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Supercomputing  
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Centro Nacional de Supercomputación



# Atmospheric dust transport models and usage

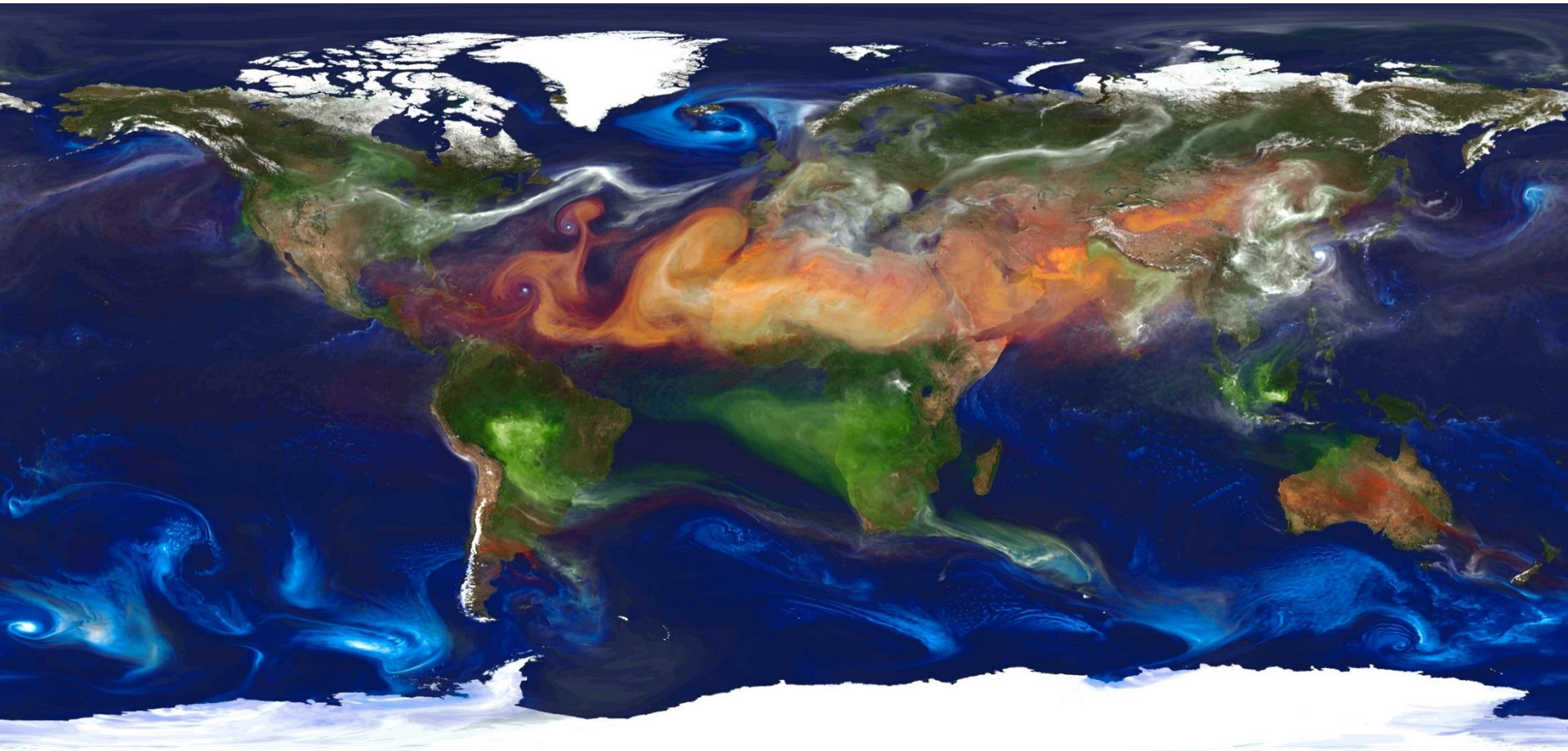
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*Earth Sciences Department,  
Barcelona Supercomputing Center (BSC)*

16/05/2019

inDust COST Action: The Effect of Soiling on  
Solar Energy, Munich, Germany

# Dust cycle and its extension



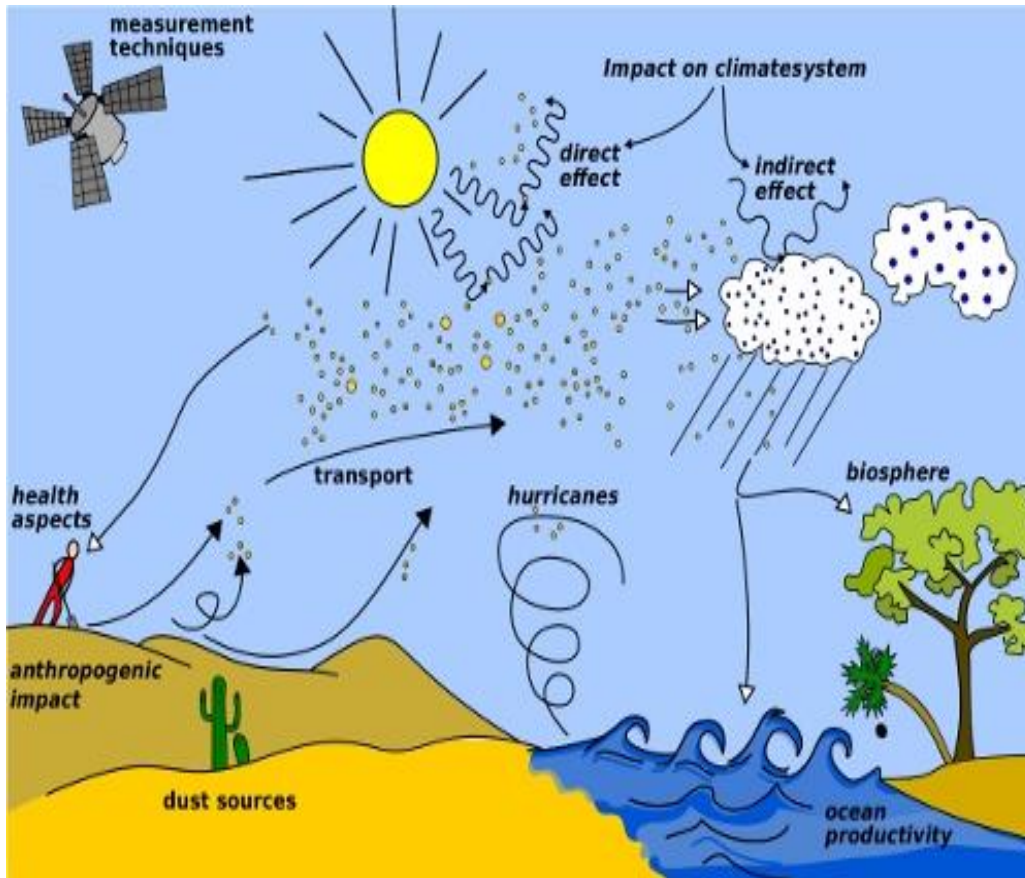
Organic Carbon + Elemental carbon

Dust

Sulfate

Sea salt

# Motivation – Dust impacts



Ecosystems, meteorology and climate

Air Quality and Human Health

Aviation and Ground Transportation

Energy and industry

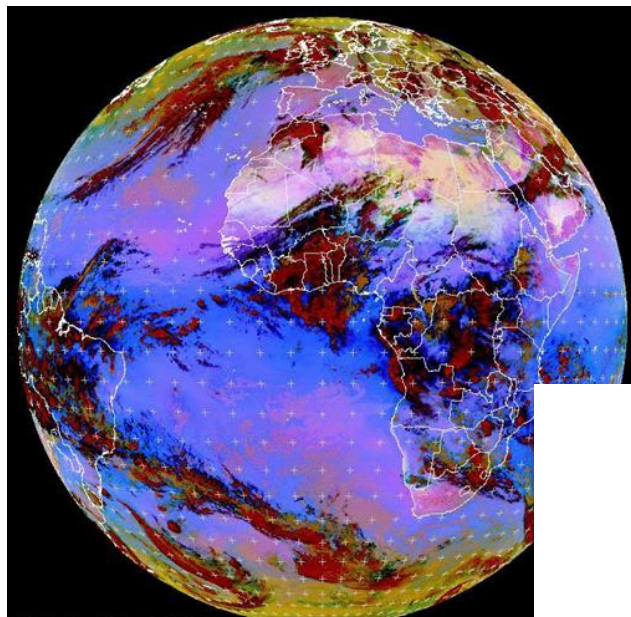
Agriculture and fishing

Astrophysics

Image from WMO website  
(<http://www.wmo.int/pages/prog/arep/wwrp/new/hurricanes.html>)

# Dust forecasting models

Dust models are a mathematical representation of atmospheric dust cycle.

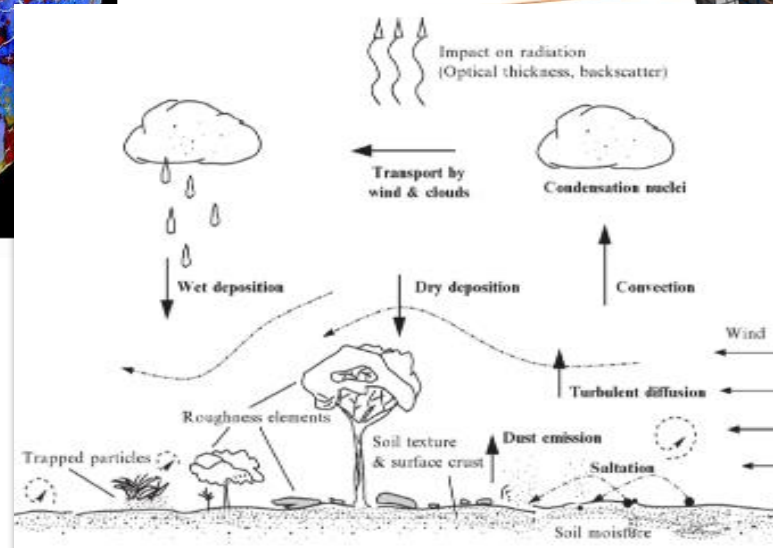
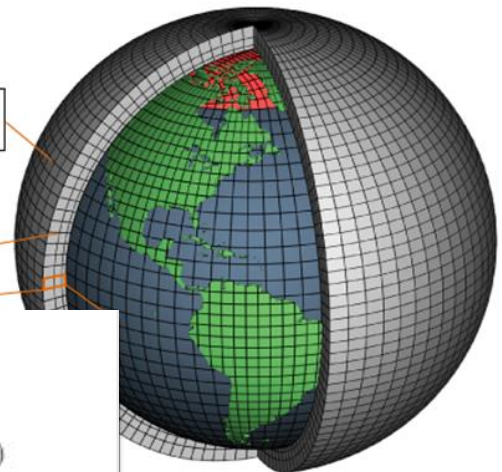


MET9 RGB-Dust 2011-04-05 00:00 UTC



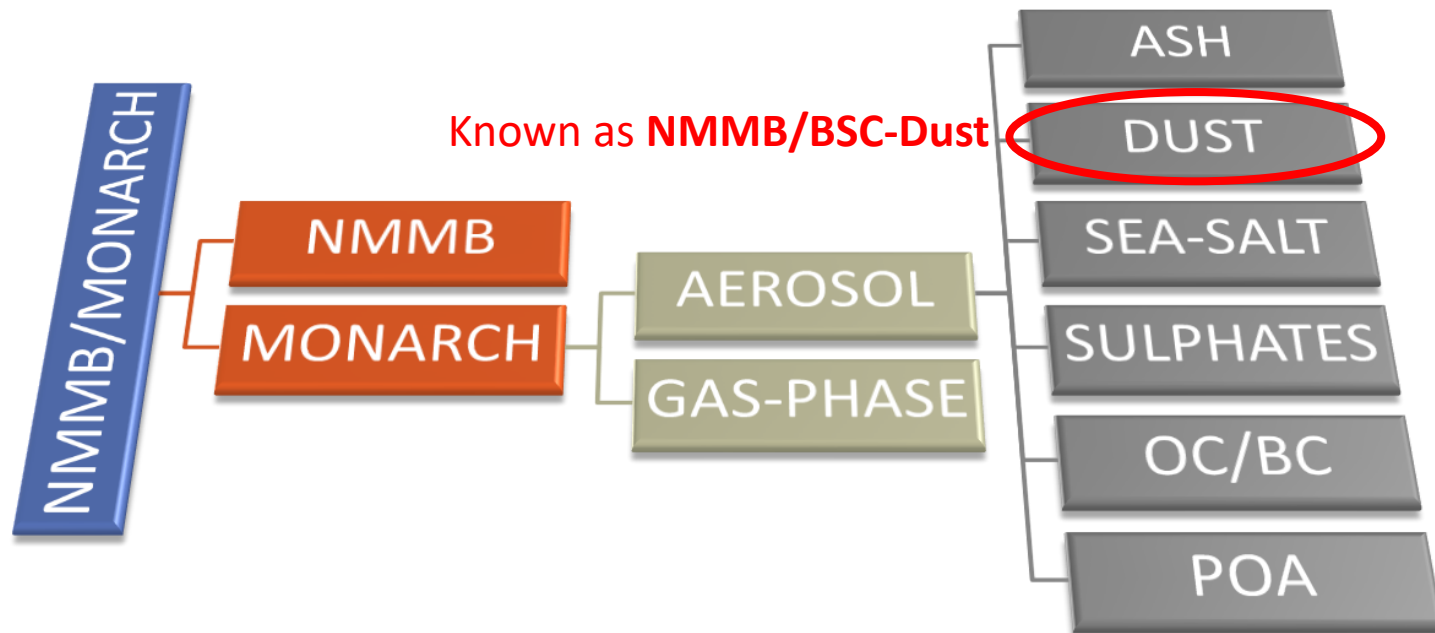
Horizontal Grid  
(Latitude-Longitude)

Vertical Grid  
(Height or Pressure)



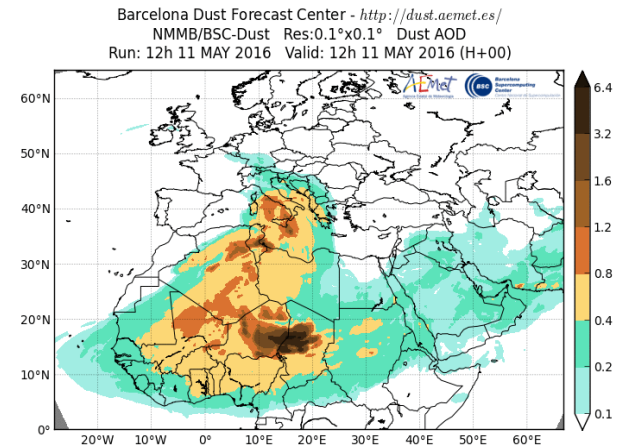
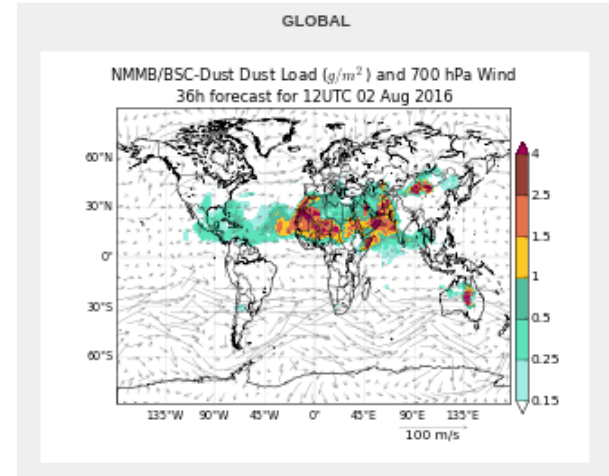
# NMMB-MONARCH: Atmospheric Composition and Air Quality

- The main system is build on the **meteorological driver NMMB**
- **Multiscale**: global to regional scales allowed (nesting capabilities)
- **Nonhydrostatic** dynamical core: single digit kilometre resolution allowed
- Fully **on-line** coupling: weather-chemistry feedback processes allowed
- Enhancement with a **data assimilation** system



# Mineral Dust Services


- **BSC dust operational forecast** (global and regional domains)
  - Contribution to the **SDS-WAS** (regional) and **ICAP** (global) multi-model ensembles
- **WMO Dust Regional Centers**
  - **Barcelona Dust Forecast Center.** First specialized WMO Center for mineral dust prediction. Started in 2014 - **Operational**
    - <http://dust.aemet.es>
    - @Dust\_Barcelona
  - **SDS-WAS Regional Center.** Sand and Dust Storm Warning Advisory and Assessment System. Started in 2010 – **Research**
    - <http://sds-was.aemet.es>



# Barcelona Dust Forecasting Center

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**BARCELONA DUST FORECAST CENTER**



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

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**LATEST NEWS**

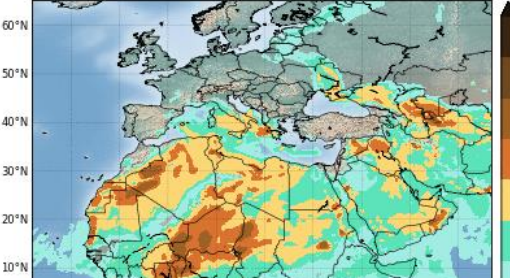
## Barcelona Dust Forecast Center starts operations

The Center will release operational dust forecasts for Northern Africa, Middle East and Europe

[Read More](#)



Barcelona Dust Forecast Center  
NMMB/BSC-Dust Res: 0.1°x0.1° Dust Surface Conc. (µg/m³)  
Run: 12h 19 MAY 2014 Valid: 18h 20 MAY 2014 (H+30)



**Dust forecast**

Latest dust forecast for Northern Africa, Middle East and Europe

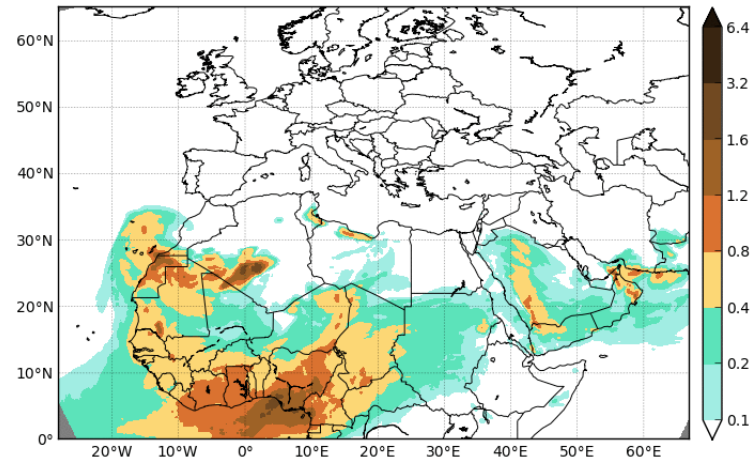
[Check it here](#)

# Barcelona Dust Forecasting Center

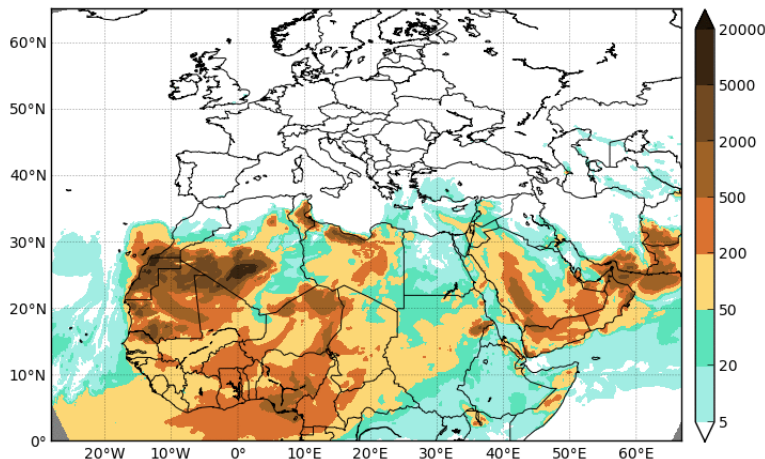
## 72-hours forecasts of:

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

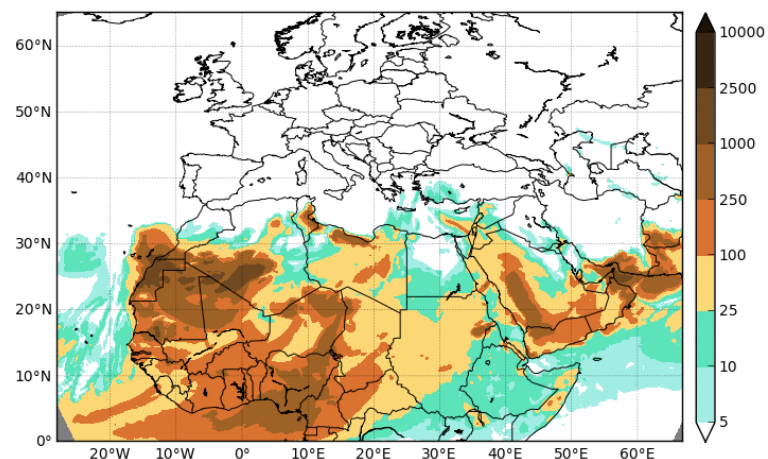
Barcelona Dust Forecast Center  
NMMB/BSC-Dust Res:0.1°x0.1° Dust AOD  
Run: 12h 07 MAR 2015 Valid: 12h 07 MAR 2015 (H+00)




Barcelona Dust Forecast Center  
NMMB/BSC-Dust Res:0.1°x0.1° Dust Surface Conc. ( $\mu\text{g}/\text{m}^3$ )  
Run: 12h 07 MAR 2015 Valid: 12h 07 MAR 2015 (H+00)



Barcelona Dust Forecast Center  
NMMB/BSC-Dust Res:0.1°x0.1° Dust Surface Ext. ( $\text{Mm}^{-1}$ )  
Run: 12h 07 MAR 2015 Valid: 12h 07 MAR 2015 (H+00)




# SDS-WAS and the NAMEE Regional Center




World Meteorological Organization  
Weather • Climate • Water

NORTHERN AFRICA-MIDDLE EAST-EUROPE (NA-ME-E) REGIONAL CENTER  
WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS)


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GOBIERNO DE ESPAÑA



AEMet  
Agencia Estatal de Meteorología



BSC  
Barcelona Supercomputing Center  
Centro Nacional de Supercomputación

WMO SDS WAS || Asia Regional Center || America Regional Center

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Latest News

[Paper on statistical evaluation of dust events in West Asia](#)  
May 08, 2018

[CAMS releases first five years of new global reanalysis data](#)

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## Northern Africa-Middle East-Europe (NA-ME-E) Regional Center

by [Francesco Benincasa](#) — last modified May 29, 2012 03:33 PM

### Outstanding

[The InDust COST Action website has been launched](#)

[RGB dust product from Himawari-8 and GOES-16](#)

[Training Workshop on Sand and Dust Storms in the Arab Region](#)

[The 9th International Workshop on Sand / Dust storm and Associated Dustfall. Call for Abstracts](#)

[InDust](#)

### Subscribe to the Public Newsletter!

To be informed about our activities, news and events related to dust. Frequency is almost monthly.

### Portal manual

Please find a brief manual [here](#).

### Dust forecasts

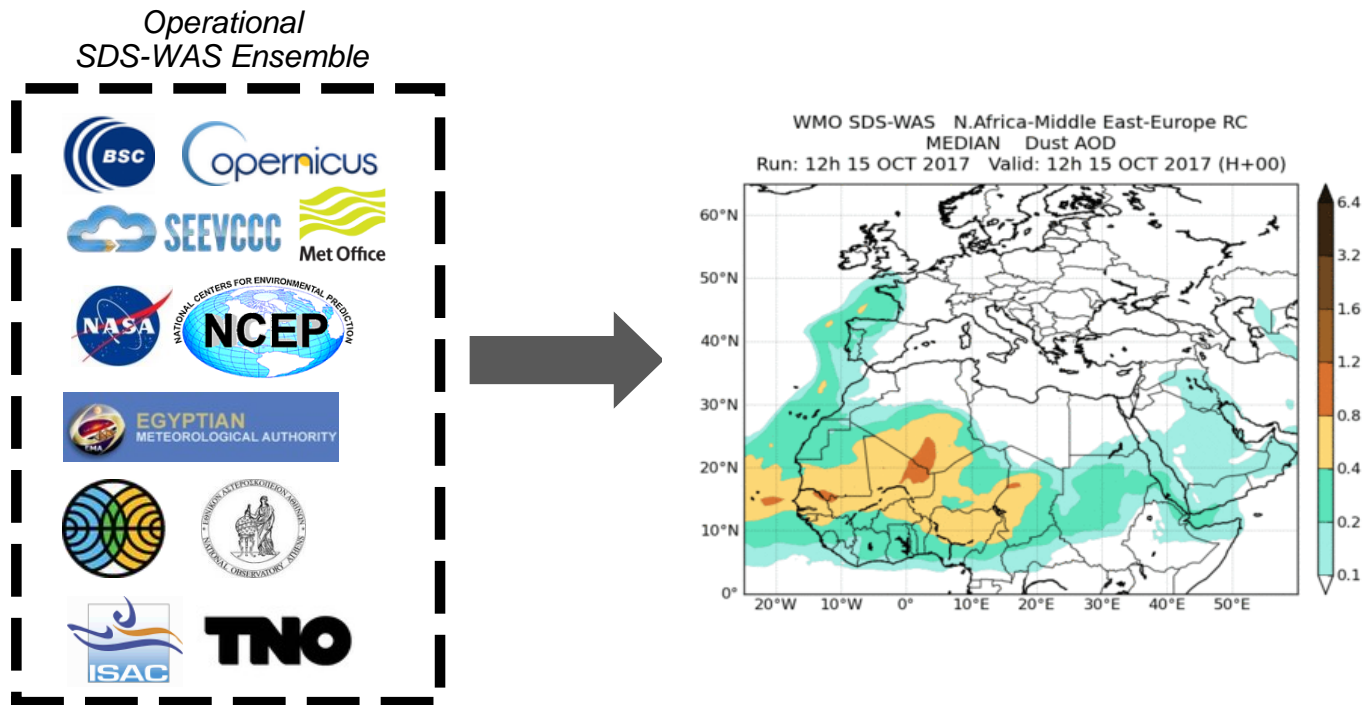
WMO SDS-WAS	N.Africa-Middle East-Europe RC
MEDIAN	Dust Surface Concentration ( $\mu\text{g}/\text{m}^3$ )

Dakar (Senegal) - April 2018

# SDS-WAS and the NAMEEE Regional Center

## Model intercomparison

- Products: **surface concentration** and **DOD maps**, the SDS-WAS multi-model product.



12 Global – Regional models from ~ 100 to 10 km

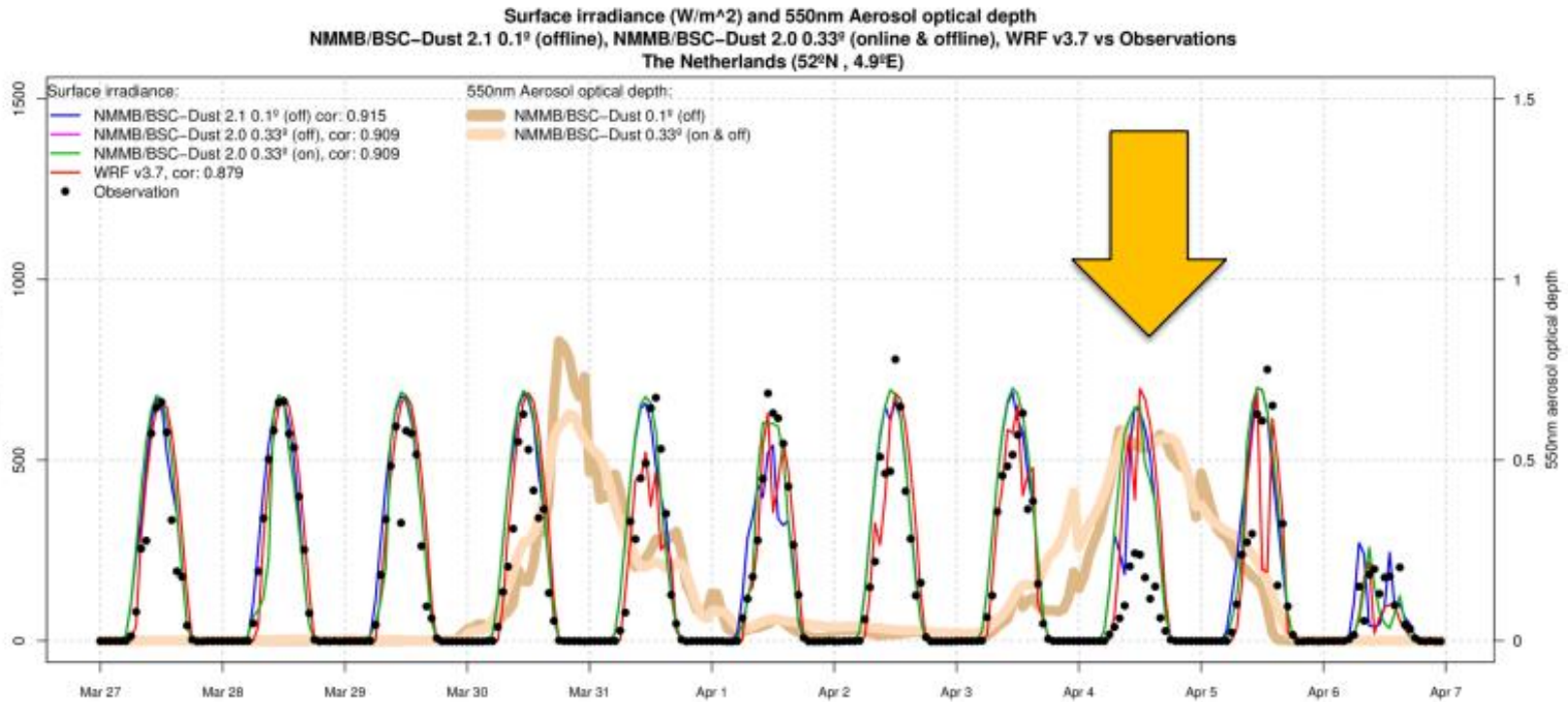


<http://sds-was.aemet.es/>

# Applications in Solar Energy

## ■ Solar irradiance

- The presence of dust **reduce the incoming solar irradiance** through direct radiative effect
- but also indirectly, through favouring **cloud formation**



Year 2014

(Soret et al., 2016)

# Applications in Solar Energy

- Soiling
  - panels efficiency and water management



# SOLWATT project

**Provide near to market solutions for reducing the water consumption of CSP**

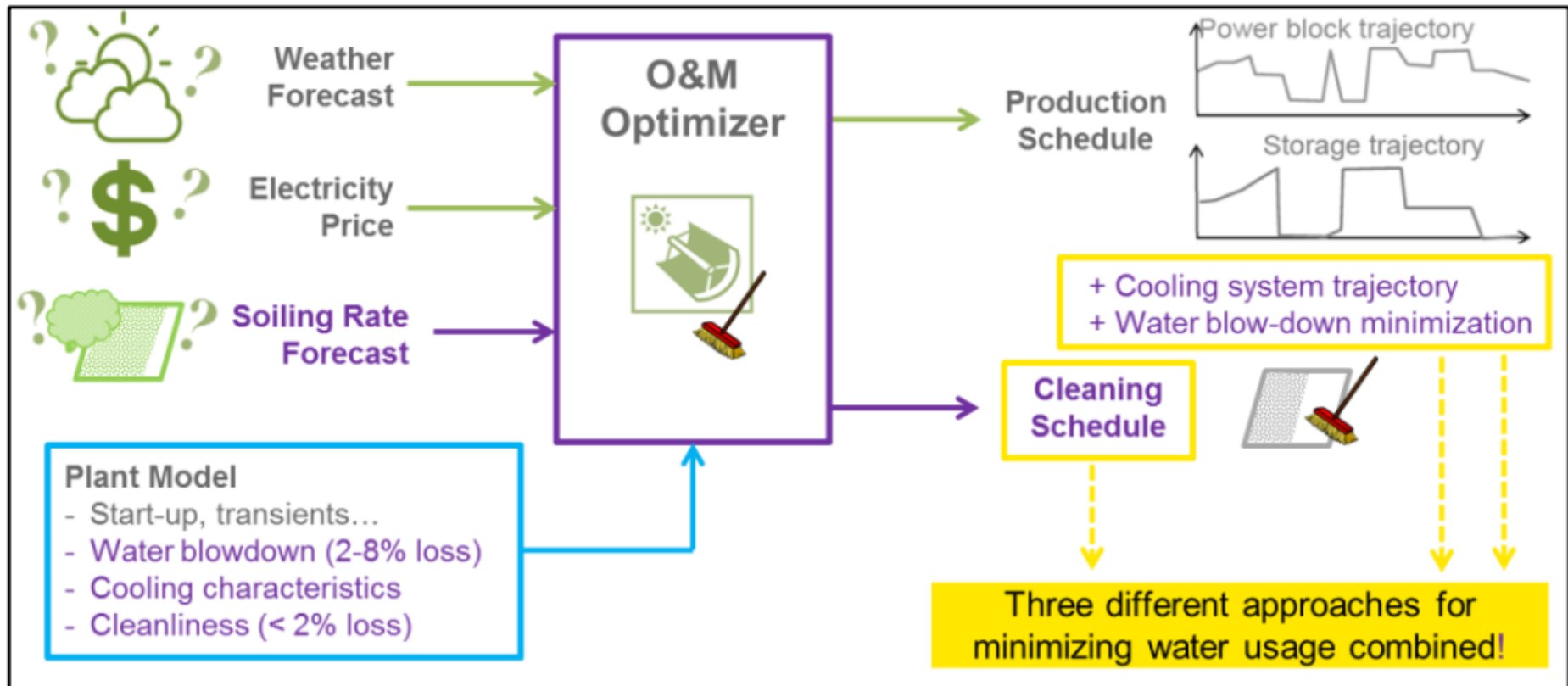
**The solutions will be implemented at two CSP operational sites:**

- La Africana, Site location: Posadas, Córdoba, Spain
- SEDC plant, Site Location: Rotem, Israel

H2020SOLWATT project targets a significant reduction in the water used by CSP plants (by 35% for wet cooled & by 90% for dry cooled). In this way more of 0.5 M€/year of operational cost for a 50 MW CSP plant will be saved in the future.

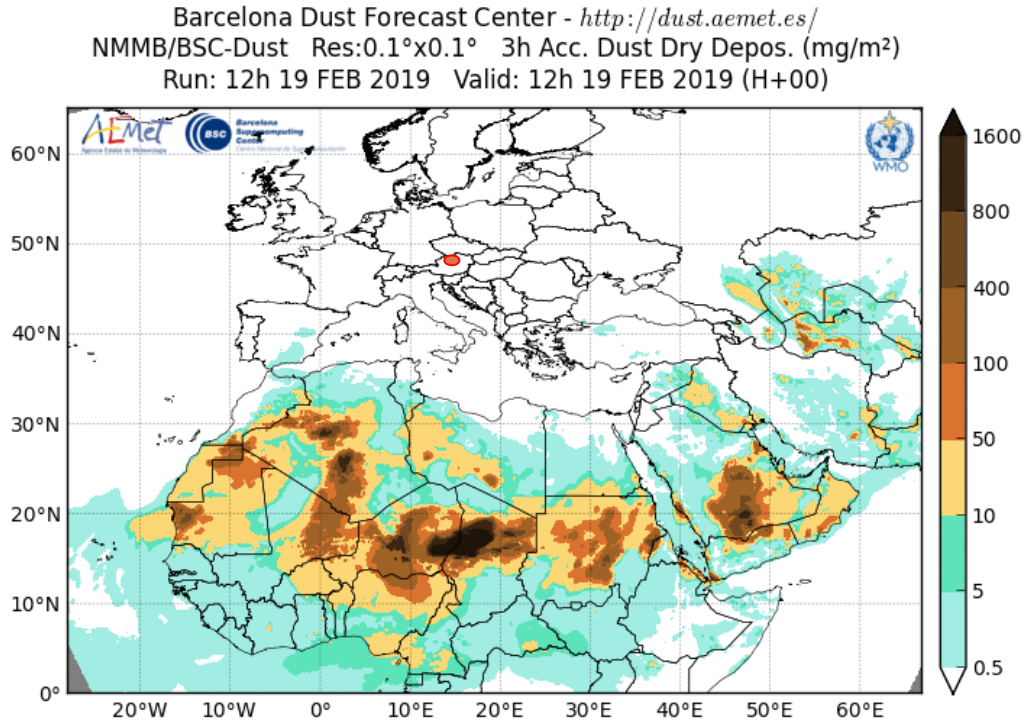


# SOLWATT project



→ O&M optimizer supported by soiling forecasts assures that innovative water-saving technologies are used in the best way.

# Soiling-Downscaling



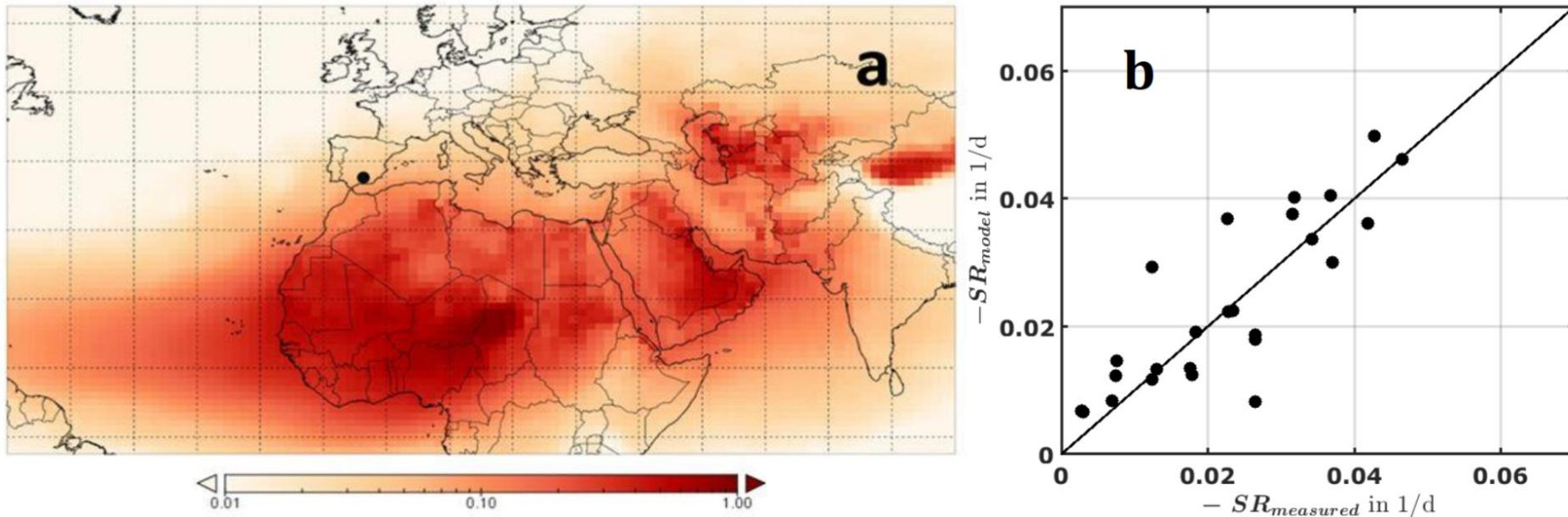
**Operational forecasts**

Biggest solar plant in EU in Hungary is 300,000m<sup>2</sup> → This is 0,3km<sup>2</sup> vs 100km<sup>2</sup> from the model



**Prediction over specific locations**

# Merge of dust-soiling model



- ❑ The DLR Institute of Solar Research (SF) is the largest research entity in Germany investigating and developing concentrating solar technologies to provide heat, electricity and fuel.
- ❑ DLR has developed a soiling model that has been validated for two sites during WASCOP –Water Saving for Concentrated Solar Power (H2020 project).

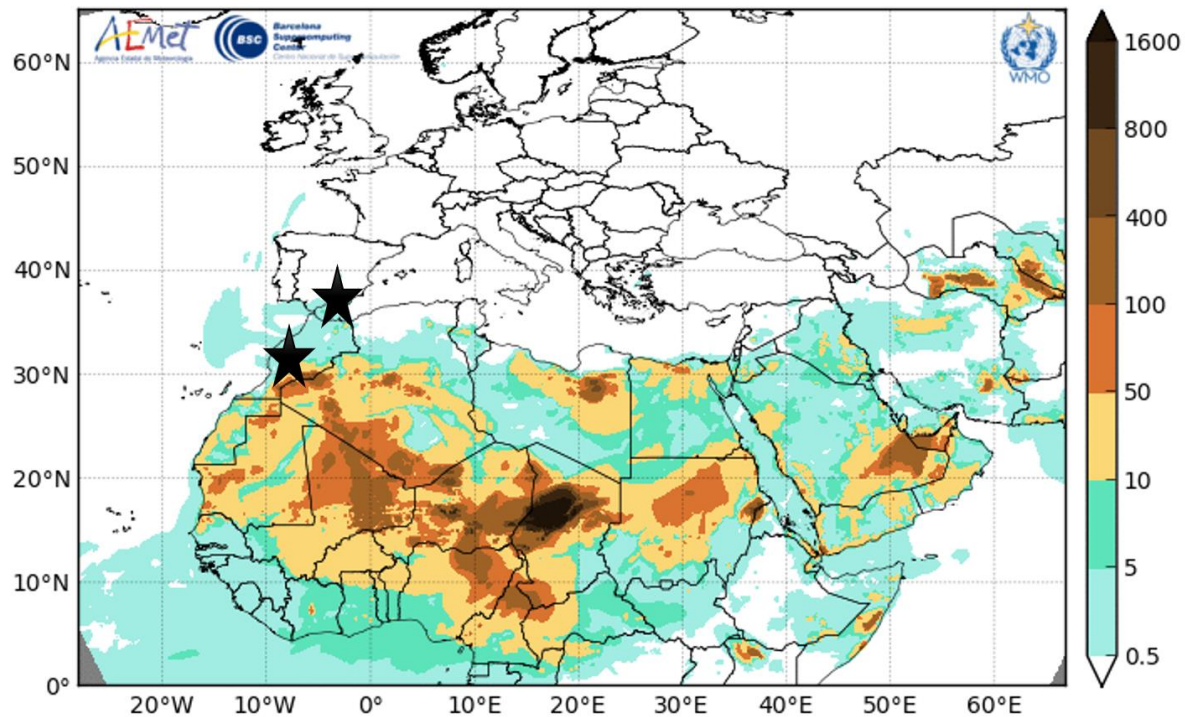
**Next presentation: Soiling modelling with ground data (Fabian Wolfertstetter)**

# Operational dust atmospheric forecast

BSC model is going to be run for the years selected from DLR in order to provide inputs for the soiling model.

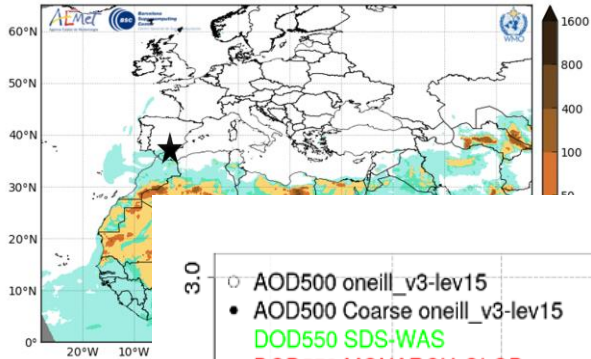
Its evaluations until now for various AERONET stations are satisfactory.

Barcelona Dust Forecast Center - <http://dust.aemet.es/>  
NMMB/BSC-Dust Res:0.1°x0.1° 3h Acc. Dust Dry Depos. (mg/m<sup>2</sup>)  
Run: 12h 13 FEB 2019 Valid: 12h 16 FEB 2019 (H+72)

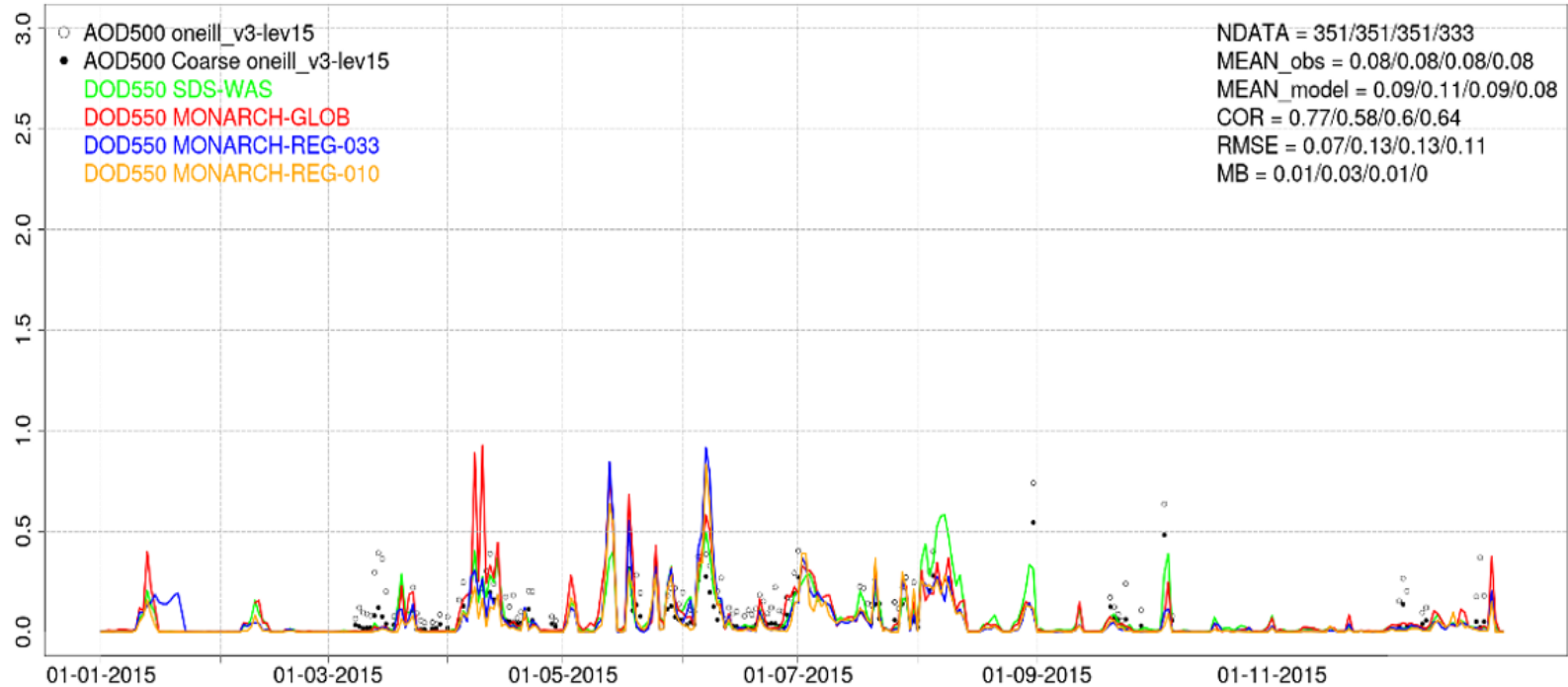


# Model evaluation results

Barcelona Dust Forecast Center - <http://dust.aemet.es/>  
NMMB/BSC-Dust Res:0.1°x0.1° 3h Acc. Dust Dry Depos. (mg/m²)  
Run: 12h 13 FEB 2019 Valid: 12h 16 FEB 2019 (H+72)

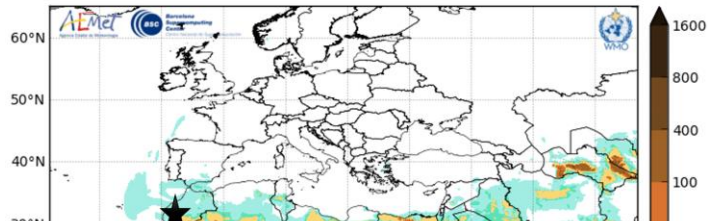


Malaga AERONET

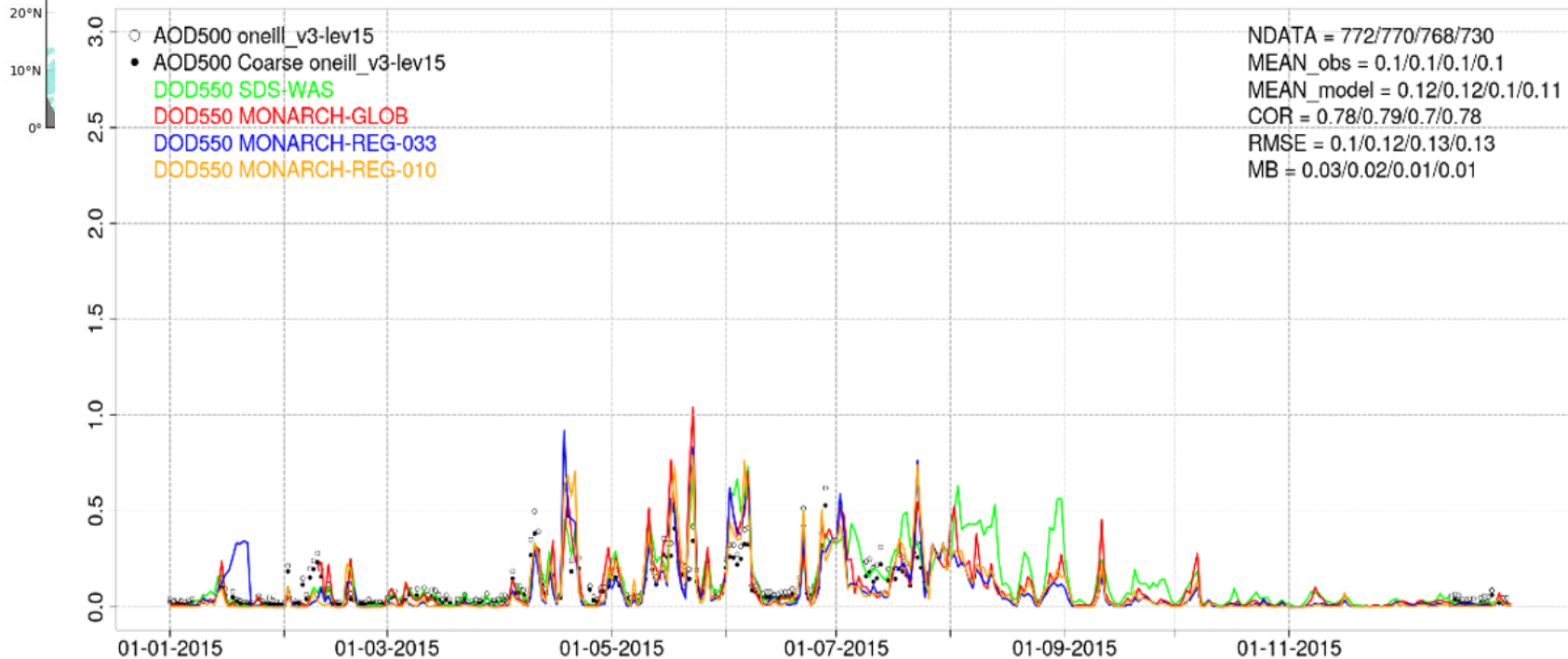


# Model evaluation results

Barcelona Dust Forecast Center - <http://dust.aemet.es/>  
NMMB/BSC-Dust Res:0.1°x0.1° 3h Acc. Dust Dry Depos. (mg/m<sup>2</sup>)  
Run: 12h 13 FEB 2019 Valid: 12h 16 FEB 2019 (H+72)



Ouarzazate AERONET



# Summary

❑ SOLWATT will provide:

- **Operational soiling forecasts:** up to 5-days soiling forecasts based on the daily operational dust NMMB-MONARCH system.

❑ To achieve this objective, the dust atmospheric NMMB-MONARCH model will be coupled with a soiling model.

❑ The evaluation of NMMB-MONARCH (the inputs used by the soiling model) shows that the model can predict the desert dust cycle over North Africa, Middle East and Europe.

- Over the Mediterranean, the model is capturing the timing and the magnitude of the dust events. The model can not reproduce the haboobs (associated to convective events) in the current operational configurations.
- In middle east the model is overestimating the summer events.

❑ Ongoing improvements in the description of the desert sources in the Middle east and Africa. Next, evaluation of the deposition fields.



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# Thank you

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# Backup slides

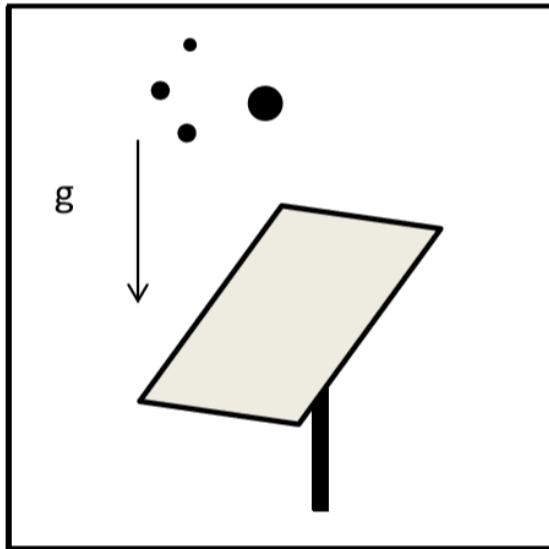


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Aim: predict soiling rate on solar mirrors from other weather data.  
 Test and validate with measurement data

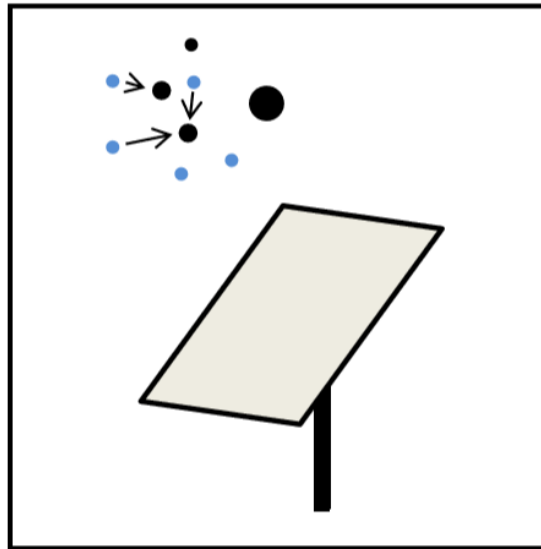
### Sedimentation



#### ➤ Gravitation

$$v_{S,p} = \frac{g d_p^2 (\rho_{\text{Aerosol}} - \rho_{\text{Luft}})}{18 \eta_{\text{Luft}}}$$

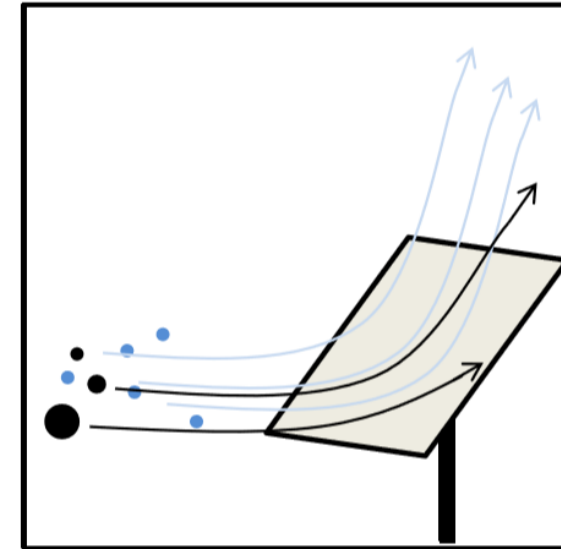
### Brownian motion



#### ➤ Thermal motion

$$v_B = a_{\text{Brown}} u_{\text{Wind}} \left( \frac{\nu_{\text{Luft}}}{D_B} \right)^{-\gamma}$$

### Impaction



#### ➤ Air stream/wind

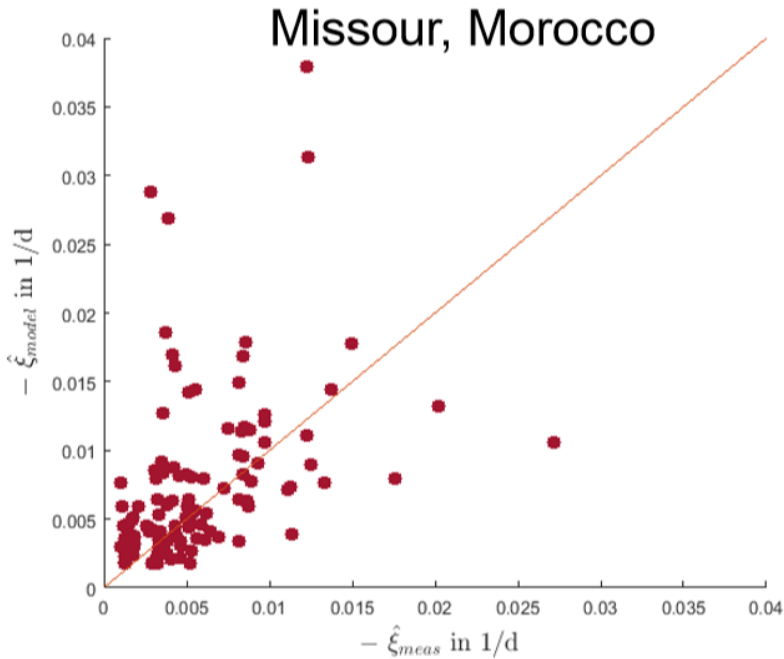
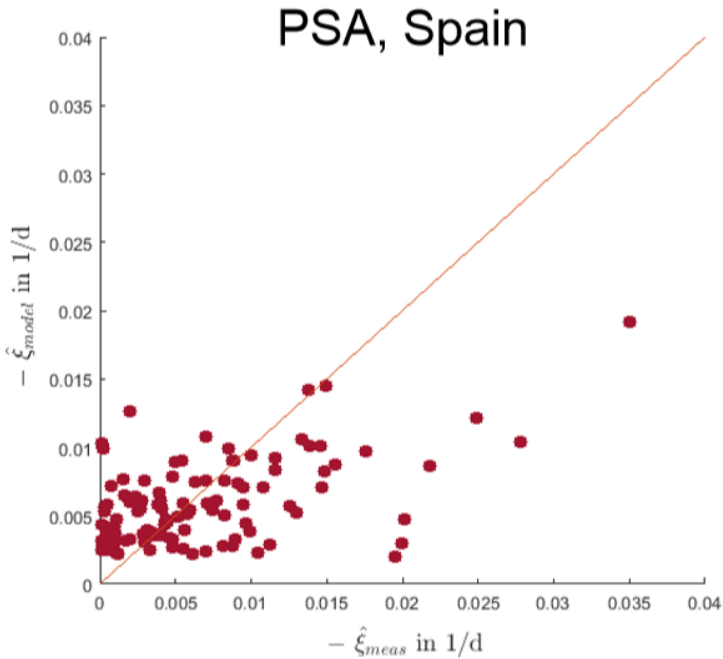
$$v_{Im} = a_{Im} \cdot \frac{\sigma_{\text{Ausrichtung}} u_{\text{Wind}}}{1 + \exp(-f_{Im} \cdot (St - 1))}$$

**Also considered:**

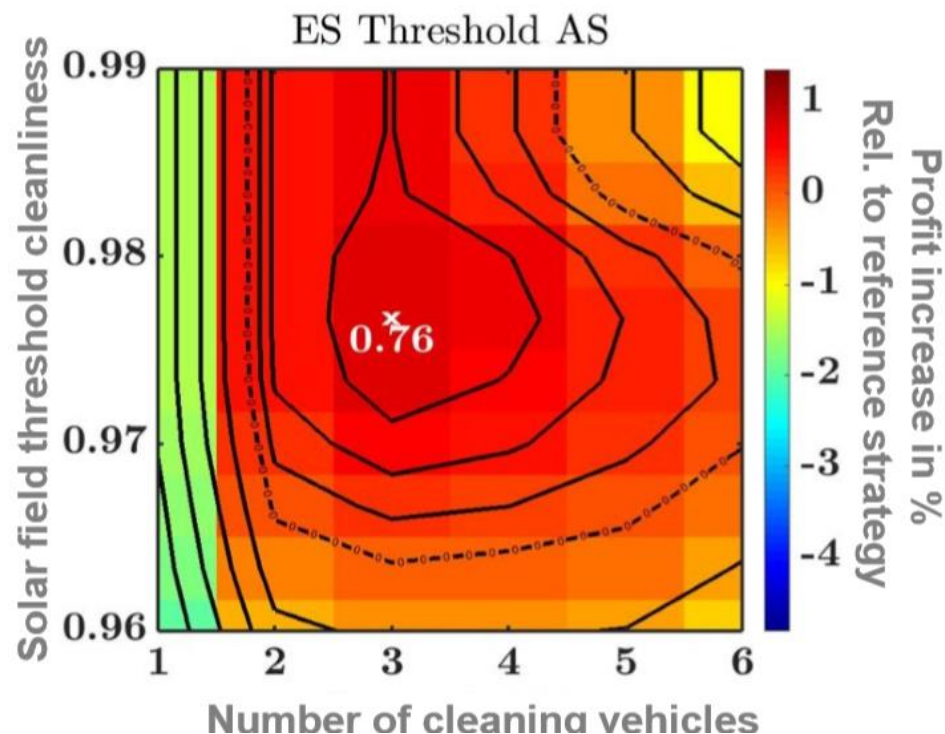
Rebound, resuspension, rain washing, cementation, mirror/panel orientation

- Model validated for two sites
- RMSE = 2 x soiling rate measurement accuracy
- Bias = 0.5 x soiling rate measurement accuracy

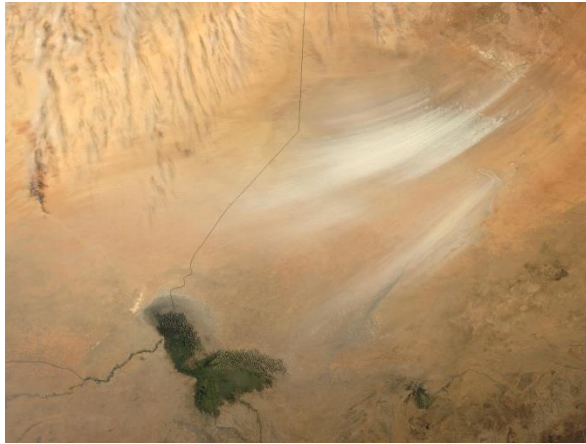
	Bias ( $\cdot\%$ / $d$ )	RMSE ( $\%$ / $d$ )
PSA Training Set	0.08	0.43
PSA Test Set	0.11	0.44
Missour	0.09	0.46



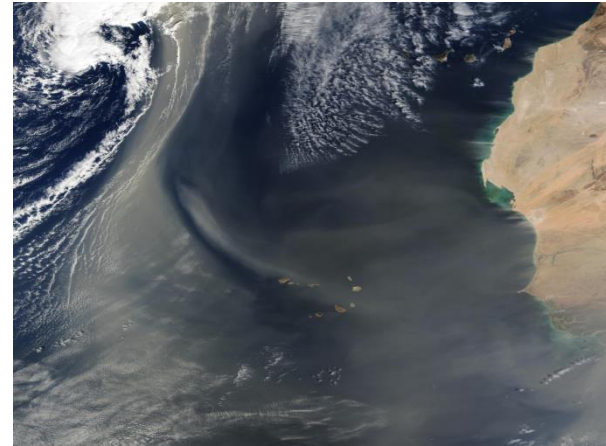
- Trade-off between **cleaning cost** minimization and **revenue** maximization
- **Time resolved soiling rate** information improves cleaning scheduling
- Adaptation of cleaning intensity on cleanliness **increases profit** significantly
- **Soiling forecast** could further increase profit during operation: planned within recently started SOLWATT H2020 project in collaboration with BSC



# Dust cycle and associated processes



MODIS true colour composite image for March 2005 depicting a dust storm initiated at the Bodélé Depression (Chad Basin)



MODIS True color Western Africa – Atlantic Ocean

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.