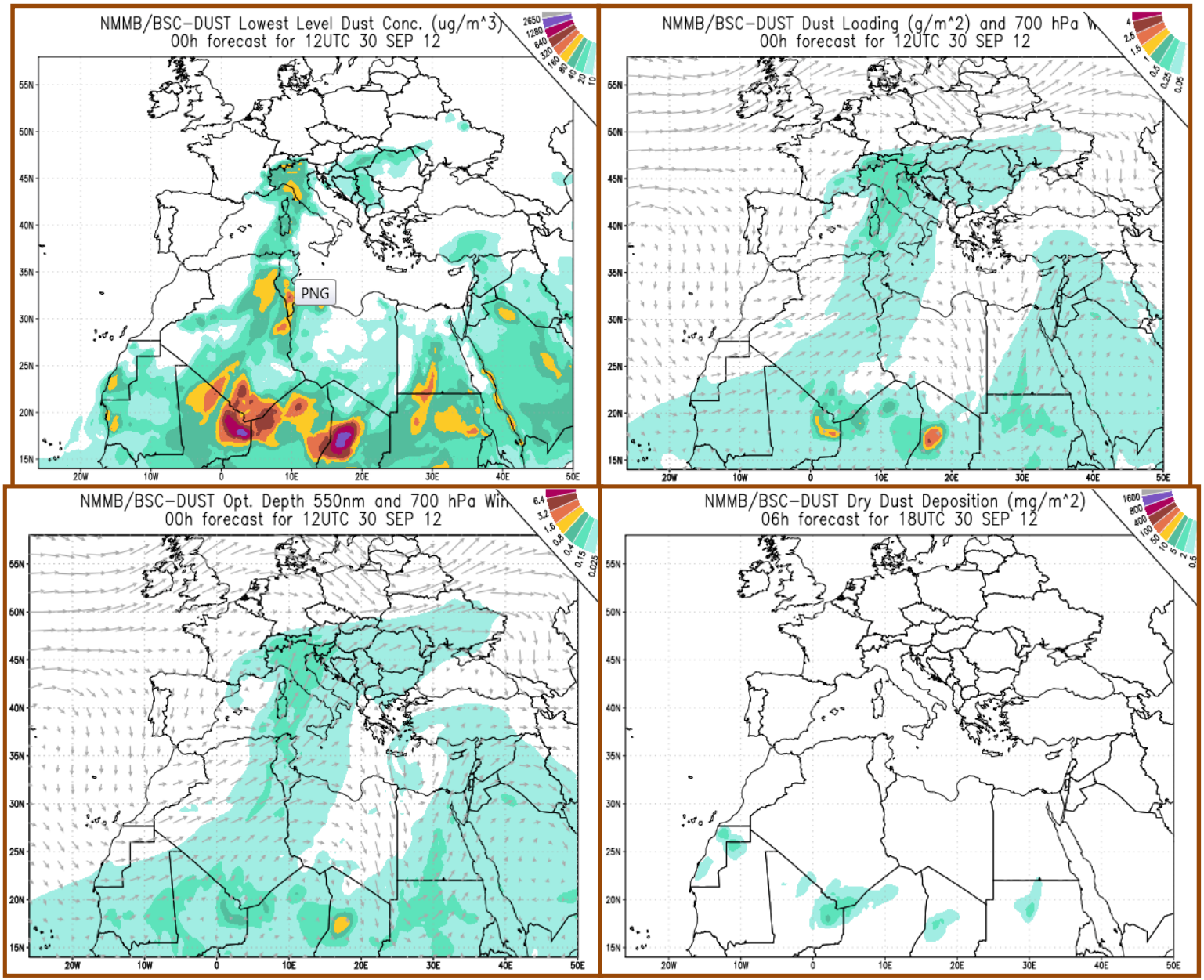
Ginoux et al. (2001) $$F = CS \sum_i u^2 s_i w_0 (u - u_{tri})$$

Prediction of atmospheric dust

NMMB/BSC-Dust model

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

Forecast products



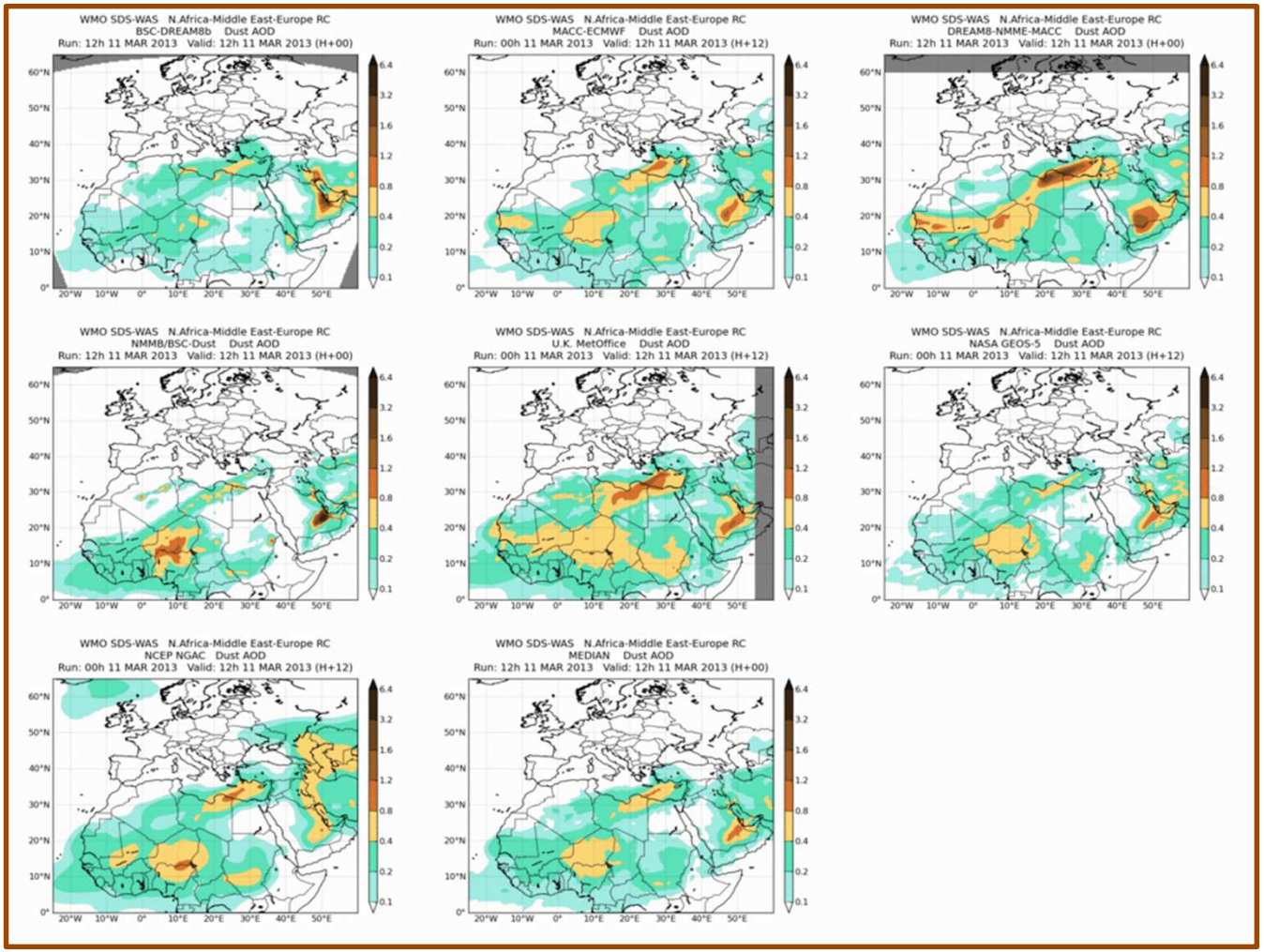
Prediction of atmospheric dust

SDS-WAS evaluation: 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	MODIS AOD
GEOS-5	NASA	00	Global	MODIS reflectances
NGAC	NCEP	00	Global	No

Prediction of atmospheric dust

Dust optical depth at 550 nm

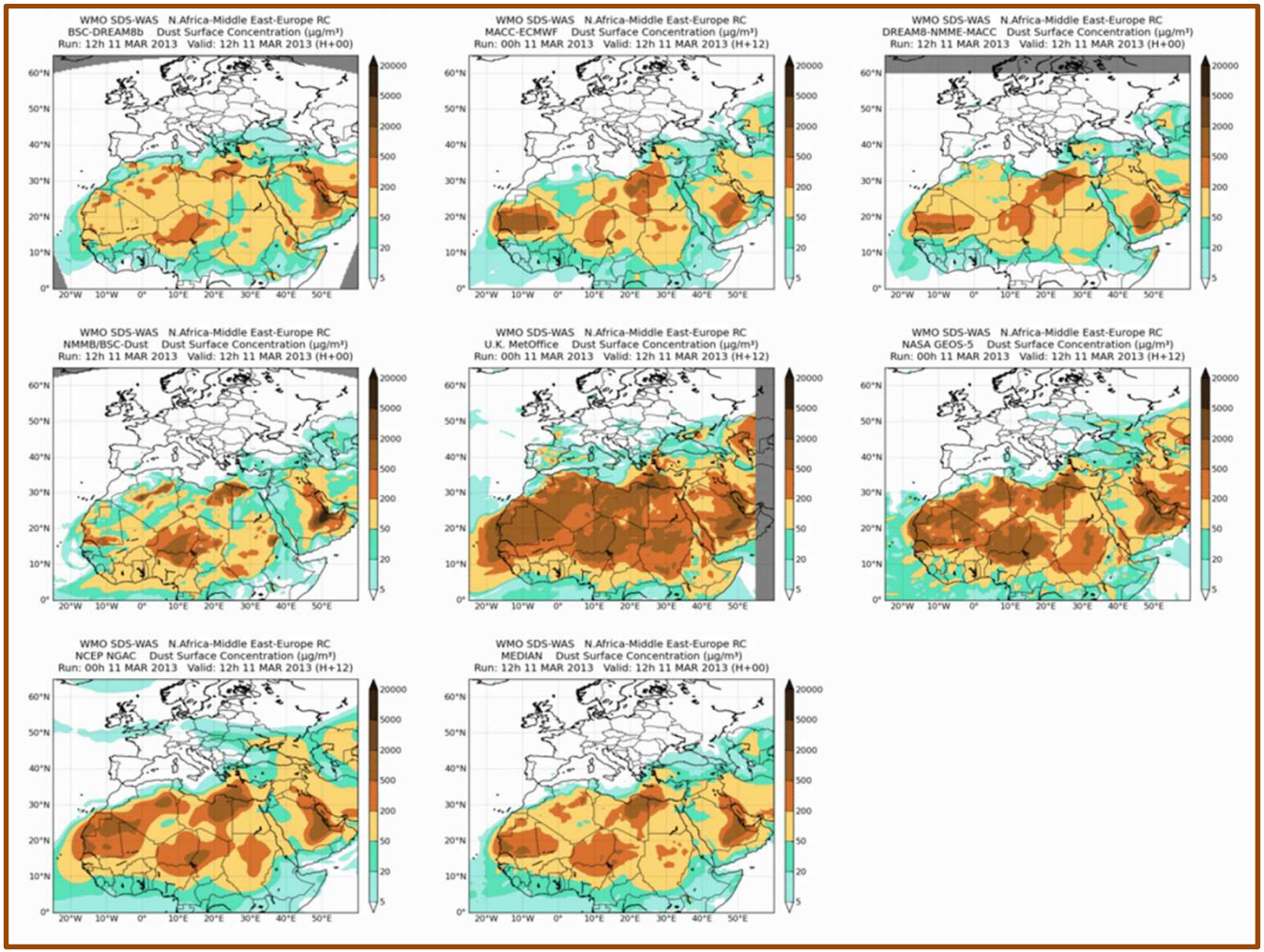


RUN: 11 Mar 2013

VALID: 11 Mar 2013 12:00 – 14 Mar 2013 00:00

Prediction of atmospheric dust

Dust surface concentration

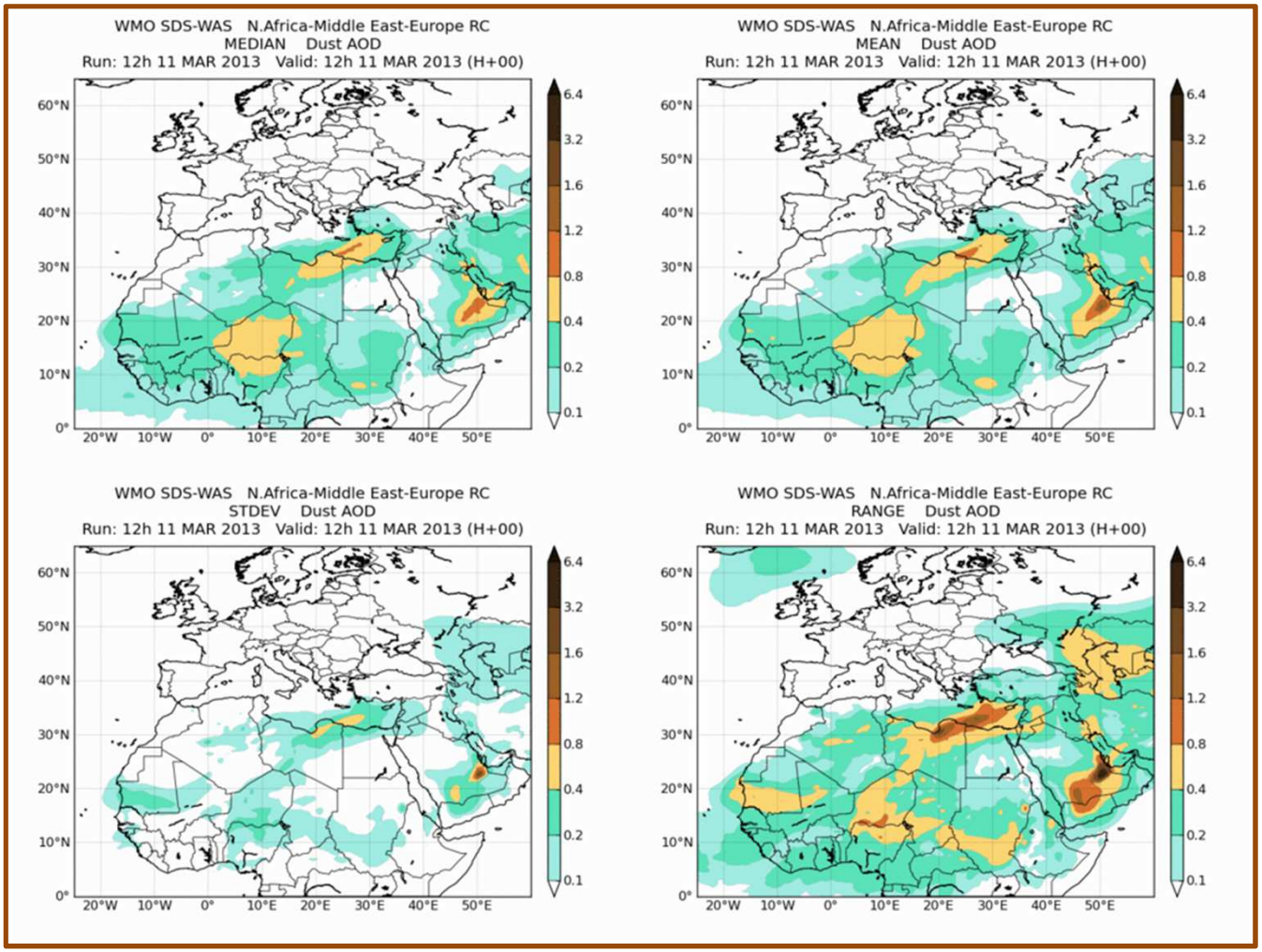


RUN: 11 Mar 2013

VALID: 11 Mar 2013 12:00 – 14 Mar 2013 00:00

Prediction of atmospheric dust

Multi-model products

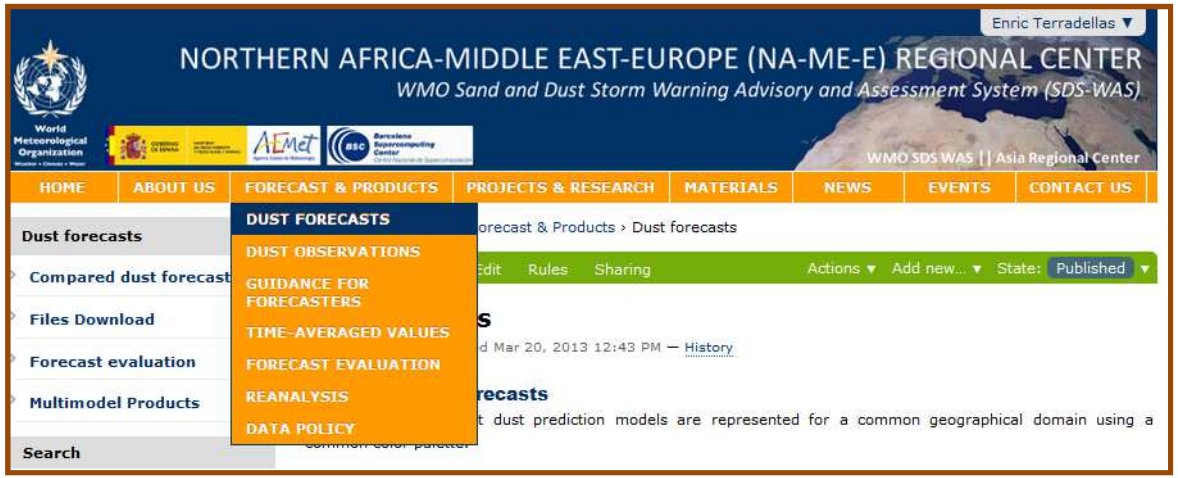


RUN: 11 Mar 2013

VALID: 11 Mar 2013 12:00 – 14 Mar 2013 00:00

Prediction of atmospheric dust

Download of numerical forecasts



Sfc. Concentración
Dust AOD 550 µm

BSC-DREAM8b v2.0	DOWNLOAD FILES	Model website	BSC Barcelona Supercomputing Center
MACC-ECMWF	DOWNLOAD FILES	Model website	macc
DREAM-NMME-MACC	DOWNLOAD FILES	Model website	SEEVCCC
NMMB/BSC-Dust	DOWNLOAD FILES	Model website	BSC Barcelona Supercomputing Center
NASA-GEOS-5	DOWNLOAD FILES	Model website	NASA
NCEP-NGAC	DOWNLOAD FILES	Model website	NCEP
Multimodel MEDIAN	DOWNLOAD FILES	Model website	

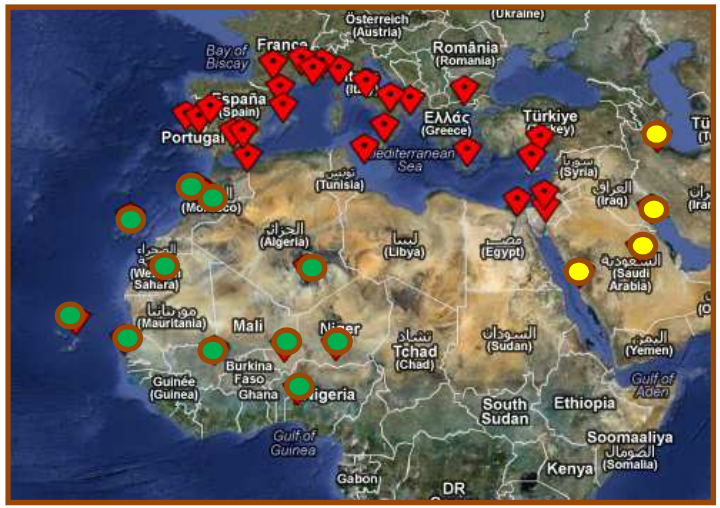
netCDF format

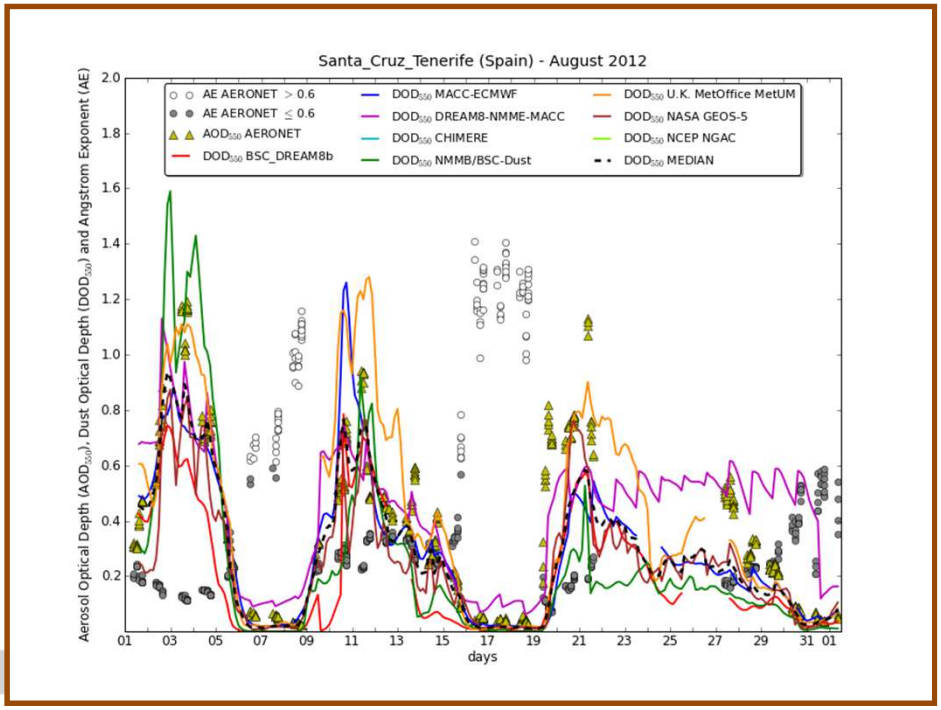
netCDF UCAR unidata

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

Prediction of atmospheric dust

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

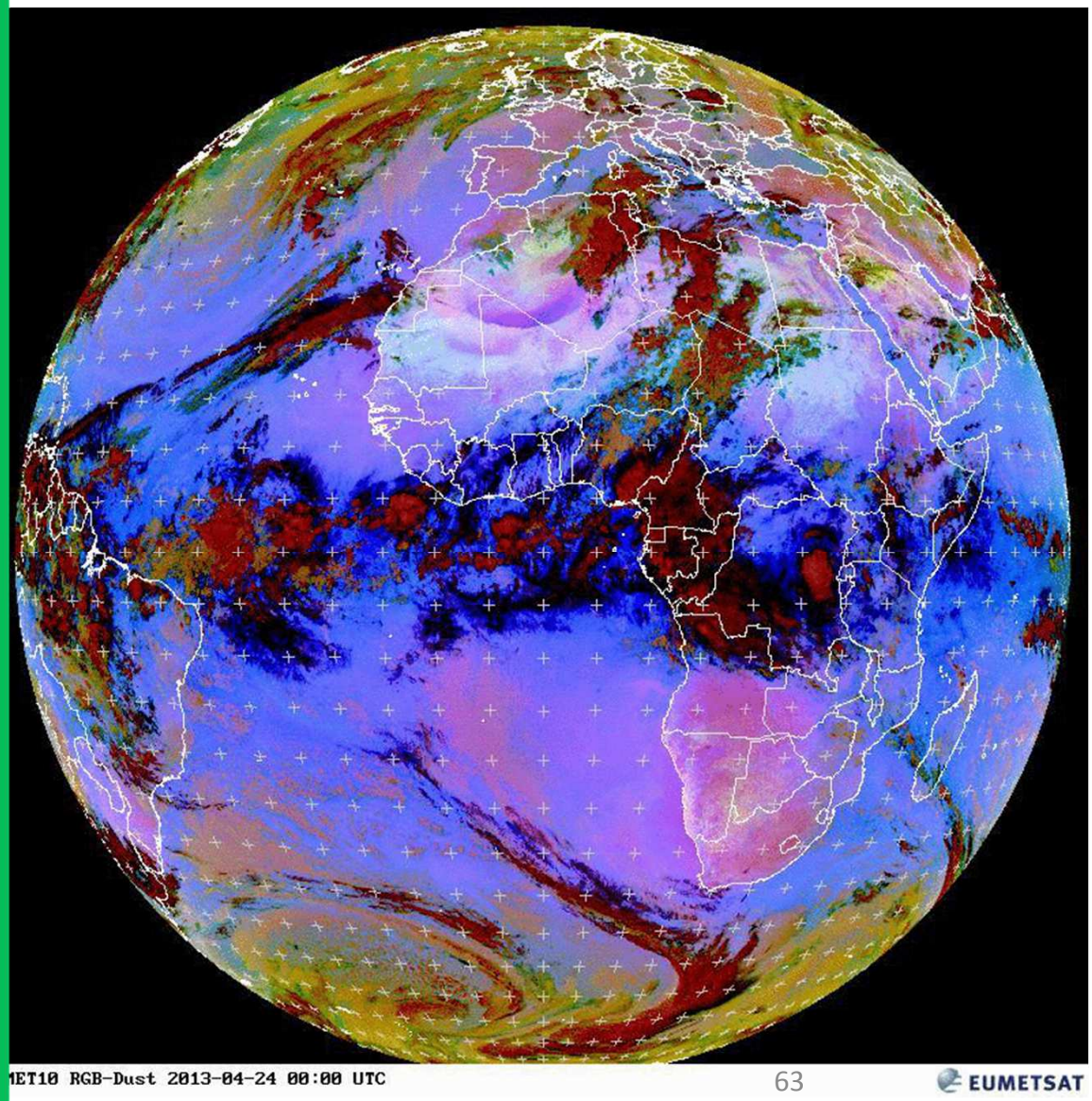
	BSC_ DREAM8b	MACC-ECMWF	DREAM8-NMME-MACC	NMMB/BSC-Dust	U.K. Met Office	NASA GEOS-5	NCEP NGAC	MEDIAN
Sahel/Sahara show stations	-0.18	-0.14	-0.14	-0.09	0.00	-0.08	-0.03	-0.11
Middle East show stations	-0.12	-0.13	-0.04	-0.22	-0.00	-0.15	-0.14	-0.13
Mediterranean show stations	-0.13	-0.14	-0.12	-0.15	-0.09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

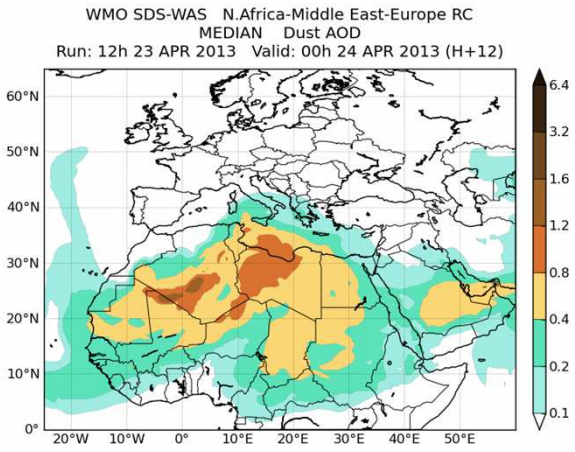
Prediction of atmospheric dust

Forecast evaluation with satellite prods.



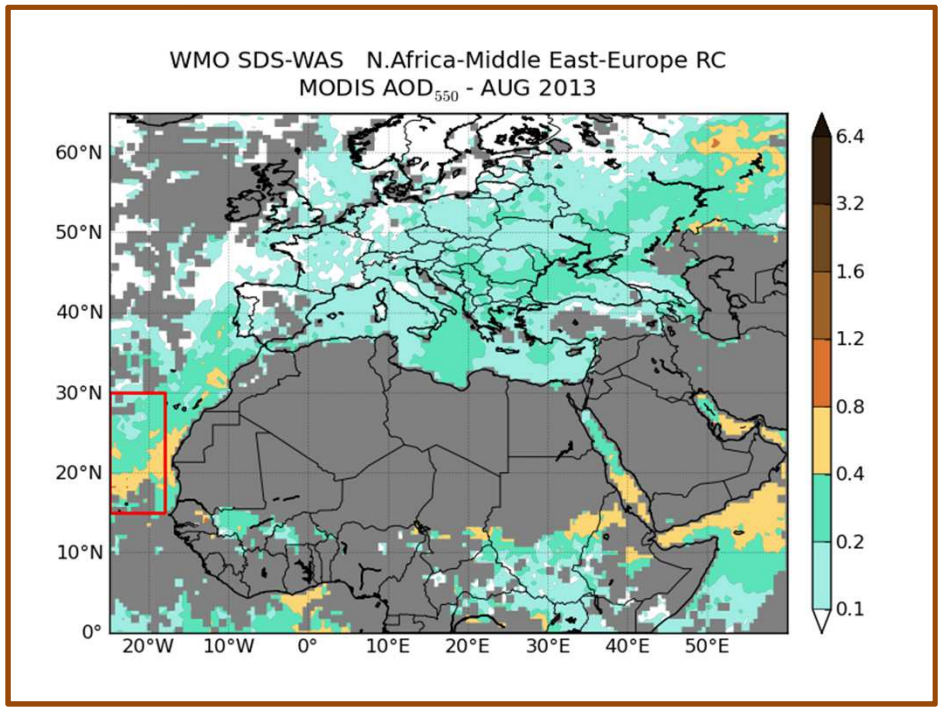
EUMETSAT

24 April 2013



Prediction of atmospheric dust

Evaluation with MODIS data

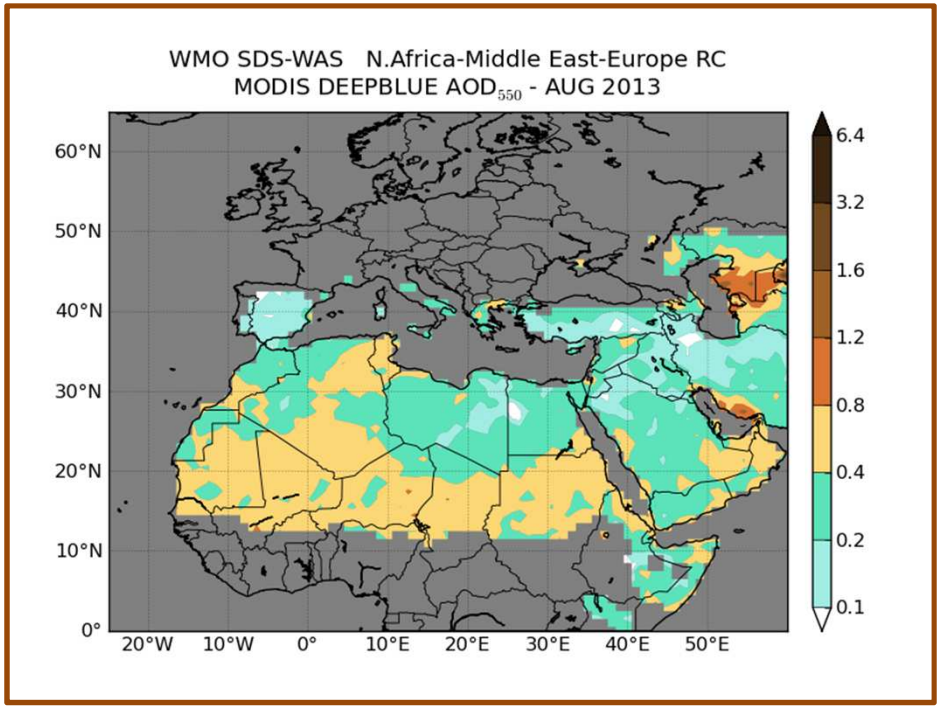


19 Aug 2013

	BIAS	ROOT MEAN SQUARE ERROR	CORRELATION COEFFICIENT	FRACTIONAL GROSS ERROR	NUMBER OF CASES
BSC_ DREAM8b	-0.16	0.21	0.70	0.87	1220
NMMB/BSC-Dust	-0.13	0.20	0.68	0.81	1038
NCEP NGAC	0.14	0.21	0.78	0.41	1228

Prediction of atmospheric dust

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

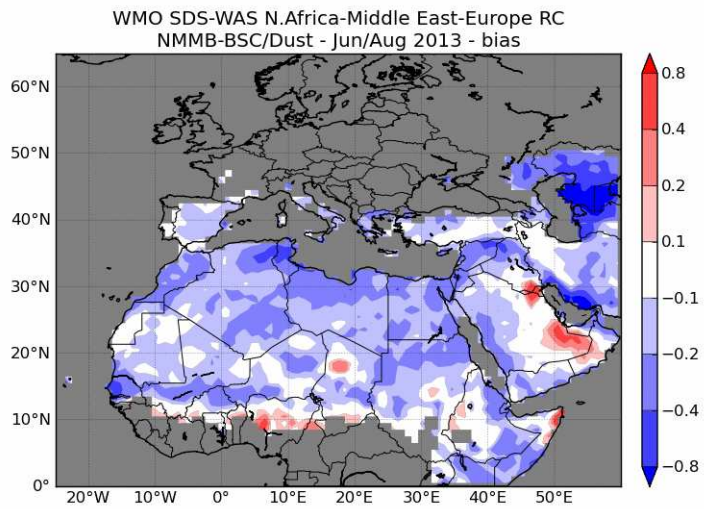
Prediction of atmospheric dust

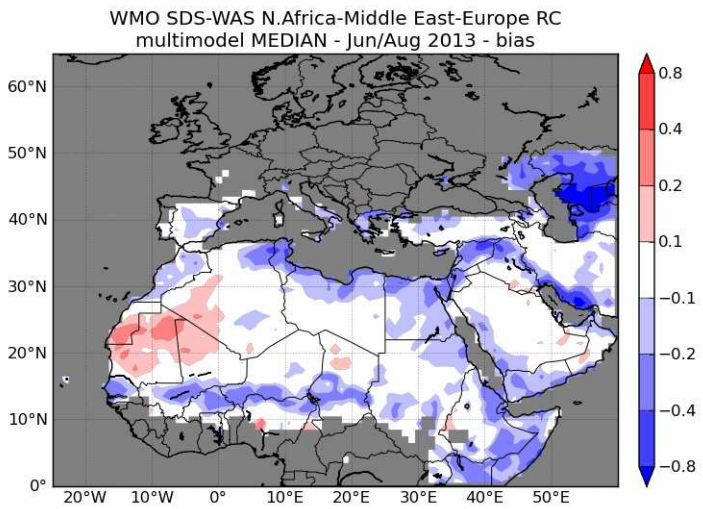
Evaluation with MODIS Deep Blue

NMMB-BSC/Dust

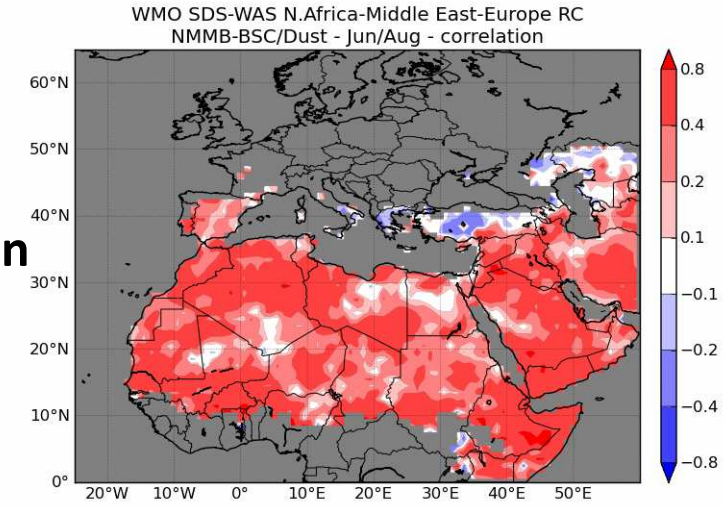
Multimodel MEDIAN

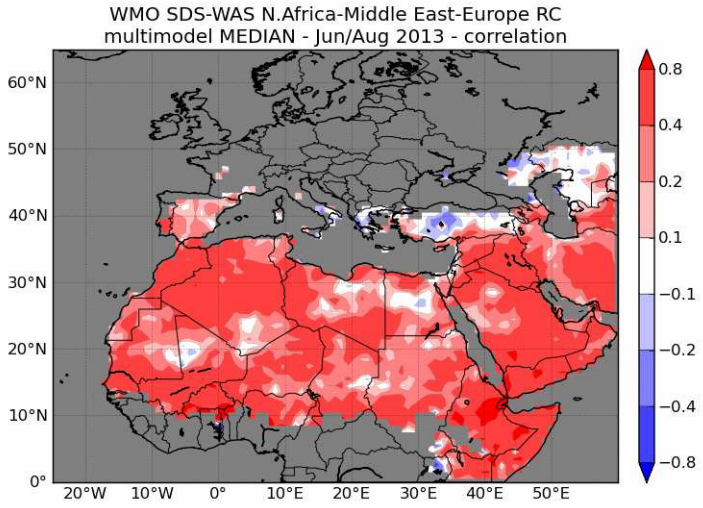
bias





correlation





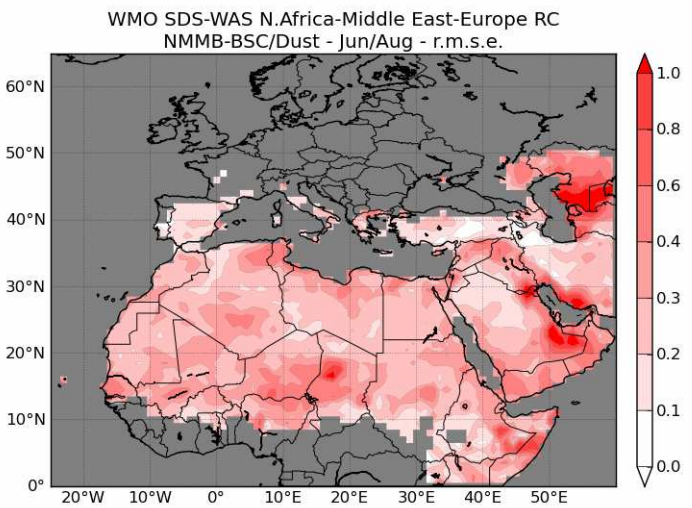
Prediction of atmospheric dust

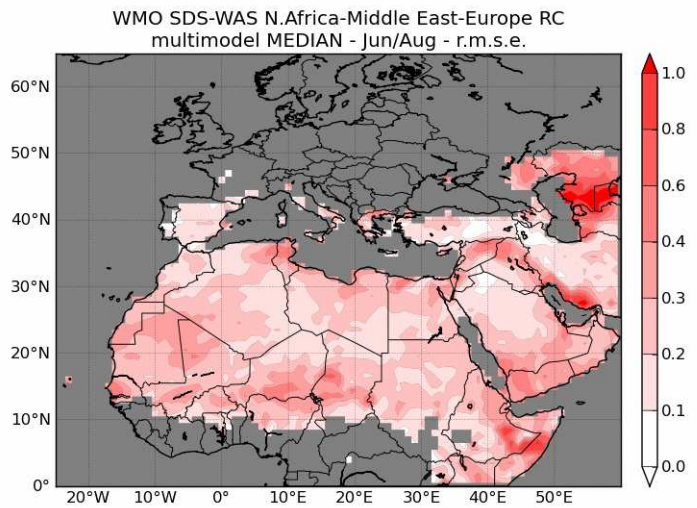
Evaluation with MODIS Deep Blue

NMMB-BSC/Dust

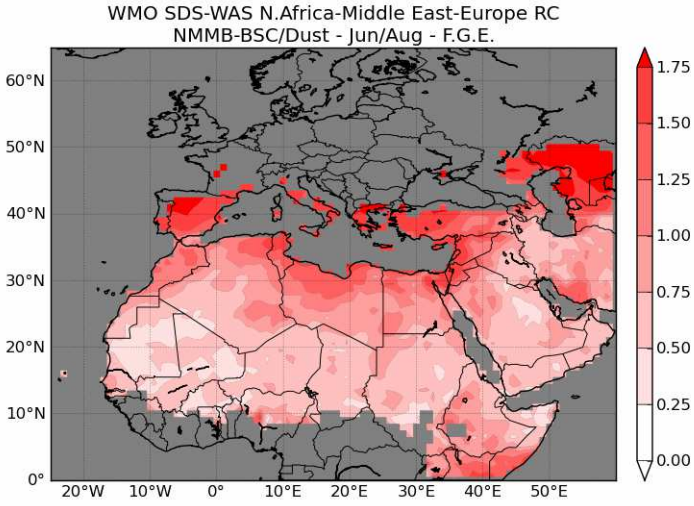
Multimodel MEDIAN

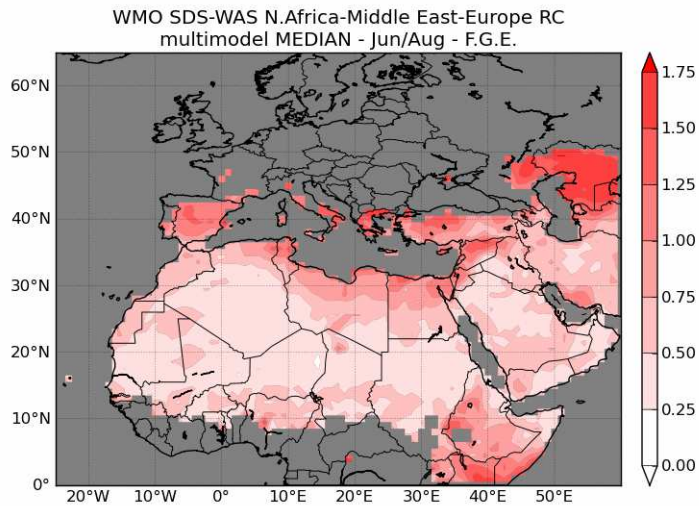
rmse





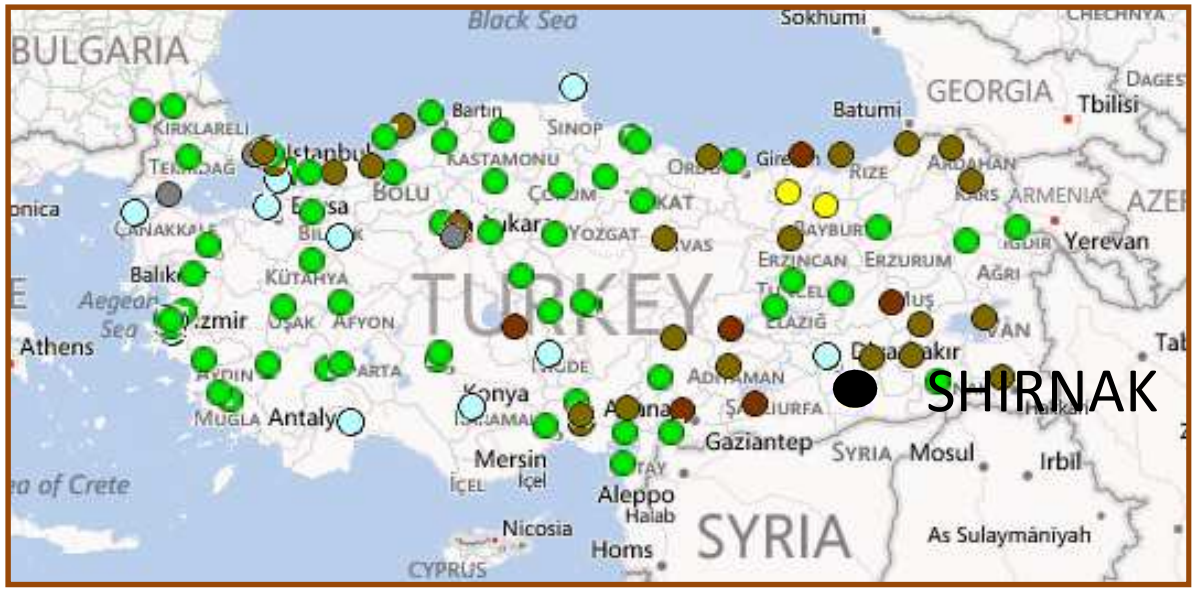
FGE

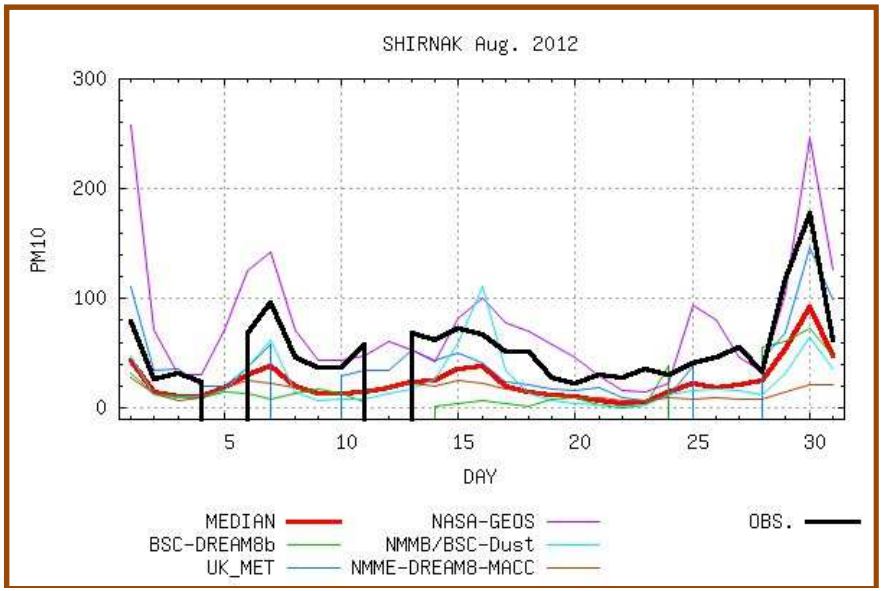




Prediction of atmospheric dust

Evaluation with PM data



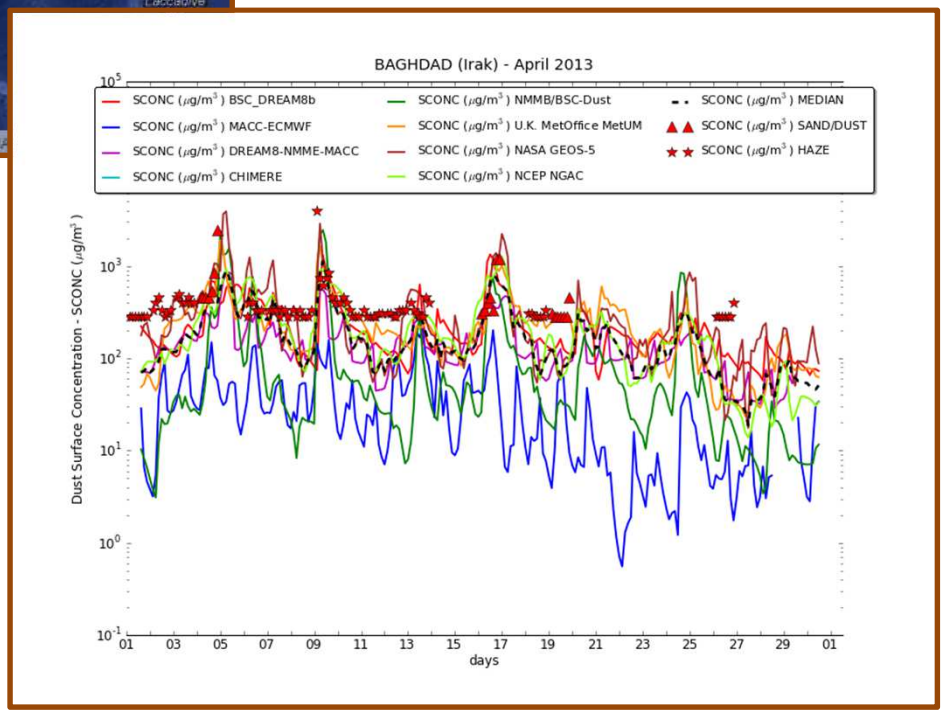


Prediction of atmospheric dust

Evaluation with visibility

PM10 = 1339.84 $V^{-0.67}$
Ben Mohamed et al. (1992)

BAGHDAD, iraq
April 2013



Prediction of atmospheric dust

LIDAR – models comparison

EARLINET

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

BSC-DREAM8B_v2

NMMB-BSC/Dust

SEEVCCC

DREAM8-NMME-MACC

Consiglio Nazionale delle Ricerche

BOLCHEM

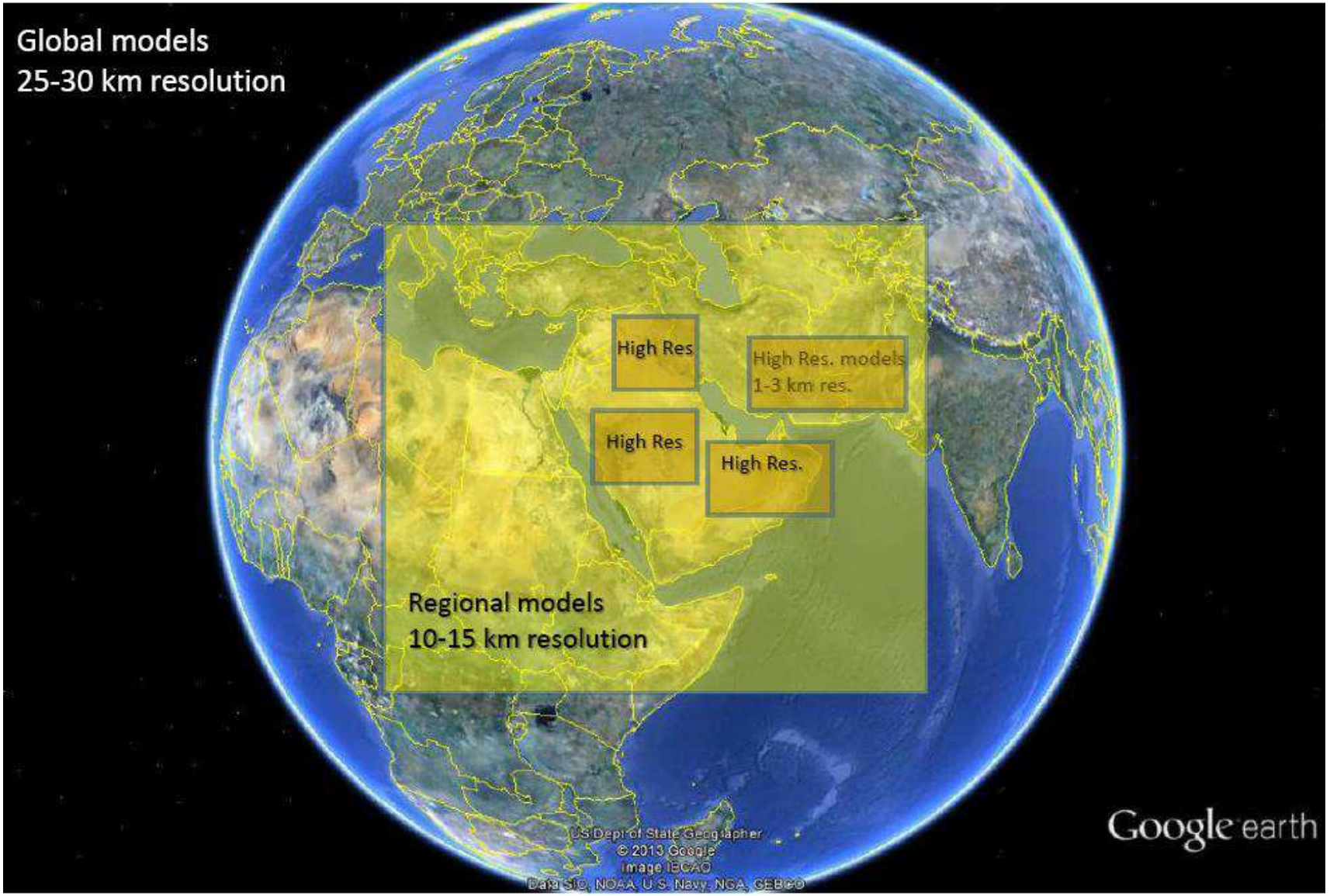
60 – 80 dust cases for the period Jan 2011 – Jun 2013

Dust predicción: outlook into the future

- **High-resolution models**
- **Improvements in data assimilation**
- **Long-range forecast**
- **Dust parameterization in operational NWP models**

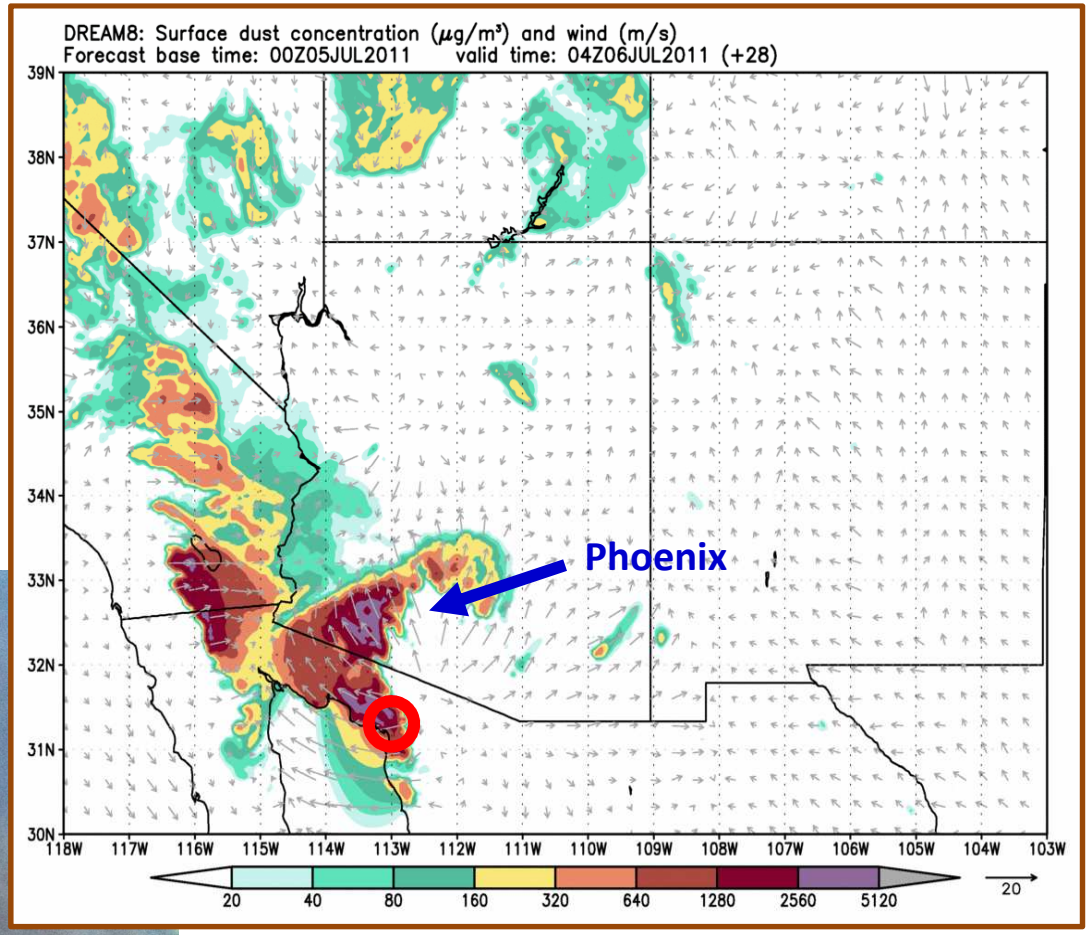
Prediction of atmospheric dust

High-resolution models



Prediction of atmospheric dust

High-resolution models

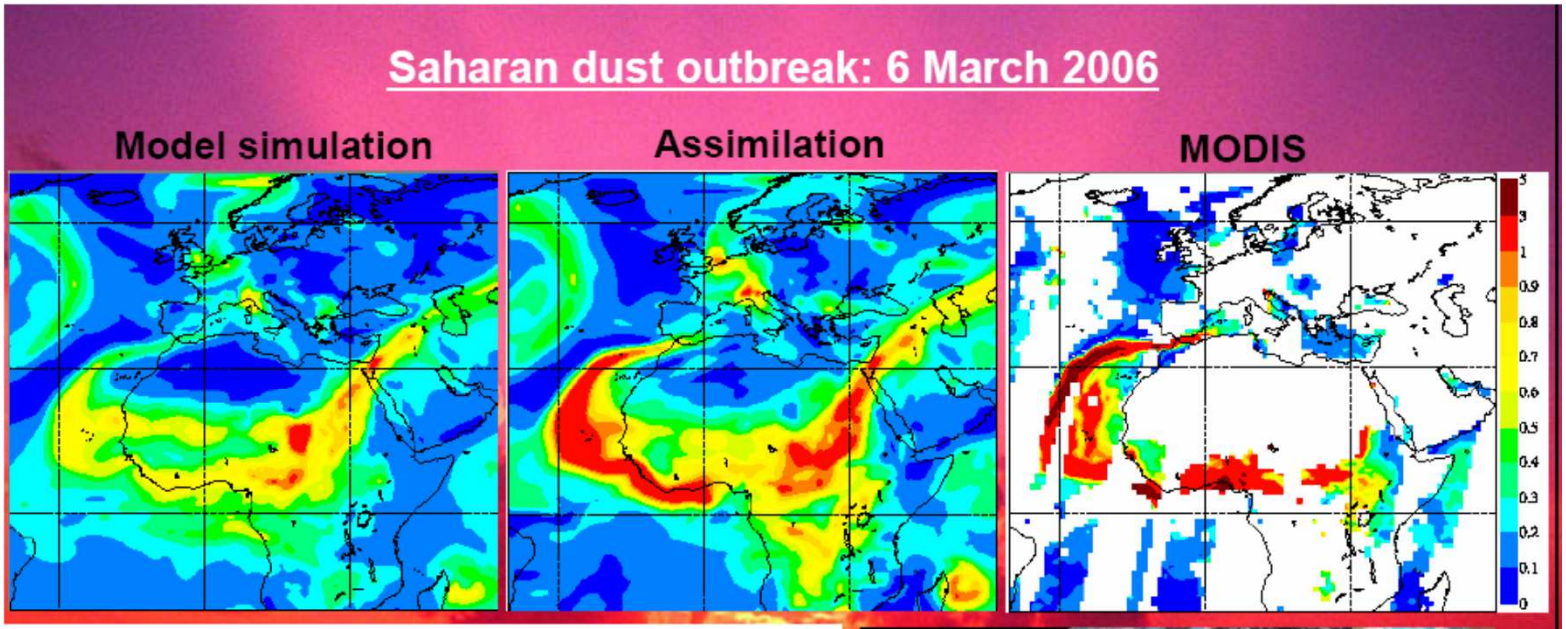


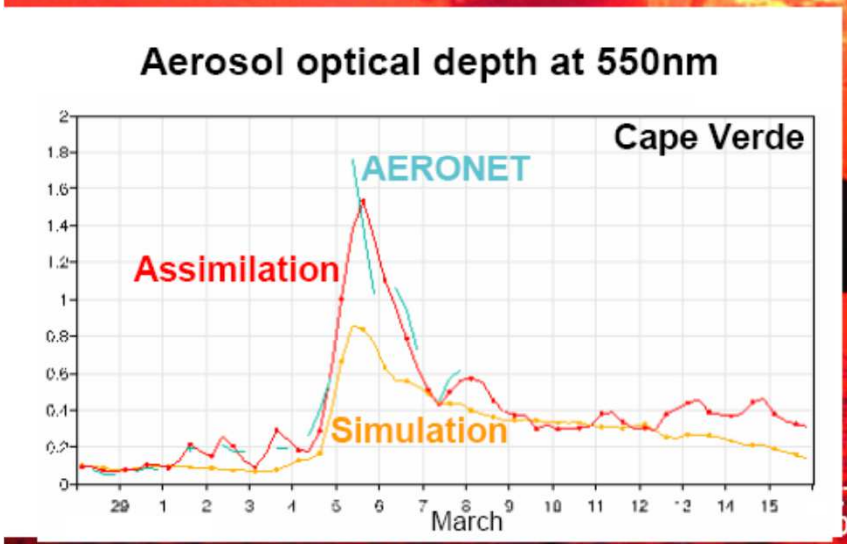
Phoenix, Az
5 Jul 2005 19:45

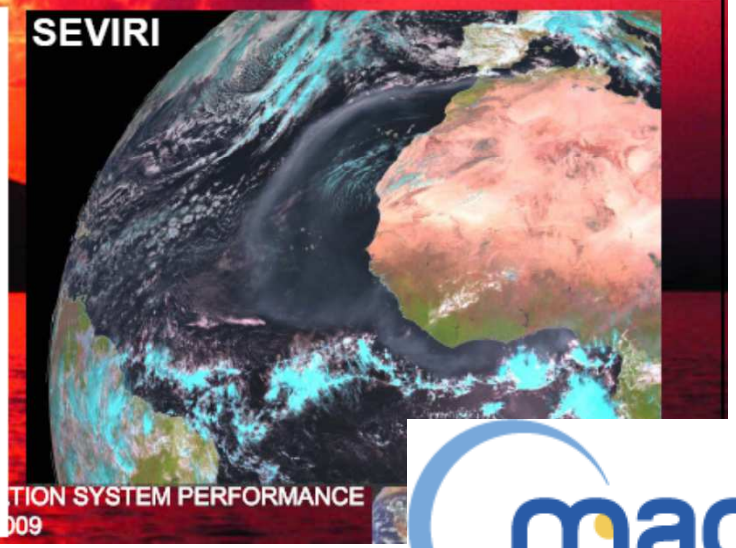
CHAPMAN UNIVERSITY

Prediction of atmospheric dust

Asimilación de datos



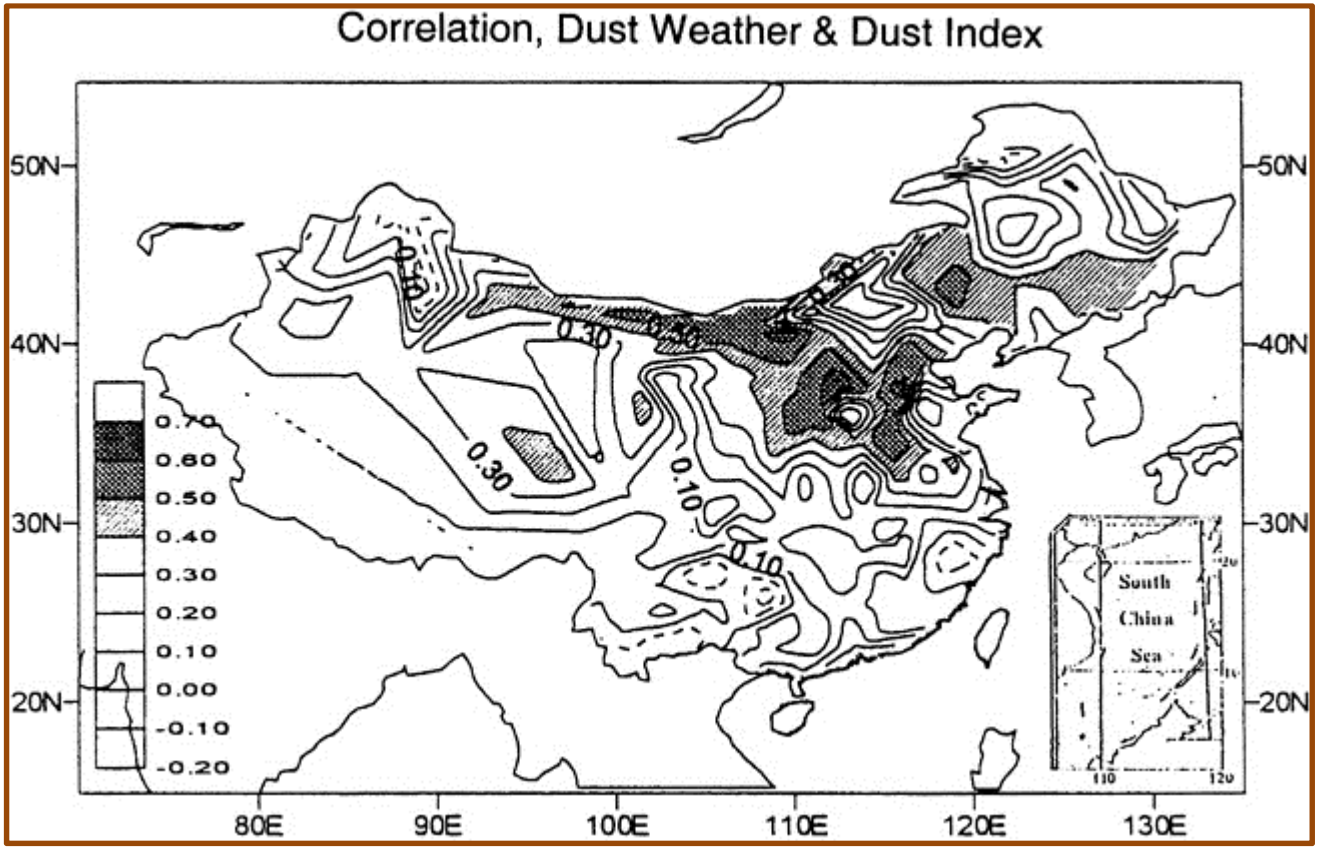




macc
Monitoring atmospheric composition & climate

Prediction of atmospheric dust

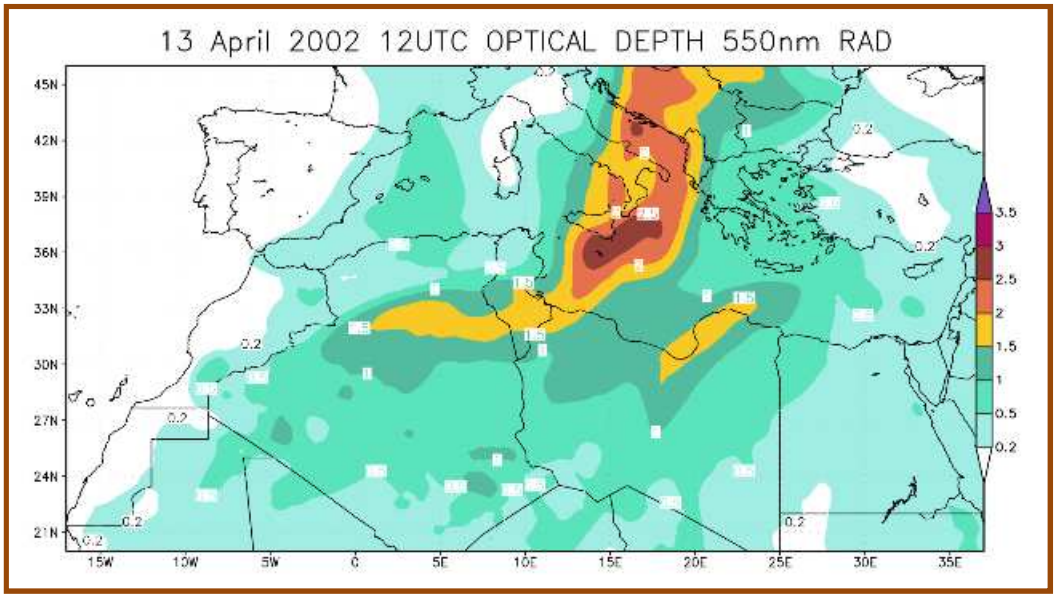
Long-term forecast

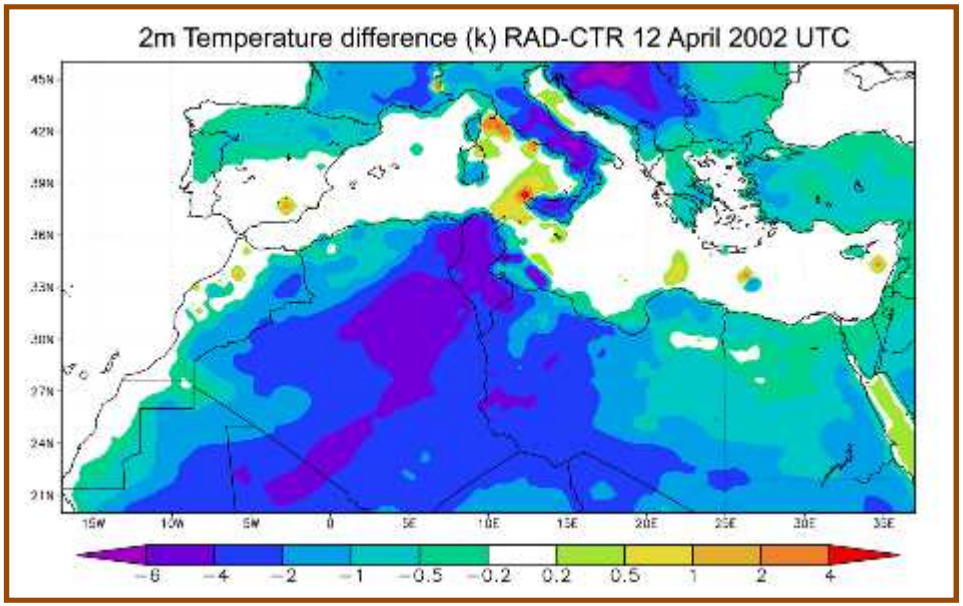


Qian et al. (2002)

Prediction of atmospheric dust

Dust parameterization in NWP models





Pérez et al. (2006)

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 (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

Thanks for your attention

شكرا لاهتمامكم

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

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