Assimilation of satellite dust aerosol observations in the MONARCH system

Enza Di Tomaso

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Living Planet Symposium 2022, Bonn, Germany

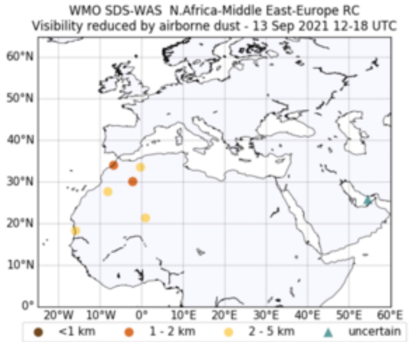
Motivation

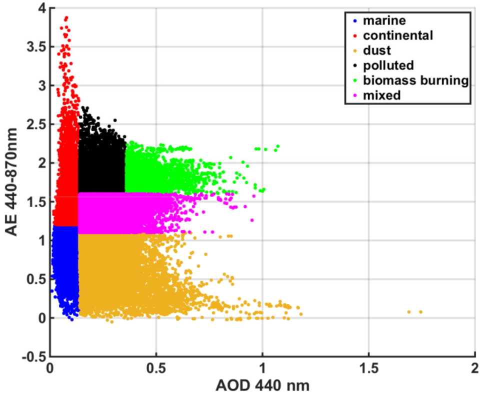
- ➢ **Paucity of direct in-situ measurements in the regions most affected by dust storms**

- ➢ **Satellites mostly provide column-integrated aerosol observations**

- ➢ **Limited information on aerosol speciation**

- ➢ **Assimilating AOD may not necessarily constrain individual aerosol components**



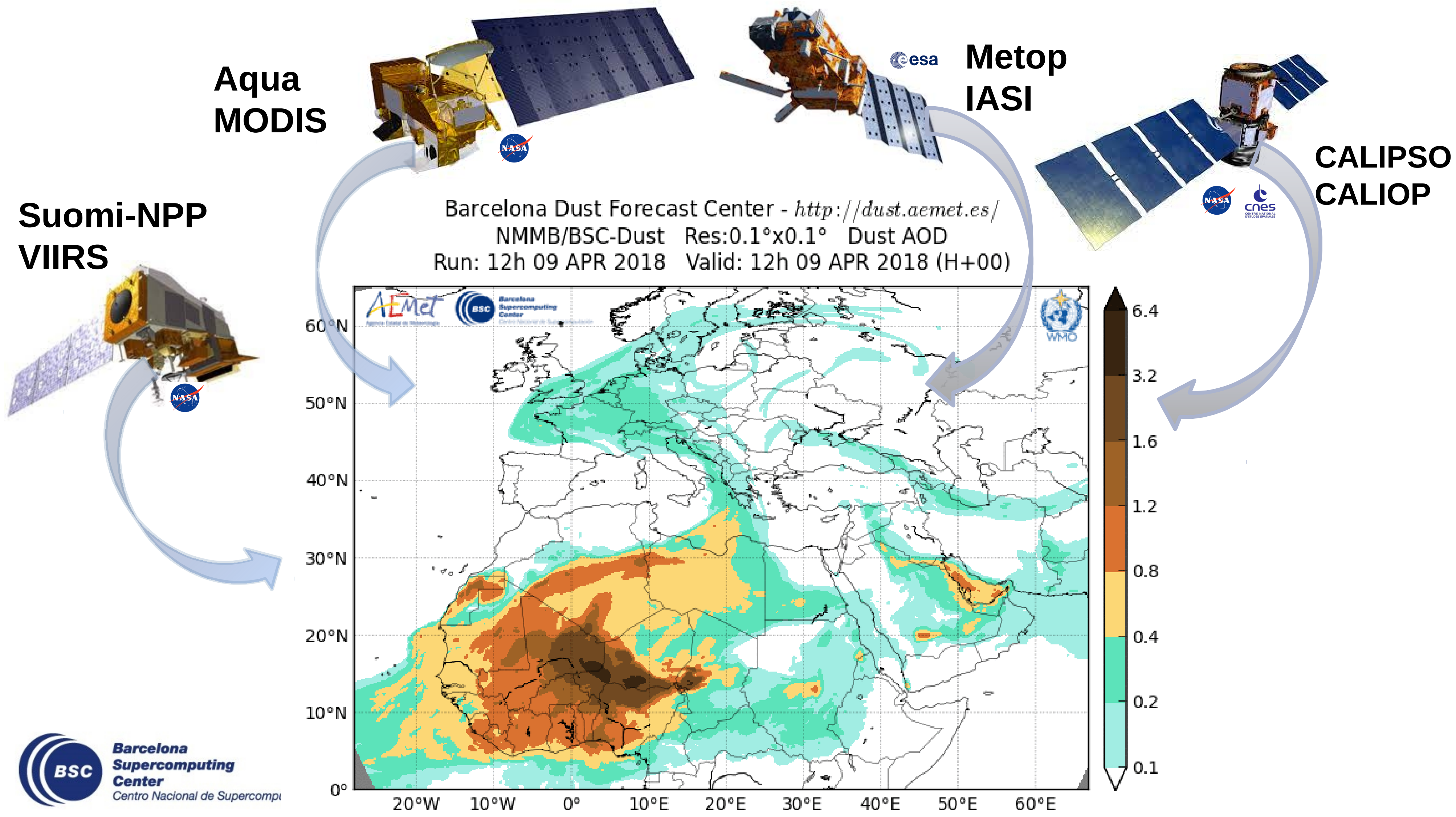


(Raptis et al., 2020)

Motivation

Operational **dust forecast** and **dust reanalyses** are produced in the framework of aerosol data assimilation, where **total AOD** is used to constrain all the main aerosol species

Assess the potential benefit of dedicated dust observation products in dust data assimilation



Aqua
MODIS
Metop
IASI
CALIPSO
CALIOP
Suomi-NPP
VIIRS
esa
NASA
cnes
Barcelona Dust Forecast Center - http://dust.aemet.es/
NMMB/BSC-Dust Res:0.1°x0.1° Dust AOD
Run: 12h 09 APR 2018 Valid: 12h 09 APR 2018 (H+00)
WMO
60°N
50°N
40°N
30°N
20°N
10°N
0°
20°W
10°W
0°
10°E
20°E
30°E
40°E
50°E
60°E
6.4
3.2
1.6
1.2
0.8
0.4
0.2
0.1
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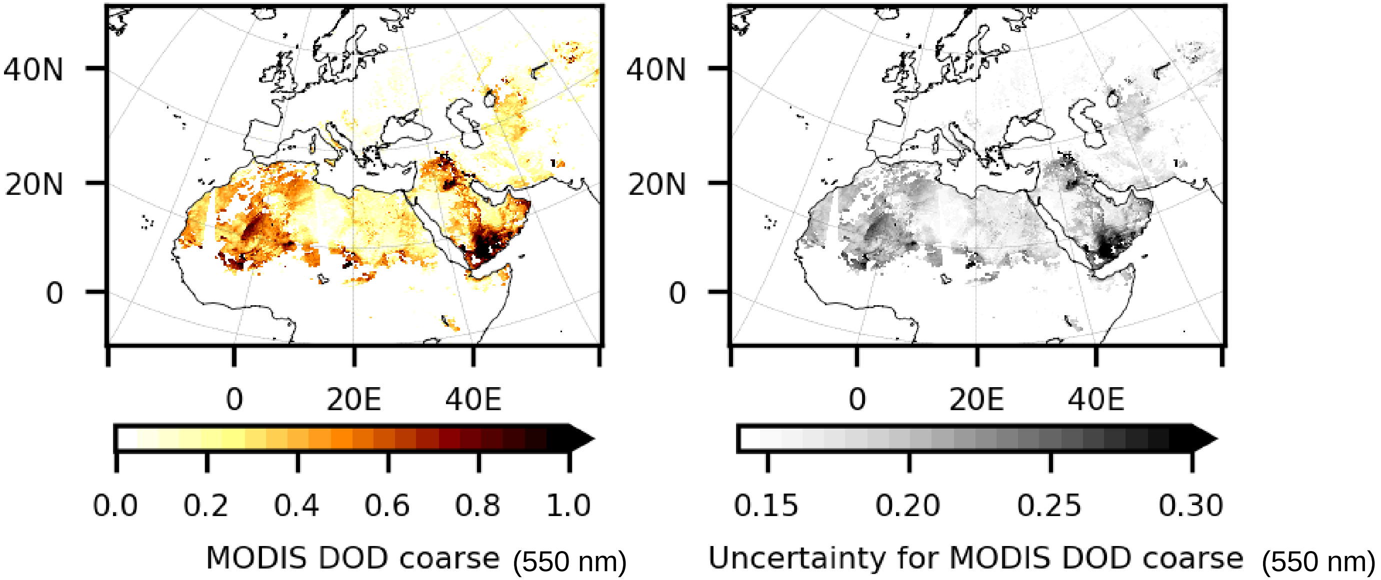
Assimilated observations: a daily sample



- coarse-mode dust optical depth retrieved from MODIS Deep Blue L2 aerosol products over cloud- and snow-free land surfaces (Ginoux et al. 2010, 2012; Pu and Ginoux 2016):
- interpolated to a regular grid of 0.1 by 0.1 degrees, AE, ω filter, coarse AOD retrieval by an empirical continuous function (Anderson et al., 2005; their Eq. 5), highest quality flag

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~120,000 observations assimilated daily (after quality control)

MONARCH high-resolution reanalysis data set of desert dust aerosol over Northern Africa, the Middle East and Europe

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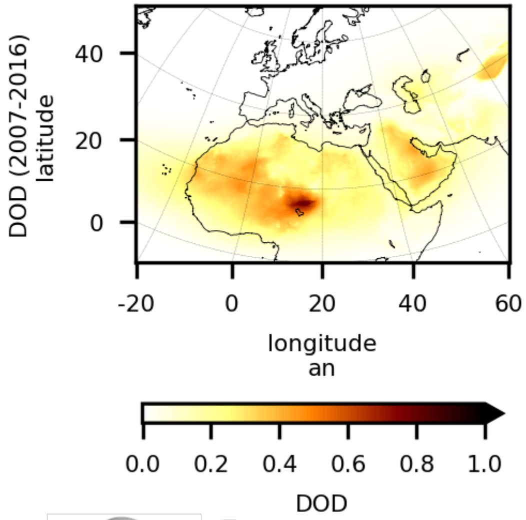
A complete and consistent, four dimensional, regional reconstruction of desert dust in a recent decade (2007-2016)

- ✓ Unprecedented **high resolution**: 0.1º x 0.1º
- ✓ Specific **dust observational constraint**
- ✓ **Uncertainty estimates** in the reanalysis output
- ✓ Link to specific **air quality** and **climate services**
- ✓ **FAIR** data guidelines



Open access. To request access to the repository, please contact reanalysis.access@bsc.es

License: Creative Commons Attribution 4.0 International (CC BY 4.0).
License url: https://creativecommons.org/licenses/by/4.0/

Dataset PID: http://hdl.handle.net/21.12146/c6d4a608-5de3-47f6-a004-67cb1d498d98

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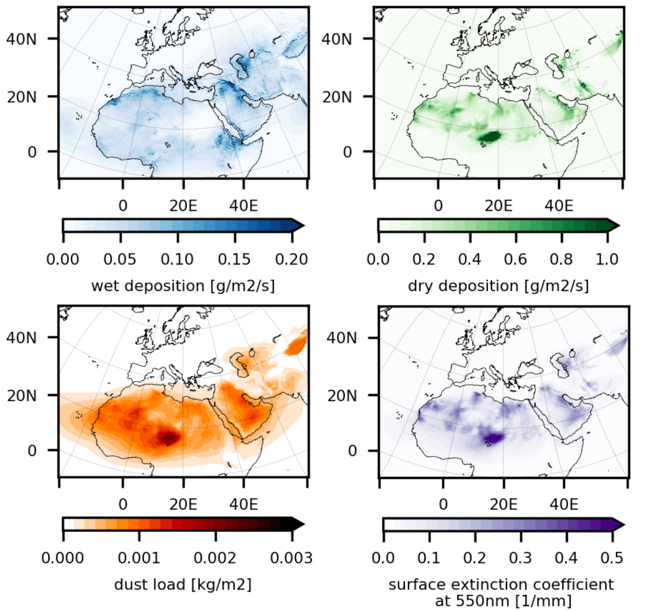
DustClim

ERA4CS European Research Area for Climate Services

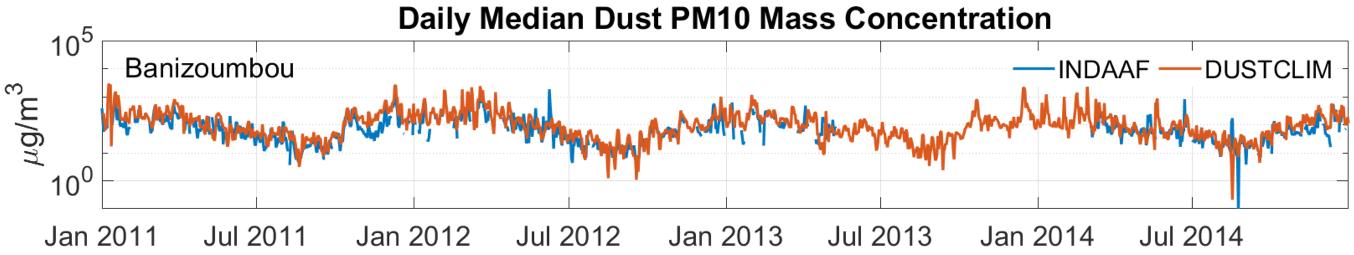
AEMet Agencia Estatal de Meteorología

Di Tomaso et al., 2021, ESSDD

MONARCH high-resolution reanalysis data set of desert dust aerosol over Northern Africa, the Middle East and Europe



Detailed evaluation of key parameters: surface concentration, dust optical depth (total and coarse fractions), extinction, PM10, size distribution and deposition



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ERA4CS European Research Area for Climate Services
AEMet Agencia Estatal de Meteorología

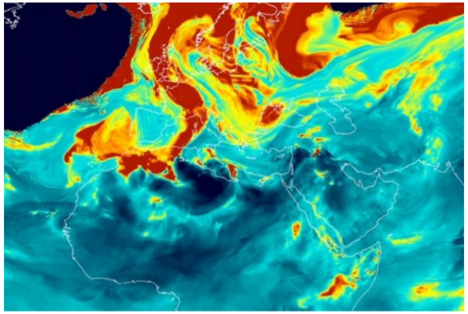
MONARCH ensemble for data assimilation

MONARCH ensemble has been generated by applying combined meteorology and emission perturbations

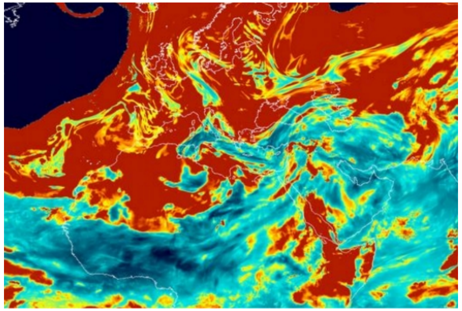
(a) emission parameter perturbations: by perturbing the threshold friction velocity and the vertical flux of dust in each of the eight dust transport bins (Di Tomaso et al., 2017)
(b) dust emission schemes: MB95 (as in Perez et al. 2011), G01 (as in Ginoux et al., 2001) and K14 (as in Kok et al. 2014)
(c) meteorological initial and boundary conditions: ERA-Interim and MERRA2_ERA5soil

Assimilation scheme: Local Ensemble Transform Kalman Filter (LETKF; Hunt et al., 2017)
- use of a flow-dependent background error covariance, spatial localization, 4D implementation

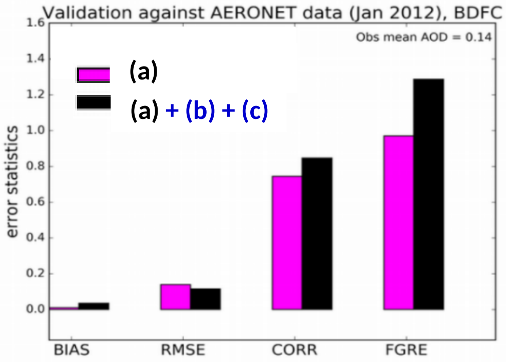
Normalized standard deviation



(a)



(a) + (b) + (c)



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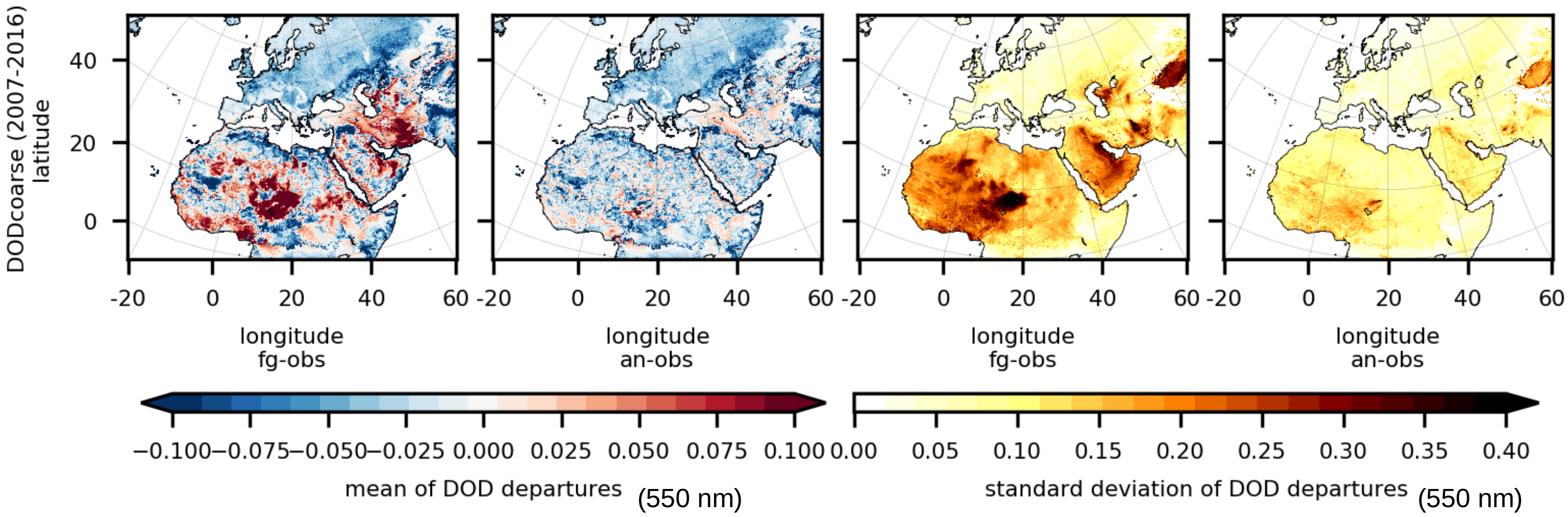
Departures from assimilated observations



- The **reduction of the standard deviation** of the analysis departures compared to the first-guess proves the consistency of our assimilation procedure
- The **positive mean departures decrease** considerably in the analysis compared to the first-guess
  - Some of the **negative mean departures** remain unchanged: lower DOD not analyzed efficiently or contamination of other aerosols than dust in the observations

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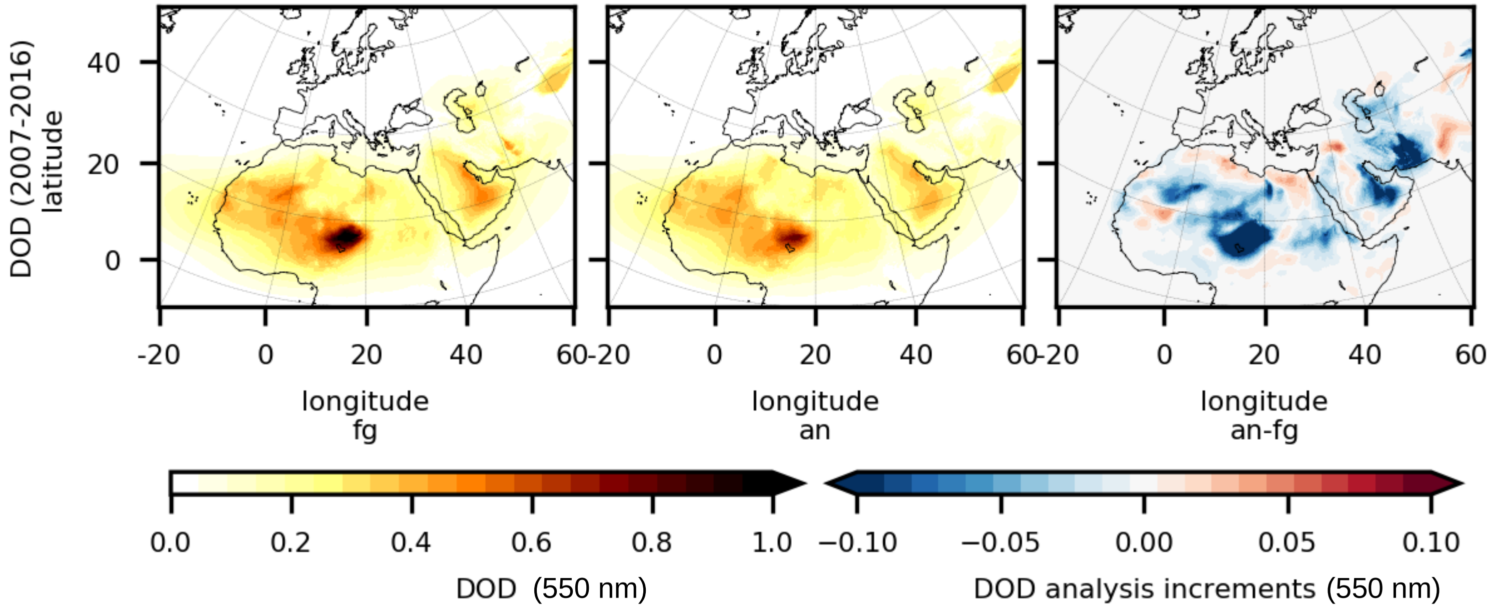
Geographical distribution & analysis increments



- **Systematic negative corrections** linked to overestimation of the major sources' strength in Africa and the Middle East (the Bodélé depression in Chad, in the Saudi Arabia lowlands and in the Balochistan region of south-western Asia)
- **Positive mean increments** over the Thar desert, in the north part of Syria, inland from the Mediterranean sea in the north of Africa, and between Mauritania and Mali

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TAILORING PRODUCTS

WHAT: Identification of **impacts** and strategy for **risk mitigation for a particular sector. Understanding users' needs.**

AIR QUALITY: *Design of AQ early warning systems, How many people are exposed to dust?*

AVIATION: *How much dust is needed to significantly damage gas turbine engines? Or to disturb operations?*

SOLAR: *How much dust is needed to significantly reduce solar production?*

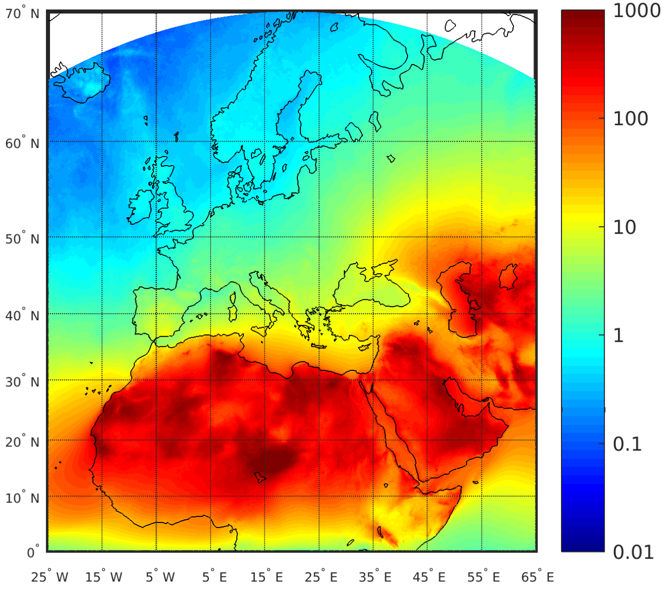
HOW: Literature review and user engagement

Slide courtesy of S. Basart

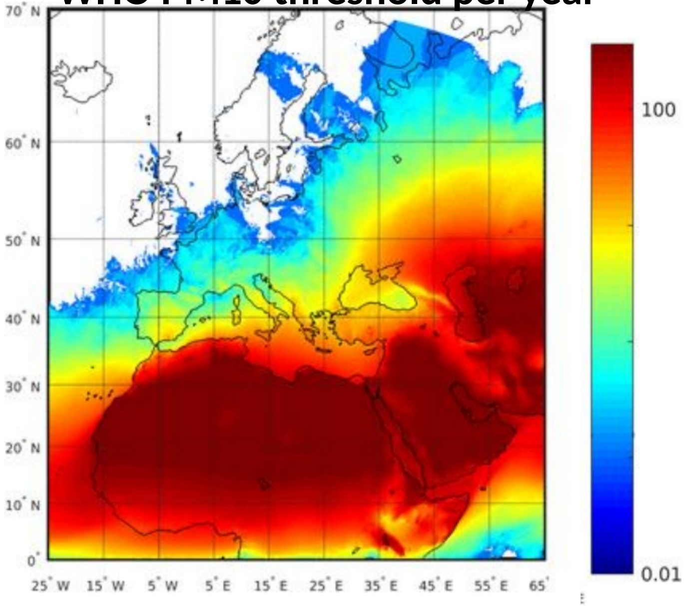
Air Quality climate services

Dust concentration and AQ exceedances

Climatological PM10 annual average

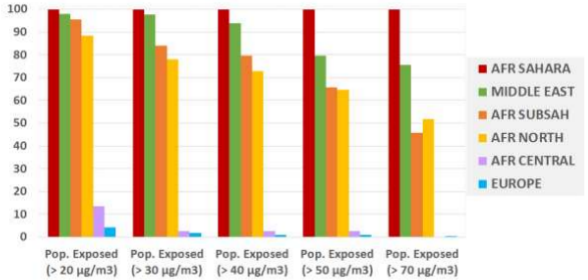


Number of exceedances of the WHO PM10 threshold per year



WHO PM10 Th: 50microg/m3

Population exposure



Slide courtesy of S. Basart

Aviation portfolio

DUST IMPACTS

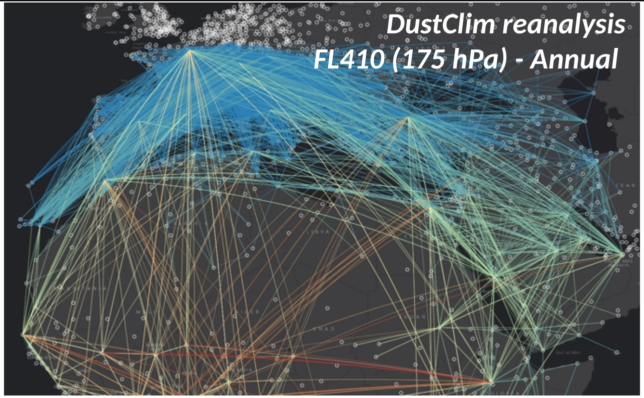
Mechanical problems

- Ice nucleation
- Dust melting in turbines
- Turbine abrasion

Reduction of visibility

- Closing airports / Traffic management →Rerouting and cancellations
- Disturbances in airport operations

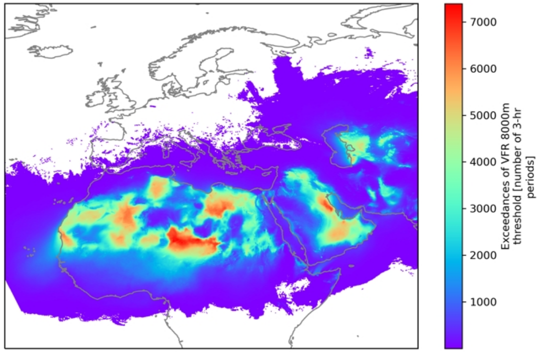
AIRCRAFT SAFETY



Aircraft Dust Exposure at Cruise level

Annual average (2007-2016)

TRAFFIC MANAGEMENT



Probability of exceedance of Visual Flight rules (> 8km)

Annual probability (2007-2016)

Slide courtesy of S. Basart

Solar energy portfolio

DUST IMPACTS

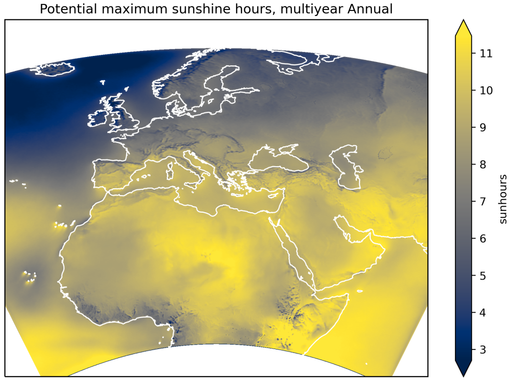
Solar production

- Direct impact on solar irradiance arriving at ground
- Ice nucleation favouring the formation of cirrus clouds

Plant operations

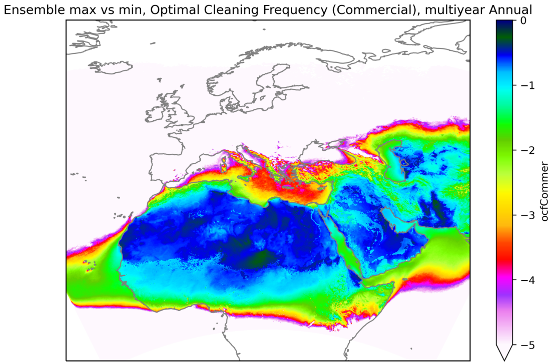
- Reduction of the efficiency of the plant due to soiling
- Water management

SOLAR PRODUCTION



Maximum sunshine hours
Annual estimation (2007-2016)

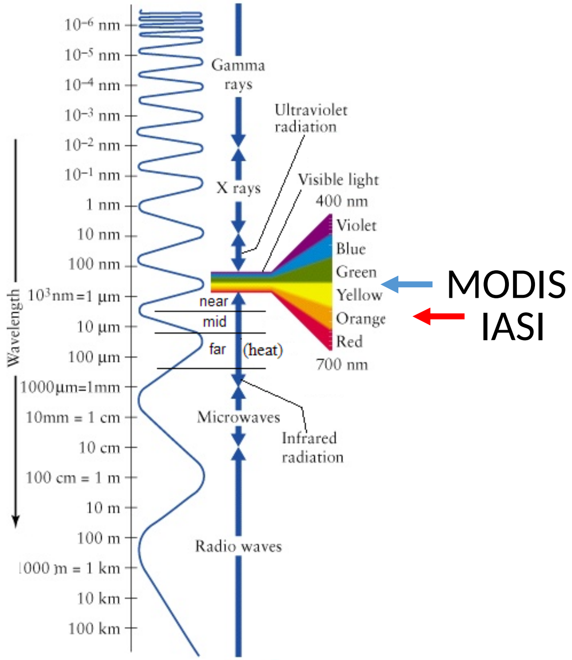
PLANT OPERATIONS



Optimal Cleaning Frequency
Annual estimation (2007-2016)

Slide courtesy of S.

Assimilation of CCI IASI dust optical depth

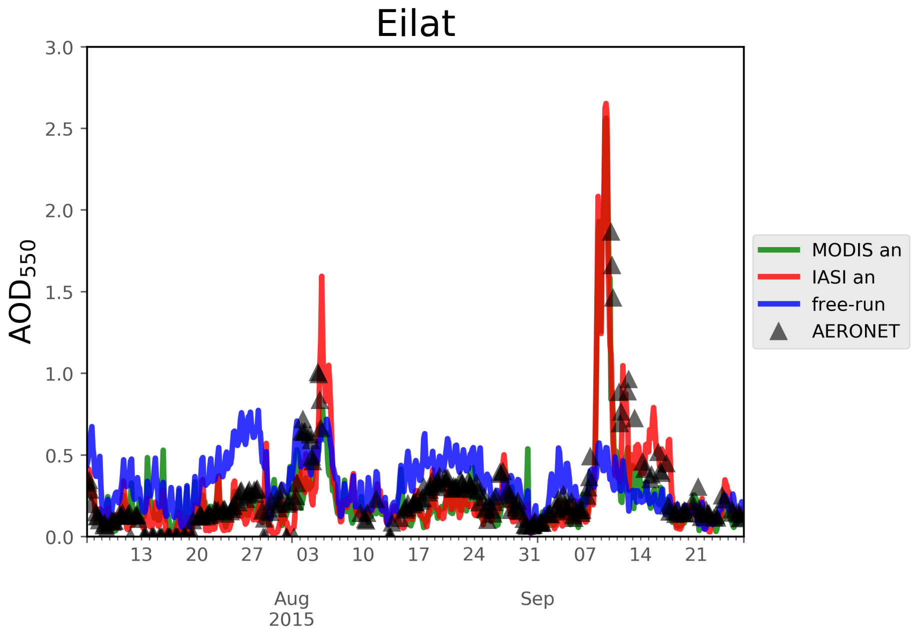


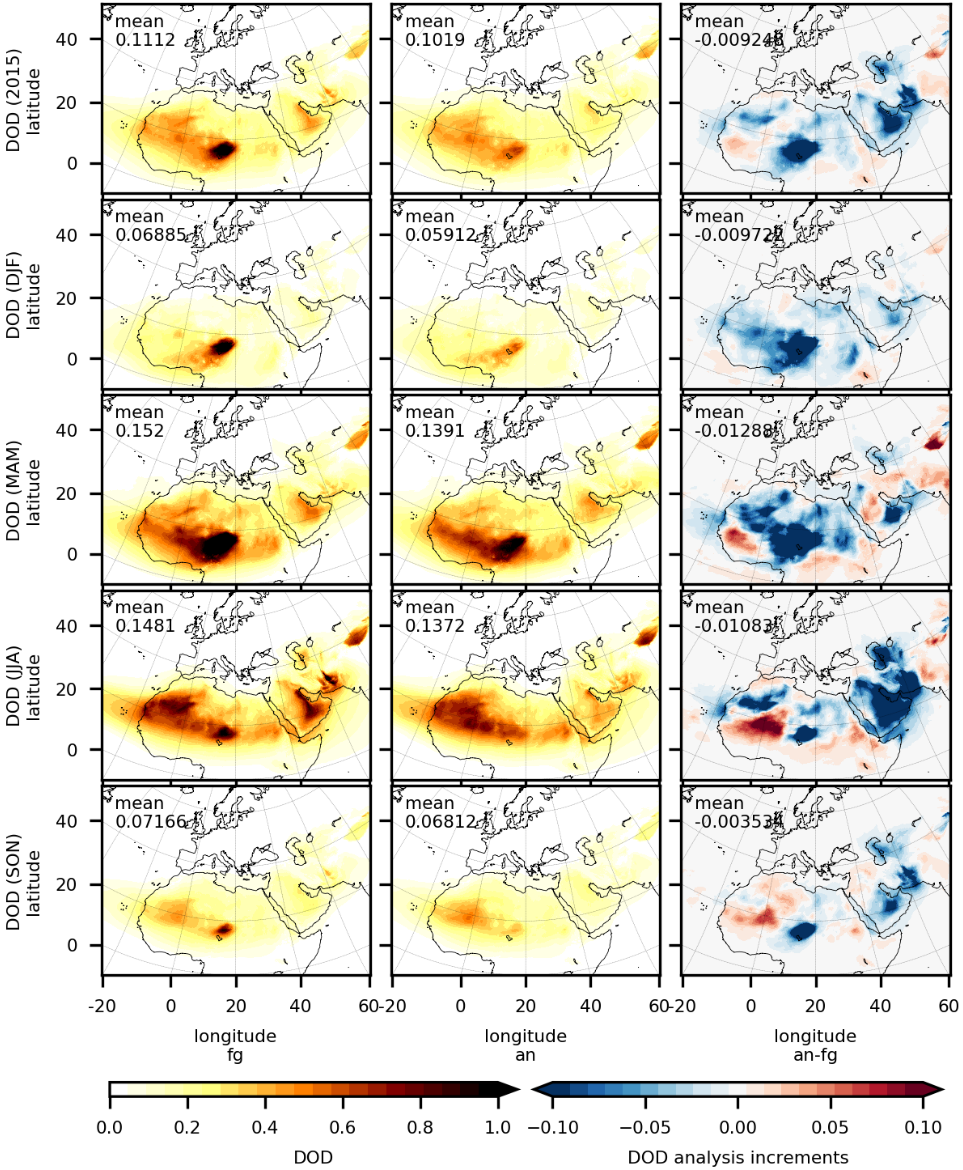
- observations available day time and night time
- over ocean and over land (desert)
- 10 µm: detection of dust aerosol coarse mode (infrared wavelengths and ''V'' shaped depression of the Brightness Temperature)
- pixel level uncertainty

- use of ULB retrievals (Neural Network-based; Clarisse et al., 2019)
- optical properties from experimental campaign data (Di Biagio et al. 2017, 2019)

aerosol cci   cmug cci   ULB UNIVERSITÉ LIBRE DE BRUXELLES

Geographical distribution
&
analysis increments





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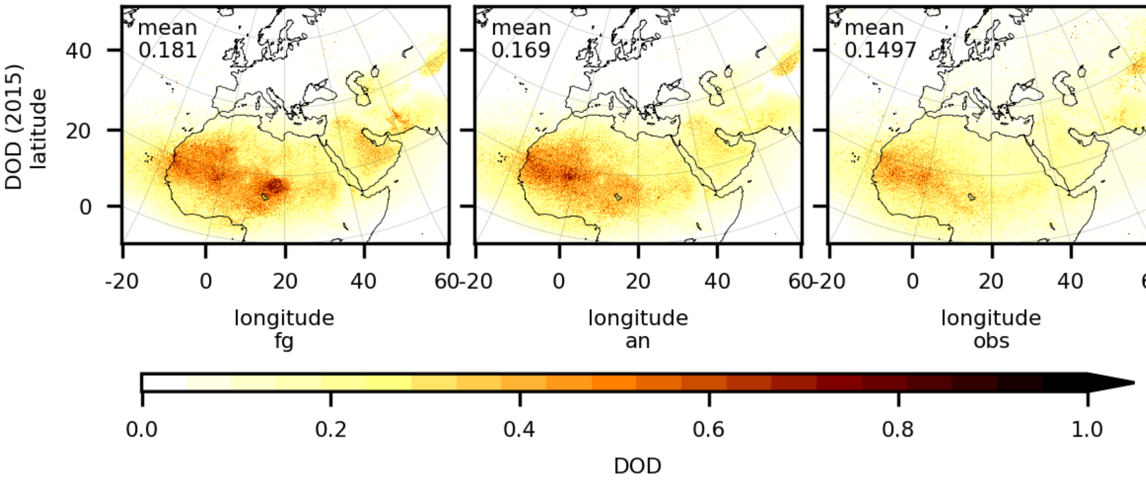
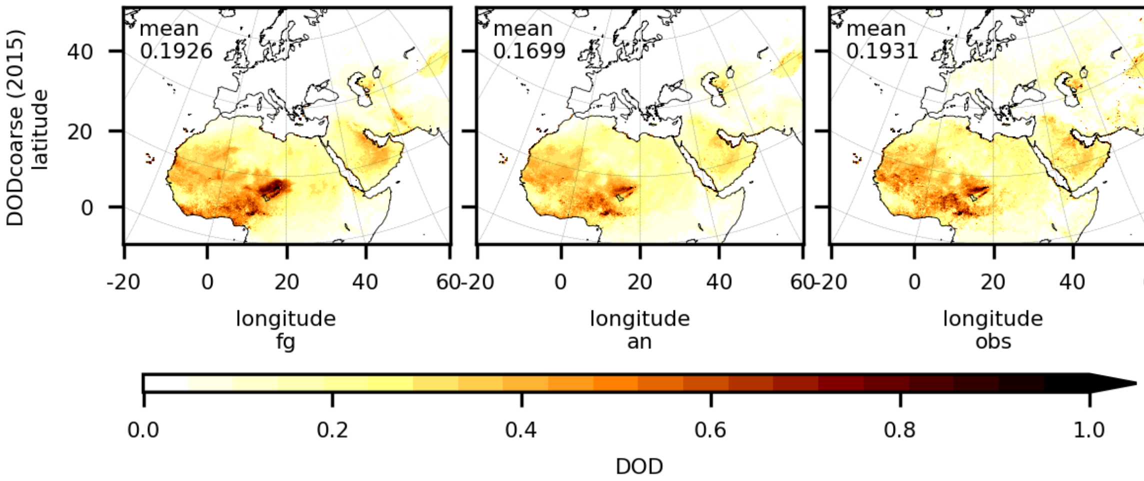
Assimilation of IASI dust optical depth



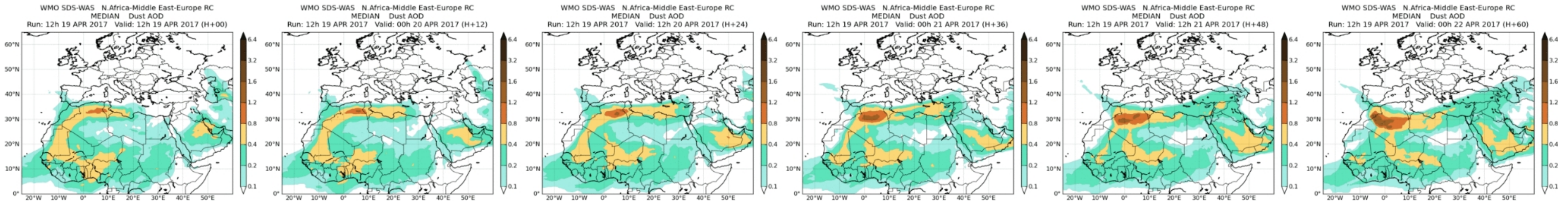


- IASI observations less sensitive to surface layers of dust

- less accurate ULB IASI dust retrievals in the winter season

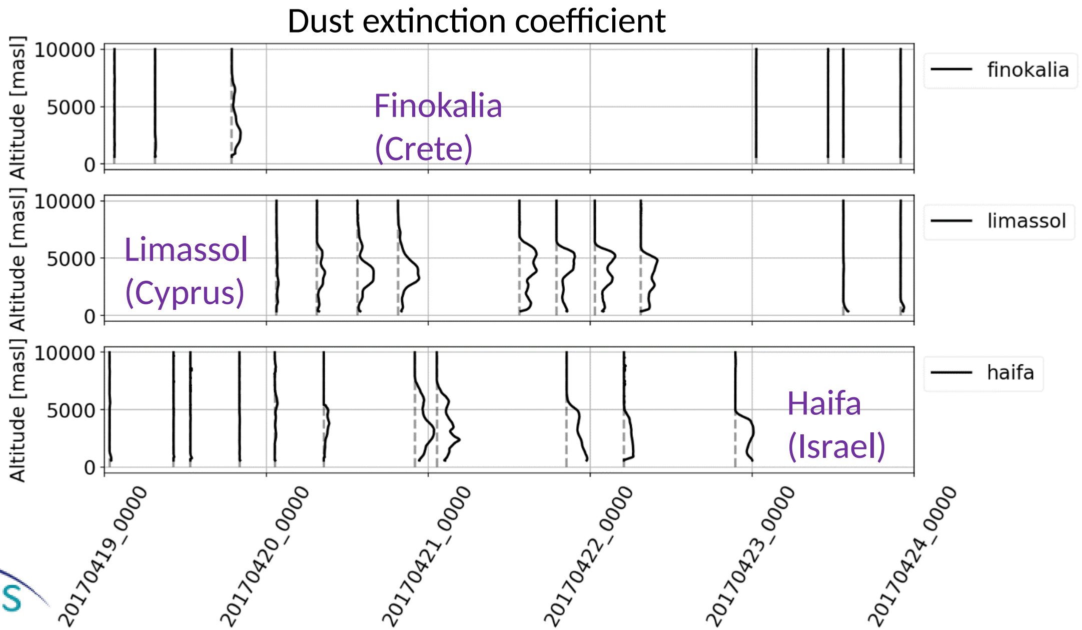
Assimilation of LIVAS extinction coefficient profiles

Three-dimensional analyses of atmospheric dust aerosol concentrations constrained by satellite vertical retrievals of dust properties, and associated uncertainty estimation.



Event observed by 3 **lidar** sensors located **in Finokalia (Crete), Limassol (Cyprus) and Haifa (Israel)** part of the PollyNet (http://polly.tropos.de/) system. Data (with uncertainty estimation) processed by TROPOS.

Escribano et al., 2021, ACP



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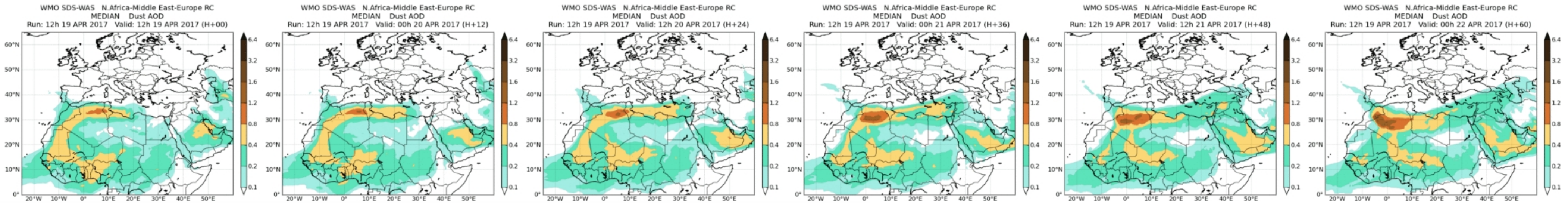
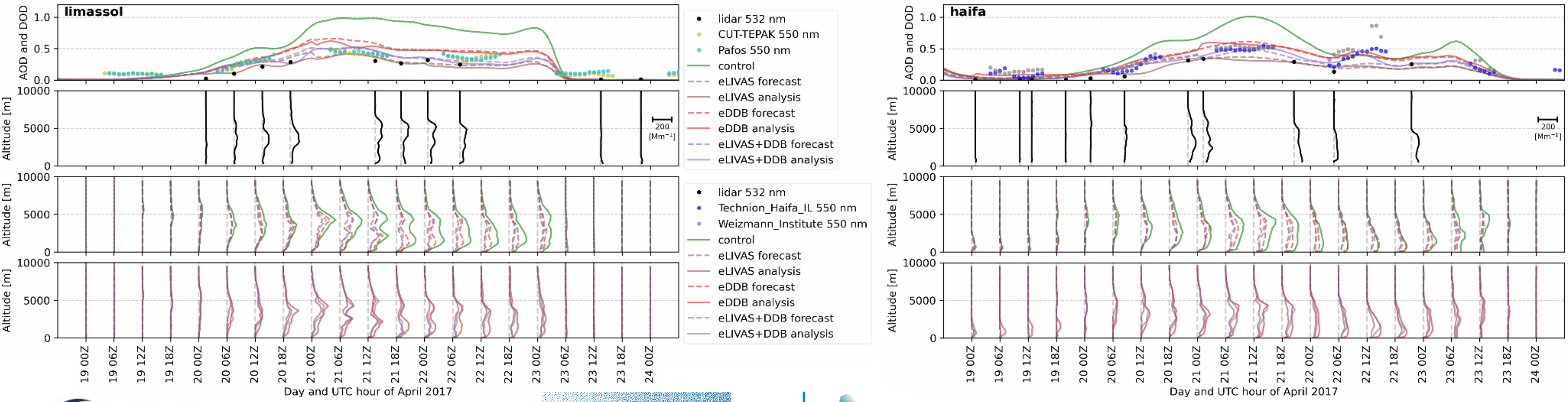
TROPOS
Leibniz Institute for Tropospheric Research

ACTRIS

Assimilation of LIVAS extinction coefficient profiles

Three-dimensional analyses of atmospheric dust aerosol concentrations constrained by satellite vertical retrievals of dust properties, and associated uncertainty estimation.





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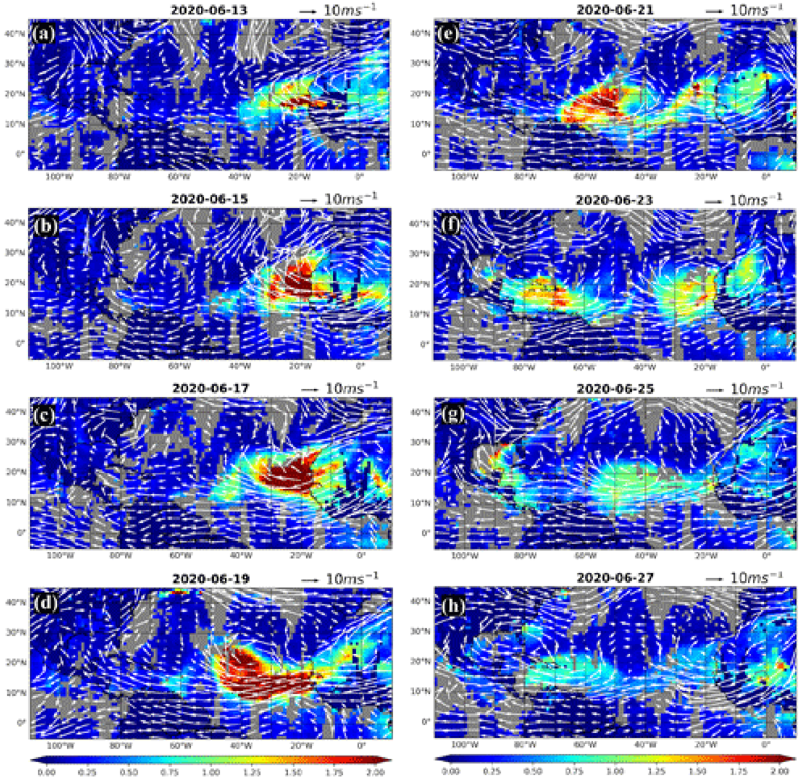
ACTRIS

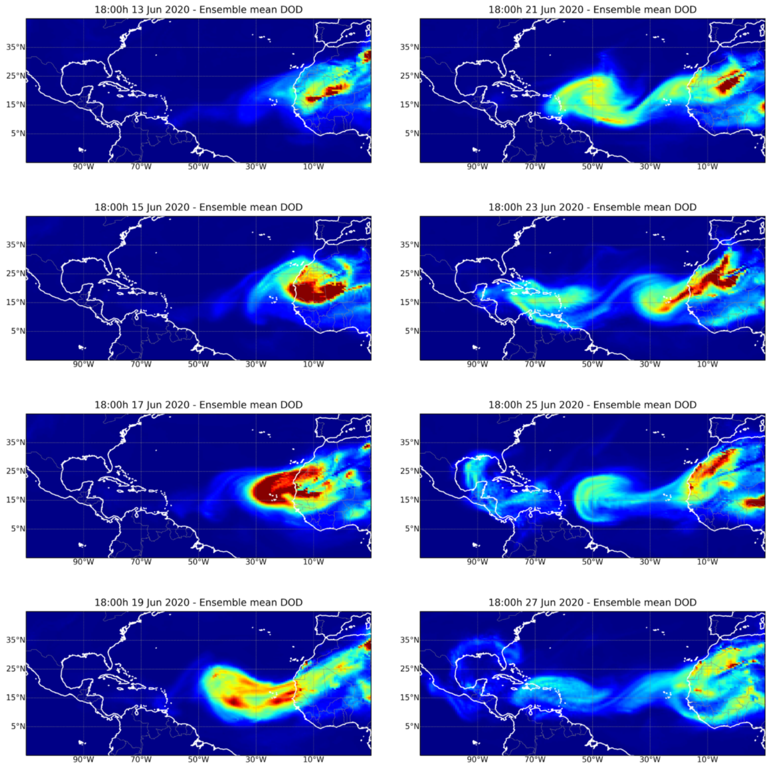
Escribano et al., 2021, ACP

June 2020 case study: MONARCH ensemble free-run

MODIS (daily, Terra and Aqua, Yu et al. 2021)



MONARCH free-run ensemble mean (at 18 UTC)



- Main tracked of the event observed by MODIS is reproduced well
- Some misplacement of the plume
- Considerably underestimation of the intensity of the event

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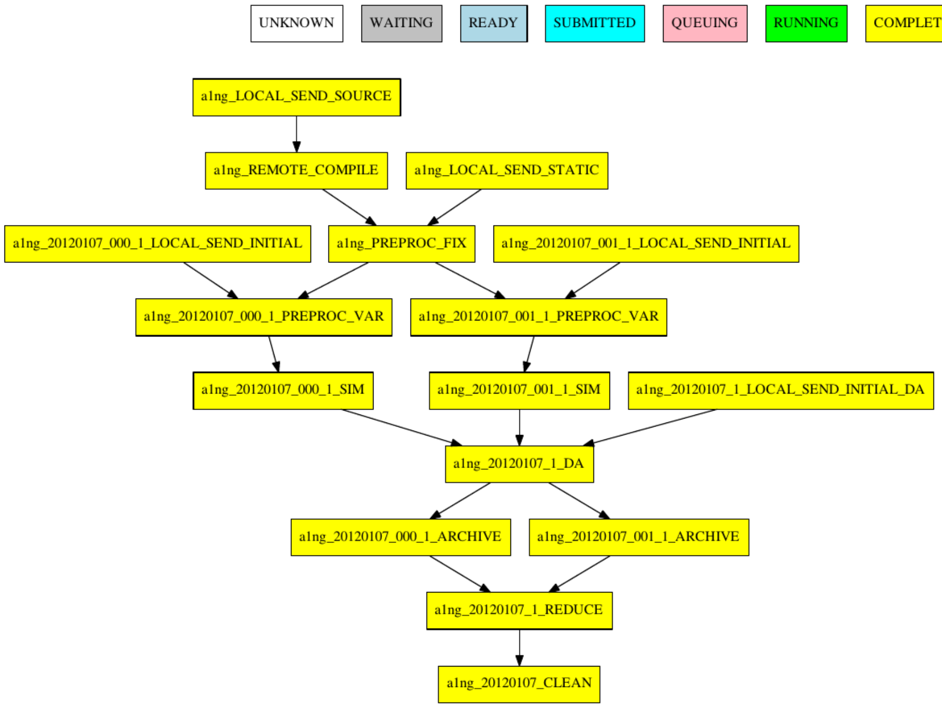
DOMOS

Simulation workflow & role of advanced HPC



- High Performance Computing (HPC) infrastructure using the Autosubmit workflow manager (Manubens-Gil et al., 2016; Uruchi et al., 2021)
- Some tasks are wrapped together and submitted to the supercomputer job scheduler in a unique job
- A crossing-date strategy to run different starting dates within the same experiment has been implemented
- Memory, data transfer and storage optimization

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Effective use of HPC resources while guaranteeing data quality, open access, reproducibility and portability in line with the goals of the EC's Green Deal and Digital Strategy

Thanks to the people taking measurements, maintaining sites, making retrievals and observation products

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