Barcelona Supercomputing Center
Centro Nacional de Supercomputación

AXA Research Fund

Modelling and forecasting Sand and Dust Storms - Model evaluation

Sara Basart (sara.basart@bsc.es)

Earth Sciences Department,
Barcelona Supercomputing Center (BSC)

Outlook

Session 1. Introduction to desert dust

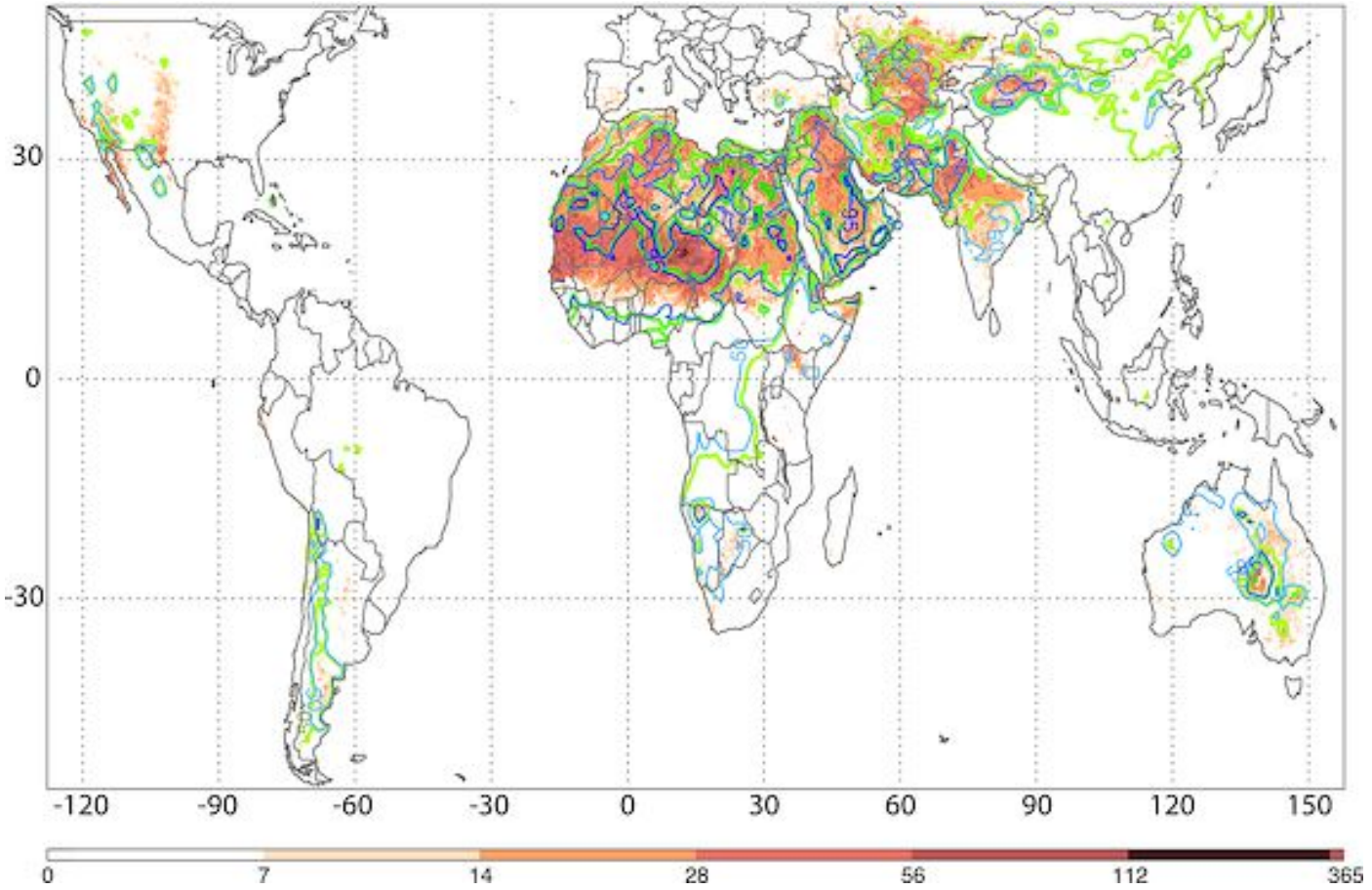
- *Atmospheric aerosols*
- *Desert dust and its cycle*
- *Types of sand and dust storms*
- *Dust global climatology*

Session 2. Evaluating models

- *Dust forecasting models*
- *Model evaluation:*
  - *NRT verification vs. long-term assessment*
  - *Dust-filtered satellite products*

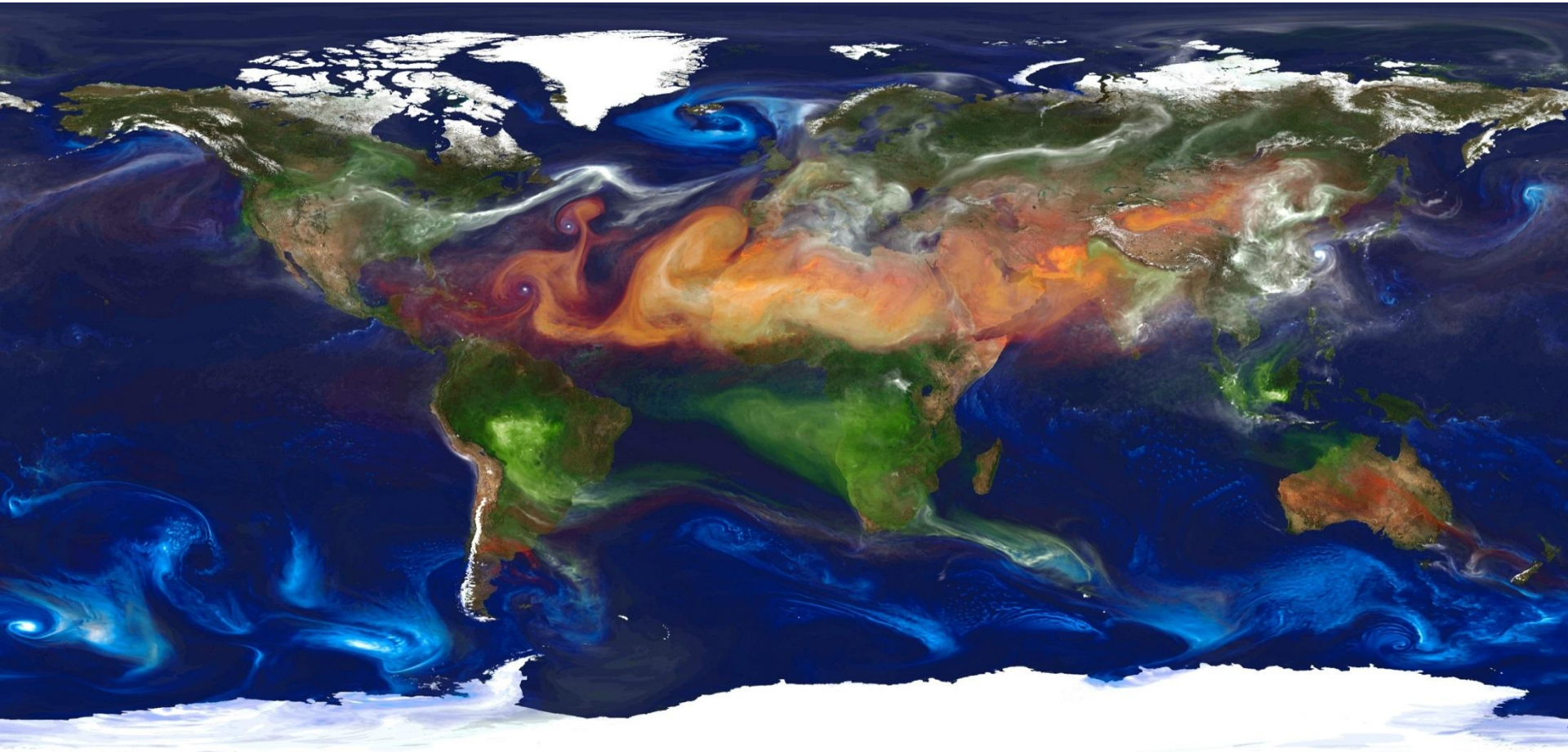
Dust impacts and its extension

Dust global distribution



Global-scale attribution of anthropogenic and natural dust sources and their emission rates based on MODIS Deep Blue aerosol products by Ginoux et al. (2012)

Dust impacts and its extension

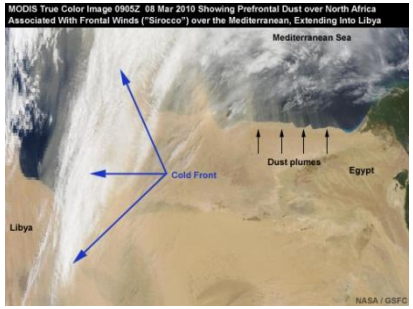


Organic Carbon + Elemental carbon
Dust
Sulfate
Sea salt

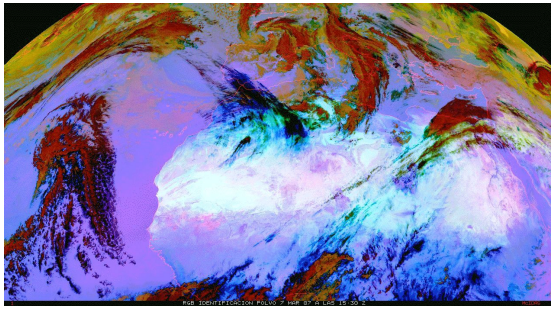
NASA | GEOS-5 Aerosols - AOD

Dust cycle and associated processes

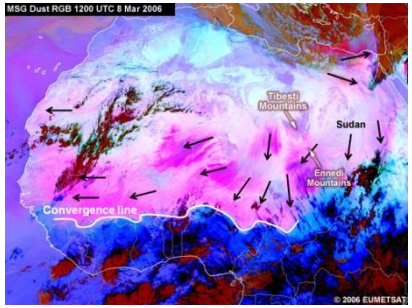
Synoptic dust storms (large scale weather systems)



Pre-frontal winds

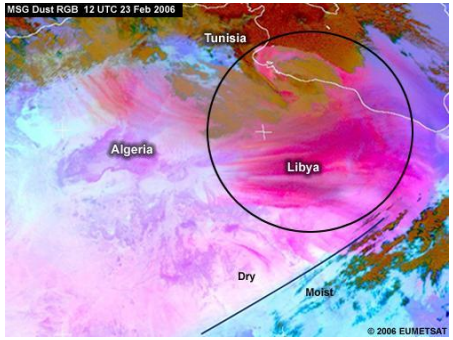


Post-frontal winds

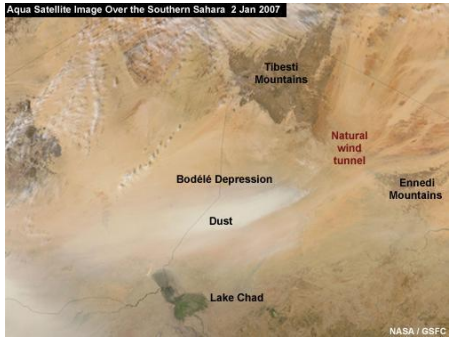


Large-scale trade winds

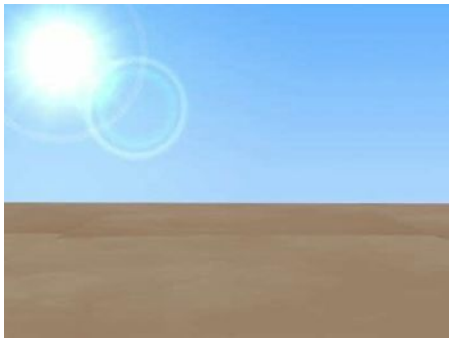
Mesoscale dust storms



Downslope winds



Gap flow

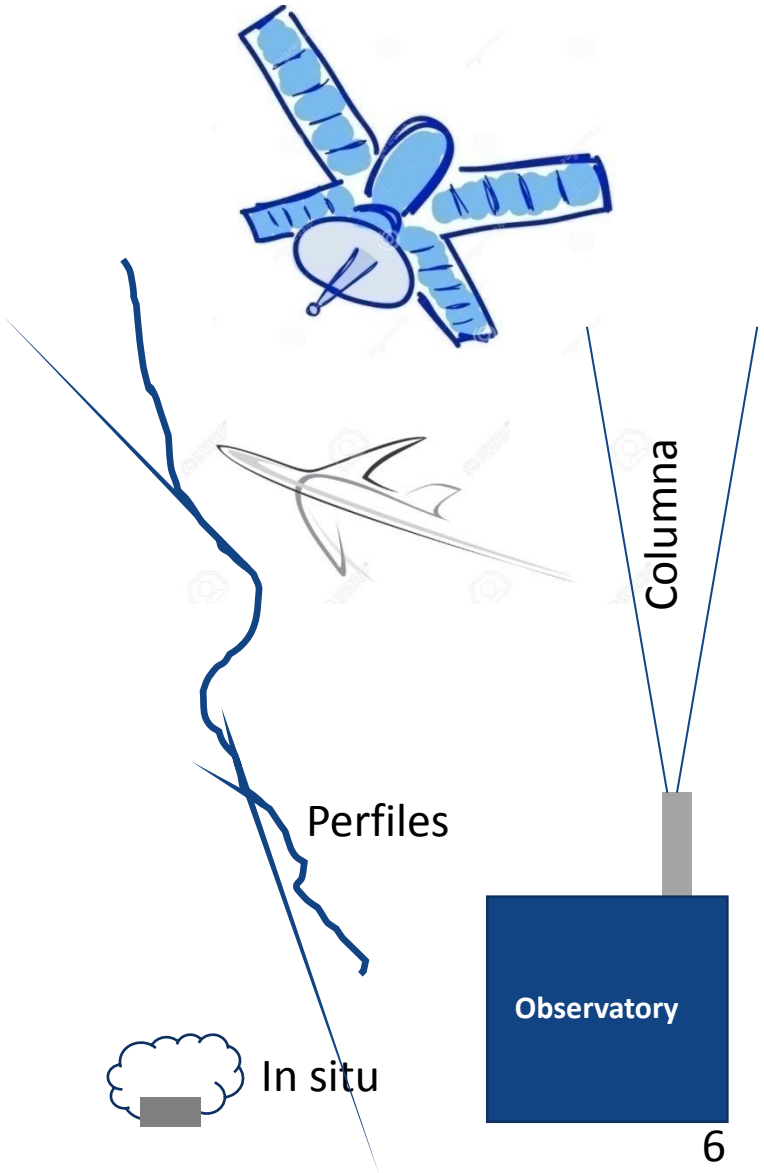


Dust devils

Haboobs

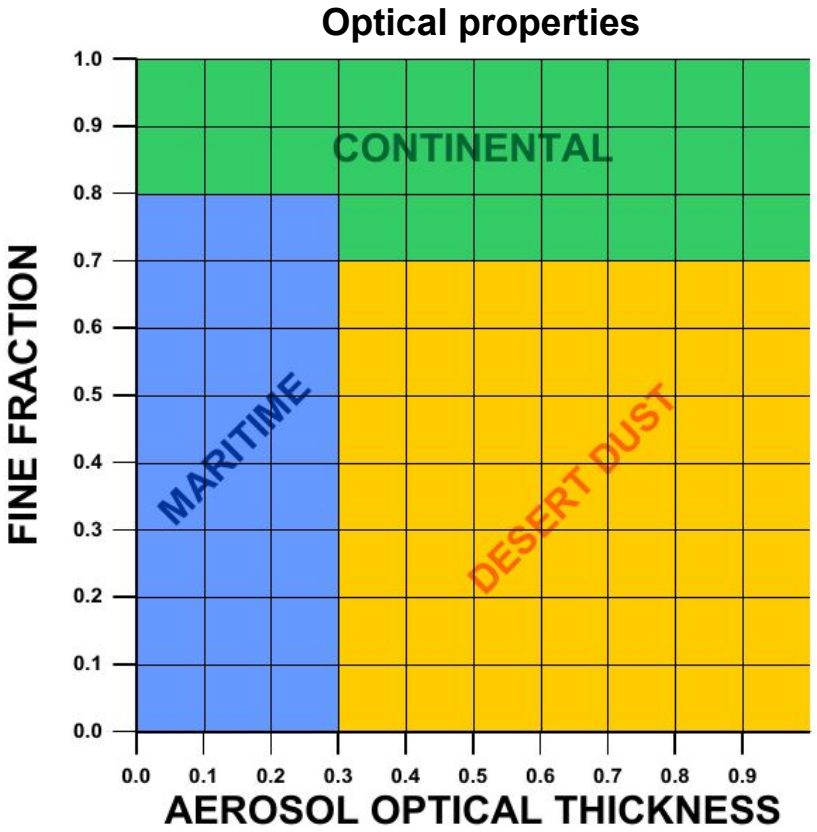
How we can characterize the state of the atmosphere?

- Satellite measurements
- Ground based remote sensing
- Near surface characterization
- Measurement campaigns
  - *Development of new methods*
- Climate and forecasting models



Atmospheric aerosols

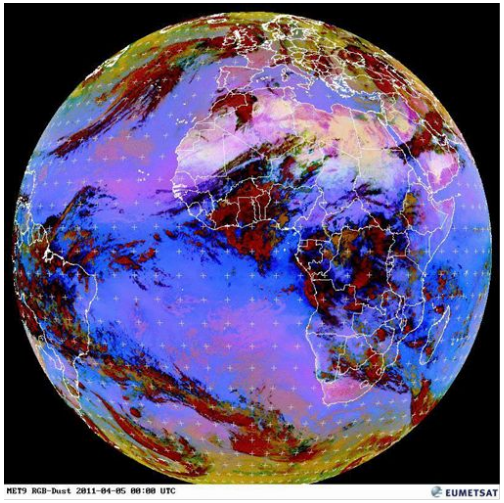
Desert dust can be characterised by its coarser size, irregular shape and large absorption.

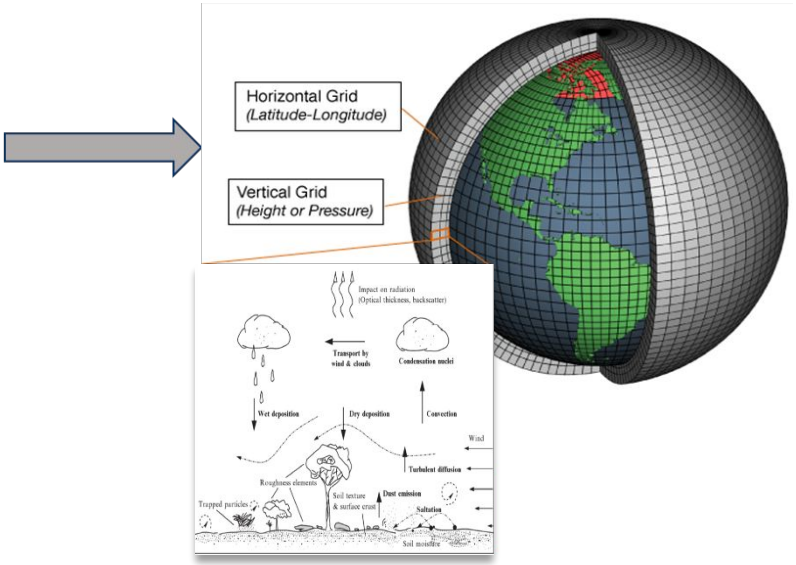


(Barnaba and Gobbi, 2004)

Dust forecasting models

Dust models are a **mathematical representation** of atmospheric dust cycle.





- ✔ *To complement dust-related observations, filling the temporal and spatial gaps of the measurements.*
- ✔ *To help us to understand the dust processes and their interaction with climate and ecosystems.*
- ✔ *To predict the impact of dust on surface level concentrations*

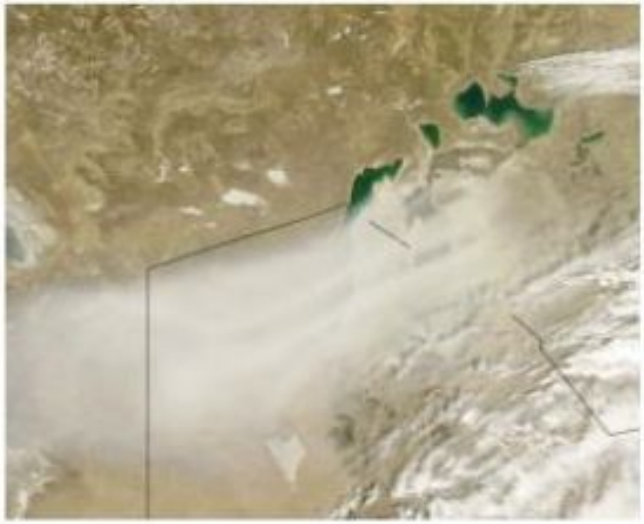
Dust forecasting models

Dust forecasting models do **NOT** take account dust **resuspension** and other anthropogenic sources

Cattle herds, Chad

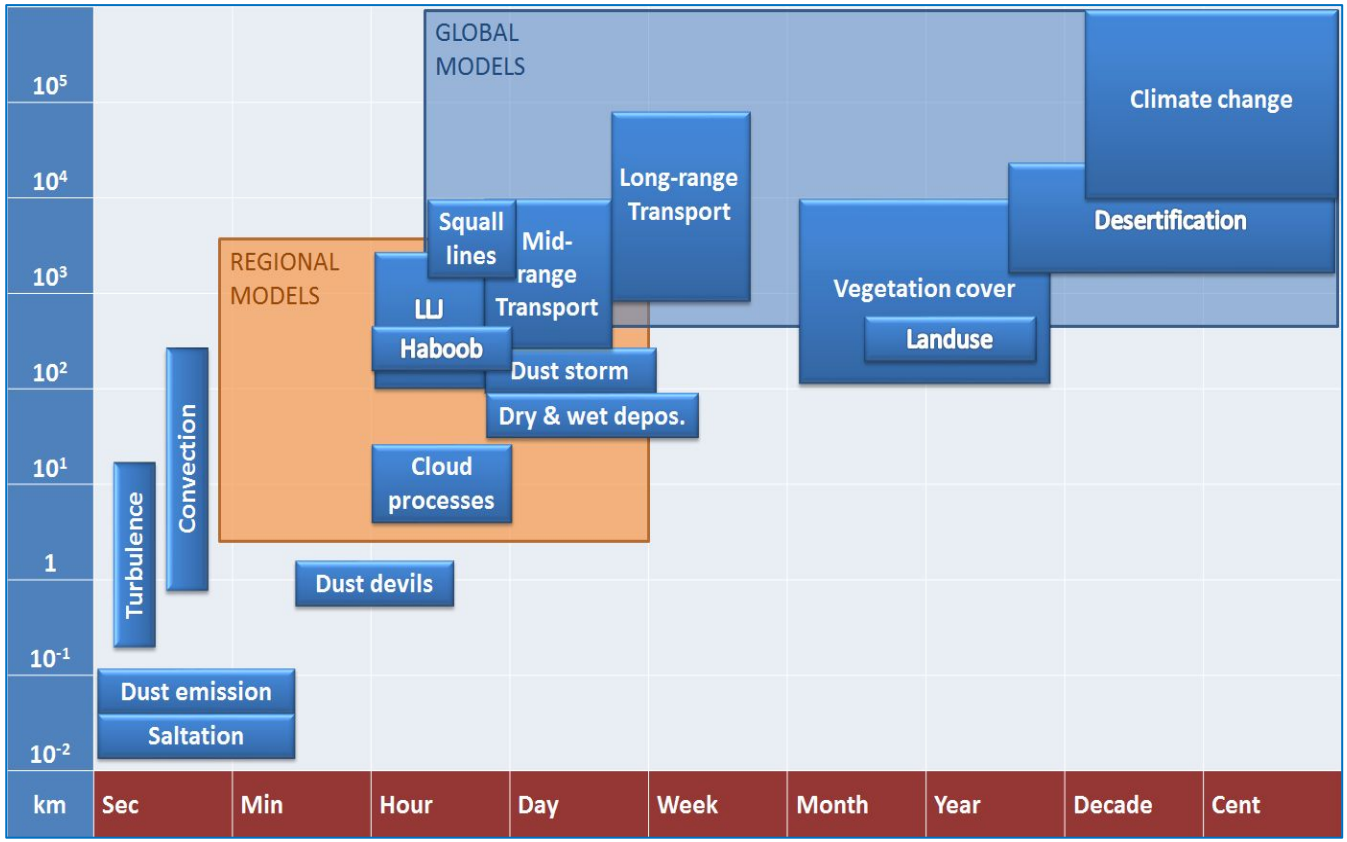
Mining, Ohio valley

Dust from dry sea bed, Aral sea (Uzbekistan)



Kathmandu, Nepal, March 2017

Dust forecasting models

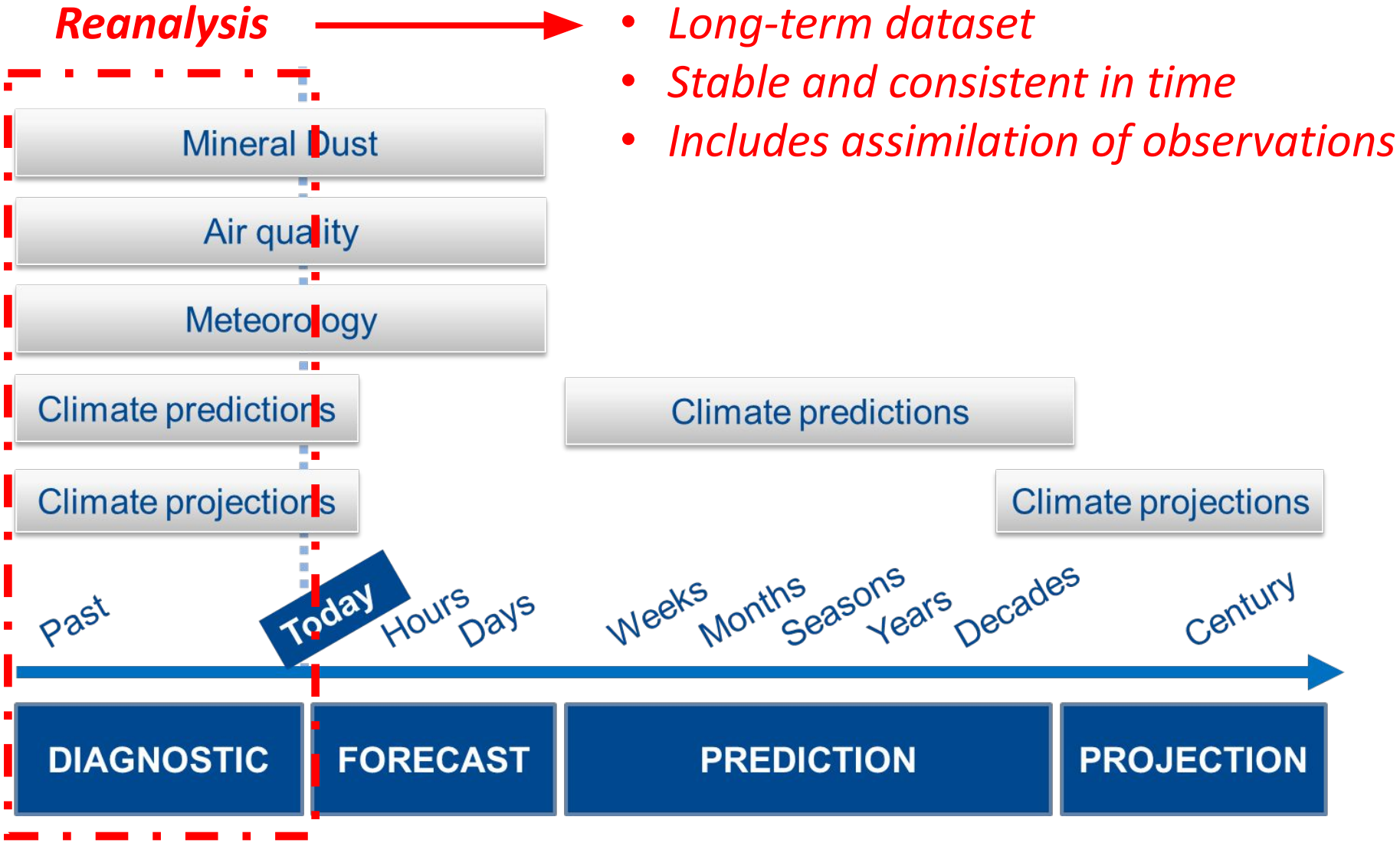


Dust processes span over five orders of magnitude in space and time. **Dust transport** is a global phenomenon. However, **dust emission** is a threshold phenomenon, sporadic and spatially heterogeneous, that is locally controlled on small spatial and temporal scales.

Accurate representation of dust sources and sinks is critical for providing realistic magnitudes and patterns of atmospheric dust fields.

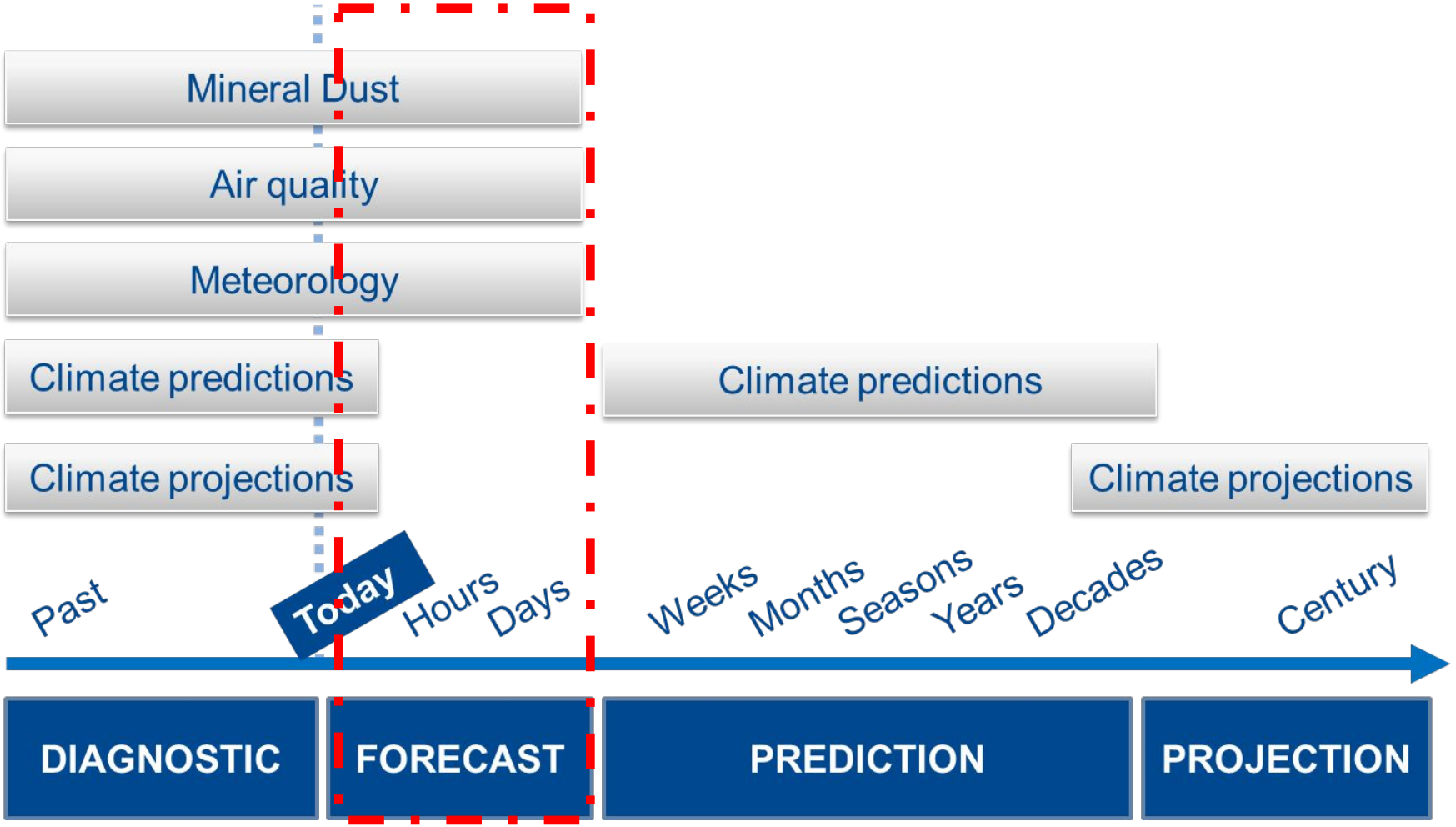
Adapted from Shao (2011)

Modelling scales



- *Long-term dataset*
- *Stable and consistent in time*
- *Includes assimilation of observations*

Modelling scales



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Short-term forecast

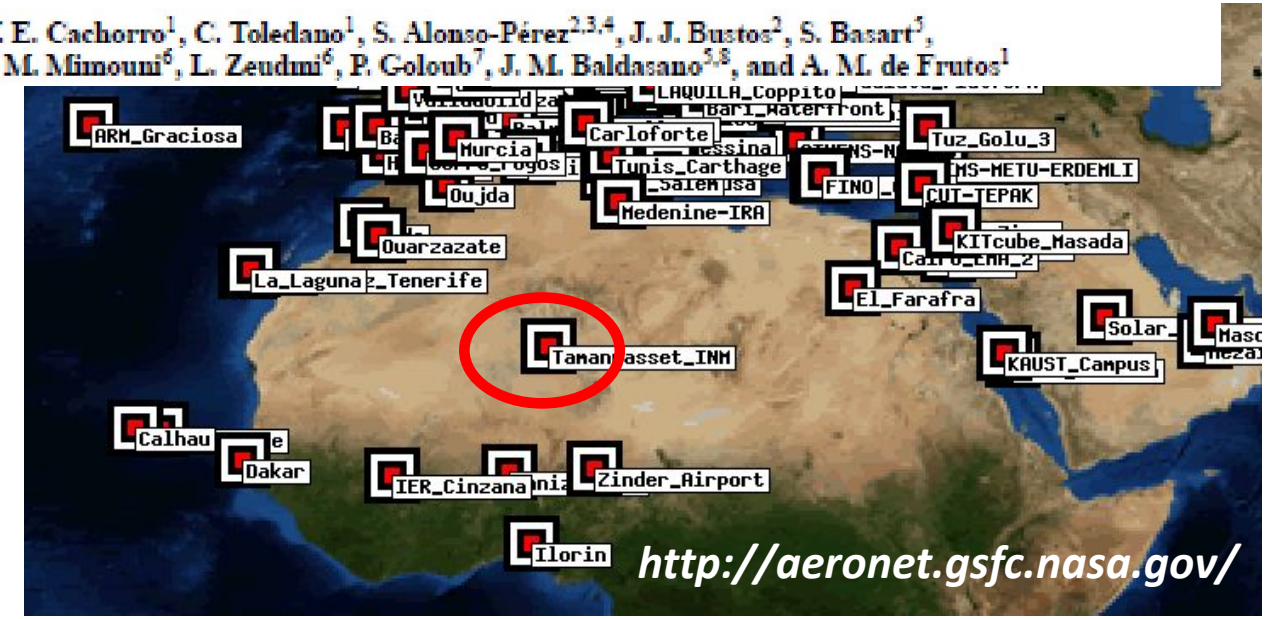
Modelling evaluation

Atmos. Chem. Phys., 14, 11753–11773, 2014
www.atmos-chem-phys.net/14/11753/2014/
doi:10.5194/acp-14-11753-2014

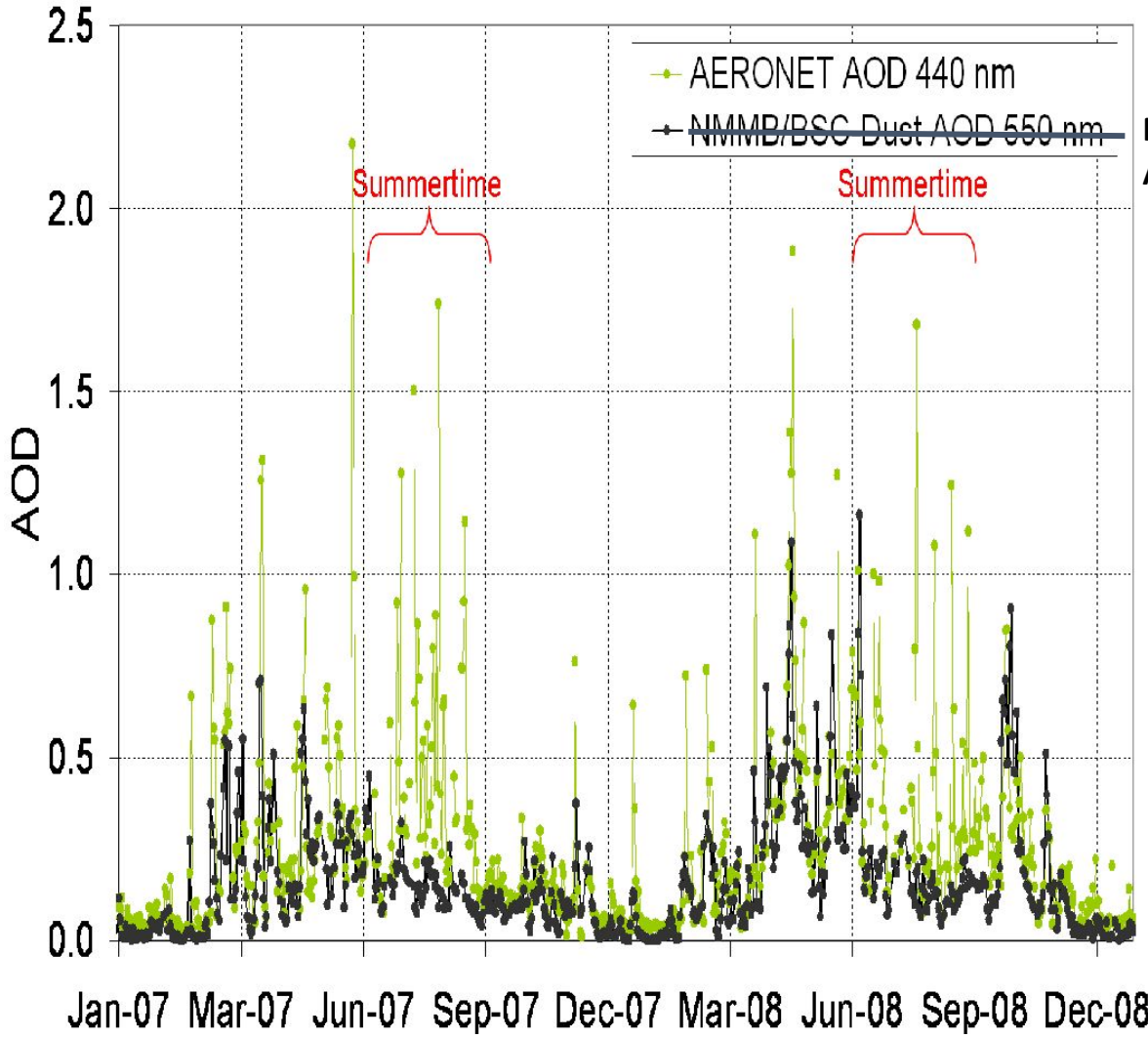
Atmospheric Chemistry and Physics
Open Access

Aerosol characterization at the Saharan AERONET site Tamanrasset

C. Guirado[1,2], E. Cuevas[2], V. E. Cachorro[1], C. Toledano[1], S. Alonso-Pérez[2,3,4], J. J. Bustos[2], S. Basart[3], P. M. Romero[3], C. Camino[2], M. Mimouni[6], L. Zeudmi[6], P. Goloub[7], J. M. Baldasano[5,8], and A. M. de Frutos[1]



Model evaluation



MONARCH AOD 550nm

Extracted from Guirado et al. (2014, ACP)
Time series from Tamanrasset, Algeria

A piece of SDS history

- Late **80's**:
  - First demonstration that SDS dynamic simulations are possible
- **90's**:
  - First satellite products capable to detect SDS
  - First successful daily SDS forecast test
  - First long-term daily SDS forecasts
- **2000's**:
  - Fast growth in dust observations and forecasting models
- **2010's**:
  - Fast growth in user-oriented applications

WE ARE **NOW** READY TO PROVIDE ADDED-VALUE DUST **INFORMATION** !

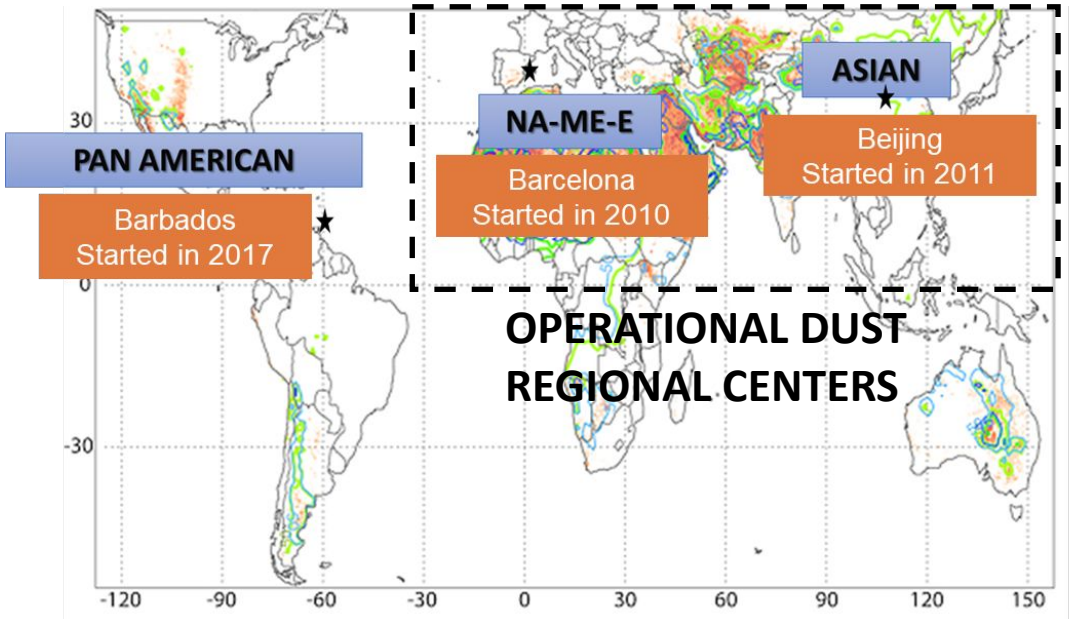
Agencia Estatal de Meteorología

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

Objectives:

- Identify and improve products to monitor and predict 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.

Regional Nodes and Centers

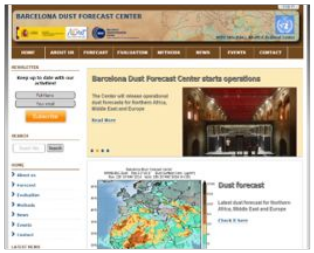


WMO Barcelona Dust Regional Center

The **WMO Barcelona Dust Regional Center** (includes operations and R&D) is coordinating the activities of the NAMEE node and participating in ongoing research projects that search to produce **dust services**.

@Dust_Barcelona

Barcelona Dust Forecast Center
Operations
http://dust.aemet.es



SDS-WAS
R&D
http://sds-was.aemet.es

Multi-model ensemble

15 Global – Regional models (from ~ 100 to 10 km)

PROBABILISTIC products can provide better information during extreme events

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Centro Nacional de Supercomputación
AXA Research Fund
inDust
cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY
AEMet Agencia Estatal de Meteorología

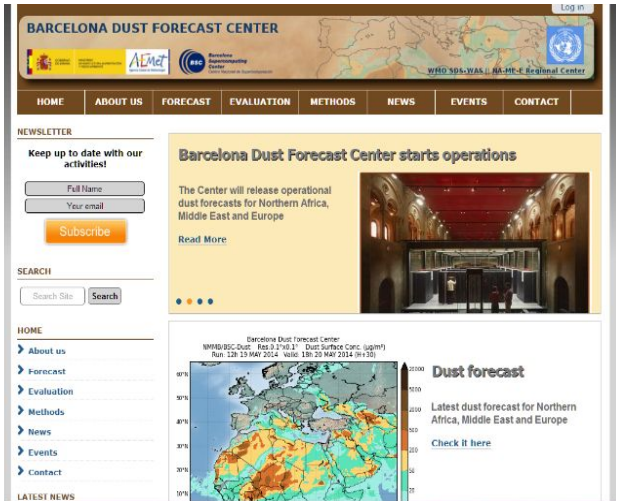
WMO Barcelona Dust Regional Center

- **SDS-WAS Regional Center**. Sand and Dust Storm Warning Advisory and Assessment System. Starting in 2010 – ***Research***
  - *http://sds-was.aemet.es*

It includes a multi-model ensemble

PROBABILISTIC products

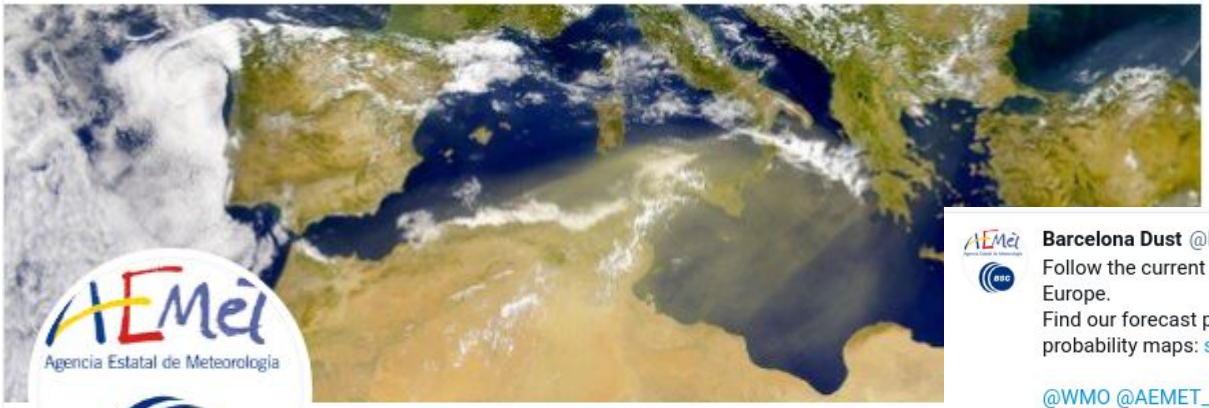
- **Barcelona Dust Forecast Center (RSMC-ASDF).** First Regional Specialized Meteorological Center with activity specialization on Atmospheric Sand and Dust Forecast. Starting in 2014 - ***Operational***
  - *http://dust.aemet.es*
  - *@Dust_Barcelona*



MONARCH is the reference model and it contributes to the SDS-WAS ensemble

Agencia Estatal de Meteorología

Barcelona Dust Regional Center



Agencia Estatal de Meteorología

BSC

Barcelona Dust

@Dust_Barcelona Te sigue

The Barcelona Dust Forecast Center is a WMO RSMC-ASDF create
produces and distributes dust forecasts for
Northern Africa, Middle East and Europe.

Traducir la biografía

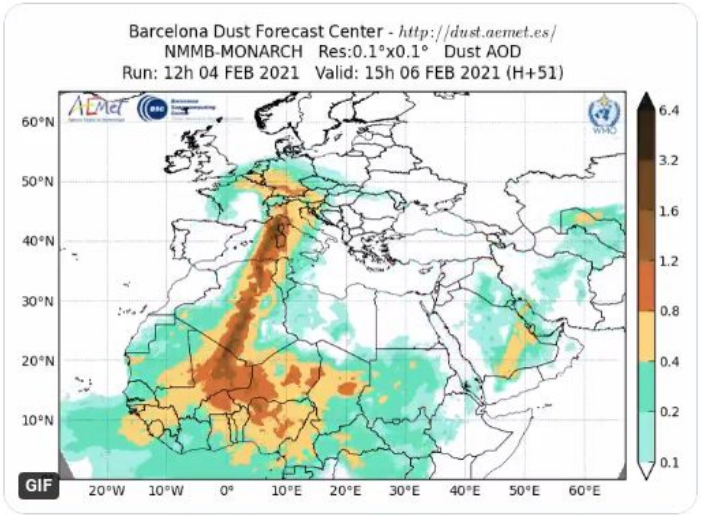
Barcelona (Spain) dust.aemet.es Se unió en noviembre

139 Siguiendo **3.393** Seguidores

Barcelona Dust @Dust_Barcelona · 5 feb.

Follow the current Saharan dust intrusion over the Mediterranean and Europe.
Find our forecast products here: dust.aemet.es/forecast/nmmb-... and probability maps: sds-was.aemet.es/forecast-produ...

@WMO @AEMET_Esp @BSC_CNS @UNCCD



119 133

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AEMet
Agencia Estatal de Meteorología

Operational Dust Forecast

*Reference model **MONARCH***

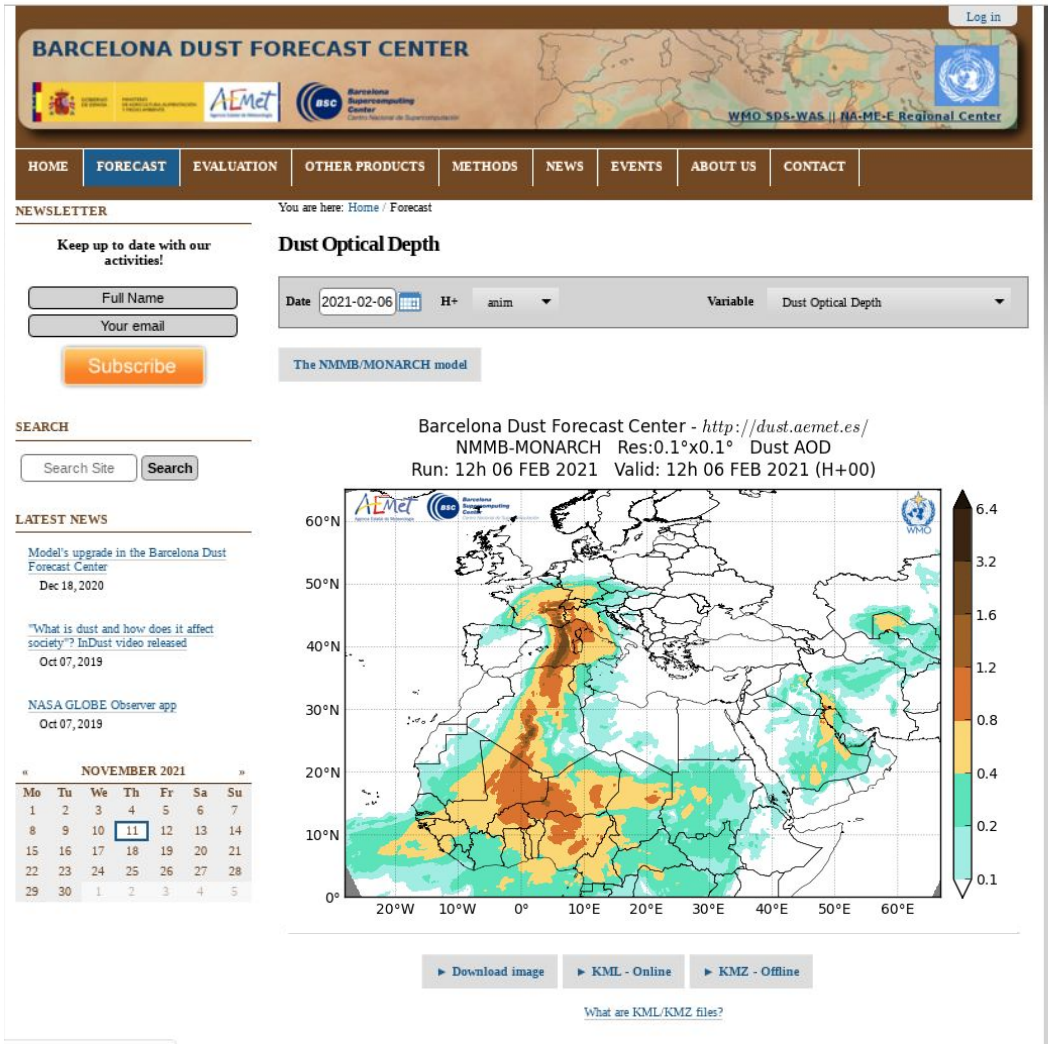
72-hours forecasts of:

- *Dust Optical Depth at 550nm*
- *Dust Dry and Wet Deposition*
- *Dust Load*
- *Dust Surface Concentration*
- *Dust Surface Extinction at 550nm*

Downloadable forecast products

- *Maps (FRAME or GIF)*
- *GoogleEarth (KMZ or KML)*

Evaluation with AERONET



@Dust_Barcelona

http://dust.aemet.es/

Multi-model ensemble

15 Global and Regional models

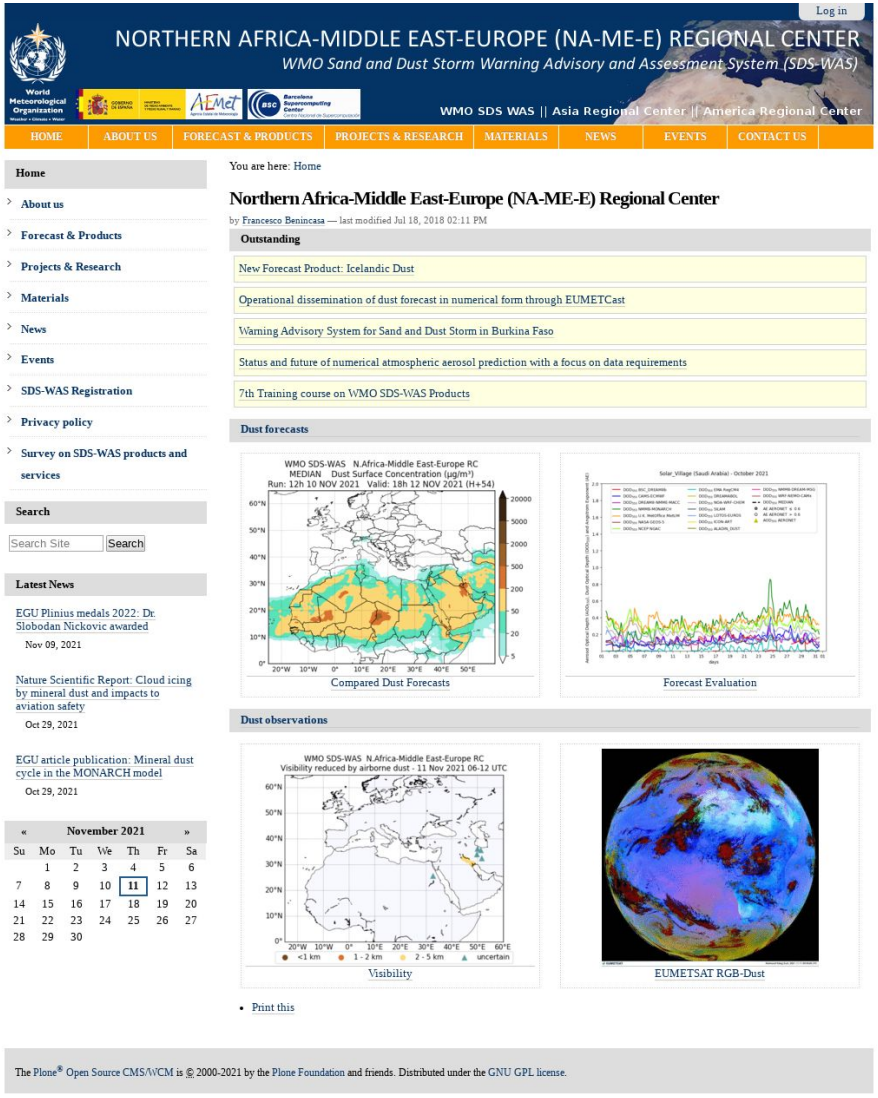
72-hours forecasts of:

- *Dust Optical Depth at 550nm*
- *Dust Surface Concentration*

Downloadable forecasts products

- *Maps (FRAME or GIF)*
- *GoogleEarth (KMZ or KML)*
- *Numerical data*

Evaluation with AERONET and MODIS



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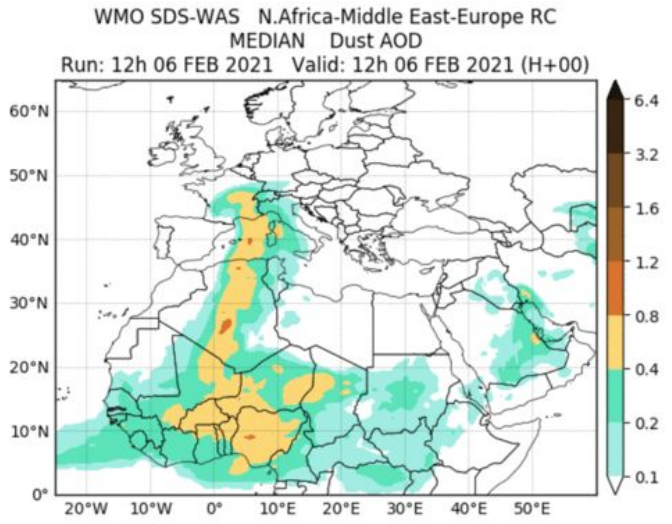
http://sds-was.aemet.es/

Multi-model ensemble

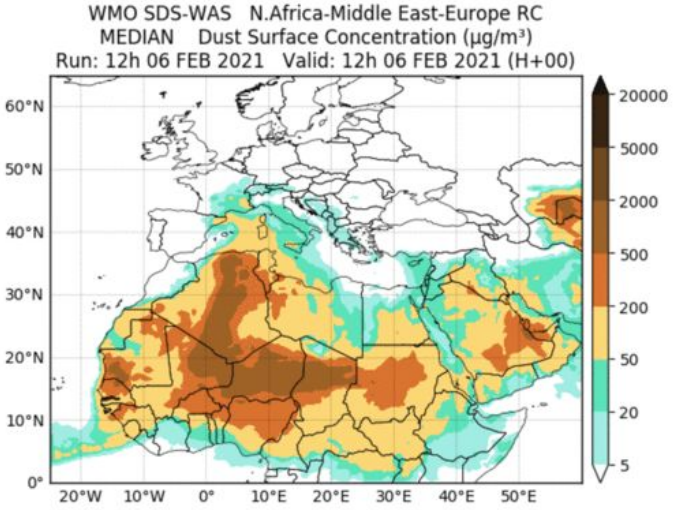
Model ensemble

15 Global – Regional models
(from ~ 100 to 10 km)

Dust column-load, DOD



Surface concentration



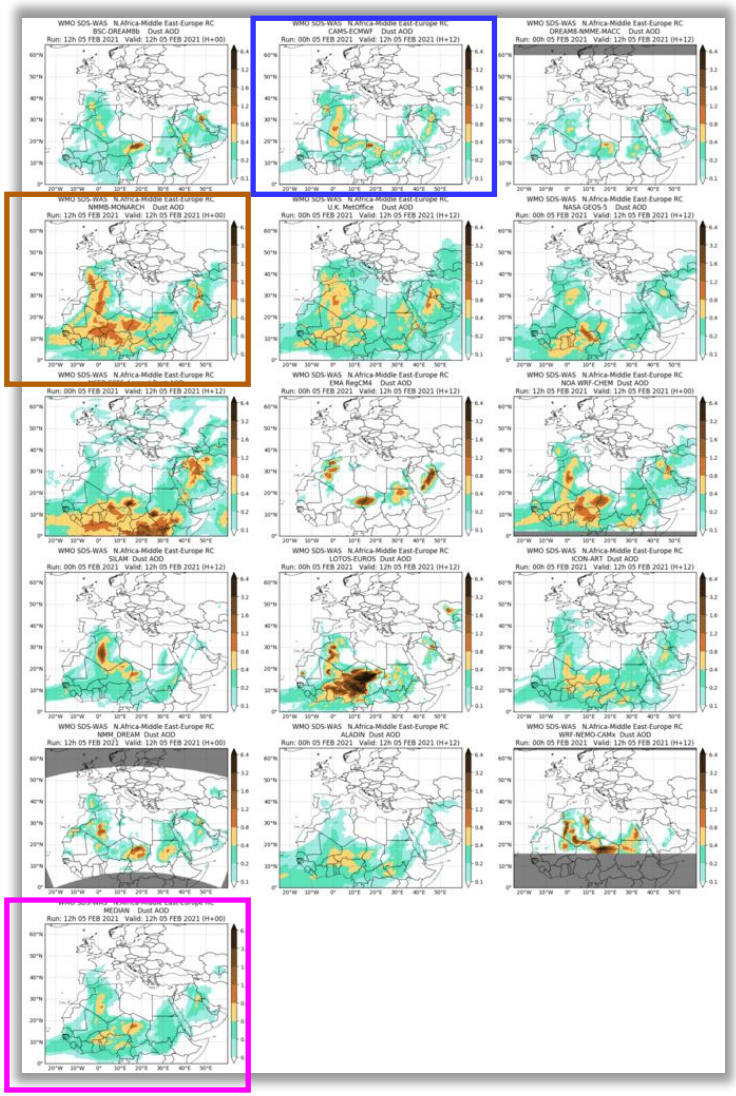
PROBABILISTIC products can provide better information during extreme events

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

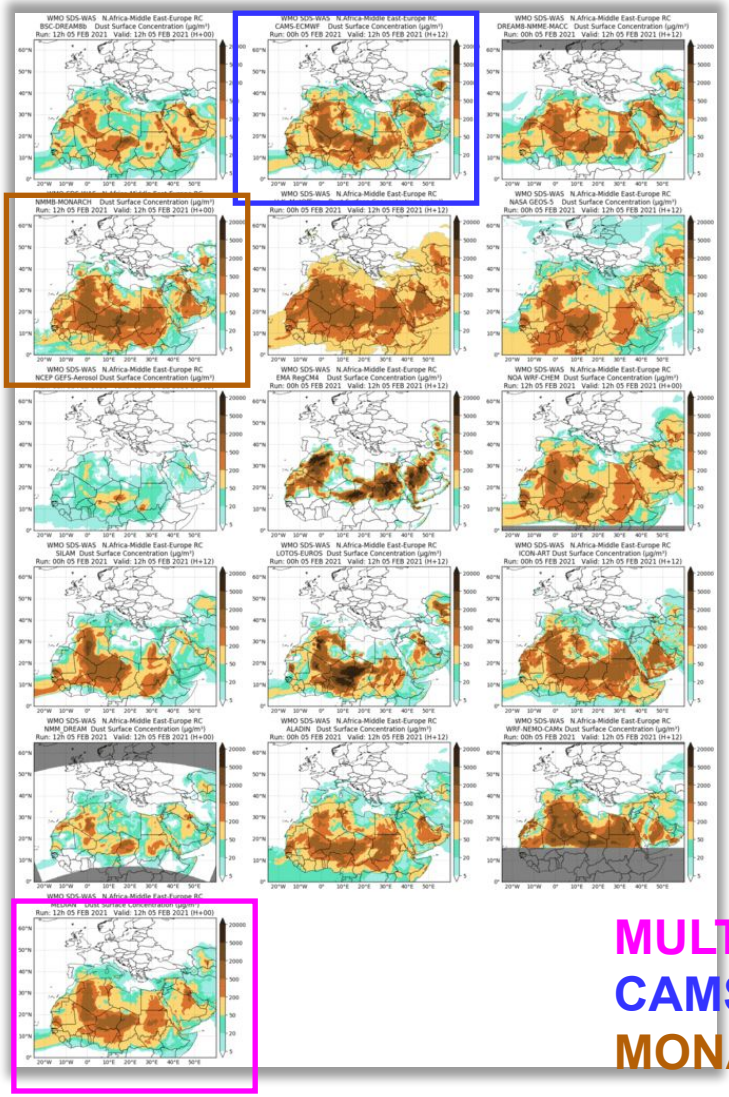
Multi-model product

3-days forecast: Example from 5-Feb-2021 to 7-Feb-2020

DOD – dust column-load



Surface concentration



MULTI-MODEL
CAMS
MONARCH

Saharan outbreak over Europe on 5-7 Feb 2021

Sara Basart @SaraBasart · 6 feb.

Saharan dust is giving an amazing reddish touch to the Pyrinees today! @Dust_Barcelona forecast captured! @m_parrington @cp_garcia_pando @SanGasso @PavlaDagsson @CALIOPE_BSC

Dani Mora @meteobenas · 6 feb.

Nos llegan espectaculares fotos de la lluvia de @llanoshospital

2 21 48

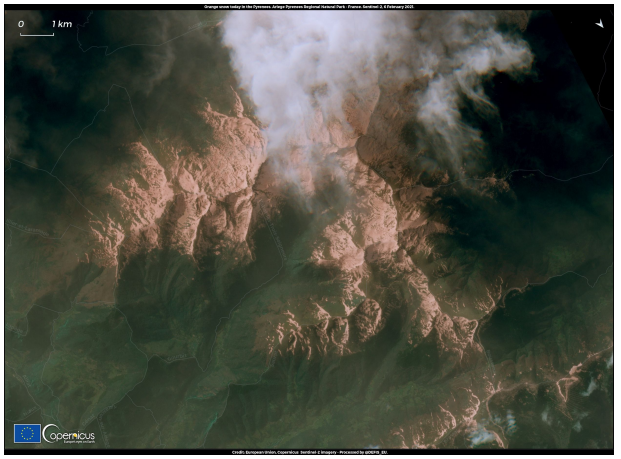
Claudia Mignani
@ClaudiaMignani

Today's Saharan dust event captured by SWITCH at Jungfraujoch, Switzerland, 3571 meters (11716 feet) above sea level.

Traducir Tweet

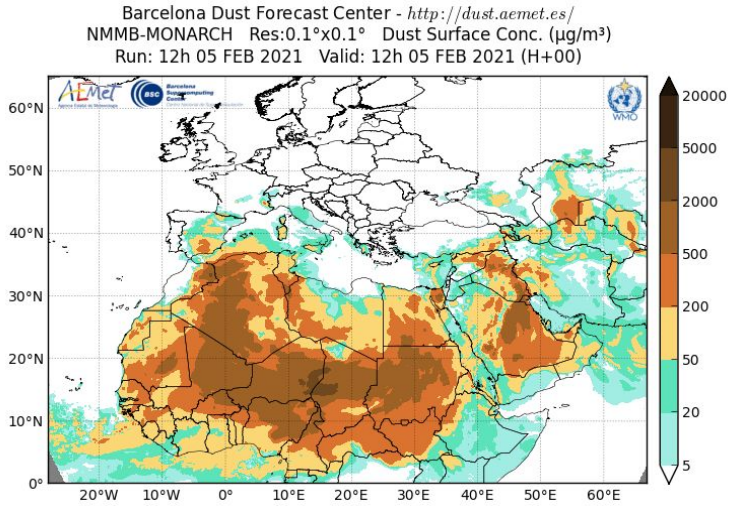
12:08 a. m. · 7 feb. 2021 · Twitter for iPhone

66 Retweets **9** Tweets citados **212** Me gusta



https://sds-was.aemet.es/forecast-products/dust-observations/msg-2013-eumetsat

Saharan outbreak over Europe on 5-7 Feb 2021
Operational Dust Forecast



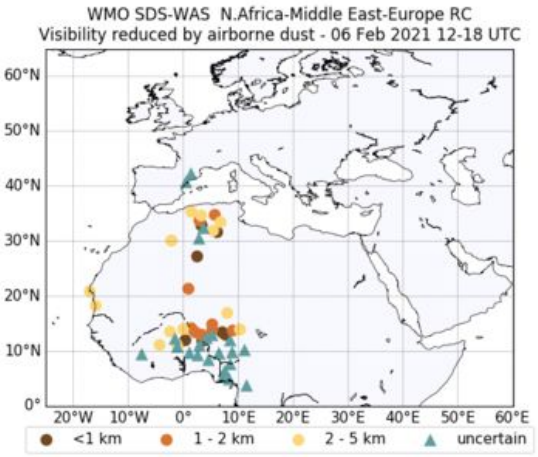
The reference dust forecast is based on **MONARCH**

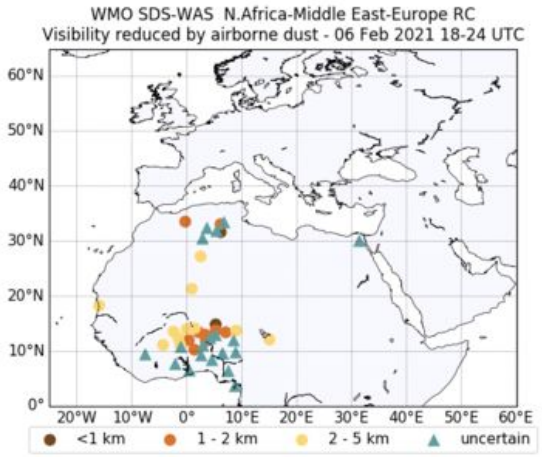
Six dust variables are available:

- Surface concentration
- Surface extinction (related with visibility)
- Dust optical depth at 550nm
- Dust load
- Wet deposition
- Dry deposition

http://dust.aemet.es

VISIBILITY OBSERVATIONS 6 February 2021



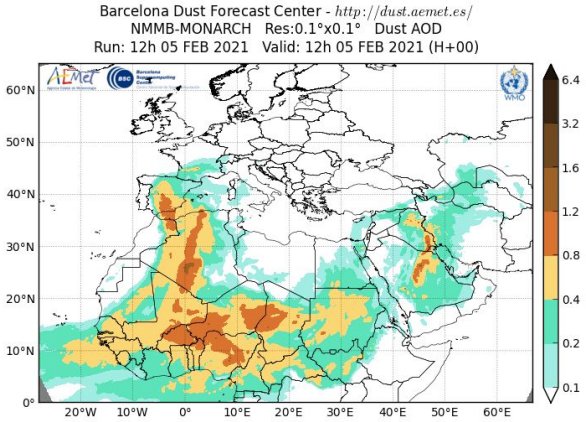


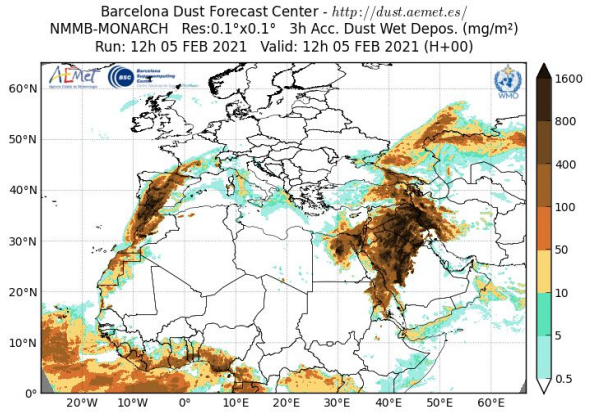
The observed reductions of **visibility** achieved few meters (< **800m**) in North Algeria where it is localised the origin of this event.
Some stations in Western Mediterranean informed on reductions of visibility during the afternoon.

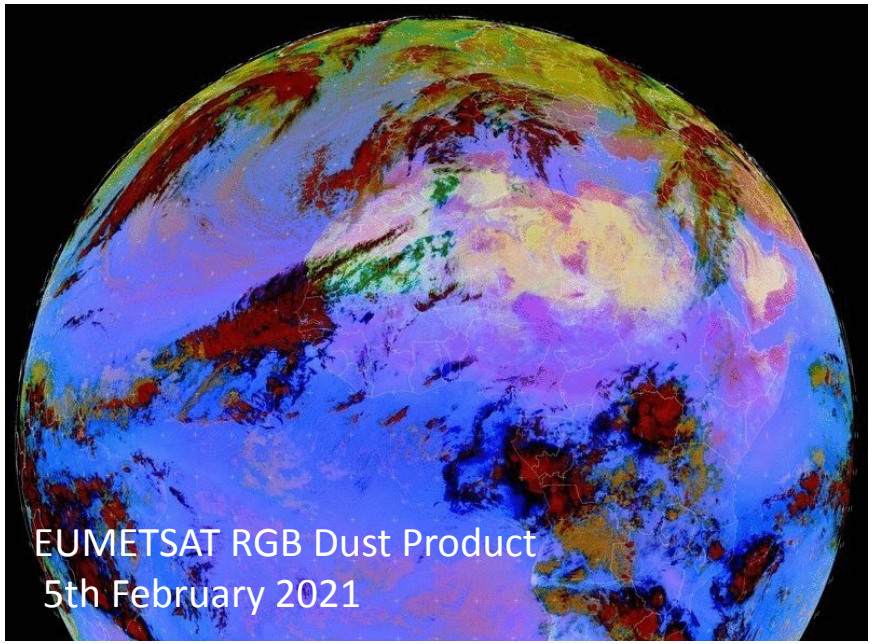
https://sds-was.aemet.es/forecast-products/dust-observations/visibility

Agencia Estatal de Meteorología

Saharan outbreak over Europe on 5-7 Feb 2021
Operational Dust Forecast







http://dust.aemet.es
https://sds-was.aemet.es/forecast-products/dust-observations/msg-2013-eumetsat

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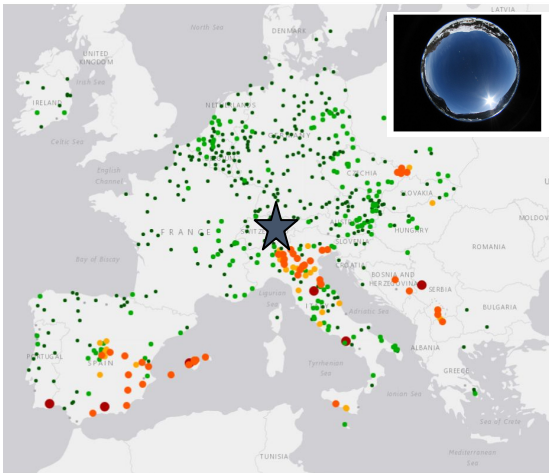
Centro Nacional de Supercomputación
AEMet Agencia Estatal de Meteorología

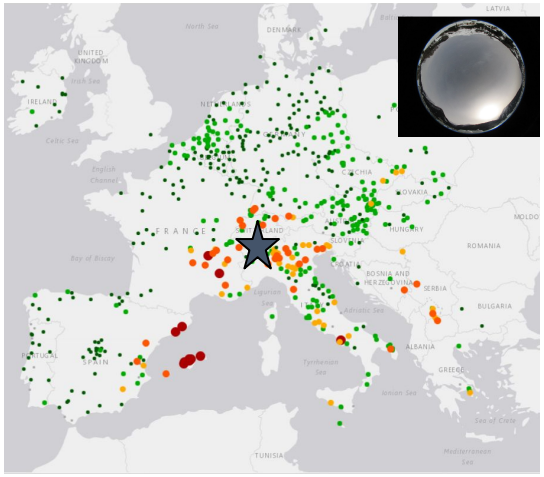
Saharan outbreak over Europe on 5-7 Feb 2021

Davos, Switzerland, 6th February
WMO-GAW PFR station
Courtesy of Stelios Kazadzis

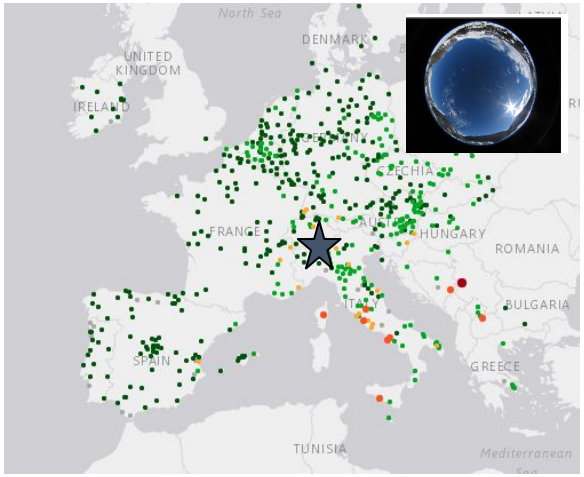
5 February 2021



6 February 2021



7 February 2021



https://www.eea.europa.eu/data-and-maps/explore-interactive-maps/up-to-date-air-quality-data

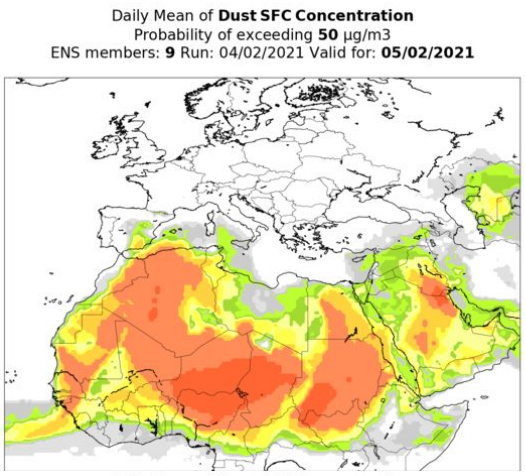
Particulate matter (PM10)

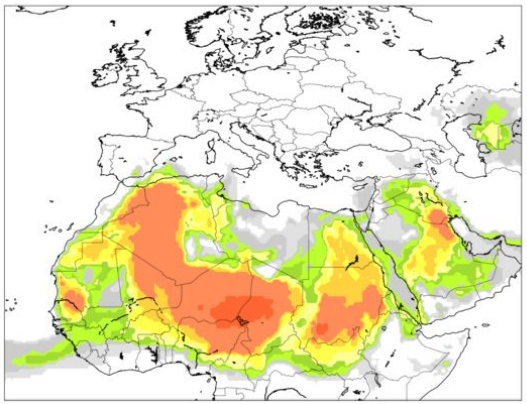
- Invalid
- 0 - 20 µg/m^3
- 20 - 40 µg/m^3
- 40 - 50 µg/m^3
- 50 - 100 µg/m^3
- 100 - µg/m^3

Agencia Estatal de Meteorología

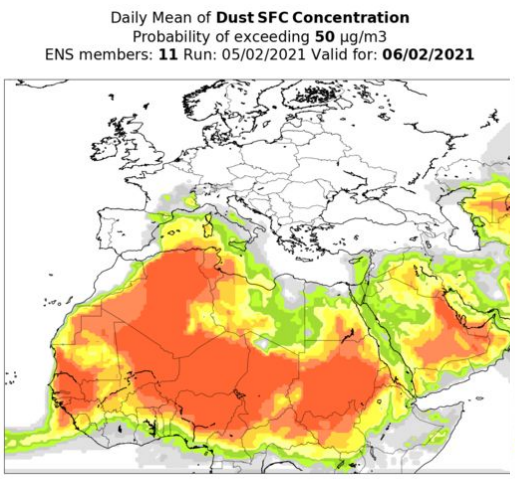
Saharan outbreak over Europe on 5-7 Feb 2021
Multi-model ensemble: Probability maps

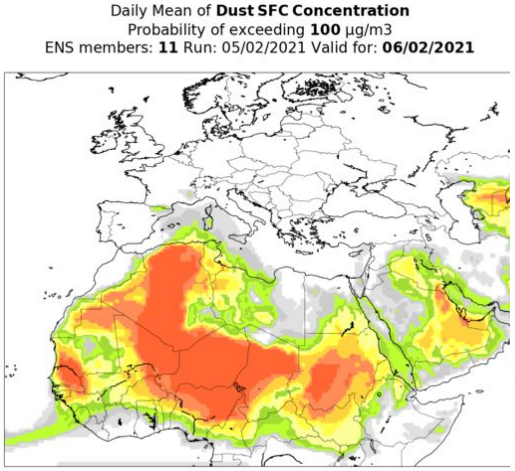
5 Feb (24h forecasts)



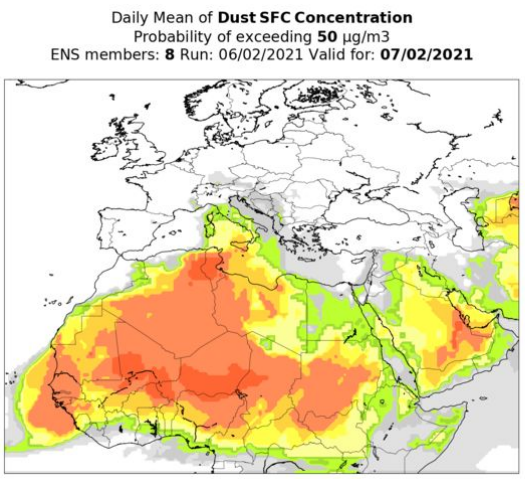


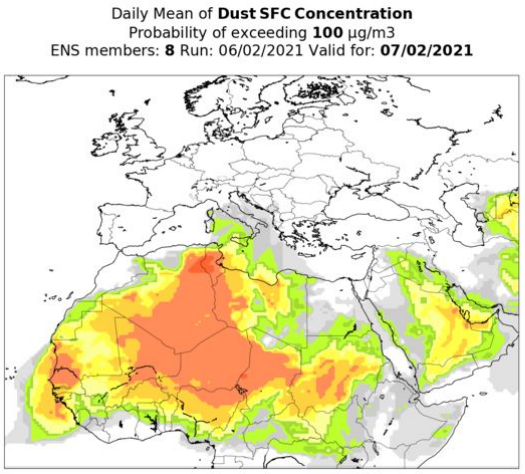
6 Feb (24h forecasts)

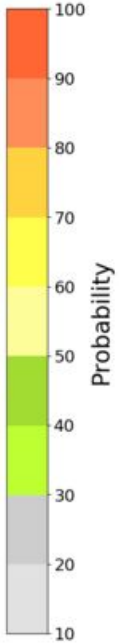




7 Feb (24h forecasts)

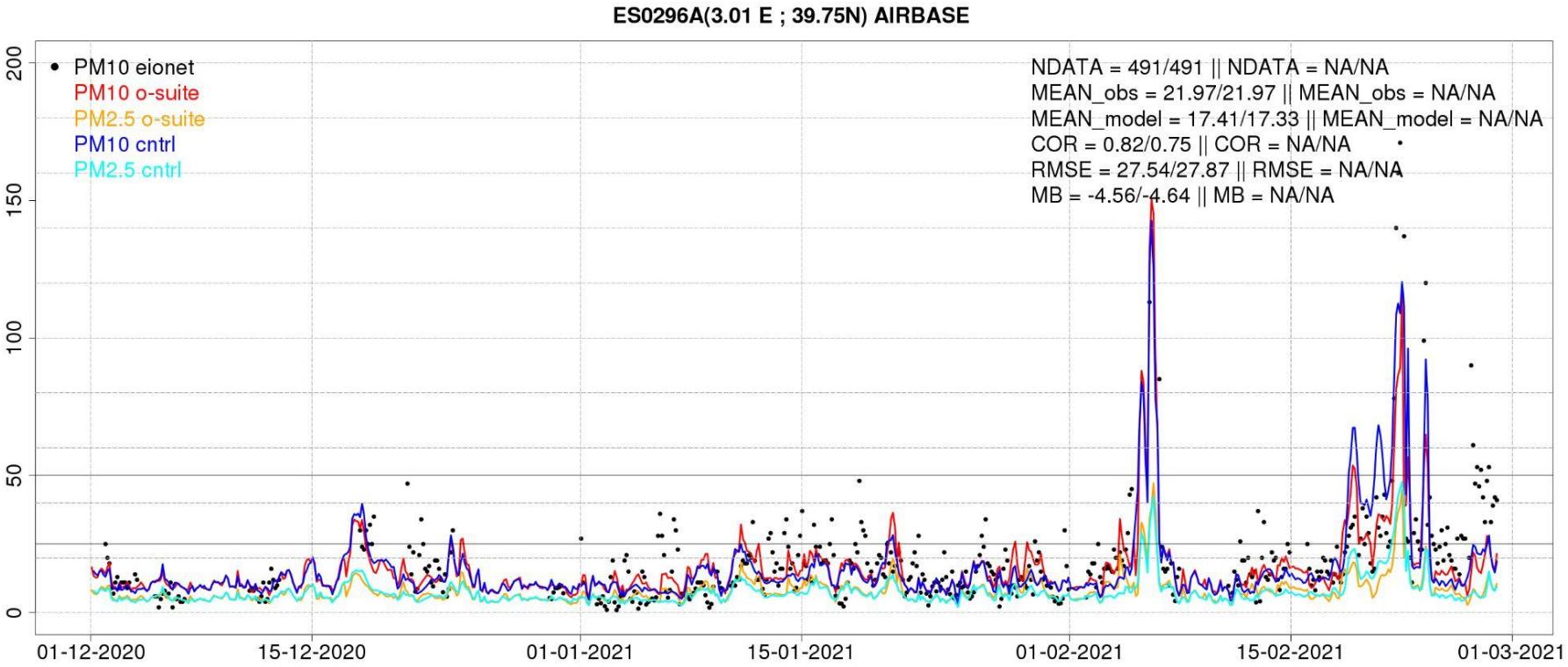






https://sds-was.aemet.es/forecast-products/dust-forecasts/probability-maps-dust-surface-concentration/

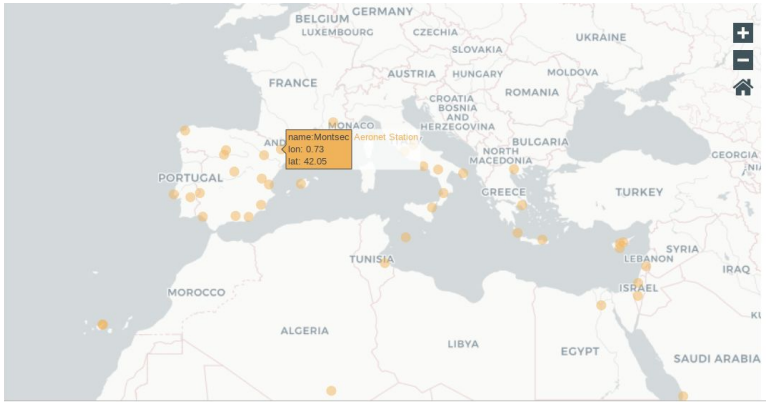
Saharan outbreak over Europe on 5-7 Feb 2021
Comparison PM of CAMS and EIONET



Extracted from CAMS Validation NRT report
(Schulz et al., 2021, doi:10.24380/ f540-kb09)

Agencia Estatal de Meteorología

Saharan outbreak over Europe on 5-7 Feb 2021
Comparison with AERONET



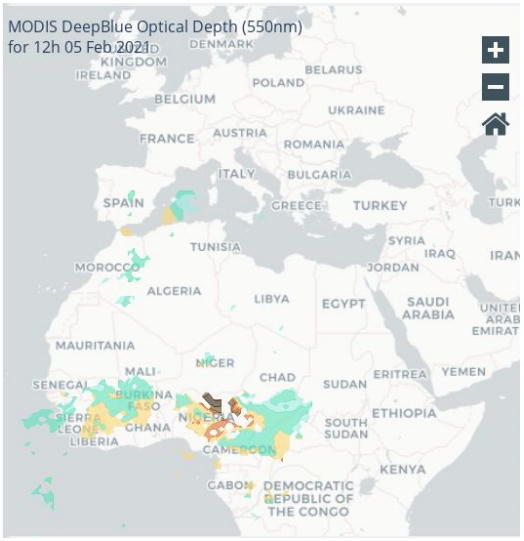
The dust-filtering of the AERONET observations is considering dust (i.e. DOD = AOD) when the Angstrom Exponent < 0.6

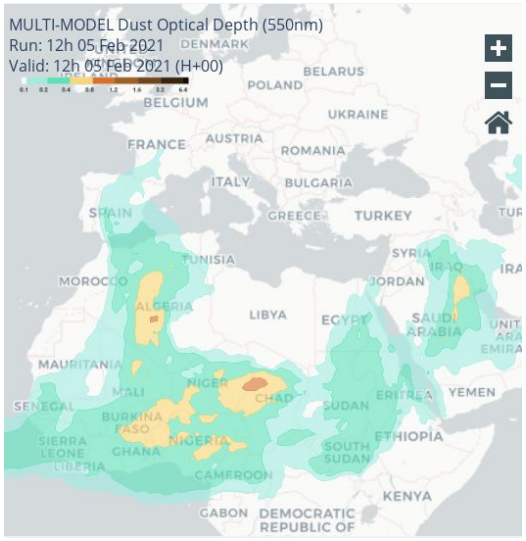
- *This is associated to coarse particles*

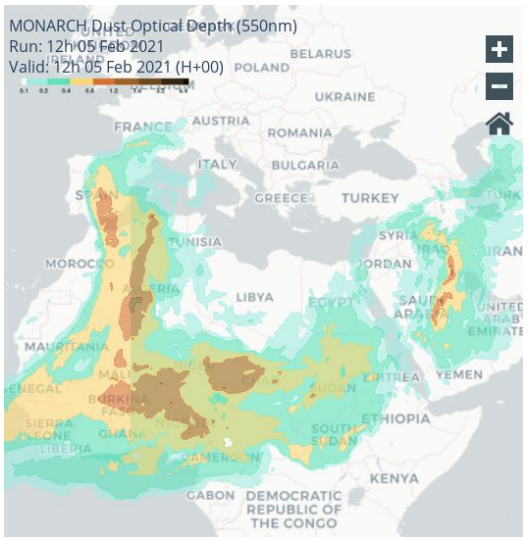
New WMO Barcelona Regional Center interactive visualisation tool
To be launched

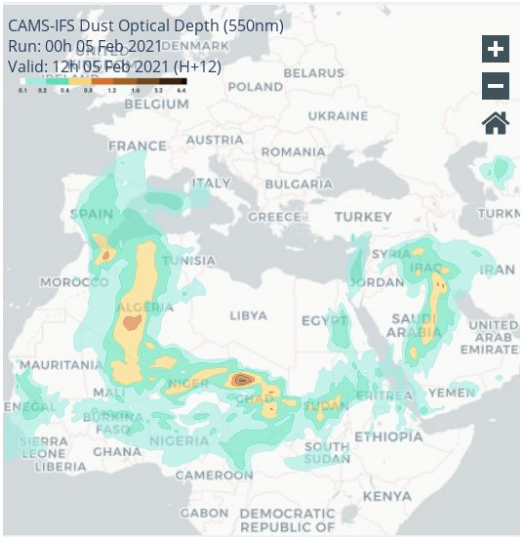
https://sds-was.aemet.es/forecast-products/forecast-evaluation

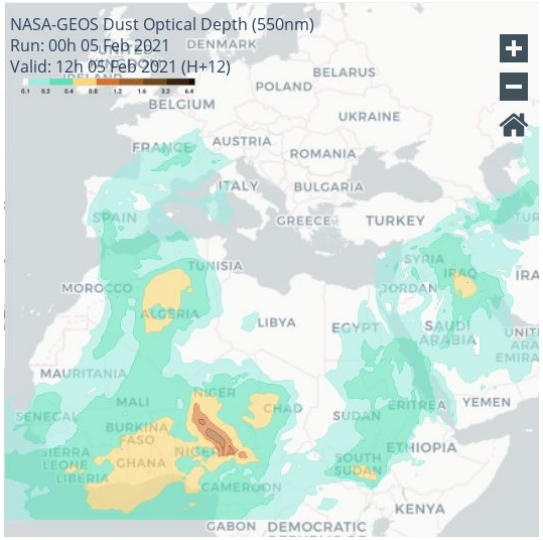
Saharan outbreak over Europe on 5-7 Feb 2021
Comparison with MODIS Deep Blue AOD











New WMO Barcelona Regional Center interactive visualisation tool
To be launched

https://sds-was.aemet.es/forecast-products/forecast-evaluation

Agencia Estatal de Meteorología

Canary Islands – February 2020


Tourists stranded in Canary Islands after Saharan sandstorm blows in

Dozens of flights cancelled due to poor visibility, leaving holidaymakers stuck at airports

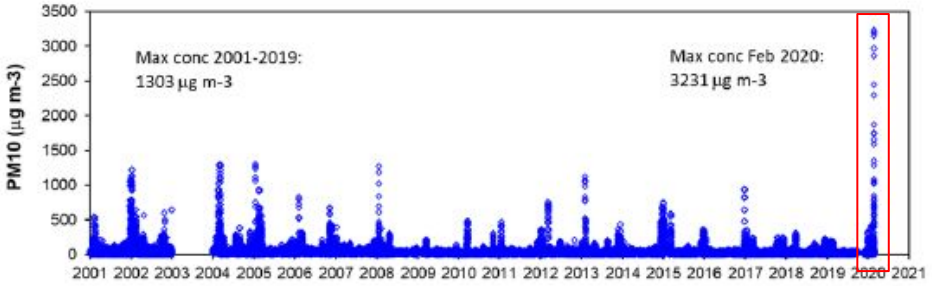
The Guardian

In pictures: Canary Islands sandstorm leaves tourists stranded


METEO cronaca DIRETTA : potente tempesta di CALIMA investe le Canarie, paesaggio MARZIANO - VIDEO

CORRIERE DELLA SERA

22-23 February is an exceptional event: it is the most intense event in Canary Islands in the last 20 years records (from 2000s)



Impacts in the archipielago:

- Increase of the number of hospitalisations (3 times more)
- 745 flight cancellations and 84 diverted flights
- Solar PV energy production fell > 50%

(Cuevas et al., WMO report, 2021)

BSC AEMet Agencia Estatal de Meteorología

Canary Islands – February 2020

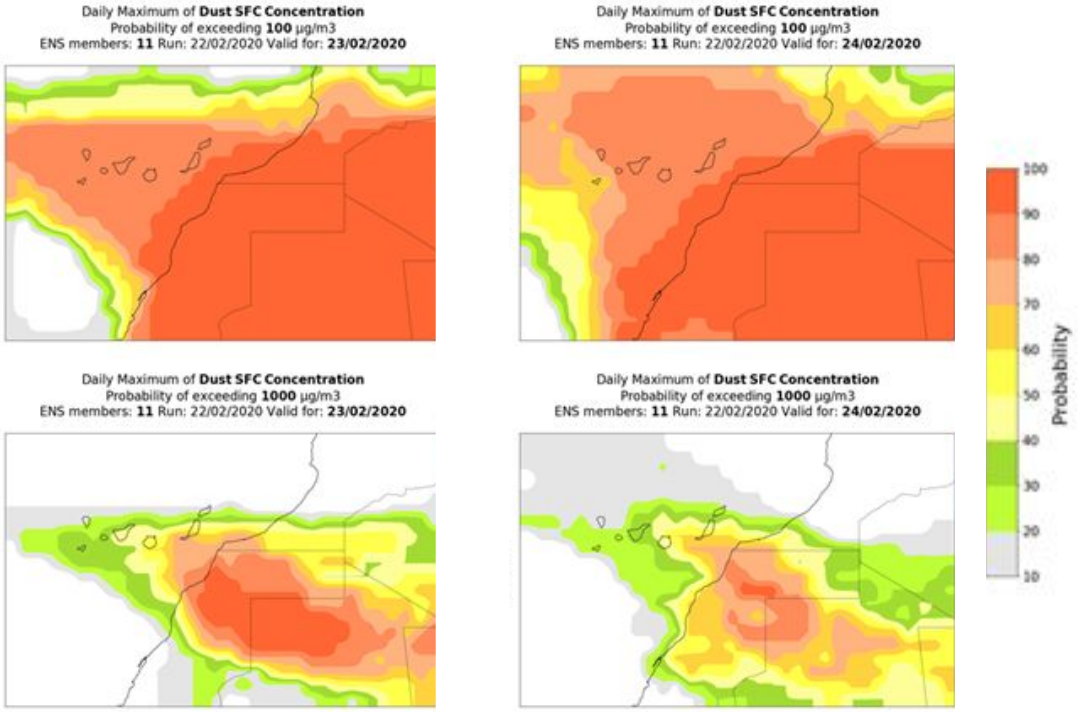
Probability maps based on the SDS-WAS ensemble

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

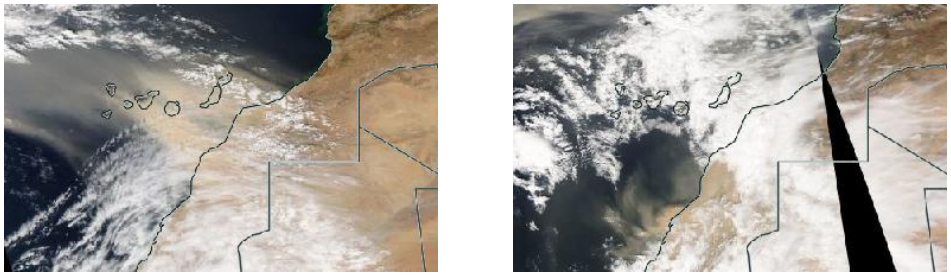
More than 40% of the SDS-WAS models predicted surface concentrations > **1000µg/m3**

23 Feb (24h forecasts)

24 Feb (48h forecasts)



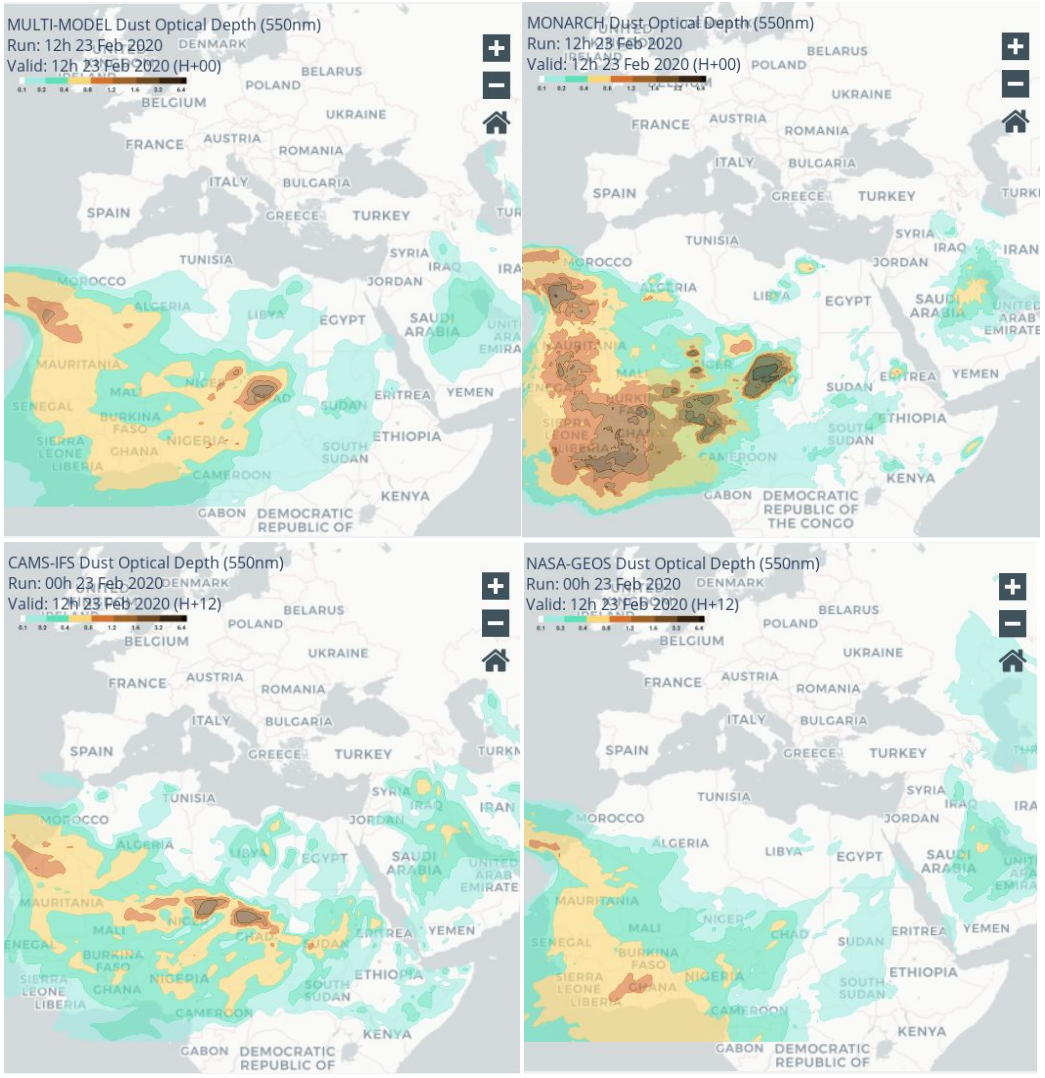
MODIS/Aqua images



(Cuevas et al., WMO report, 2021)

Agencia Estatal de Meteorología

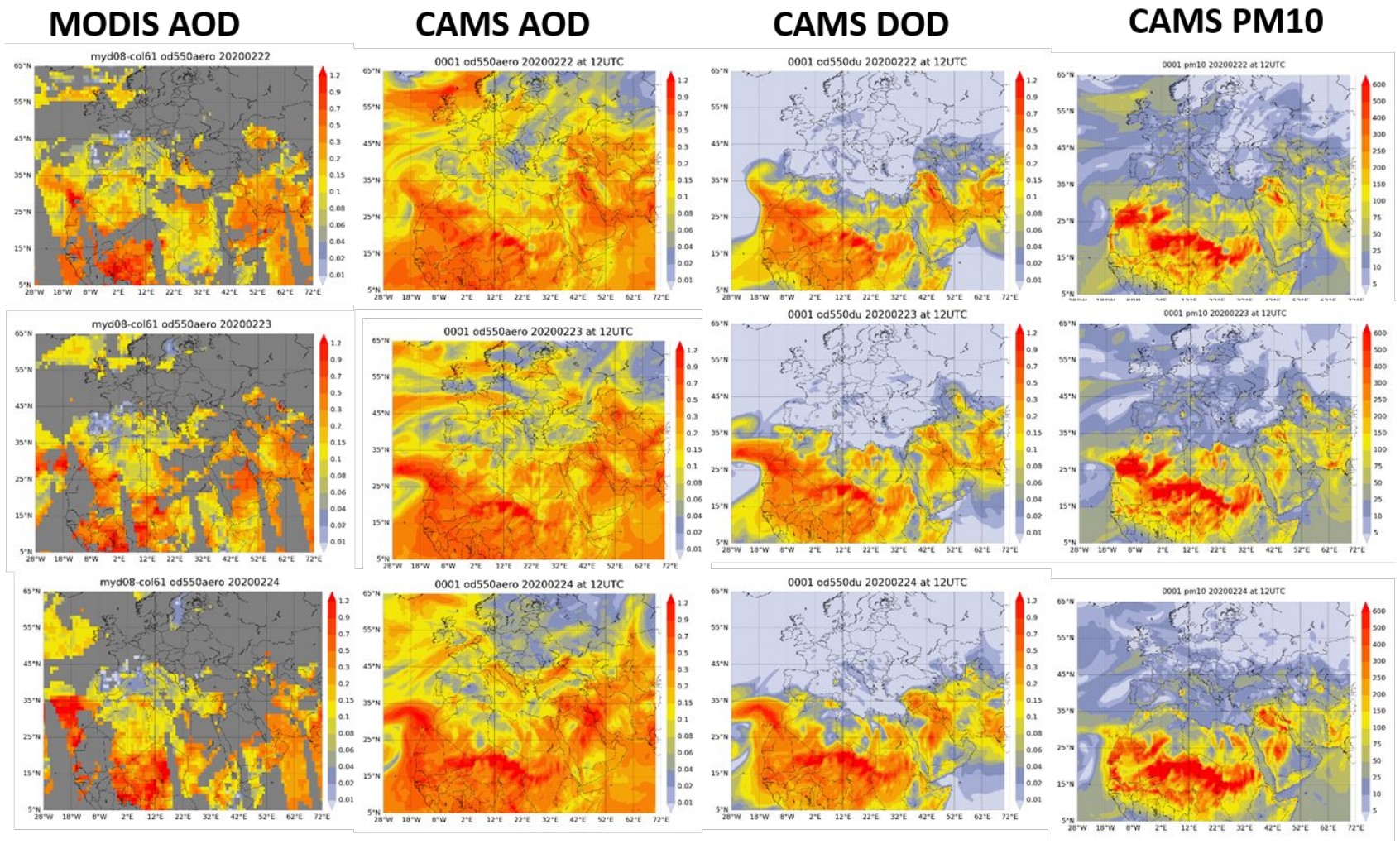
Canary Islands – February 2020
Comparison with MODIS Visible



New WMO Barcelona Regional Center interactive visualisation tool
To be launched

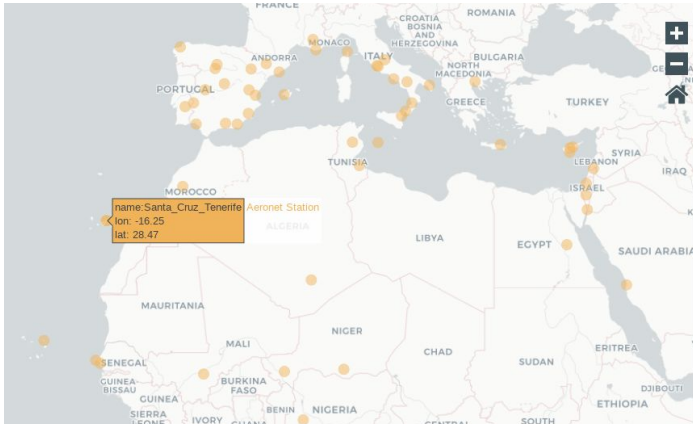
https://sds-was.aemet.es/forecast-products/forecast-evaluation

Canary Islands – February 2020
CAMS results



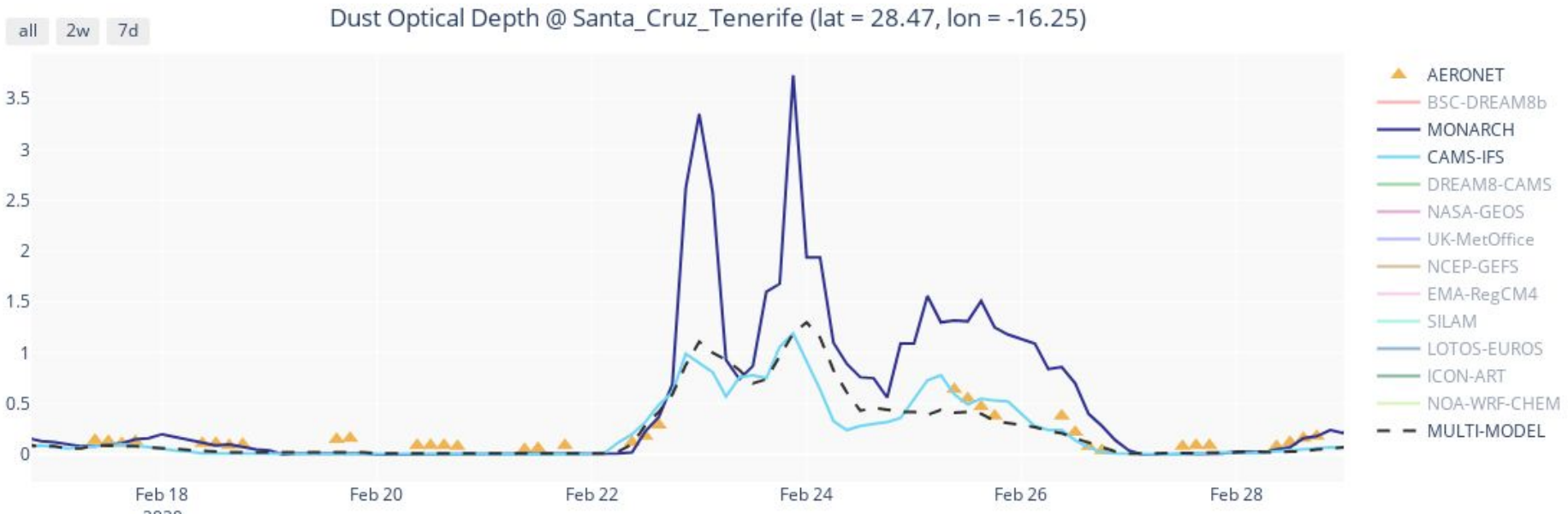
Extracted from CAMS Validation NRT report
(Schulz et al., 2020, doi:10.24380/322n-jn39)

Canary Islands – February 2020
Comparison with AERONET



The dust-filtering of the AERONET observations is considering dust (i.e. DOD = AOD) when the Angstrom Exponent < 0.6

- *This is associated to coarse particles*



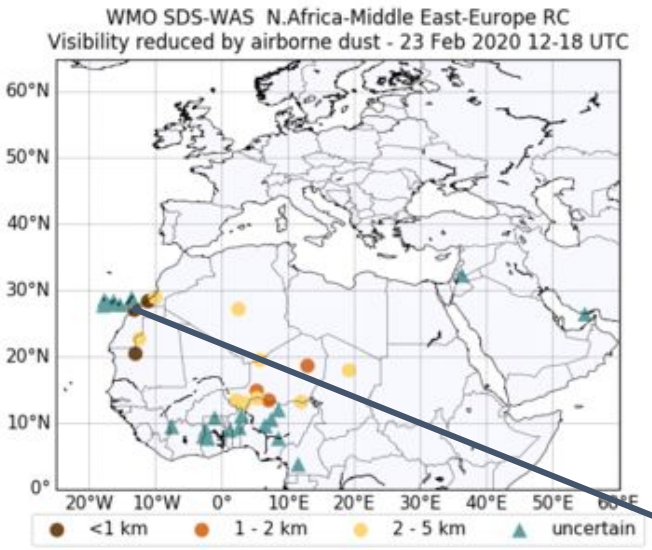
New WMO Barcelona Regional Center interactive visualisation tool
To be launched

https://sds-was.aemet.es/forecast-products/forecast-evaluation

Agencia Estatal de Meteorología

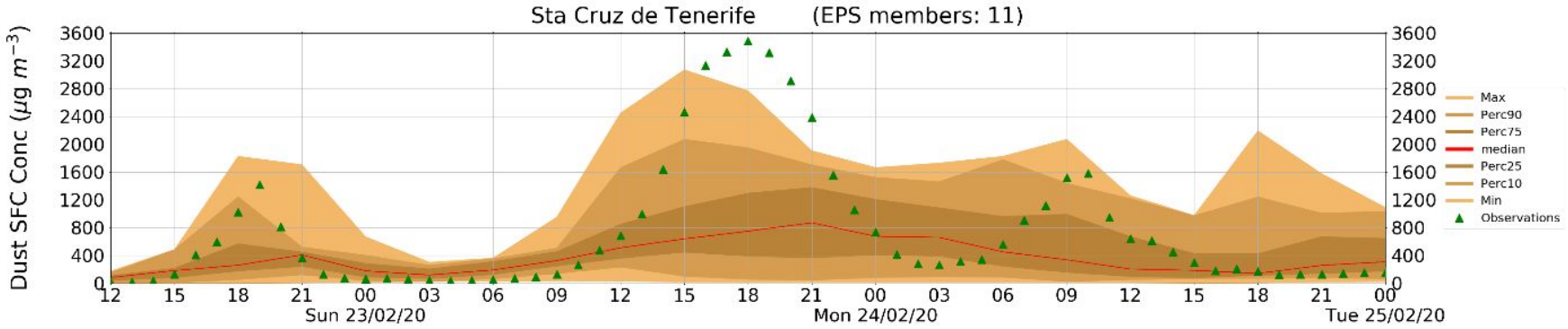
Canary Islands – 22-23 February 2020

OBSERVATIONS



The observed reductions of **visibility** achieved few meters (< **800m**) in the Canary Islands

More than 50% of the SDS-WAS models predicted surface concentrations > 1000µg/m3 with some models predicting surface concentrations > **3000µg/m3**

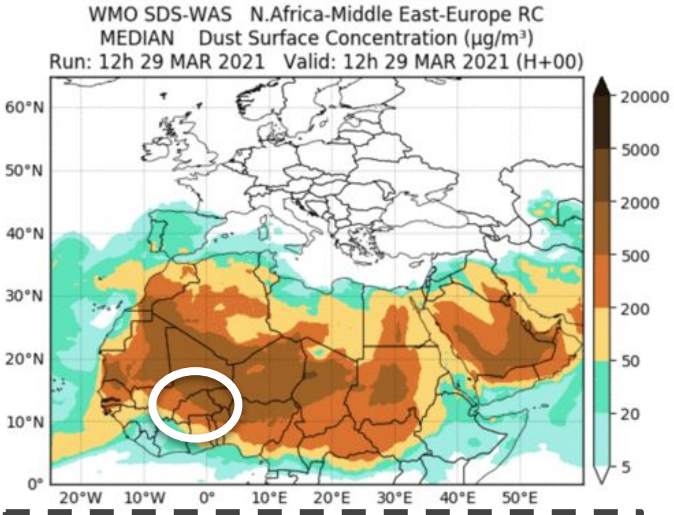


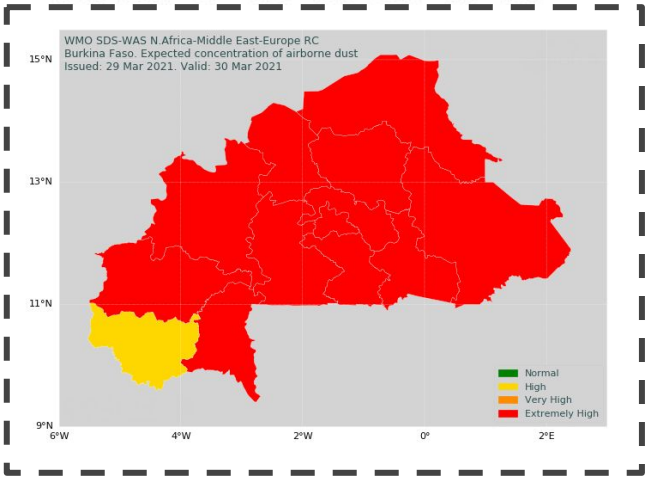
(Cuevas et al., WMO report, 2021)

Warning System for Burkina Faso

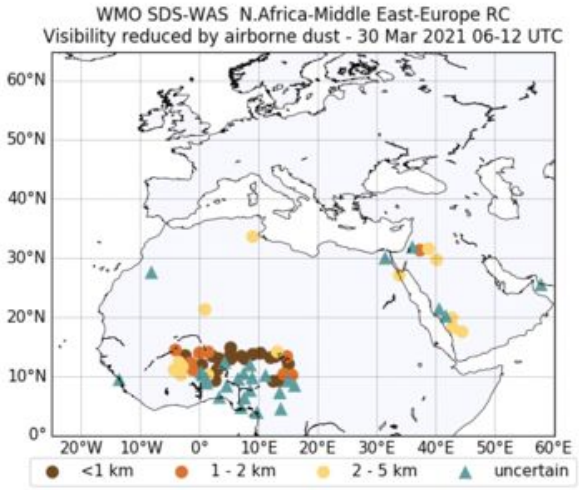
30th March 2020

FORECASTS





VISIBILITY OBSERVATIONS



Why models? *Burkina Faso does not have any Air Quality observational network*

CREWS CLIMATE RISK & EARLY WARNING SYSTEMS

Météo Burkina

BSC AEMet Agencia Estatal de Meteorología

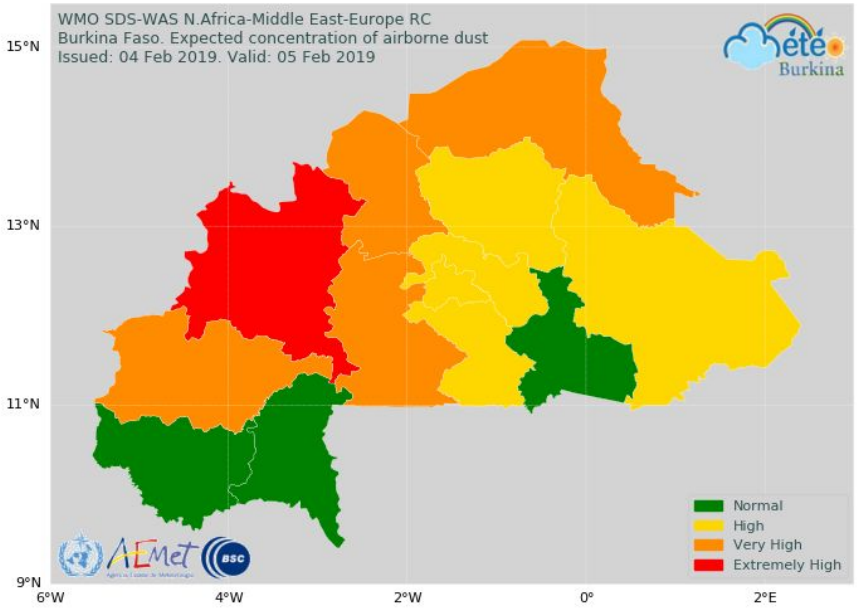
http://sds-was.aemet.es/

Warning System for Burkina Faso

Warnings for the next two days over Burkina Faso targeting on civil protection

Traffic light system based on the **dust surface concentration** information provided by the WMO multi-model ensemble.

Thresholds of each category are defined based on the percentiles obtained from more than **10-years** dust surface concentration **multi-model ensemble.**

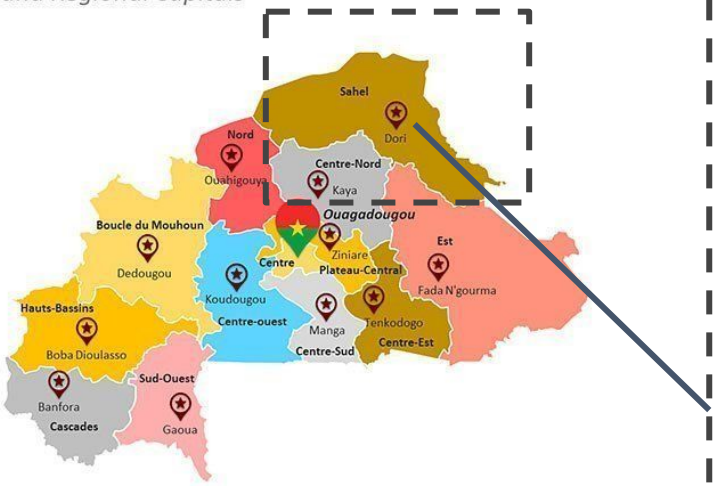


80th percentile
90th percentile
97.5th percentile

Warning System for Burkina Faso
Extension to other countries in the Sahelian region SOON!

Warning System for Burkina Faso

Burkina Faso
National and Regional Capitals



Verification with **VISIBILITY observations**
(NO surface concentration observations)

Province: Sahel (SYNOP: Dori)
201911-202004 (Days: 176)

OBSERVATIONS \ FORECAST	green	yellow	orange	red
green	67.0%	7.4%	3.4%	2.8%
yellow	3.4%	1.7%	2.8%	1.1%
orange	2.3%	1.1%	4.5%	1.1%
red	0.0%	0.0%	0.6%	0.6%

FALSE ALARM

MISSES

HITS

NRT Dust Profiles Evaluation Exchange protocol

OBSERVATIONS

Extinction profiles at 12UTC
available in a window of 24 hours

3 ceilometers
1 lidar

SDS-WAS MODELS

- **BSC-DREAM8b**
- ~~**NMMB/BSC-Dust**~~ **MONARCH**
- **CAMS**
- **DREAM8-NMME**
- ....

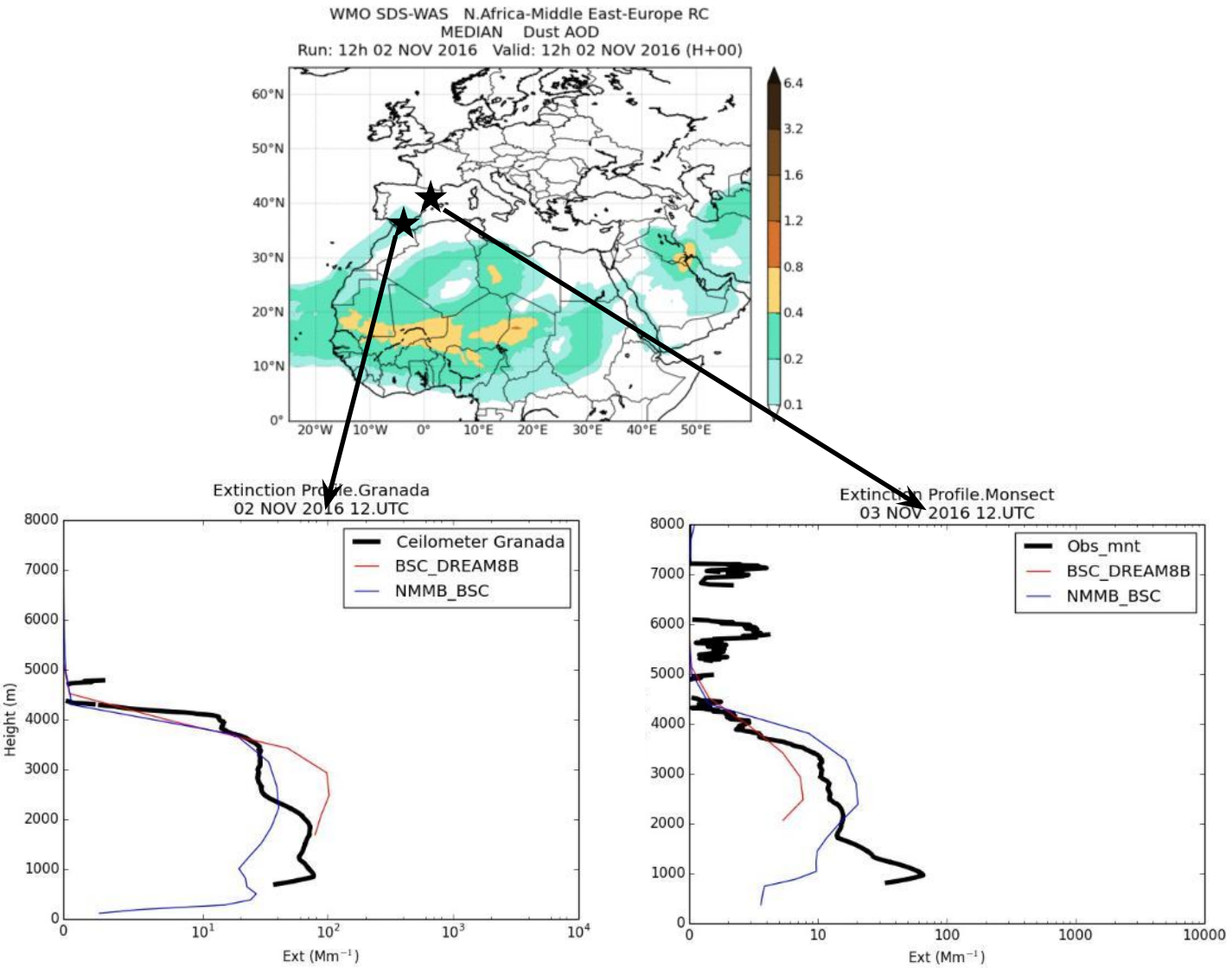
```
2016040512_3H_BSC_DREAM8B_profiles {
dimensions:
    time = 73 ;
    station = 67 ;
    lev = 24 ;
char station_name(station, strlen) ;
    station_name:missing_value = -9999. ;
    station_name:long_name = "station long name" ;
    station_name:units = "-" ;
char station_code(station, codlen) ;
    station_code:missing_value = -9999. ;
    station_code:long_name = "station code" ;
    station_code:units = "-" ;
double time(time) ;
```

Data format
Exchange operational protocol includes 72 hours forecasts

http://sds-was.aemet.es/projects-research/evaluation-of-model-derived-dust-vertical-profiles

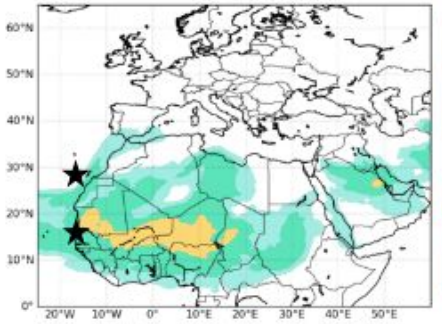
NRT Dust Profiles Evaluation

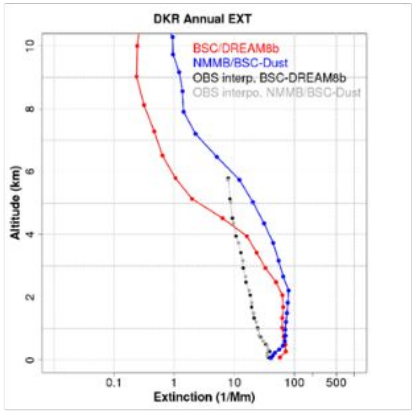
Atlantic dust event: 2 - 5 November 2016

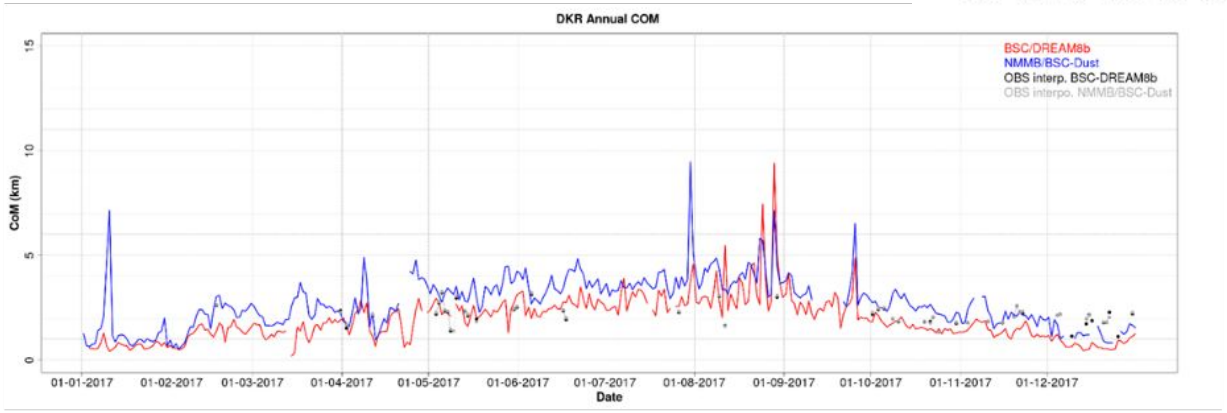


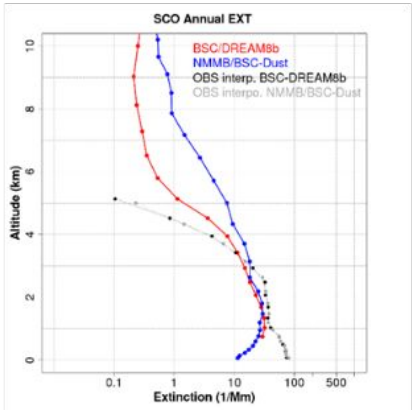
NRT Dust Profiles Evaluation

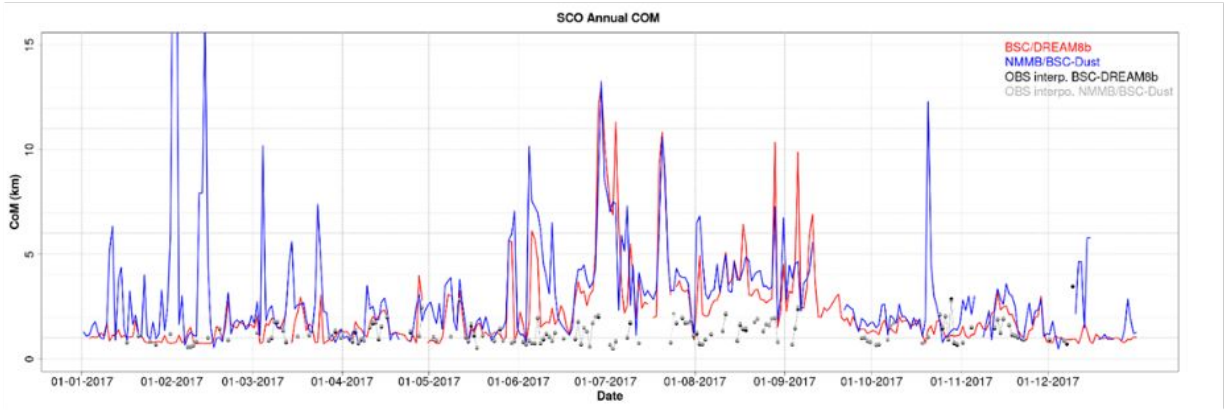
Evaluation results for 2017











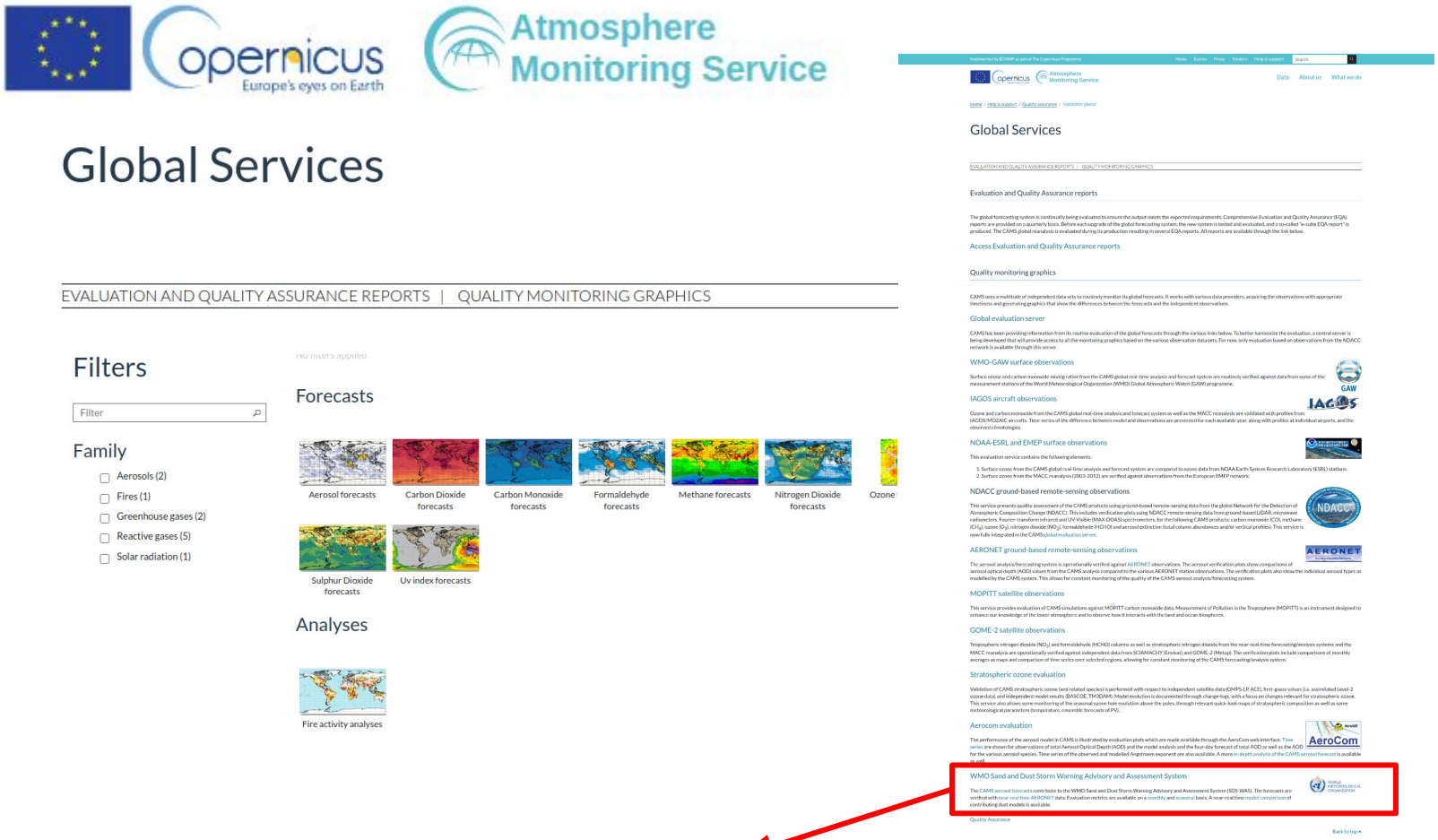
http://sds-was.aemet.es/projects-research/evaluation-of-model-derived-dust-vertical-profiles

NRT Dust Profiles Evaluation

Ceilometers are potential instruments for NRT “verification” of vertical dust forecasts.

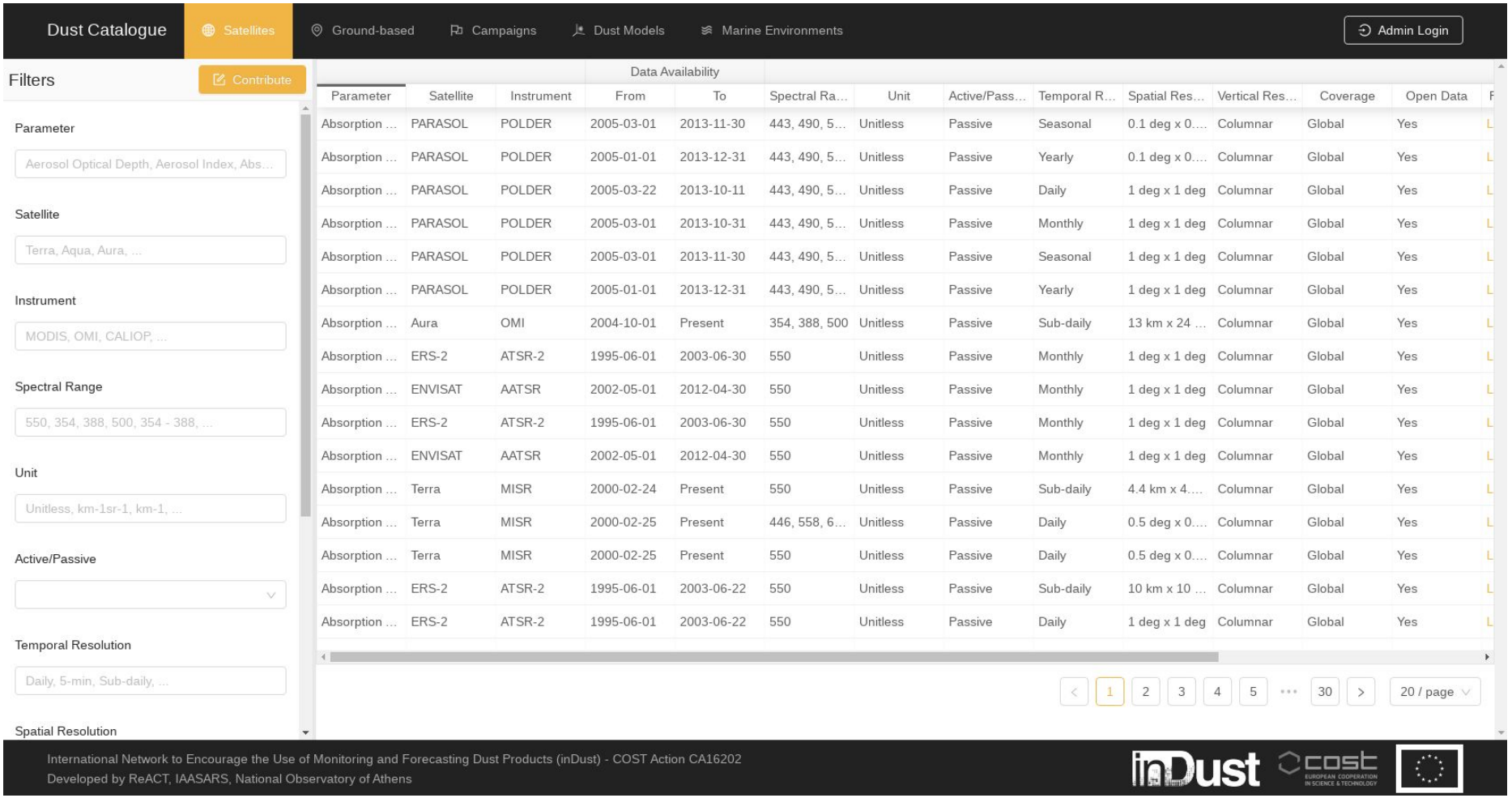
- Skills score calculation:
  - *Definition of a common vertical reference profile for the participating models → Vertical interpolation is sensible to the original model and observations vertical resolution. The most standard product is based on pressure levels.*
  - *Center of Mass (CoM), Top and Base of the dust layer present some challenges*
    - *PBL and/or maritime boundary layer*
    - *multiple dust layers*
    - *laser signal*

CAMS Global Products catalogue



https://atmosphere.copernicus.eu/global-services

Dust Products catalogue



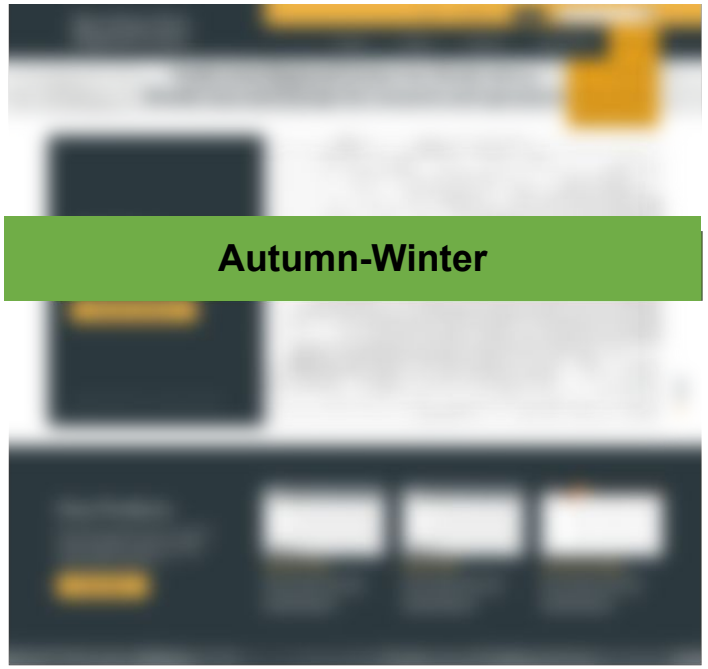
https://react.space.noa.gr/indust-inventory/

WMO Barcelona Dust Regional Center

The **WMO Barcelona Dust Regional Center** is coordinating and active in the ongoing research projects that search to produce **dust services**. Our activities are taking as a reference by the **UN SDS initiatives** that searches to help on the **mitigation of dust impacts**.

Barcelona Dust Forecast Center
Operations
http://dust.aemet.es

SDS-WAS
R&D and operations
http://sds-was.aemet.es



http://dust.aemet.es
@Dust_Barcelona

The work presented here it is possible thanks to the support of collaboration of the active members of the WMO SDS-WAS NAMEE Regional Node and associated researchers from NASA (i.e. AERONET, MODIS) as well as the inDust networks.

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
AEMet Agencia Estatal de Meteorología
World Meteorological Organization
Weather · Climate · Water

Upcoming event

Registrations and upcoming events: https://cost-indust.eu/events/indust-events

@Dust_Barcelona

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

AXA Research Fund

inDust

AEMet
Agencia Estatal de Meteorología

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

AXA Research Fund

Copernicus Atmosphere Monitoring Service

AEMet Agencia Estatal de Meteorología

inDust

Thank you

Acknowledge to Carlos Pérez García-Pando, Emilio Cuevas, Slodoban Nickovic, Francesco Benincasa, Enza DiTomaso, Oriol Jorba, Paul Ginoux as well as AERONET, MODIS, U.K. Met Office MSG, MSG Eumetsat and EOSDIS World Viewer principal investigators and scientists for establishing and maintaining data used in the present contribution. Also special thank to all researchers, data providers and collaborators of the WMO SDS-WAS NA-ME-E Regional Node and CAMS-84 global validation team.

sara.basart@bsc.es