

# Dust climatology from spaceborne remote sensing observations

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# Outline

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**Introduction**

02

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04

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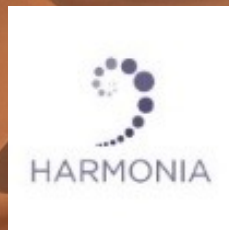
**MIDAS dataset  
exploitation**

06

**MIDAS upgrade and  
upcoming activities**



# Introduction



# Dust within the Earth-Atmosphere system

**Deserts**

- Haboobs are extreme and short-lived sand and dust storms caused by strong winds resulting in a "wall of dust" that occur fairly regularly in isolated desert regions
- Dust interferes with the incoming solar irradiance which has a direct consequence in solar energy production
- Extraordinary events affect infrastructures by abrasion, and visibility reduction increases artificial lighting and electricity consumption
- Visibility reduction can close airports, disrupt ground transport services and cause traffic accidents

**Oceans**

- Dust can contribute to cloud condensation and ice nucleation, affecting cloud formation and consequently altering precipitation patterns
- Dust can cause mechanical damages in planes during flight
- Iron and phosphorous in mineral dust favors fertilisation of marine and continental ecosystems
- Dust deposition on ice and snow surfaces of Earth (the cryosphere) can reduce the amount of sunlight reflected (albedo), affecting climate

**Land**

- Dust introduces errors in remote sensing measurements from telescopes and satellites
- Sand and dust storms have negative impacts on agriculture: reducing crop yields by affecting seedlings, causing loss of plant tissue, reducing photosynthetic activity and increasing soil erosion
- Exposure to moderate levels of particulate matter (PM) can cause respiratory and cardiovascular diseases
- Dust deposition over solar panels reduces their efficiency

**Impact Summary:**

- Deserts:** Weather, climate and ecosystems; Aviation and ground transportation; Solar energy
- Oceans:** Weather, climate and ecosystems; Aviation; Fisheries
- Land:** Weather, climate and ecosystems; Agriculture; Solar energy; Astrophysics and tele-detection; Health and air quality; Aviation

www.cost-indust.eu

indust is an international network that connects desert dust experts with stakeholders in socioeconomic sectors affected by mineral aerosol dust

JOIN THE NETWORK

**inDust**

INTERNATIONAL NETWORK TO ENCOURAGE THE USE OF MONITORING AND FORECASTING DUST PRODUCTS

This Network is based upon work from COST Action inDust CA11119, supported by COST (European Cooperation in Science and Technology). The Chair holder of inDust is the Barcelona Supercomputing Center (BSC) where long-term dust research program is associated with the AAA Research Fund.

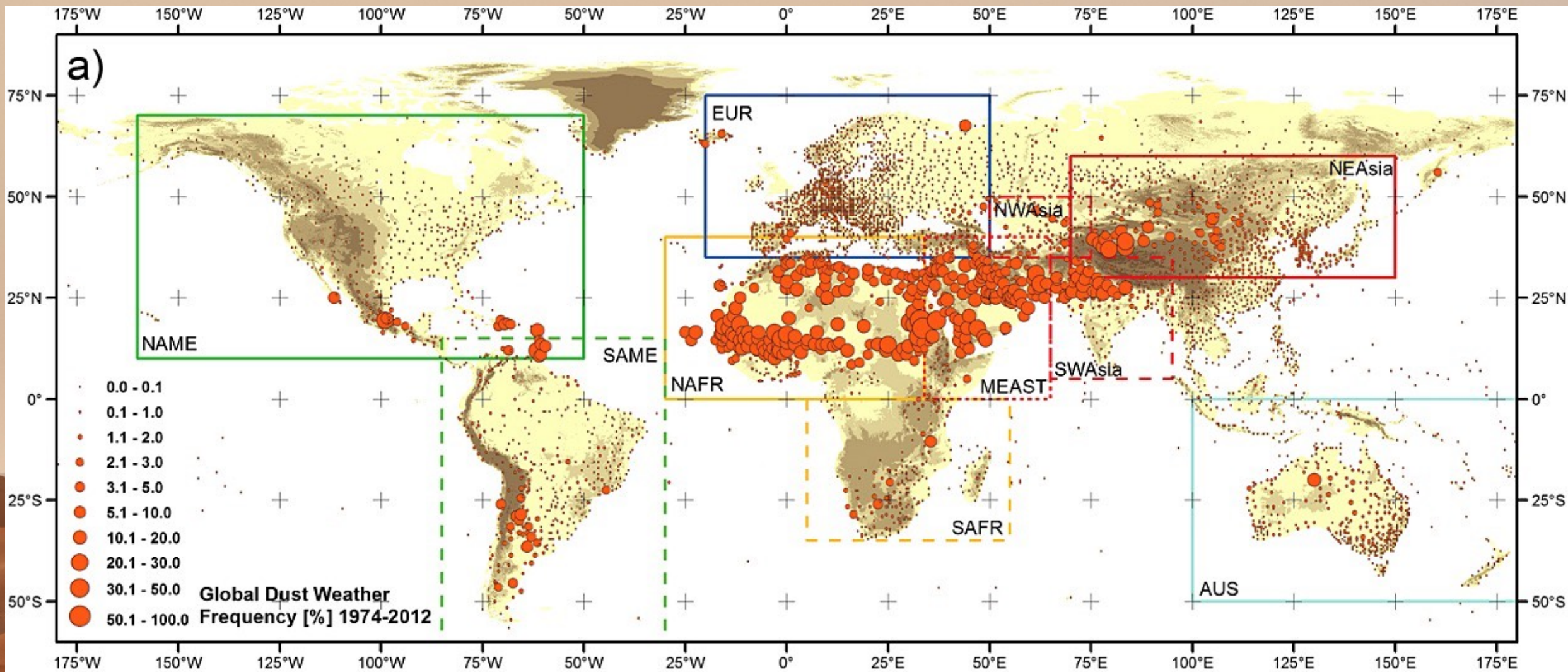
COST is a funding agency for research and innovation networks. COST Actions help connect researchers across Europe and enable scientists to grow their ideas by sharing them with their peers. This benefits research, careers and innovation.

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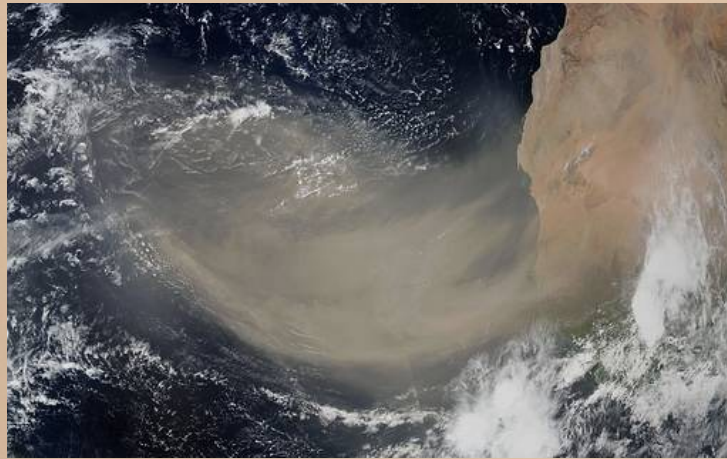
# Dust "belt"



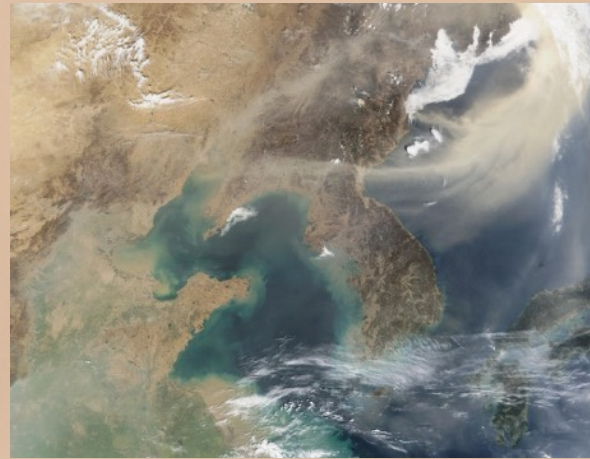
[Shao et al. \(2013\)](#)

# Dust transport over downwind areas

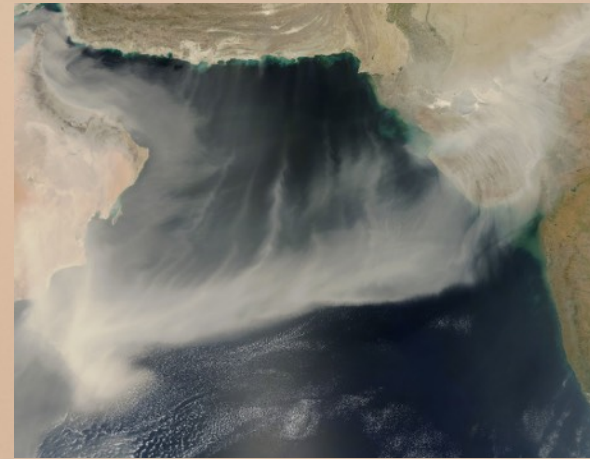
## Atlantic



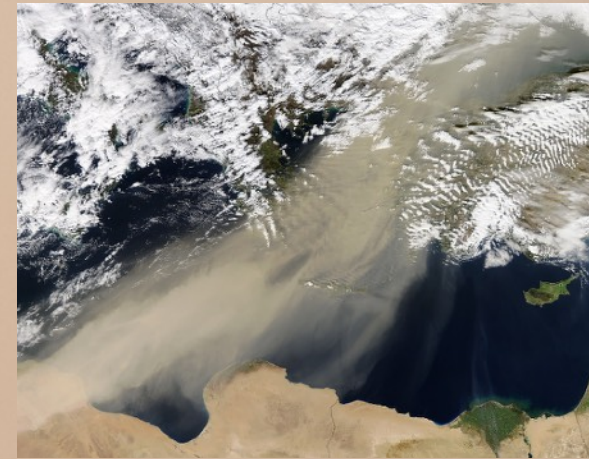
## Pacific



## Arabian Sea



## Mediterranean



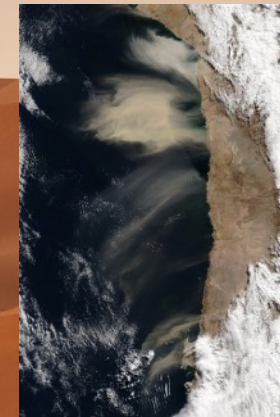
## Patagonia



## Namibia



## Chile

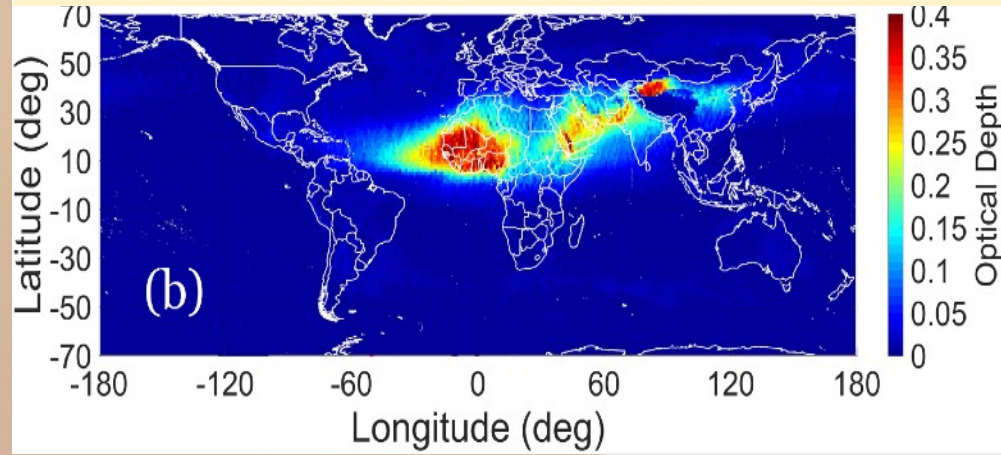


## Australia



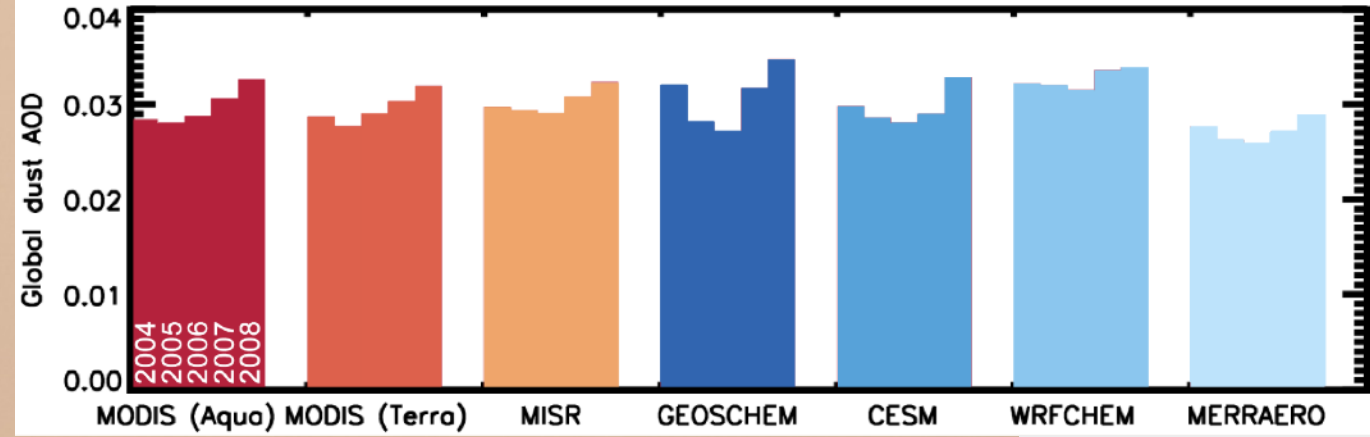
# Dust monitoring from space

## LIVAS-CALIPSO



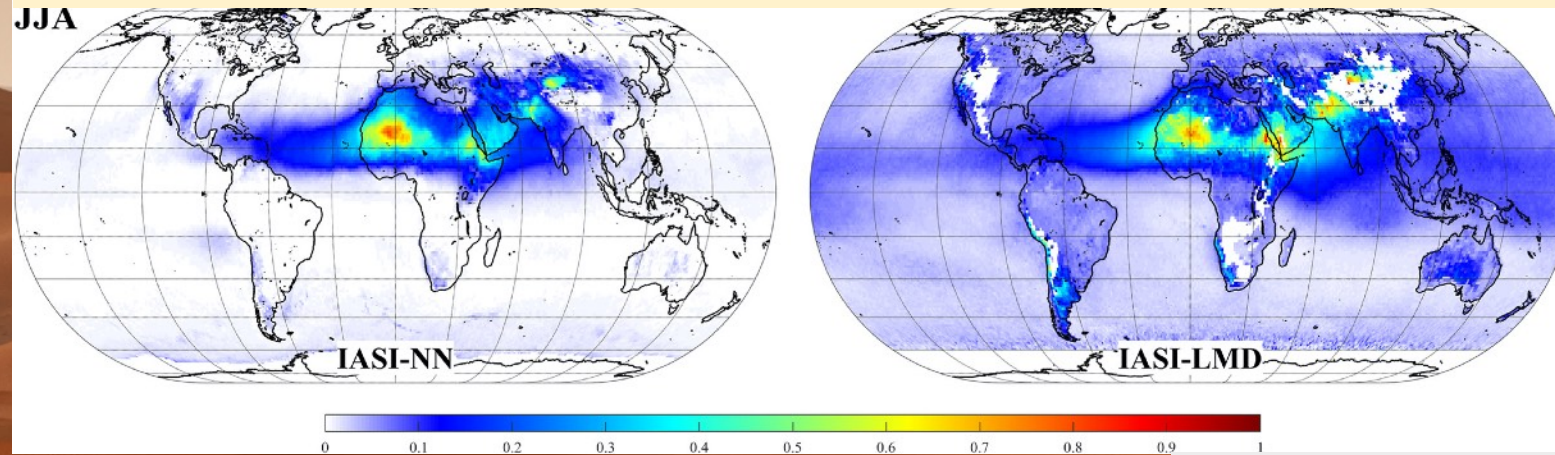
[Amiridis et al. \(2015\)](#)

## Passive spaceborne retrievals & models



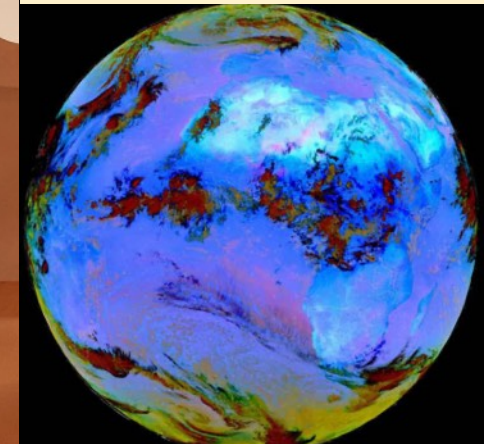
[Ridley et al. \(2016\)](#)

## IASI



[Clarisse et al. \(2019\)](#)

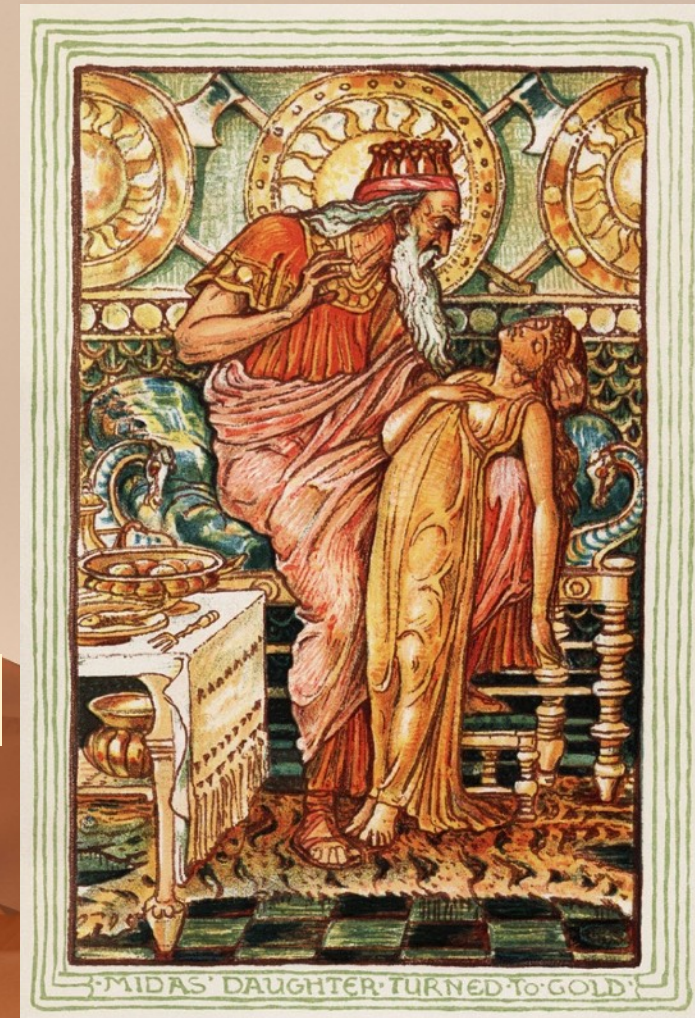
## METEOSAT



[EUMETSAT](#)

# ModIs Dust AeroSol [MIDAS]

- Synergy of passive spaceborne retrievals (**MODIS-Aqua**) and reanalysis products (**MERRA-2**)
- **Columnar dust optical depth at 550nm** along with the associated **uncertainty**
- **Global coverage at fine spatial resolution ( $0.1^\circ \times 0.1^\circ$ )**
- **15-year temporal coverage (2003-2017)** on a **daily** basis



[Illustration by Walter Crane \(1893\)](#)



# MIDAS publications

Atmos. Meas. Tech., 14, 309–334, 2021  
<https://doi.org/10.5194/amt-14-309-2021>  
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Atmospheric  
Measurement  
Techniques  
Open Access  
EGU

## ModIs Dust AeroSol (MIDAS): a global fine-resolution dust optical depth data set

Antonis Gkikas<sup>1</sup>, Emmanouil Proestakis<sup>1</sup>, Vassilis Amiridis<sup>1</sup>, Stelios Kazadzis<sup>2,3</sup>, Enza Di Tomaso<sup>4</sup>, Alexandra Tsekeri<sup>1</sup>, Eleni Marinou<sup>5</sup>, Nikos Hatzianastassiou<sup>6</sup>, and Carlos Pérez García-Pando<sup>4,7</sup>

Atmos. Chem. Phys., 22, 3553–3578, 2022  
<https://doi.org/10.5194/acp-22-3553-2022>  
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Atmospheric  
Chemistry  
and Physics  
Open Access  
EGU

## Quantification of the dust optical depth across spatiotemporal scales with the MIDAS global dataset (2003–2017)

Antonis Gkikas<sup>1</sup>, Emmanouil Proestakis<sup>1</sup>, Vassilis Amiridis<sup>1</sup>, Stelios Kazadzis<sup>2,3</sup>, Enza Di Tomaso<sup>4</sup>, Eleni Marinou<sup>1,5</sup>, Nikos Hatzianastassiou<sup>6</sup>, Jasper F. Kok<sup>7</sup>, and Carlos Pérez García-Pando<sup>4,8</sup>

Atmos. Chem. Phys., 21, 16499–16529, 2021  
<https://doi.org/10.5194/acp-21-16499-2021>  
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Atmospheric  
Chemistry  
and Physics  
Open Access  
EGU

## 15-year variability of desert dust optical depth on global and regional scales

Stavros-Andreas Logothetis<sup>1</sup>, Vasileios Salamalikis<sup>1</sup>, Antonis Gkikas<sup>2</sup>, Stelios Kazadzis<sup>3,4</sup>, Vassilis Amiridis<sup>2</sup>, and Andreas Kazantzidis<sup>1</sup>

### A DUST-DERIVED SATELLITE DATASET BY A.GKIKAS



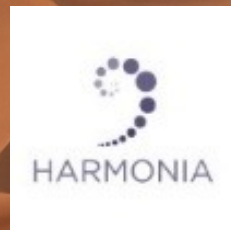
inDust webinar by Antonis Gkikas (National Observatory of Athens, Greece). The lecture focused on the presentation of MIDAS which is a global fine-resolution dust optical depth dataset and its applications for DA.

Download the webinar slides [here](#).

# inDust

# MIDAS development

Gkikas, A., Proestakis, E., Amiridis, V., Kazadzis, S., Di Tomaso, E., Tsekeri, A., Marinou, E., Hatzianastassiou, N., and Pérez García-Pando, C.: Modls Dust AeroSol (MIDAS): a global fine-resolution dust optical depth data set, *Atmos. Meas. Tech.*, 14, 309–334, <https://doi.org/10.5194/amt-14-309-2021>, 2021.

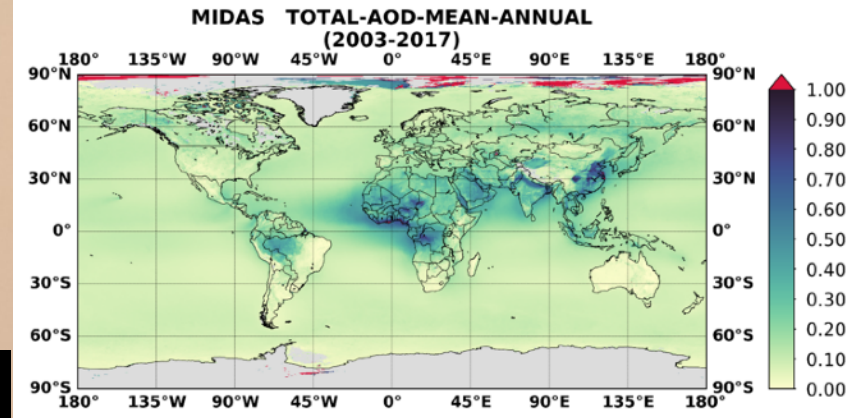


# Overview of the applied methodology

MODIS-Aqua AOD<sub>550nm</sub>

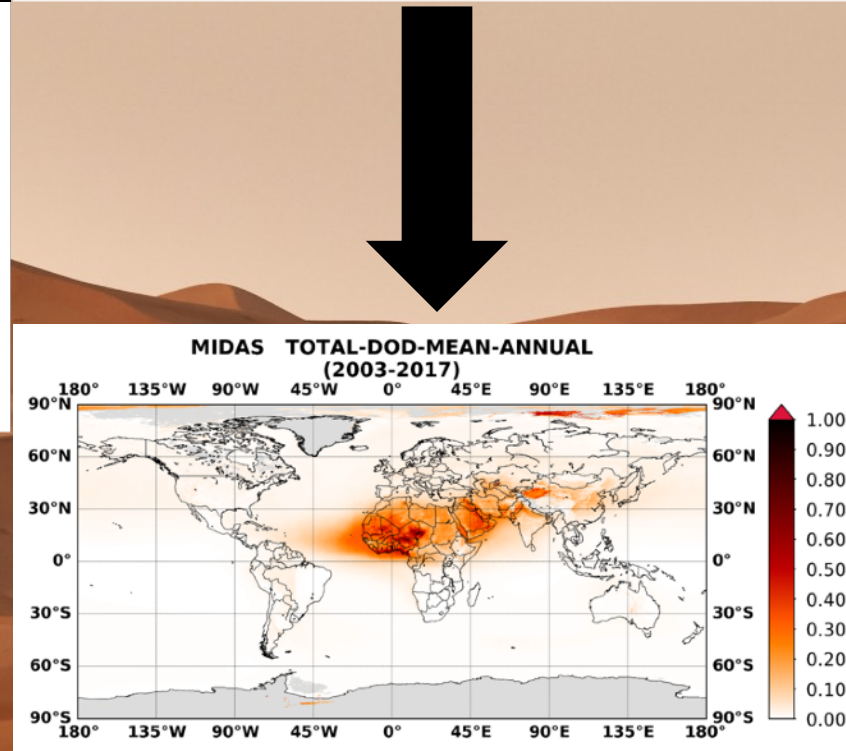
Derivation of MIDAS DOD  
[MODIS-MERRA-2]

MERRA-2 Dust Fraction (MDF)



Evaluation of MDF vs LDF

LIVAS Dust Fraction (LDF)



- Evaluation vs AERONET
- Intercomparison against MERRA-2 and LIVAS

MIDAS DOD<sub>550nm</sub>

# Derivation of the MIDAS dataset

## MERRA-2

**Database:** Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) [Randles et al., 2017]

**SDS:** Total and dust extinction at 550 nm

**Spatial/Temporal resolution:** 0.5° x 0.625° (lat-lon) / hourly

## MODIS - Aqua

**Sensor:** MODerate resolution Imaging Spectroradiometer [Levy et al., 2013]

**SDS:** AOD at 550 nm (Collection 6.1) → **quality screened**

**Spatial/Temporal resolution:** 10km x 10km (nadir) / 5min (Level 2)

$$MDF = \frac{AOD_{DUST;MERRA-2}}{AOD_{TOTAL;MERRA-2}}$$

Contribution of DOD to the total AOD based on MERRA-2 reanalysis

$$DOD_{MIDAS} = AOD_{MODIS} * MDF$$

Derivation of MIDAS DOD from MODIS AOD Level 2 retrievals

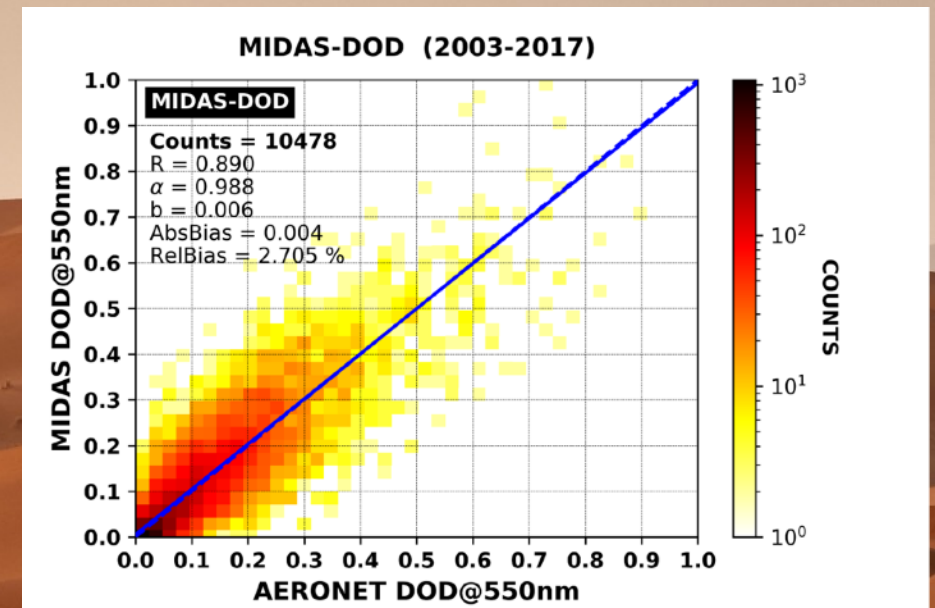
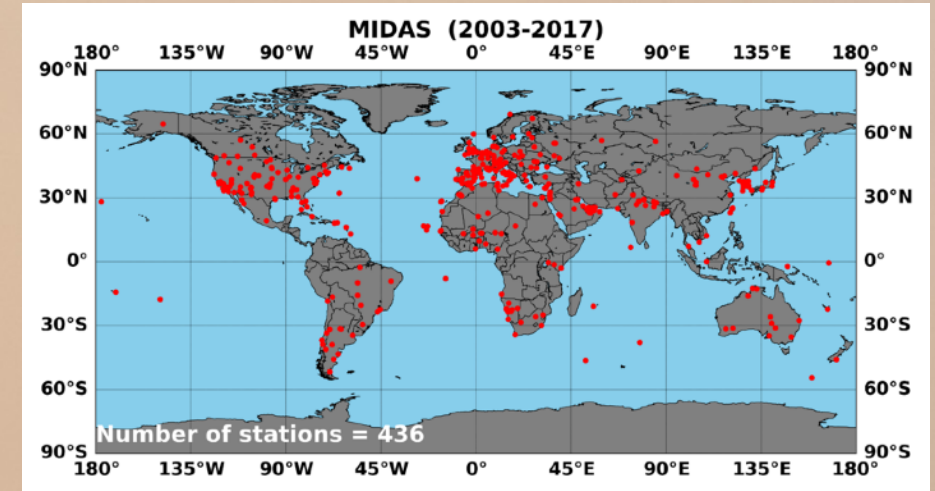
# Evaluation versus AERONET [Global metrics]

## AERONET data

- AERONET V3 (Giles et al., 2019) almucantar retrievals (Dubovik et al., 2006) – All points files
- Spectral AODs and Ångström exponent (440 – 870nm) – Level 2
- Spectral SSAs [Level 2 and Level 1.5]

## AERONET-derived DOD

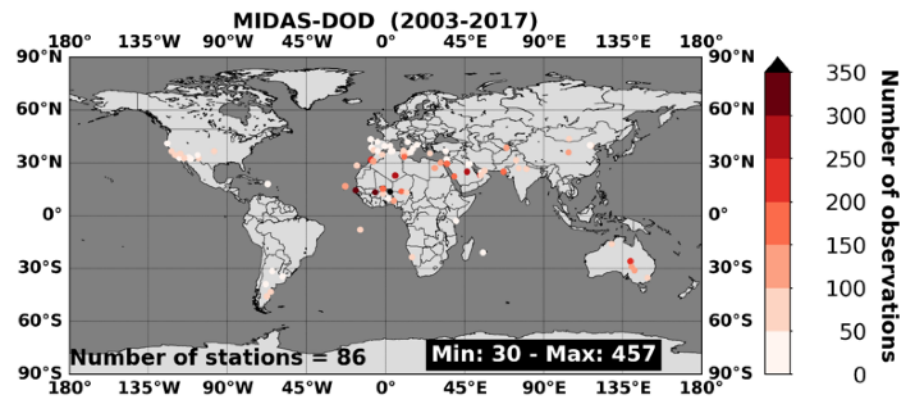
- Selection of records when  $\alpha_{440-870\text{nm}} \leq 0.75$  (predominance of coarse aerosols) and  $\text{SSA}_{675\text{nm}} - \text{SSA}_{440\text{nm}} > 0$  (dust discrimination from sea-salt particles)
- SSA: decreasing absorptivity for increasing wavelengths in the visible spectrum in pure or dust-rich environments (Giles et al., 2012).
- From coarse AODs (440, 675 and 870nm) it is calculated the Ångström exponent in order to obtain the coarse AOD at 550nm which is considered as the **AERONET-derived DOD**
- Mitigation of non-dust aerosols' contribution to the columnar aerosol load
- Fine dust particles are ignored



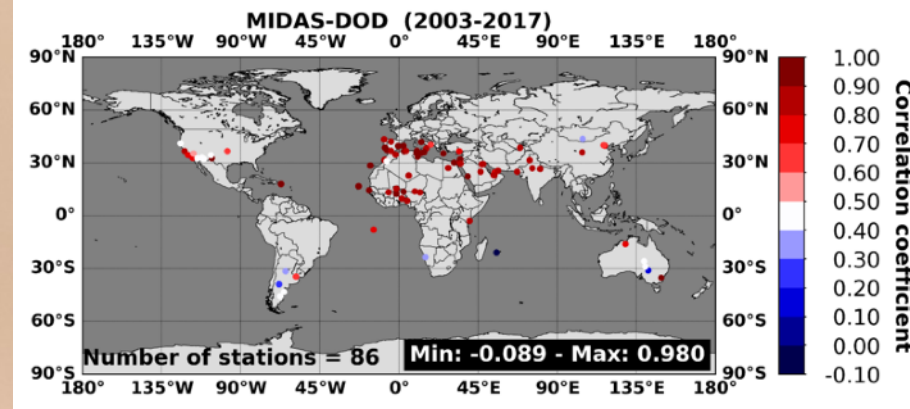
# Evaluation versus AERONET [Stations]

Selection of sites with at least 30 matchups between ground-based and spaceborne DODs

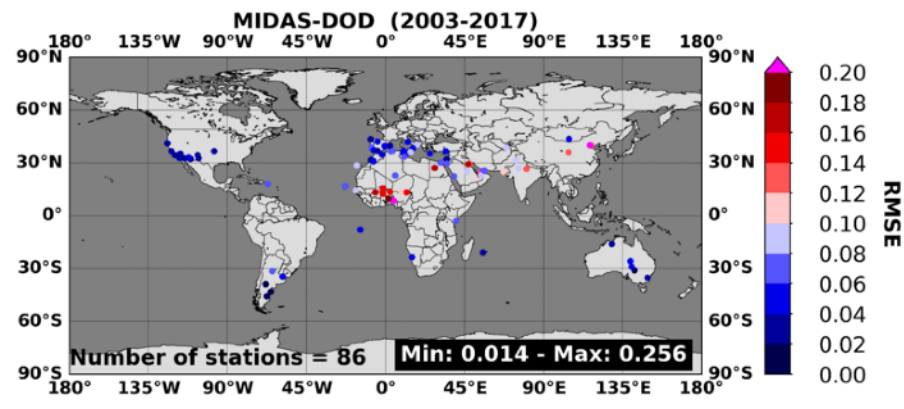
## Number of observations



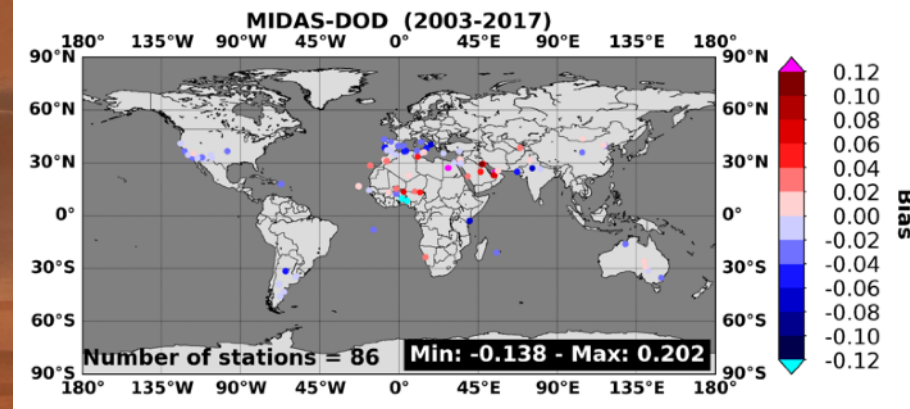
## Correlation coefficient



## Root-mean-square-error



## Bias

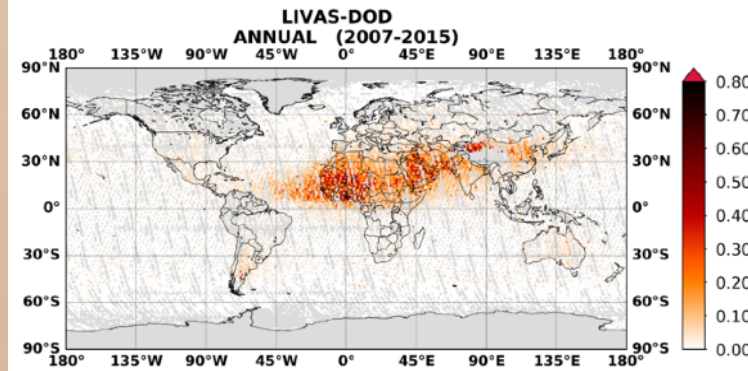


- Very high R values ( $>0.8$ ) over sources and downwind regions
- Maximum RMSE levels in the sub-Saharan
- Mainly positive biases are recorded in the main dust sources of planet (fine dust particles are not taken into account in AERONET DODs)

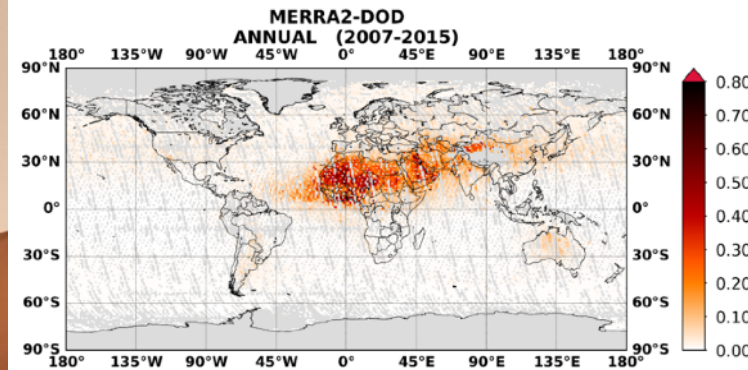
# Intercomparison of MERRA-2, LIVAS, MIDAS DODs

## Geographical distributions

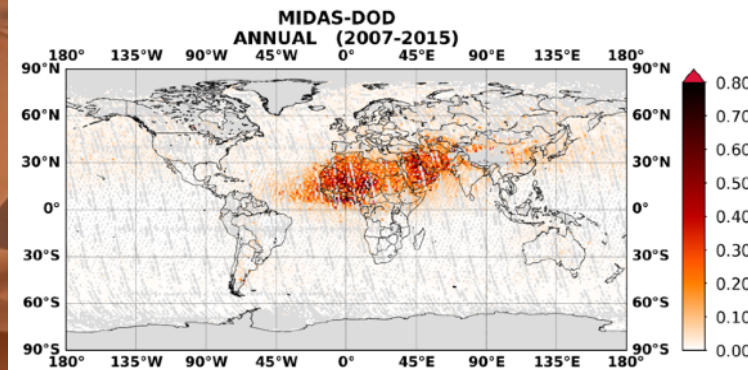
LIVAS



MERRA-2



MIDAS

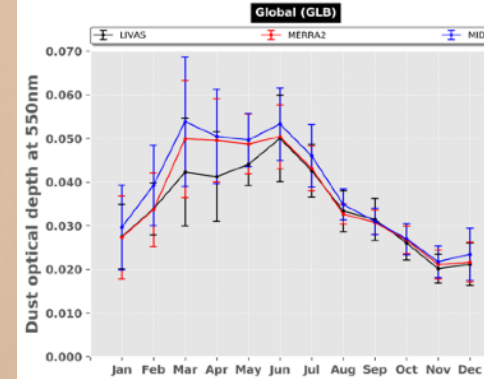


2007-2015  
1°x1°

## Intra-annual variation

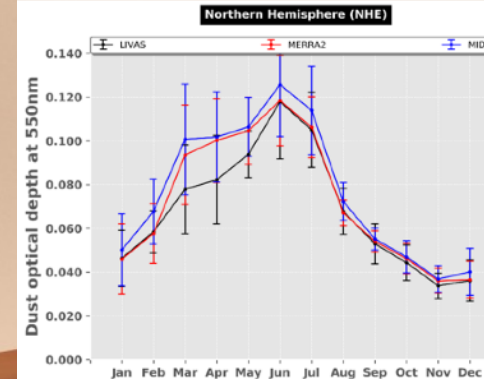
Global

0.029 | 0.031 | 0.033



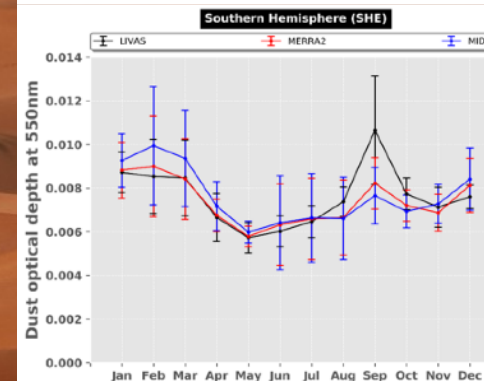
N. Hemisphere

0.051 | 0.056 | 0.060



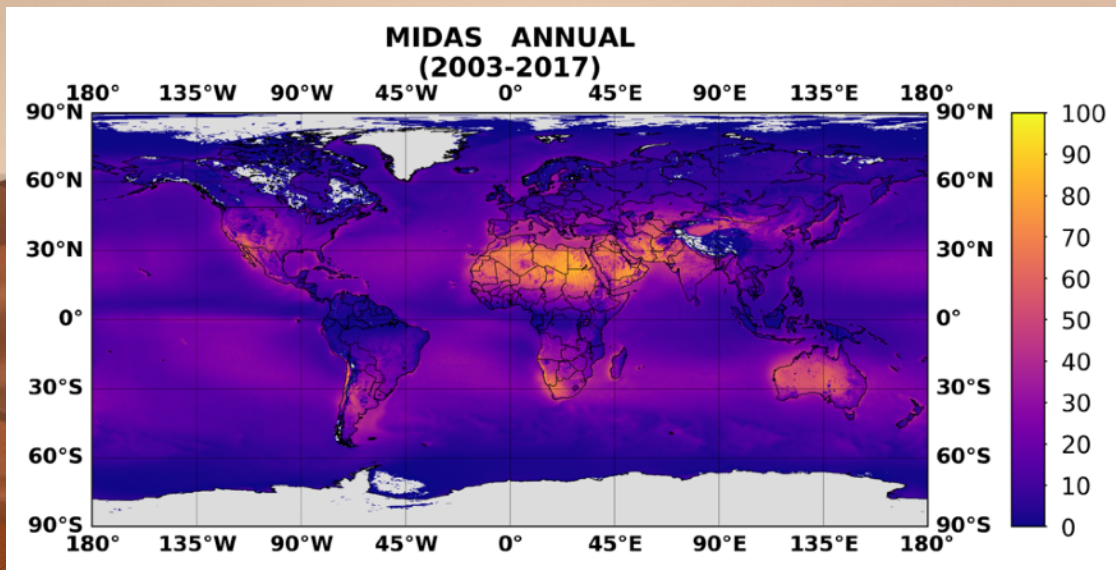
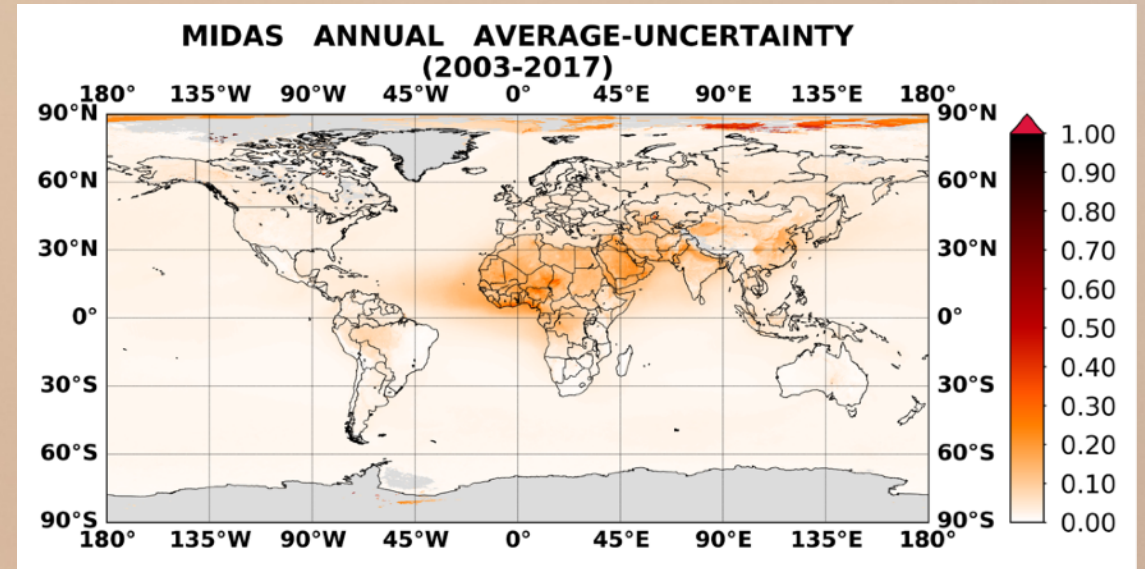
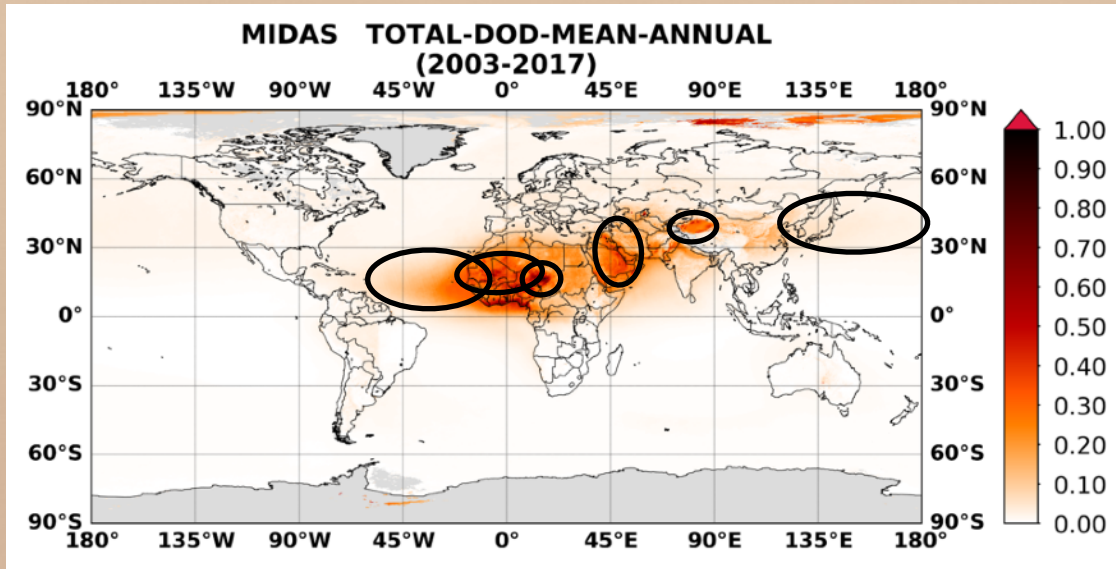
S. Hemisphere

0.008 | 0.008 | 0.008



LIVAS  
MERRA-2  
MIDAS

# MIDAS DOD annual global patterns

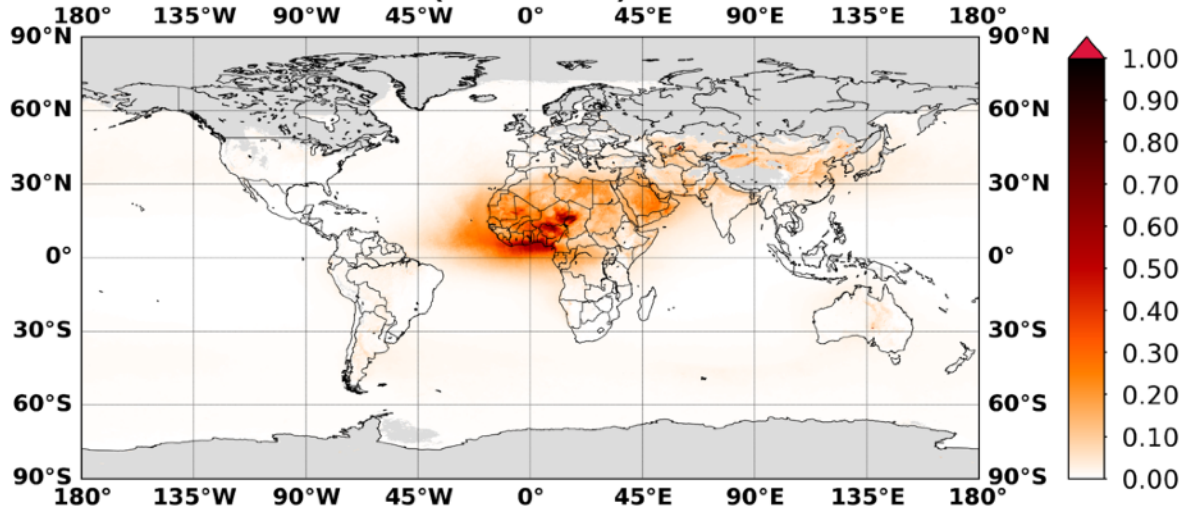


- Maximum DODs up to  $\sim 1.2$  in the Bodélé Depression (northern Lake Chad)
- Moderate-to-high DODs are recorded in the W. Sahara, Middle East and the Taklamakan Desert
- Dust transport over the Atlantic and Pacific Oceans
- Average of DOD uncertainties (up to 0.5) scales with DOD
- MIDAS DOD availability is higher than 70% in areas less affected by clouds

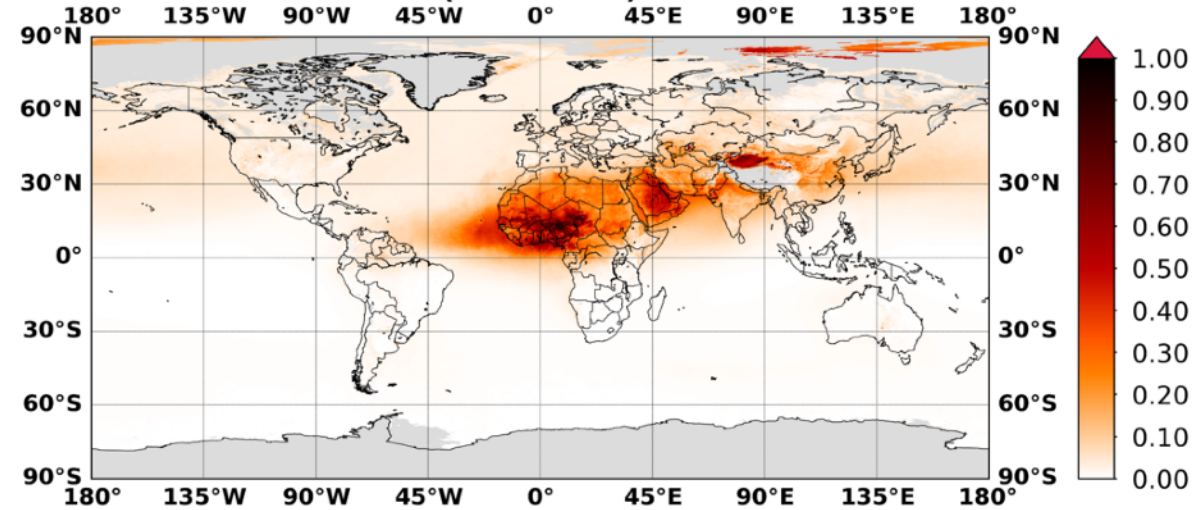


# MIDAS DOD seasonal global patterns

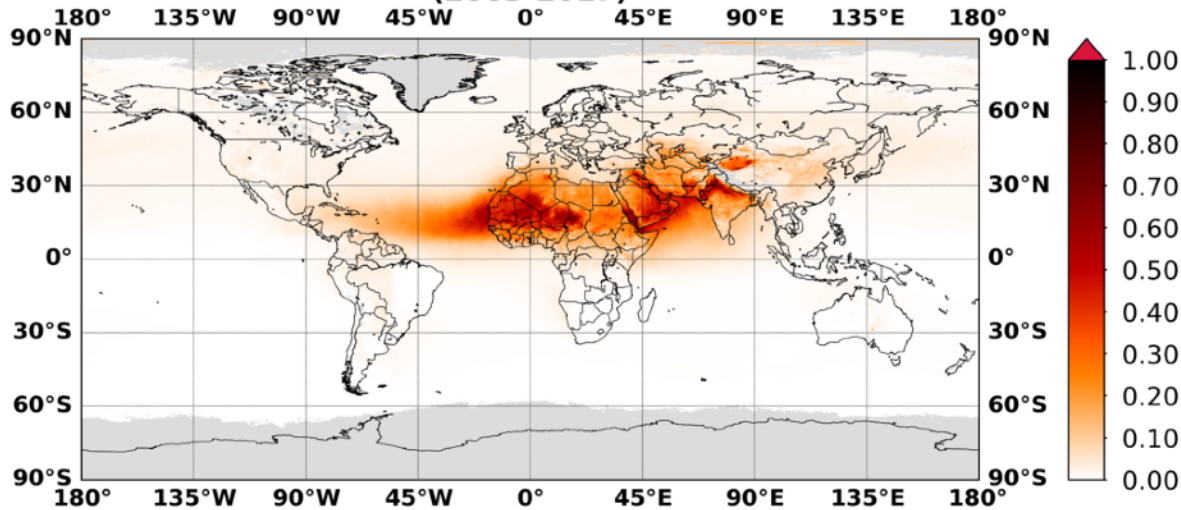
**MIDAS TOTAL-DOD-MEAN-DJF  
(2003-2017)**



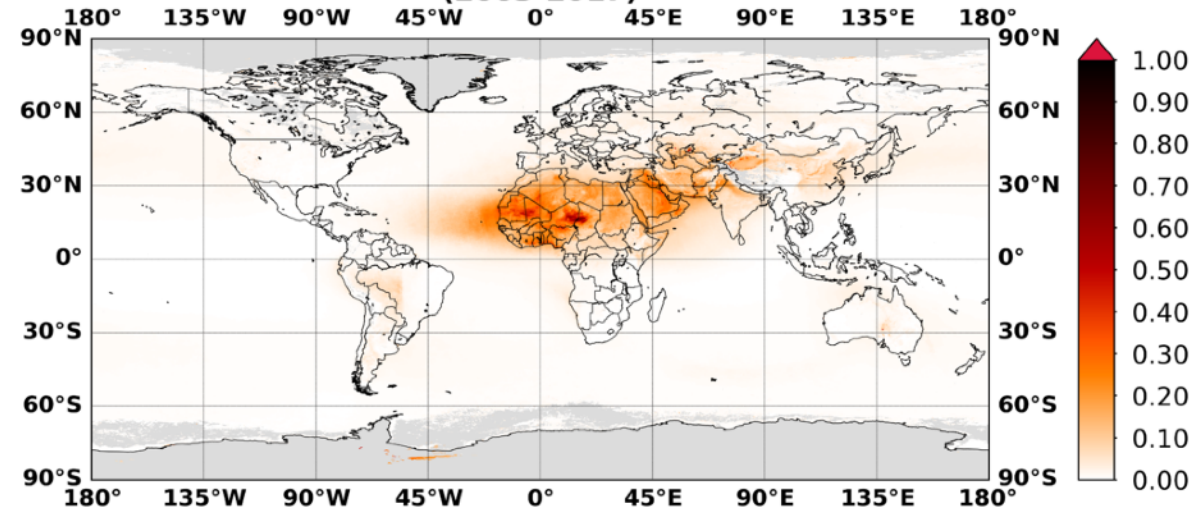
**MIDAS TOTAL-DOD-MEAN-MAM  
(2003-2017)**



**MIDAS TOTAL-DOD-MEAN-JJA  
(2003-2017)**

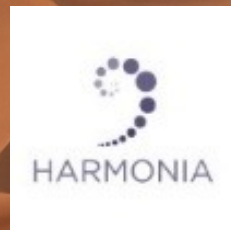


**MIDAS TOTAL-DOD-MEAN-SON  
(2003-2017)**



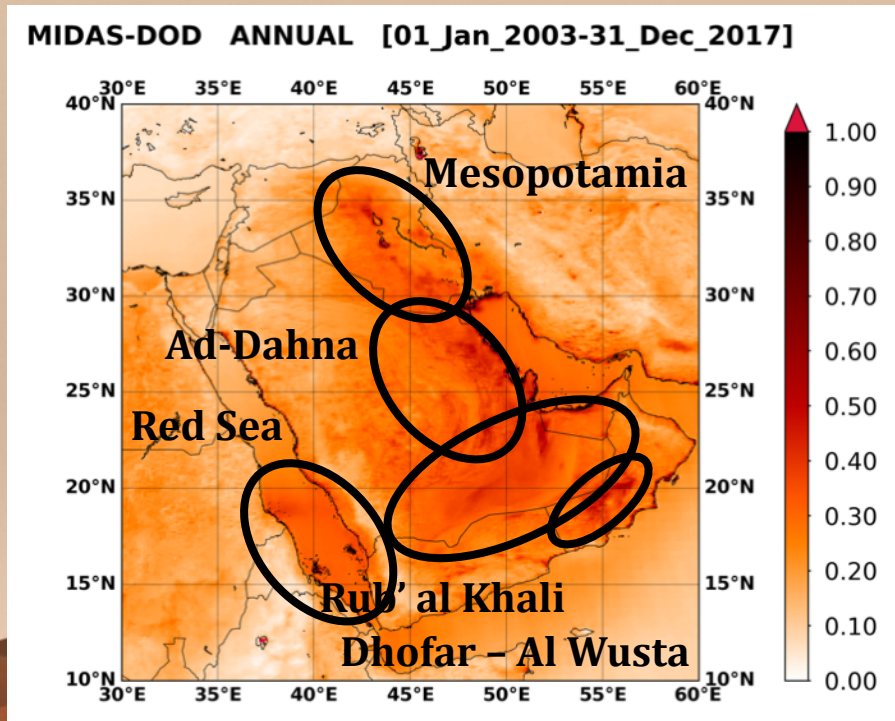
# Global and regional dust climatologies

Gkikas, A., Proestakis, E., Amiridis, V., Kazadzis, S., Di Tomaso, E., Marinou, E., Hatzianastassiou, N., Kok, J. F., and García-Pando, C. P.: Quantification of the dust optical depth across spatiotemporal scales with the MIDAS global dataset (2003–2017), *Atmos. Chem. Phys.*, 22, 3553–3578, <https://doi.org/10.5194/acp-22-3553-2022>, 2022.

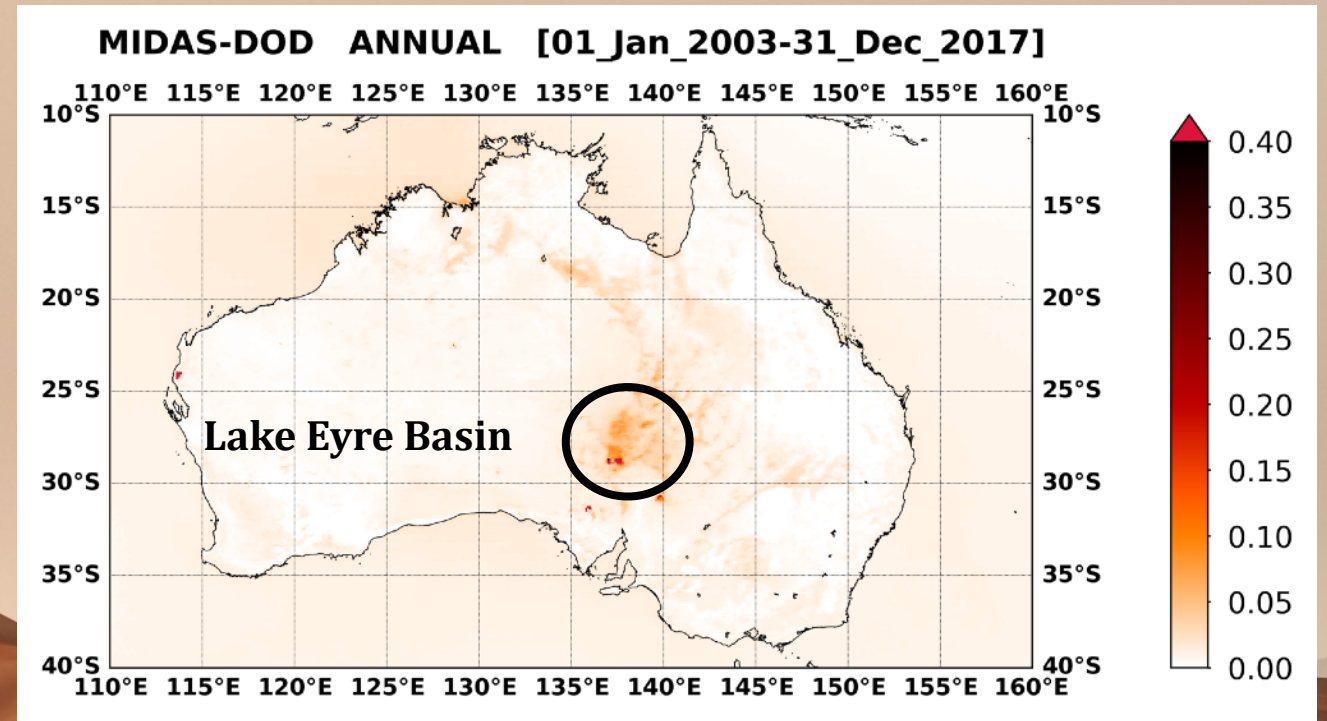


# Focus on dust sources and downwind areas

## Middle East

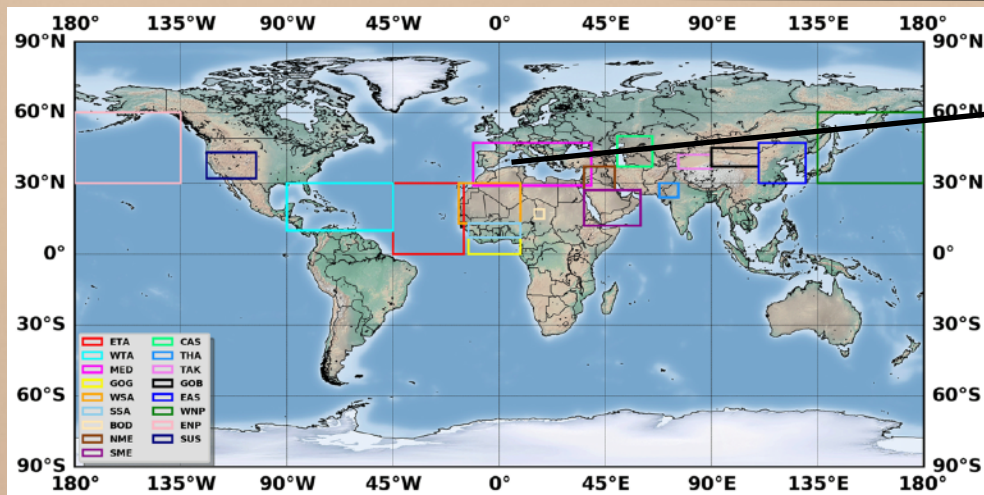


## Australia



**Description of dust aerosols' regime in 9 regions of the planet encompassing the major sources and areas subjected to dust transport**

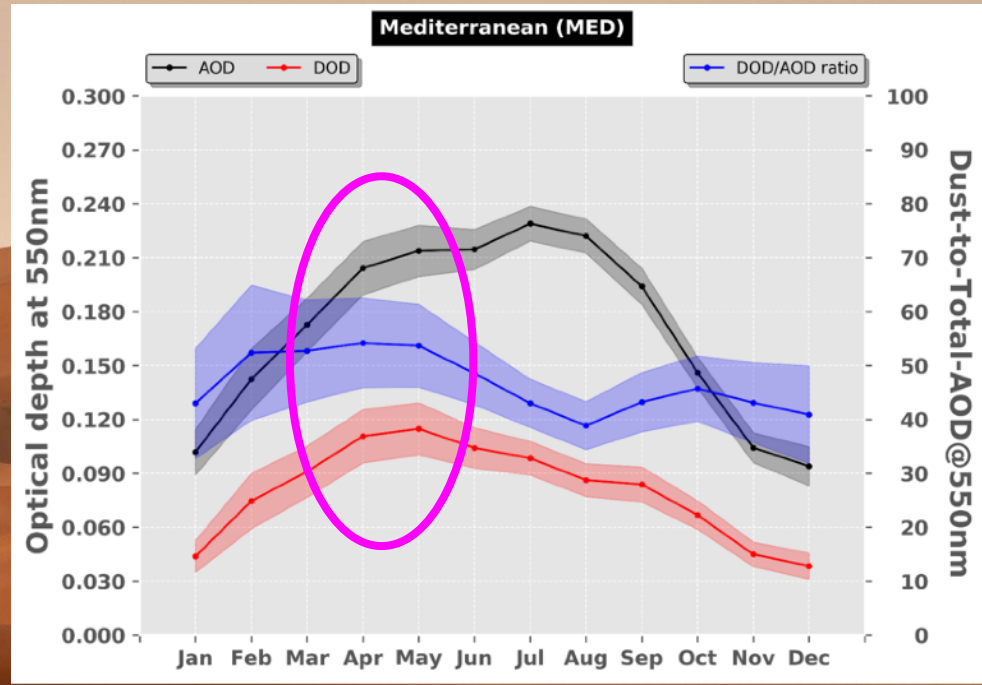
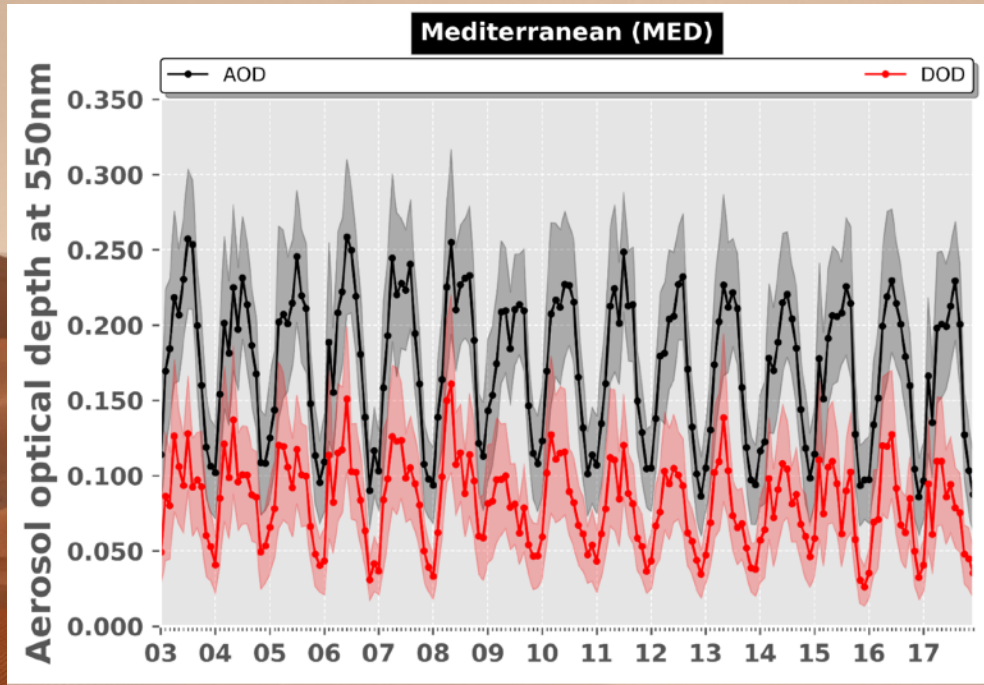
# Interannual and intra-annual DOD variability



**Mediterranean**

**AOD | DOD | DOD-AOD ratio**

**Stronger dust loads and higher dust contribution to the total AOD in spring**



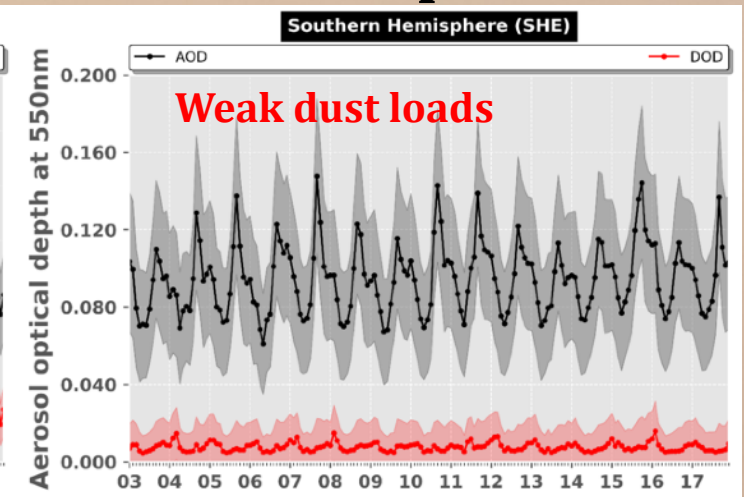
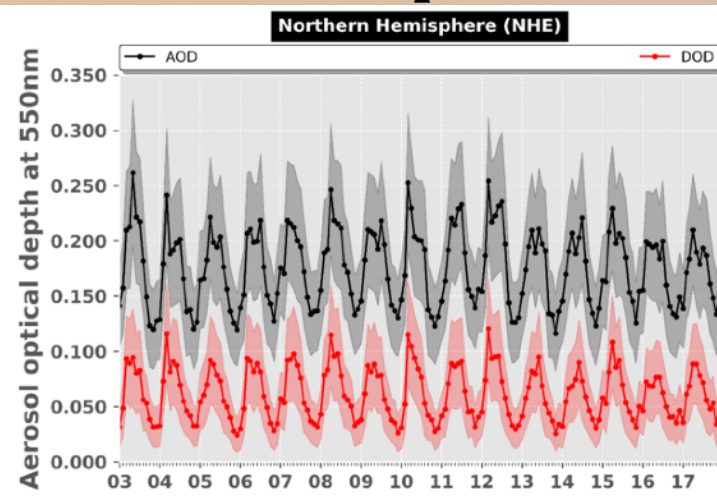
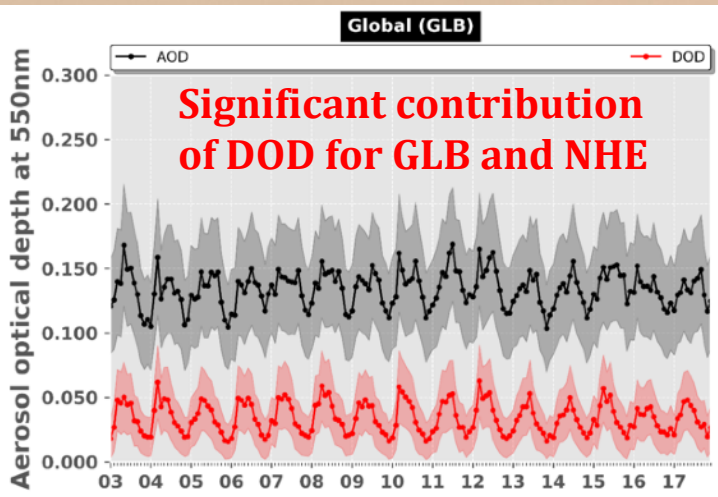
# Temporal variation of global and hemispherical averages

Interannual

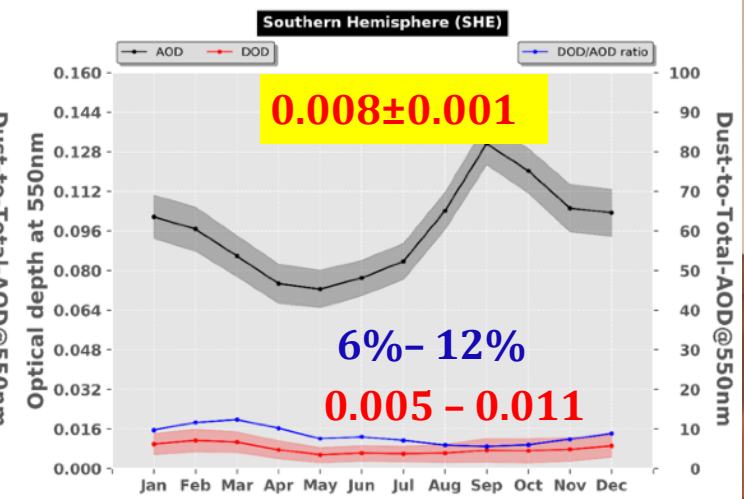
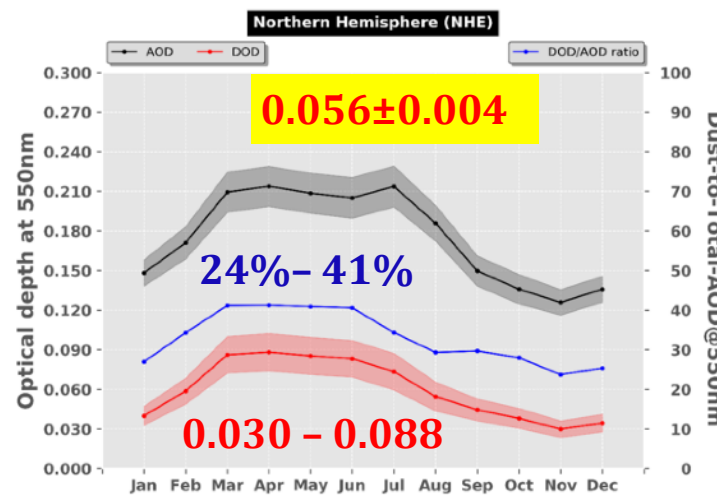
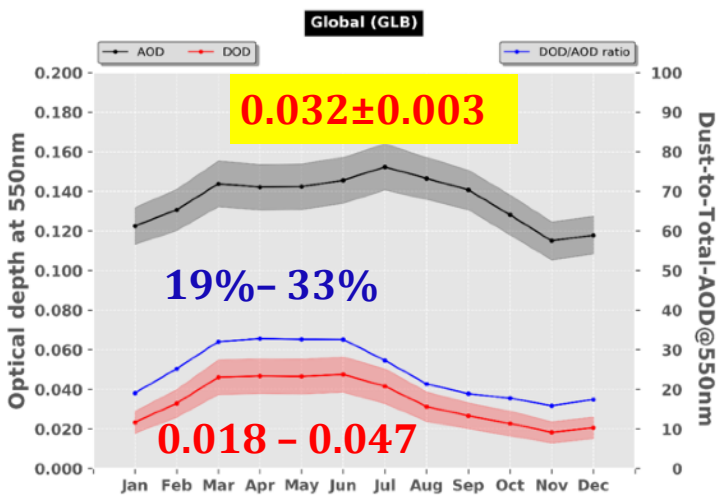
Global

N. Hemisphere

S. Hemisphere



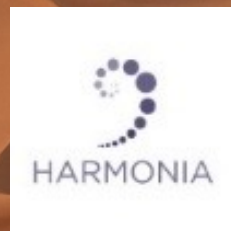
Intra-annual



AOD | DOD | DOD-AOD ratio

# Global and regional dust trends

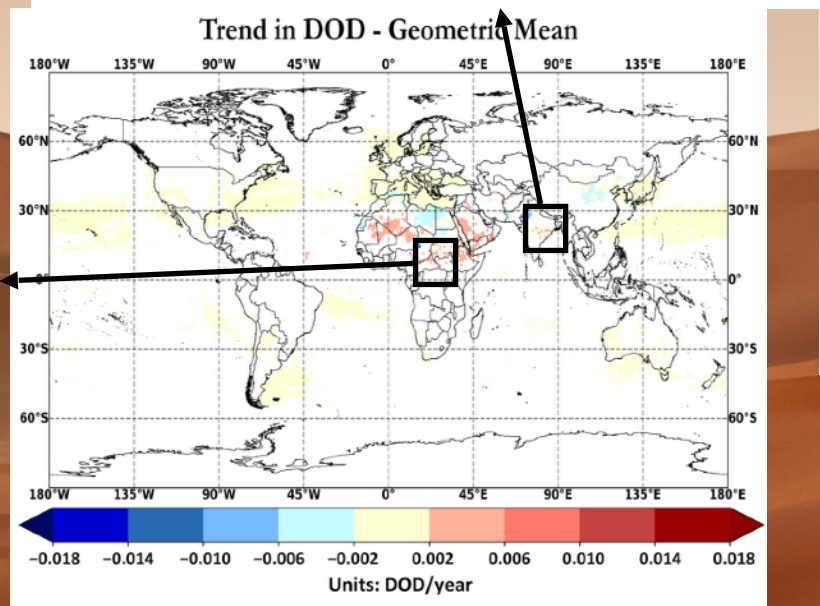
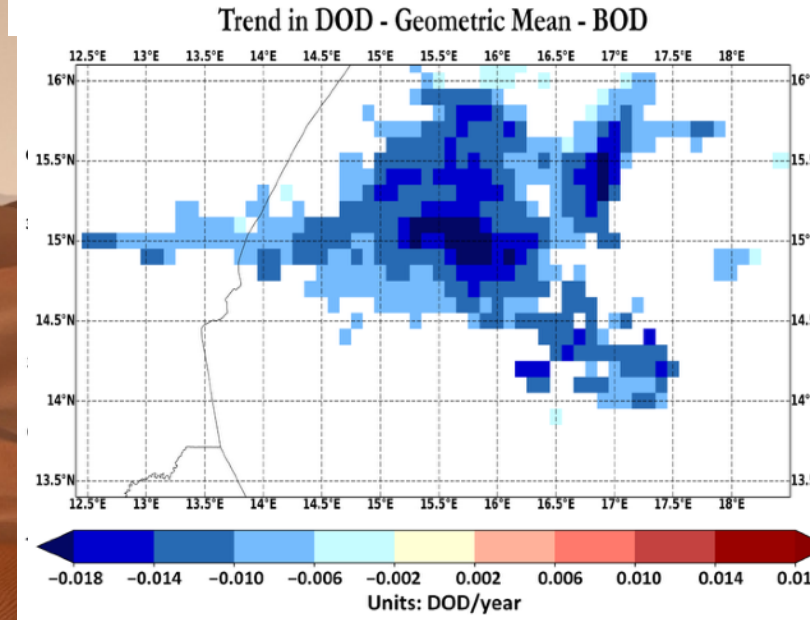
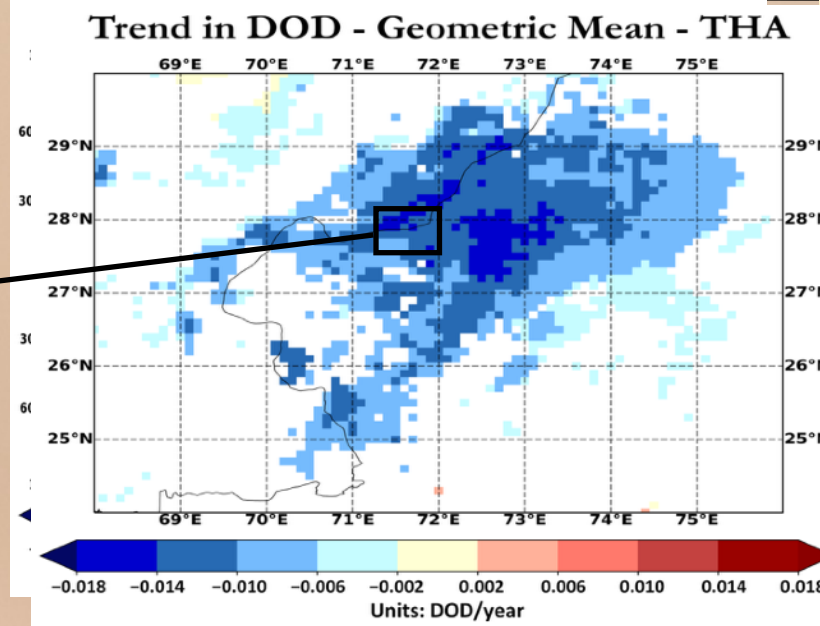
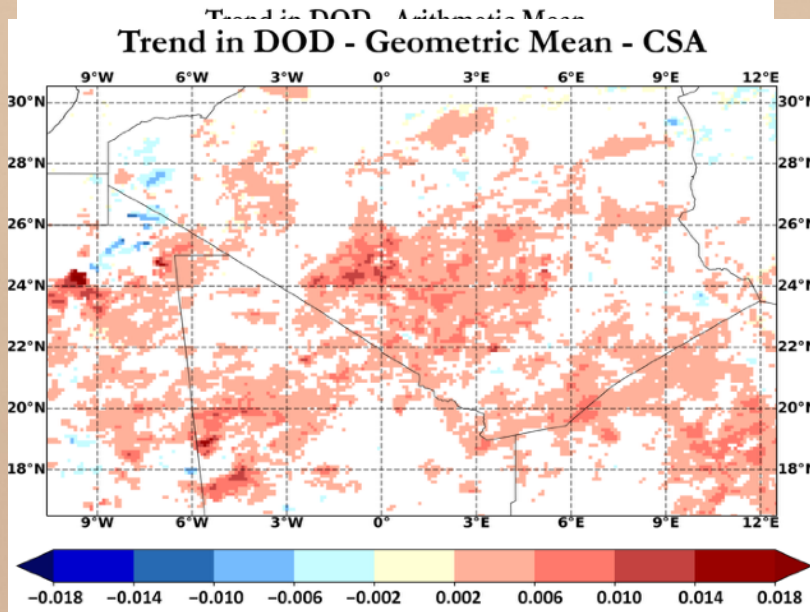
Logothetis, S.-A., Salamalikis, V., Gkikas, A., Kazadzis, S., Amiridis, V., and Kazantzidis, A.: 15-year variability of desert dust optical depth on global and regional scales, *Atmos. Chem. Phys.*, 21, 16499–16529, <https://doi.org/10.5194/acp-21-16499-2021>, 2021.



# Dust trends [2003-2017]

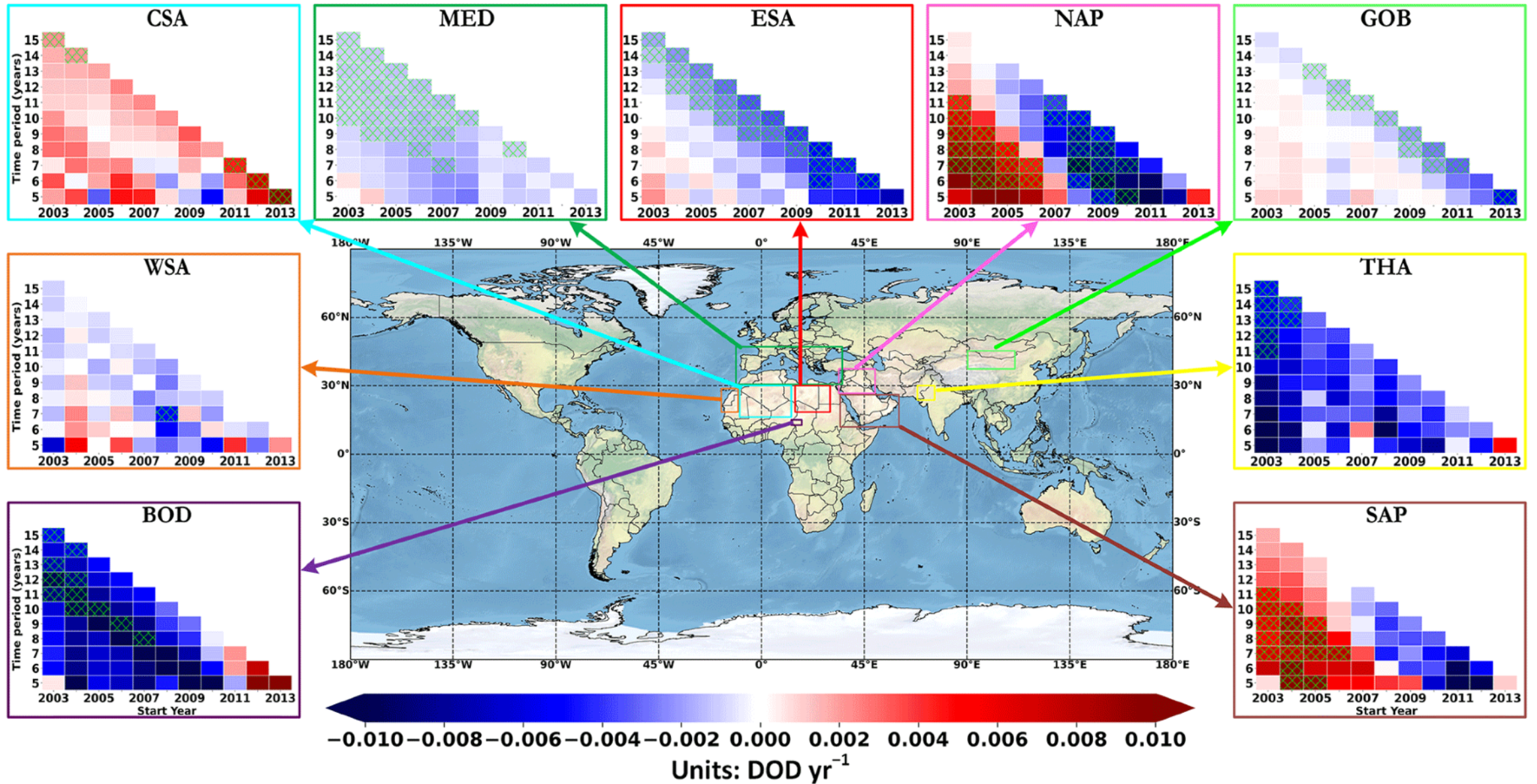
0.1° x 0.1°

1° x 1°



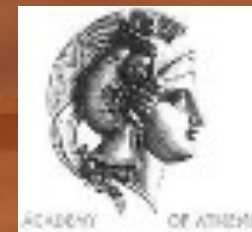
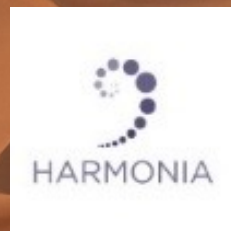
- Calculation of monthly arithmetic and geometric averages when at least 6 days are available at each grid-cell
- Trends of deseasonalized DODs when at least 5 out of 15 years are available (Hsu et al., 2012)
- 95% confidence level (Weatherhead et al., 1998)
- Maximum **positive trends** in the western part of Sahara
- Maximum **negative trends** in the Bodélé and the Thar Desert
- **Contributing factors on the obtained DOD trends (ongoing work)**

# Dust trends in regions of interest

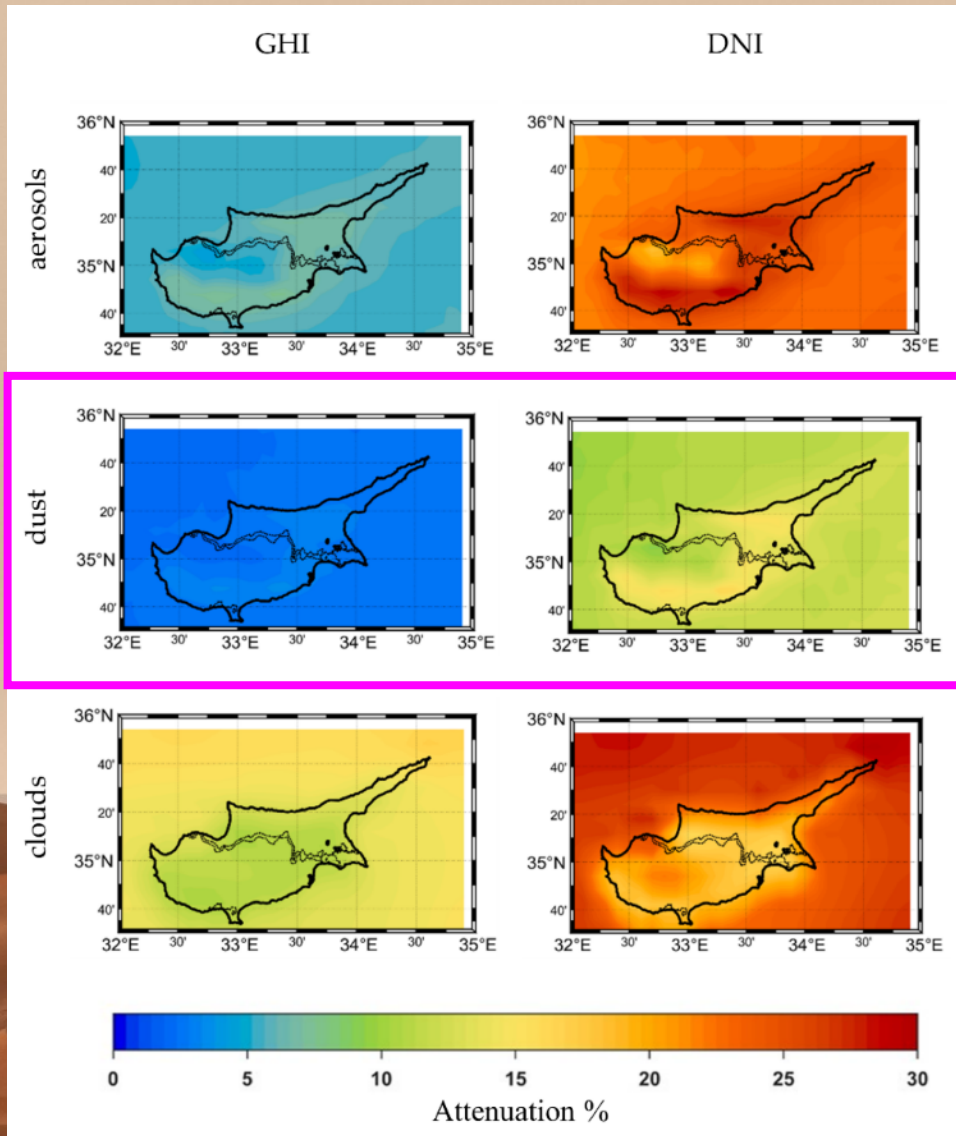




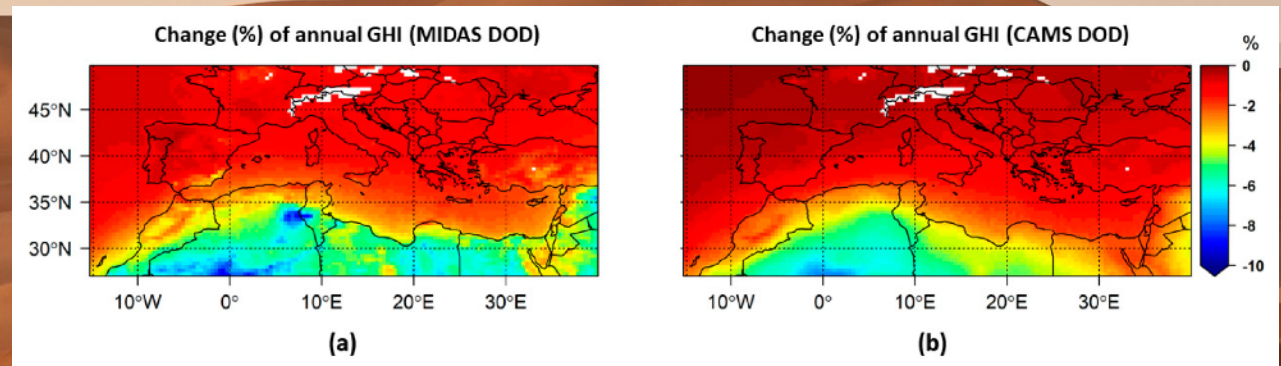
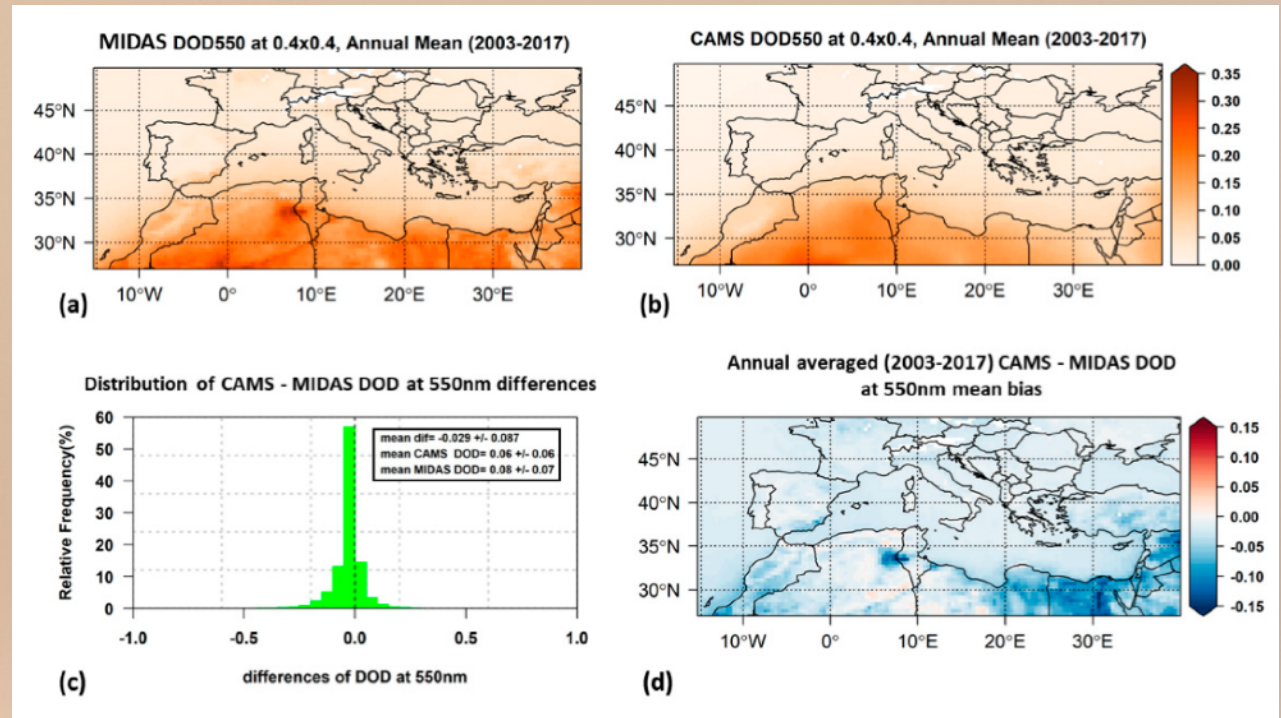
# MIDAS dataset exploitation



# Radiative effects

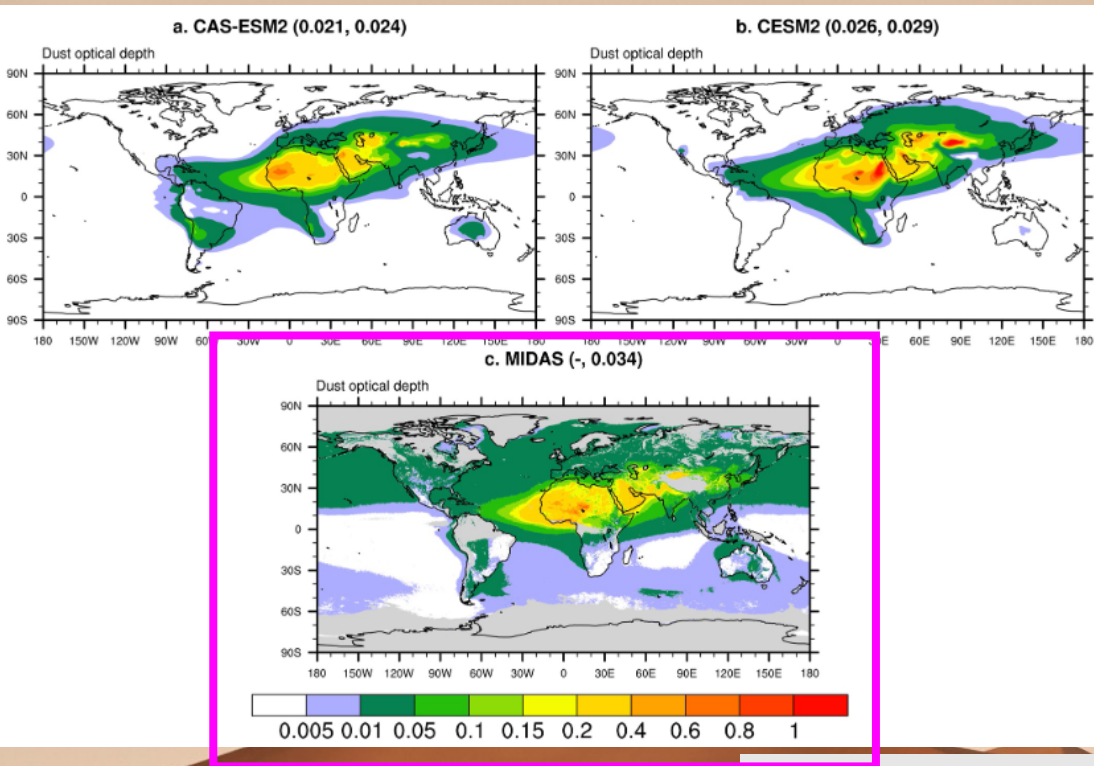


[Fountoulakis et al. \(2021\)](#)

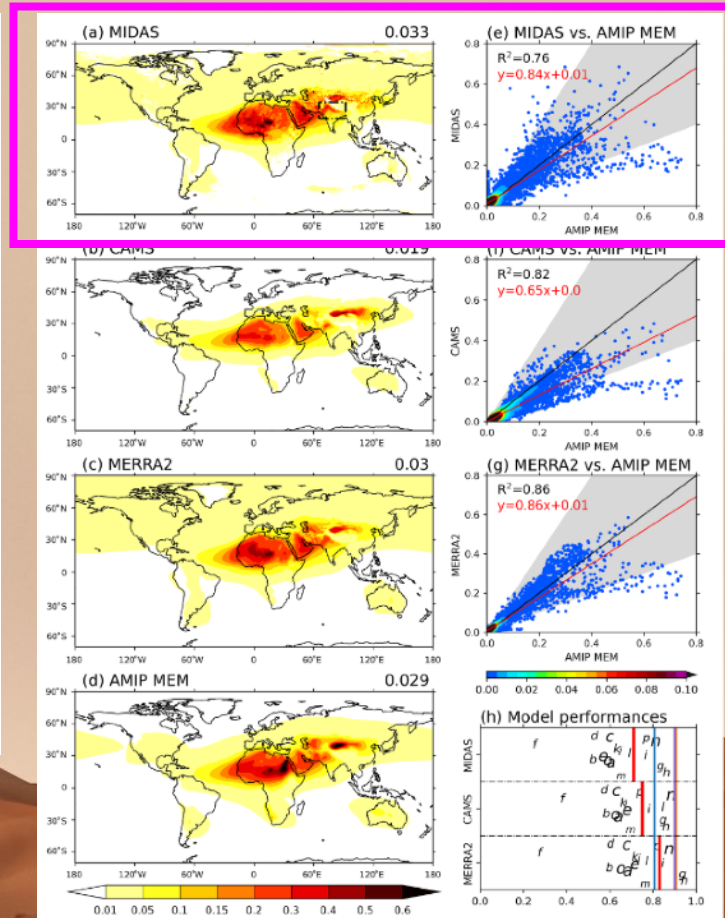


[Papachristopoulou et al. \(2022\)](#)

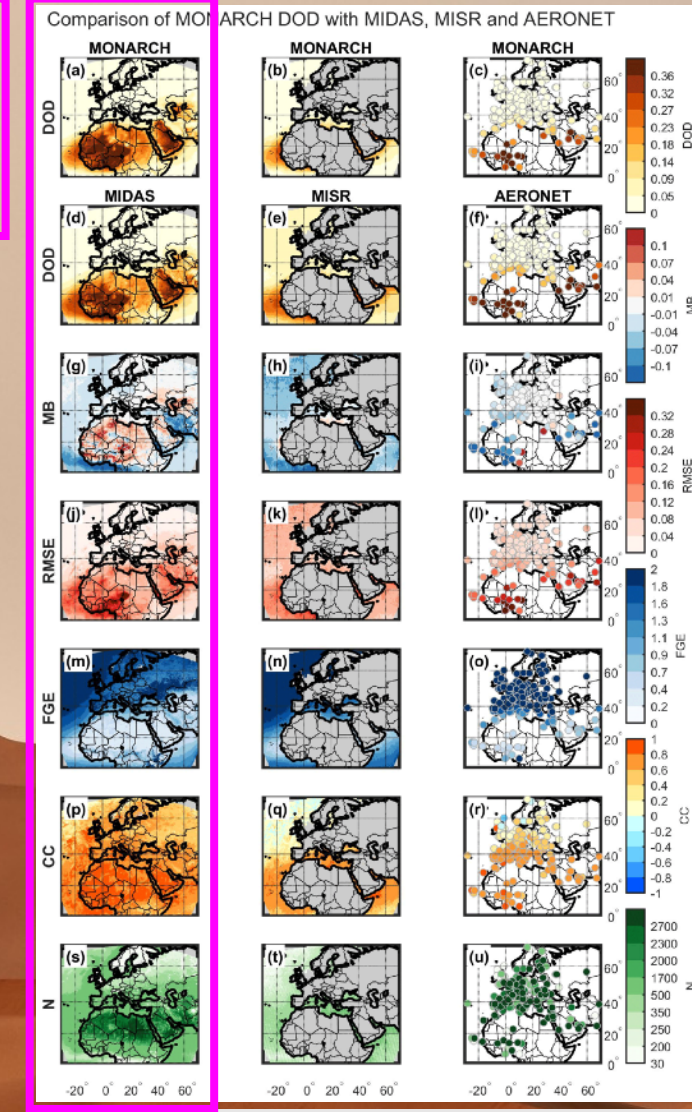
# Model evaluation



[Wu et al. \(2021\)](#)



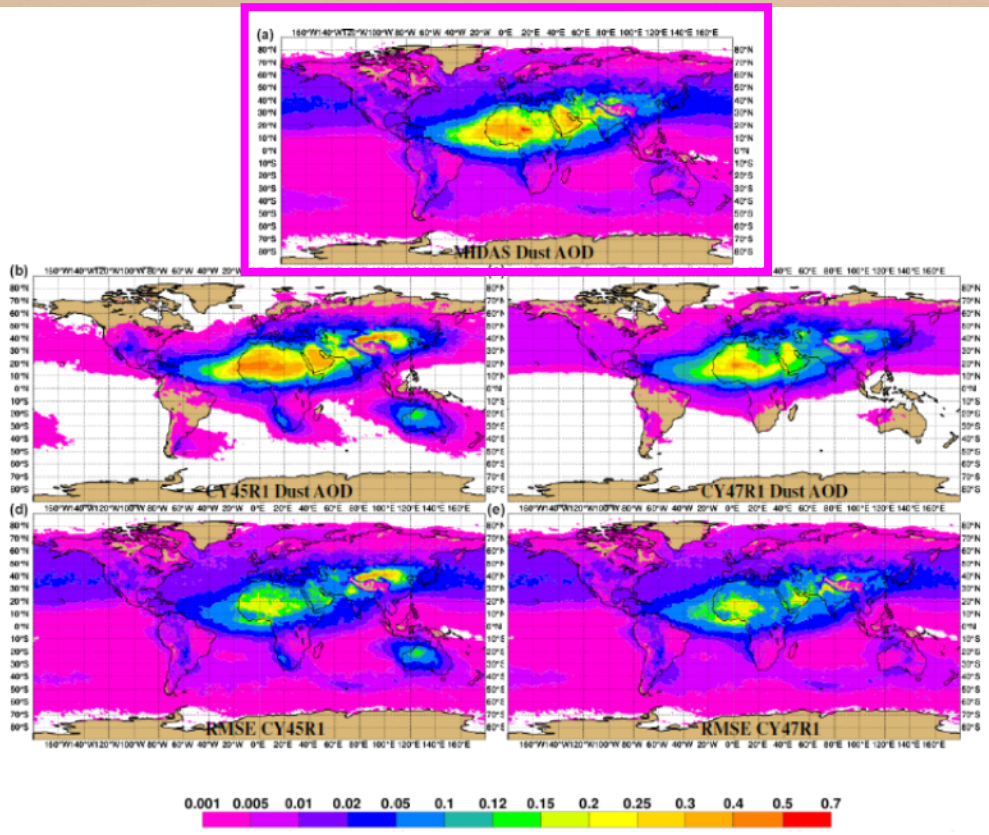
[Zao et al. \(2022\)](#)



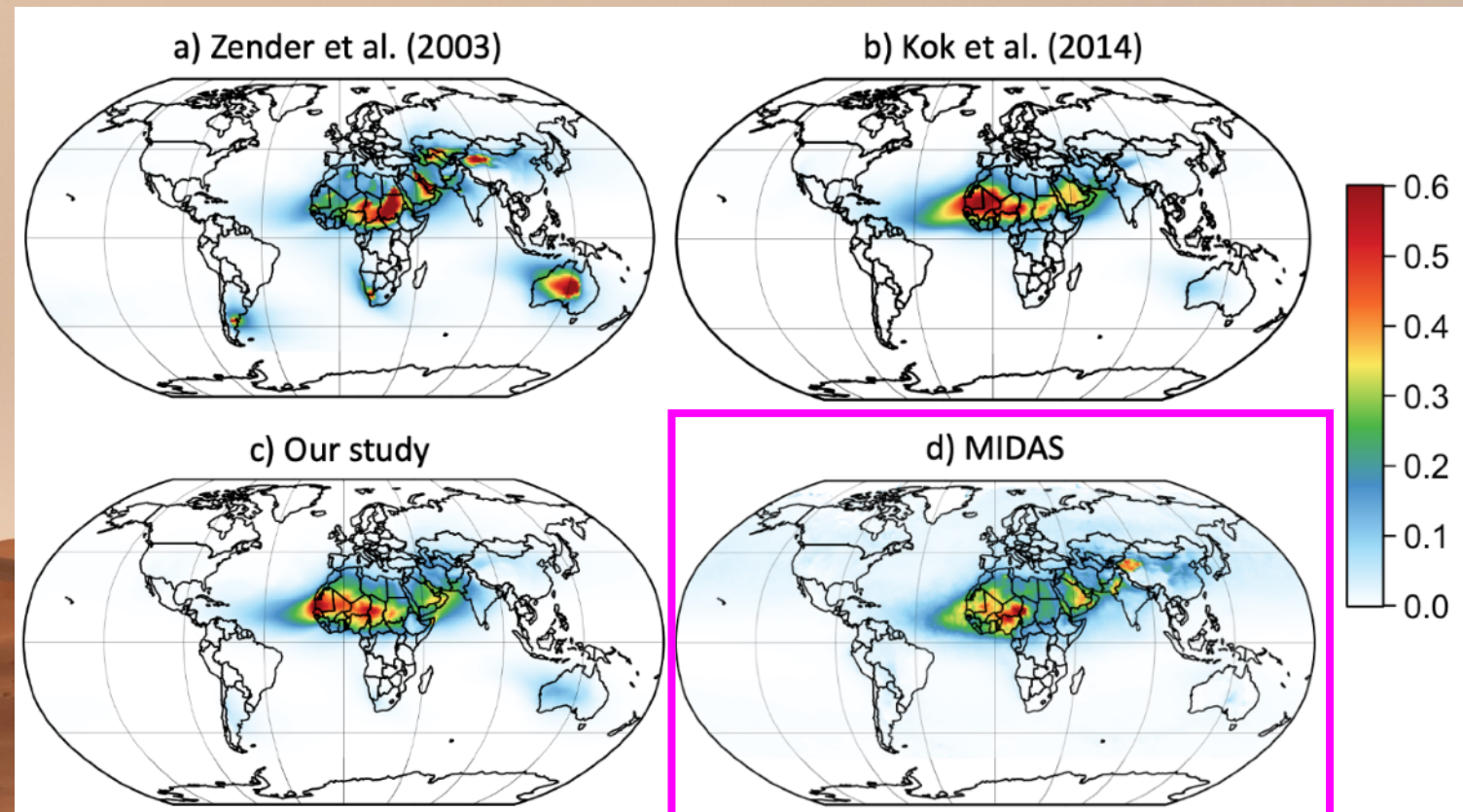
[Mytilinaios et al. \(2023\)](#)

# Model evaluation

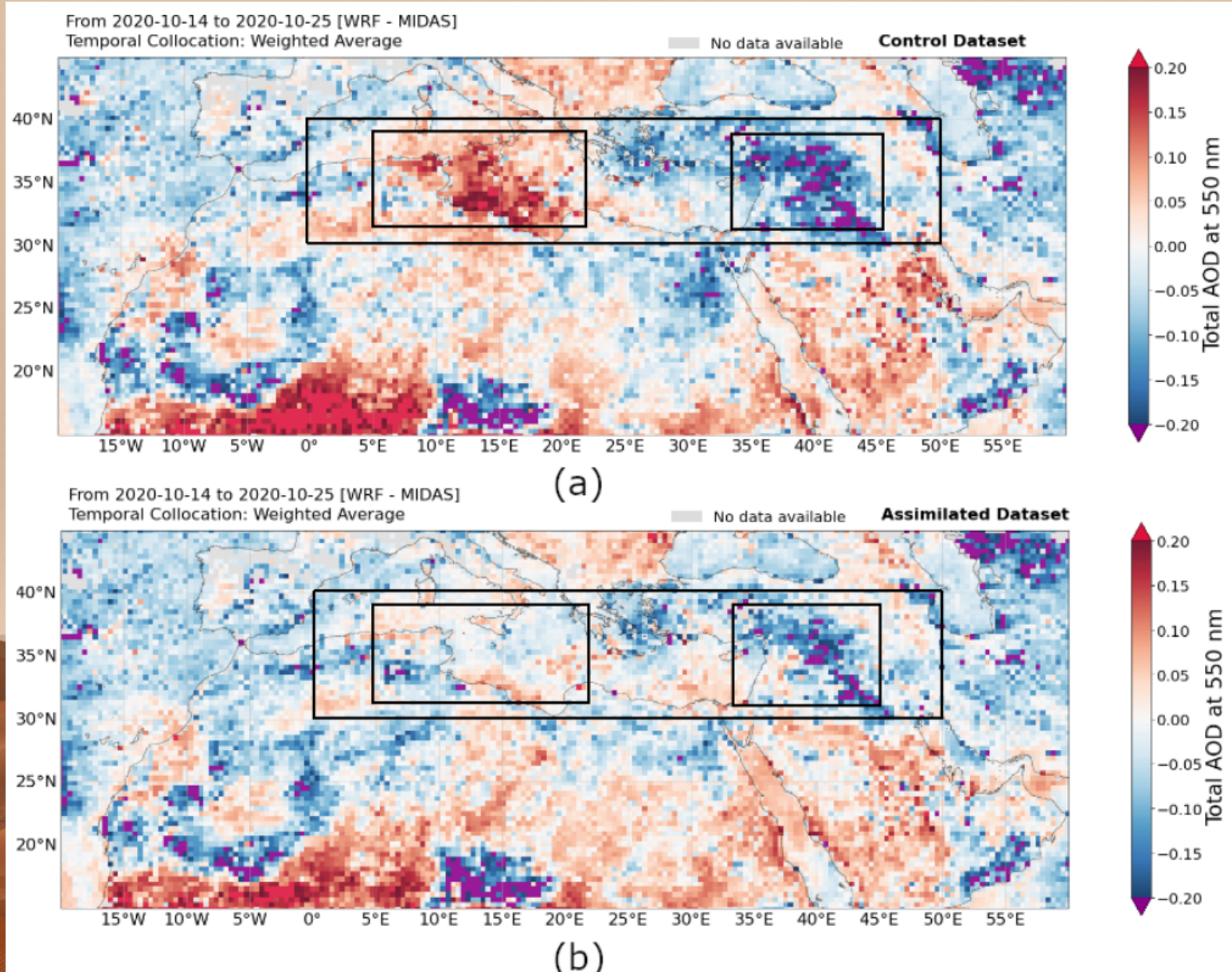
[Remy et al. \(2022\)](#)



[Leung et al. \(2023\)](#)



# Model evaluation



[Kiriakidis et al. \(2023\)](#)



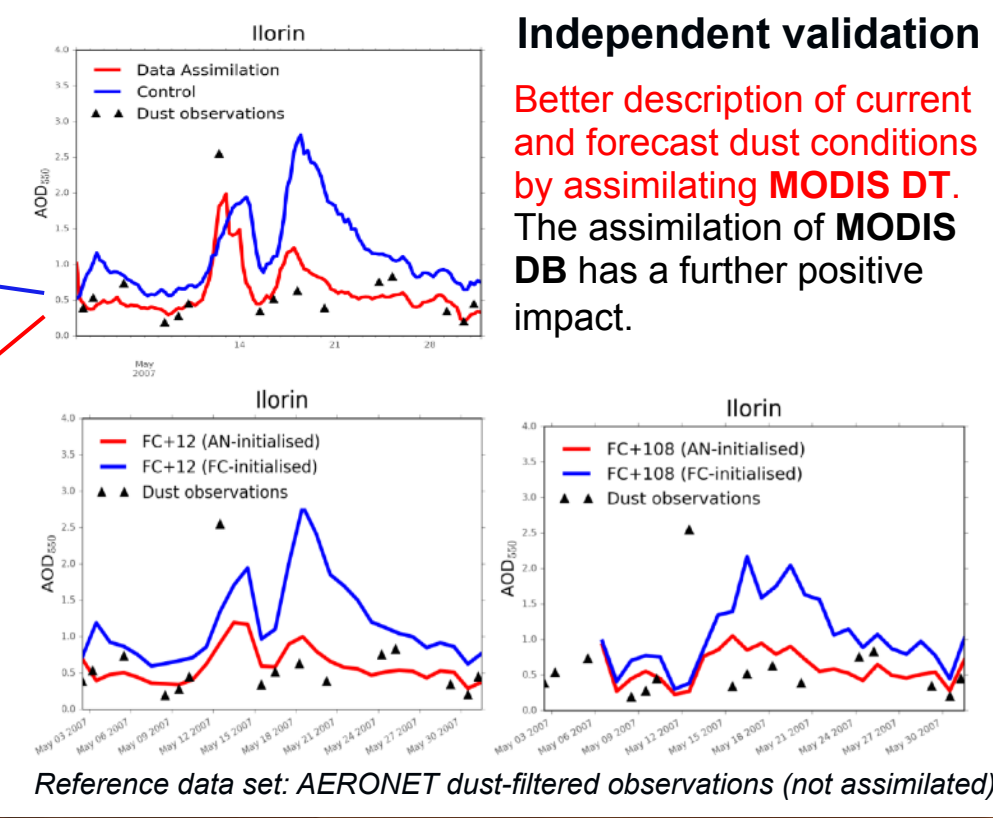
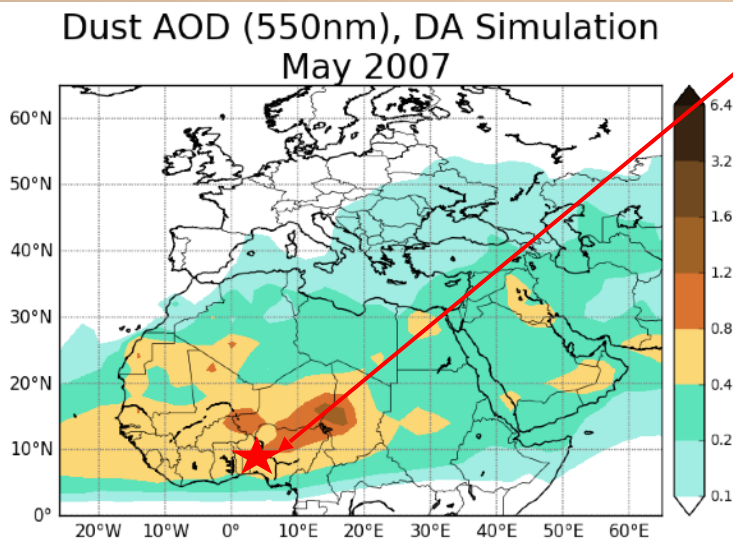
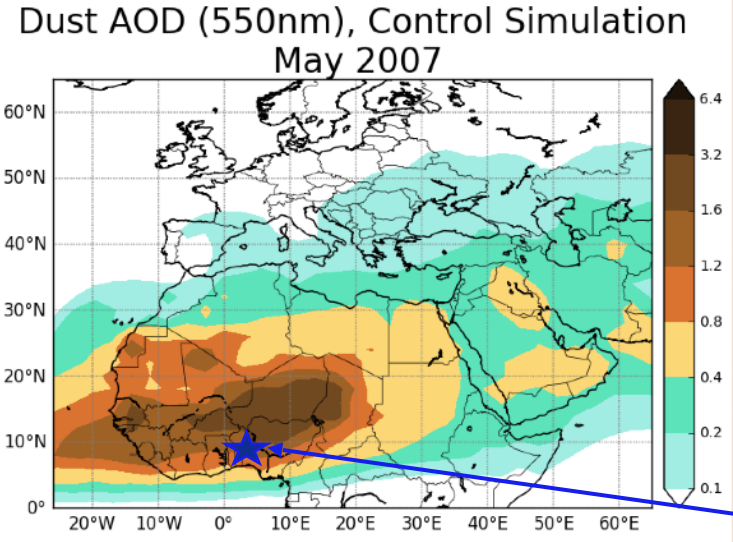
# MIDAS assimilation in the MONARCH model

**MIDAS**



- MONARCH ensemble simulations. First tested configuration:
  - 12-member ensemble
  - 2 datasets of initial and boundary conditions (ERAinterim, MERRA-2 with ERA5soil)
  - 2 dust emission schemes (Pérez et al., 2011; Ginoux et al., 2001)
  - Random perturbations on emission dust size distribution at sources and friction velocity threshold

**Control | DA | Observations**



**Independent validation**  
 Better description of current and forecast dust conditions by assimilating **MODIS DT**. The assimilation of **MODIS DB** has a further positive impact.

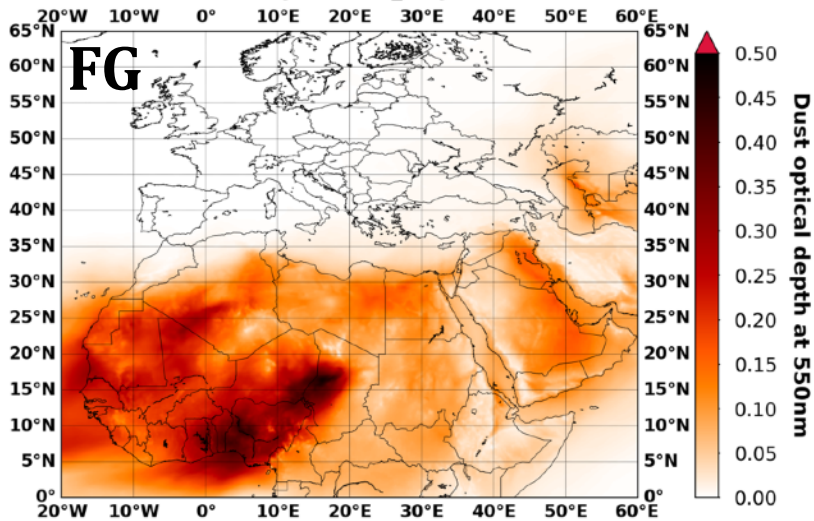
Reference data set: AERONET dust-filtered observations (not assimilated)

*Di Tomaso et al. (2017)*

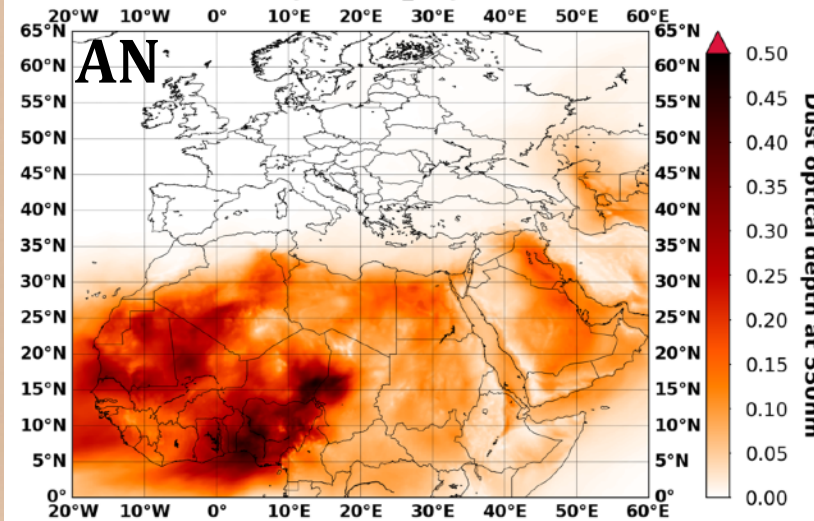
**MIDAS provides an improved data set for data assimilation applications**

# MIDAS assimilation: First test [January 2012]

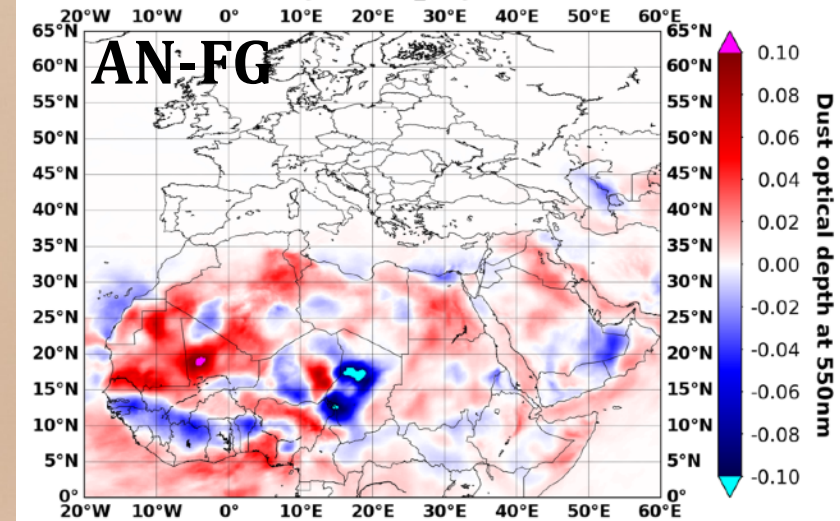
SDS: od550du Type: ensemble-stats Metric: MEAN  
 Model configuration: FIRST GUESS  
 Period: 01-Jan-2012\_31-Jan-2012



SDS: od550du Type: ensemble-stats Metric: MEAN  
 Model configuration: ANALYSIS  
 Period: 01-Jan-2012\_31-Jan-2012

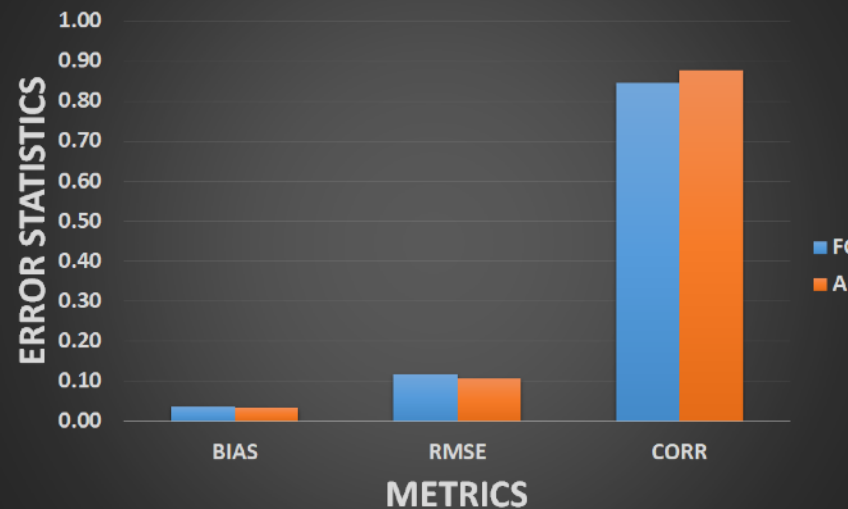


SDS: od550du Type: ensemble-stats Metric: MEAN  
 Model configuration: INCREMENTS  
 Period: 01-Jan-2012\_31-Jan-2012



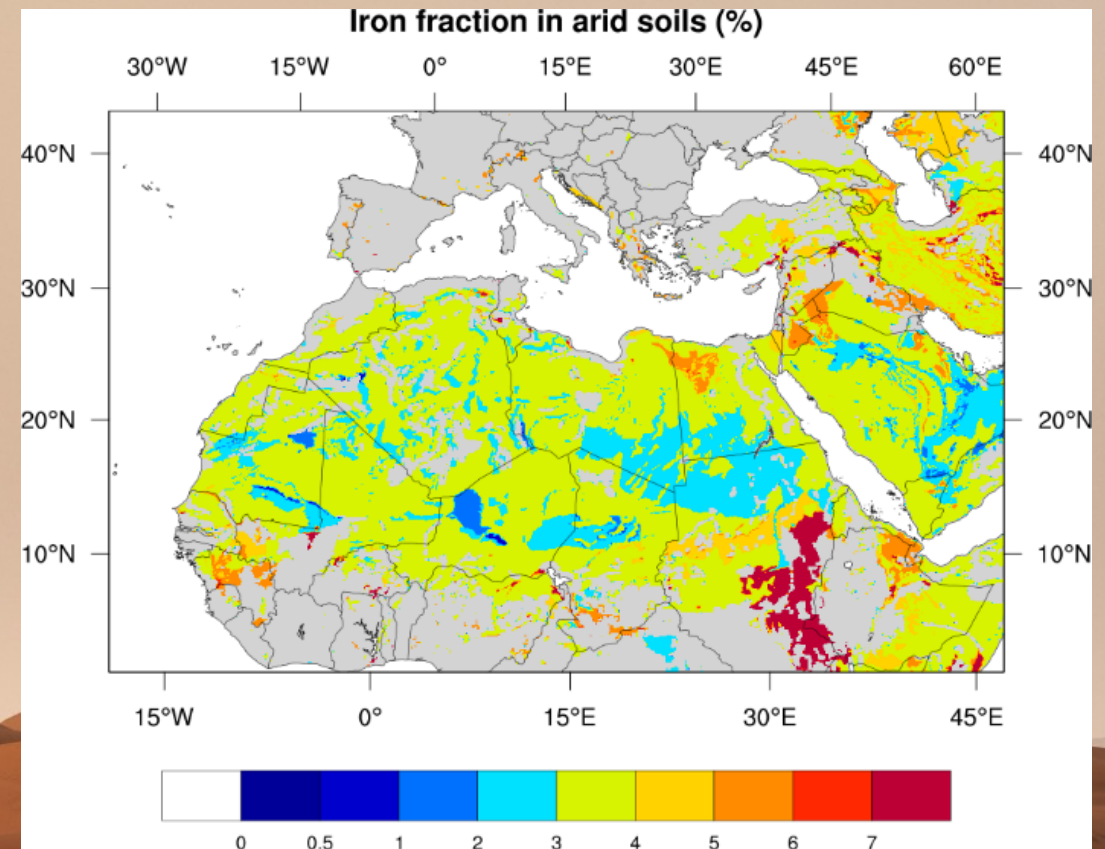
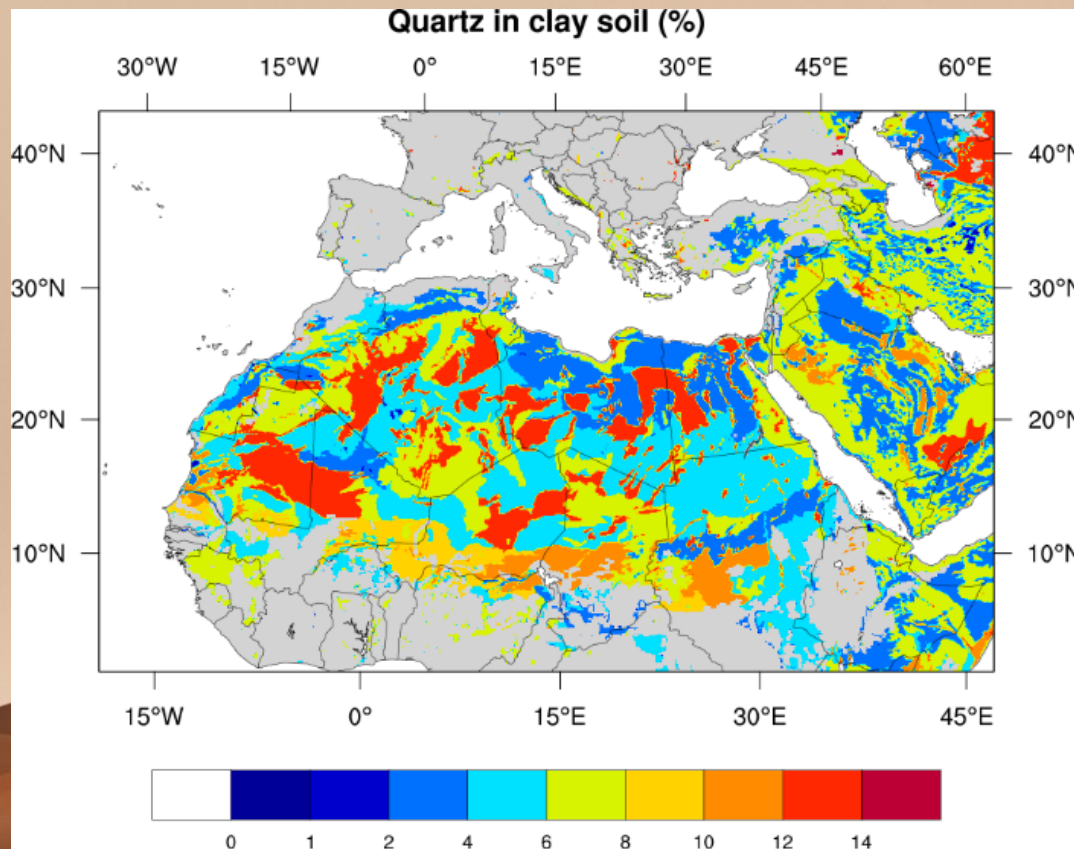
Evaluation against  
 AERONET SDA retrievals

Validation against AERONET data (January 2012)



Better evaluation metrics  
 for the analysis compared to  
 the first-guess (i.e., an  
 analysis-initialized forecast)

# Implementation of dust mineralogy in the WRF model

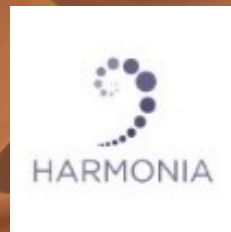


*Stavros Solomos, Christos Spyrou, Africa Baretto, Emilio Cuevas, Sergio Rodríguez, Yenny González, Marina Neophytou, Petros Mouzourides, Nicolaos Bartsotas, Christina Kalogeri, Vassilis Amiridis, Olga Sykioti, Slobodan Nickovic, Goran Pejanovic, Bojan Cvetkovic, Antonis Gkikas, Christos Zerefos, Development of METAL-WRF model for the seamless description of dust mineralogy, in submission, Atmosphere*



# MIDAS upgrade and upcoming activities

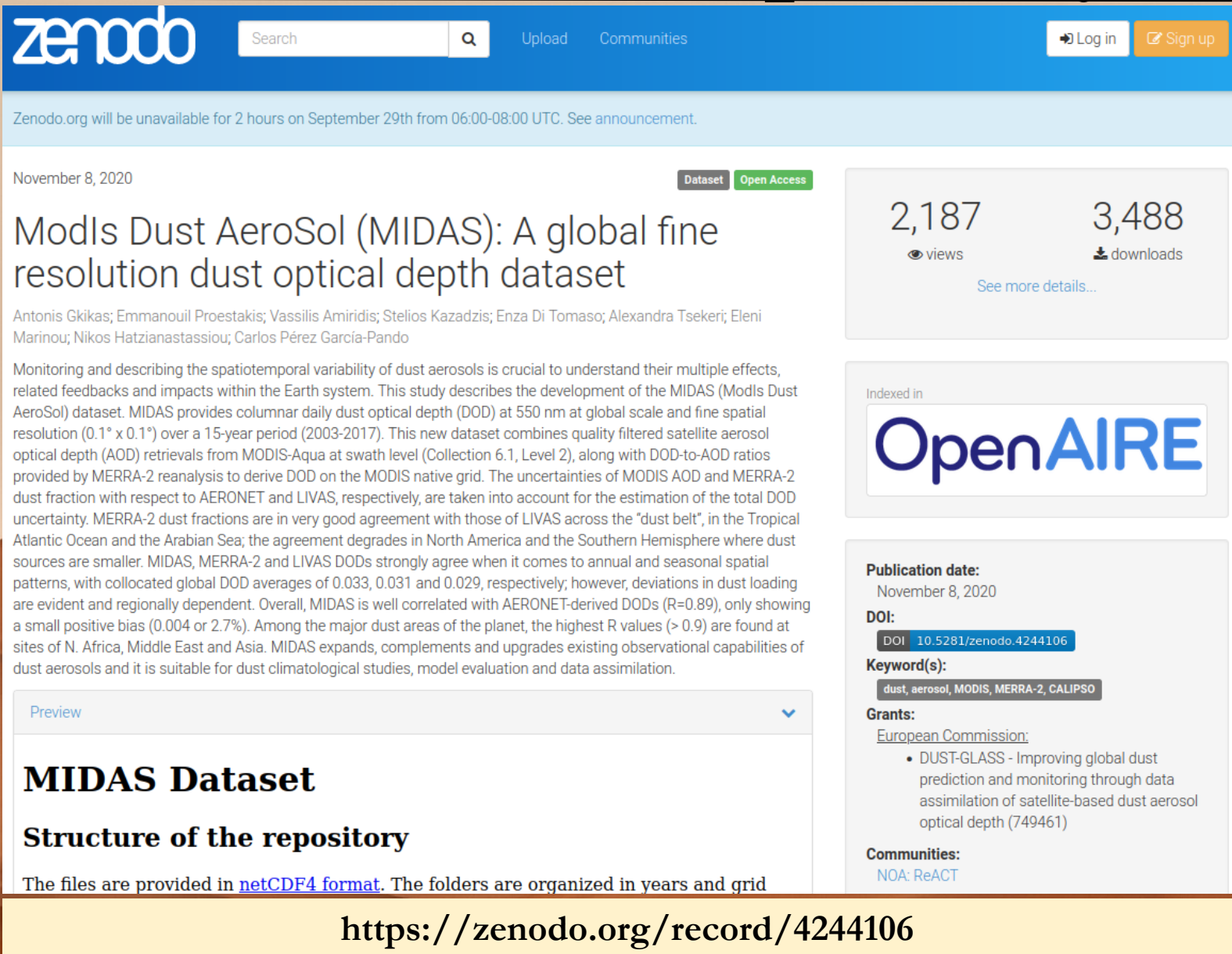
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# Ongoing work and future activities

- Temporal expansion until the end of 2022
- Processing of MODIS-Terra retrievals (increase of sampling frequency within the course of day)
- Dust trends in the Mediterranean – Governing processes – Future projections
- Assimilation experiments

# MIDAS data repository



The screenshot shows the Zenodo record page for the MIDAS dataset. The header includes the Zenodo logo, a search bar, and navigation links for 'Upload' and 'Communities'. A notification banner states that Zenodo.org will be unavailable for 2 hours on September 29th. The main content area features the dataset title 'ModIs Dust AeroSol (MIDAS): A global fine resolution dust optical depth dataset', the authors' names, and a detailed abstract. A statistics box on the right shows 2,187 views and 3,488 downloads. Below this is the OpenAIRE logo. A metadata box on the right lists the publication date (November 8, 2020), DOI (10.5281/zenodo.4244106), keywords (dust, aerosol, MODIS, MERRA-2, CALIPSO), grants (European Commission), and communities (NOA: ReACT). A preview section on the left shows the title 'MIDAS Dataset' and the subtitle 'Structure of the repository', with a brief description of the file format and organization.

zenodo Search Upload Communities Log in Sign up

Zenodo.org will be unavailable for 2 hours on September 29th from 06:00-08:00 UTC. See announcement.

November 8, 2020 Dataset Open Access

## ModIs Dust AeroSol (MIDAS): A global fine resolution dust optical depth dataset

Antonis Gkikas; Emmanouil Proestakis; Vassilis Amiridis; Stelios Kazadzis; Enza Di Tomaso; Alexandra Tsekeri; Eleni Marinou; Nikos Hatzianastassiou; Carlos Pérez García-Pando

Monitoring and describing the spatiotemporal variability of dust aerosols is crucial to understand their multiple effects, related feedbacks and impacts within the Earth system. This study describes the development of the MIDAS (ModIs Dust AeroSol) dataset. MIDAS provides columnar daily dust optical depth (DOD) at 550 nm at global scale and fine spatial resolution ( $0.1^\circ \times 0.1^\circ$ ) over a 15-year period (2003-2017). This new dataset combines quality filtered satellite aerosol optical depth (AOD) retrievals from MODIS-Aqua at swath level (Collection 6.1, Level 2), along with DOD-to-AOD ratios provided by MERRA-2 reanalysis to derive DOD on the MODIS native grid. The uncertainties of MODIS AOD and MERRA-2 dust fraction with respect to AERONET and LIVAS, respectively, are taken into account for the estimation of the total DOD uncertainty. MERRA-2 dust fractions are in very good agreement with those of LIVAS across the "dust belt", in the Tropical Atlantic Ocean and the Arabian Sea; the agreement degrades in North America and the Southern Hemisphere where dust sources are smaller. MIDAS, MERRA-2 and LIVAS DODs strongly agree when it comes to annual and seasonal spatial patterns, with collocated global DOD averages of 0.033, 0.031 and 0.029, respectively; however, deviations in dust loading are evident and regionally dependent. Overall, MIDAS is well correlated with AERONET-derived DODs ( $R=0.89$ ), only showing a small positive bias (0.004 or 2.7%). Among the major dust areas of the planet, the highest R values ( $> 0.9$ ) are found at sites of N. Africa, Middle East and Asia. MIDAS expands, complements and upgrades existing observational capabilities of dust aerosols and it is suitable for dust climatological studies, model evaluation and data assimilation.

2,187 views 3,488 downloads See more details...

Indexed in OpenAIRE

**Publication date:** November 8, 2020  
**DOI:** DOI 10.5281/zenodo.4244106  
**Keyword(s):** dust, aerosol, MODIS, MERRA-2, CALIPSO  
**Grants:** European Commission:

- DUST-GLASS - Improving global dust prediction and monitoring through data assimilation of satellite-based dust aerosol optical depth (749461)

**Communities:** NOA: ReACT

Preview

## MIDAS Dataset

### Structure of the repository

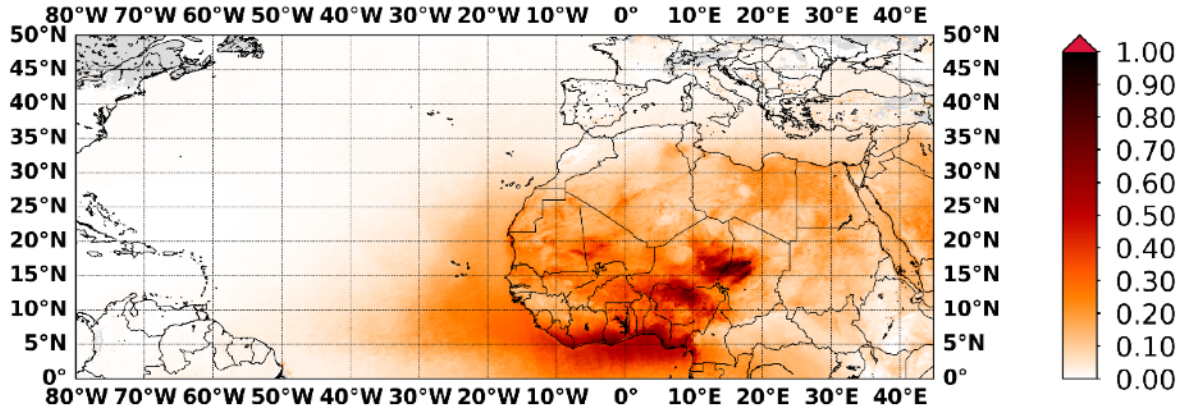
The files are provided in [netCDF4 format](#). The folders are organized in years and grid

<https://zenodo.org/record/4244106>

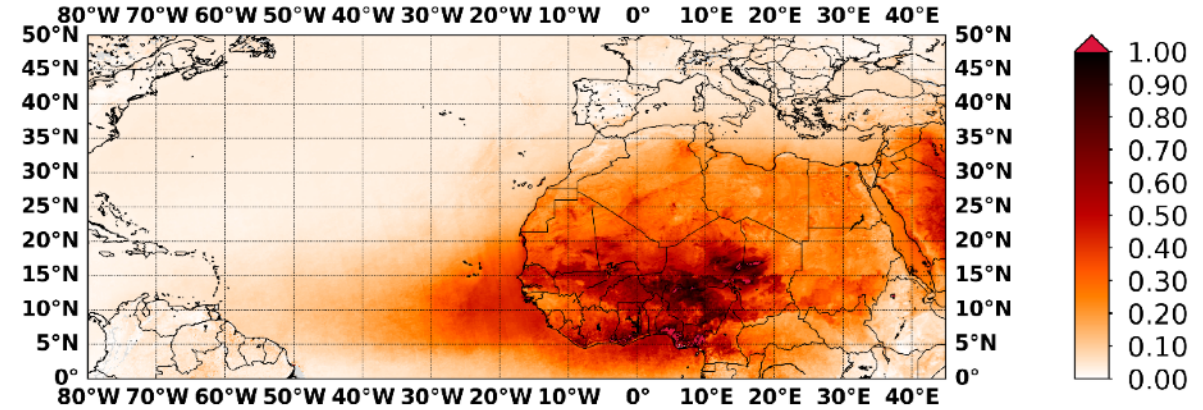
# MIDAS DOD seasonal global patterns

## Sahara - Tropical Atlantic Ocean - Mediterranean

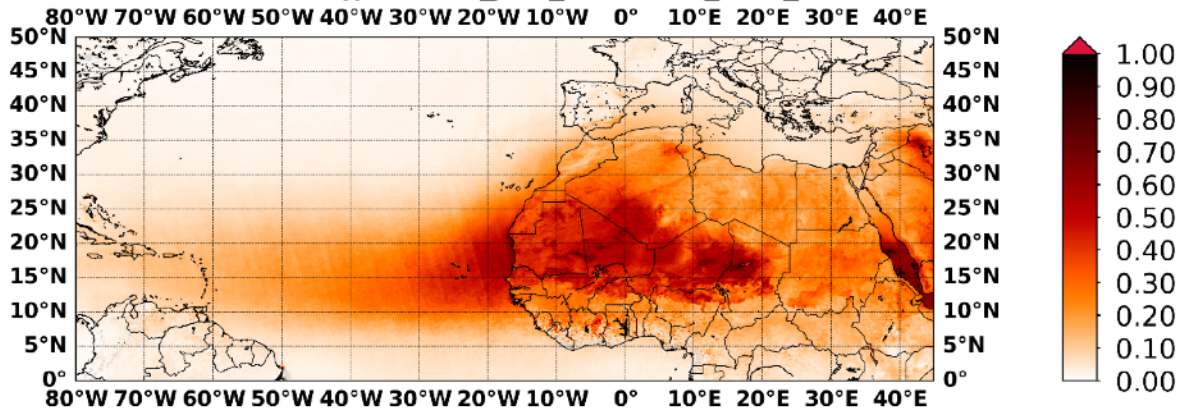
MIDAS-DOD DJF [01\_Jan\_2003-31\_Dec\_2017]



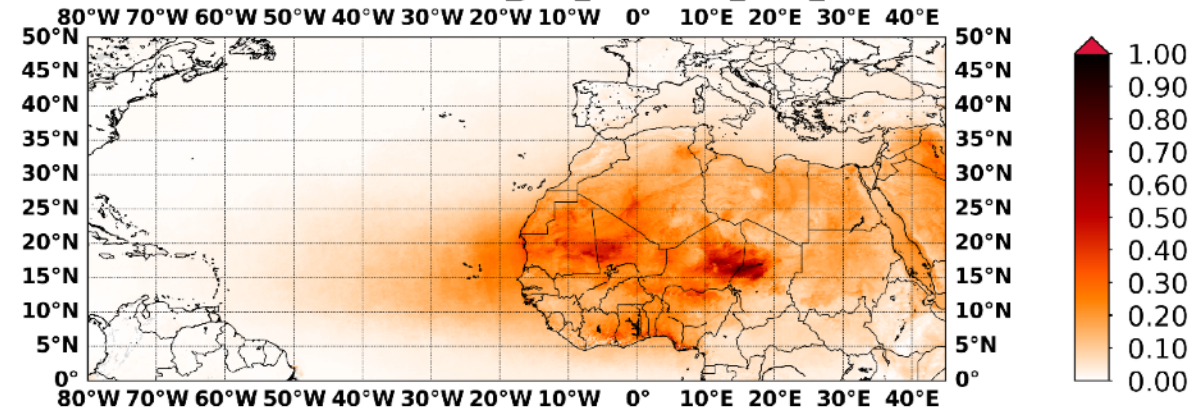
MIDAS-DOD MAM [01\_Jan\_2003-31\_Dec\_2017]



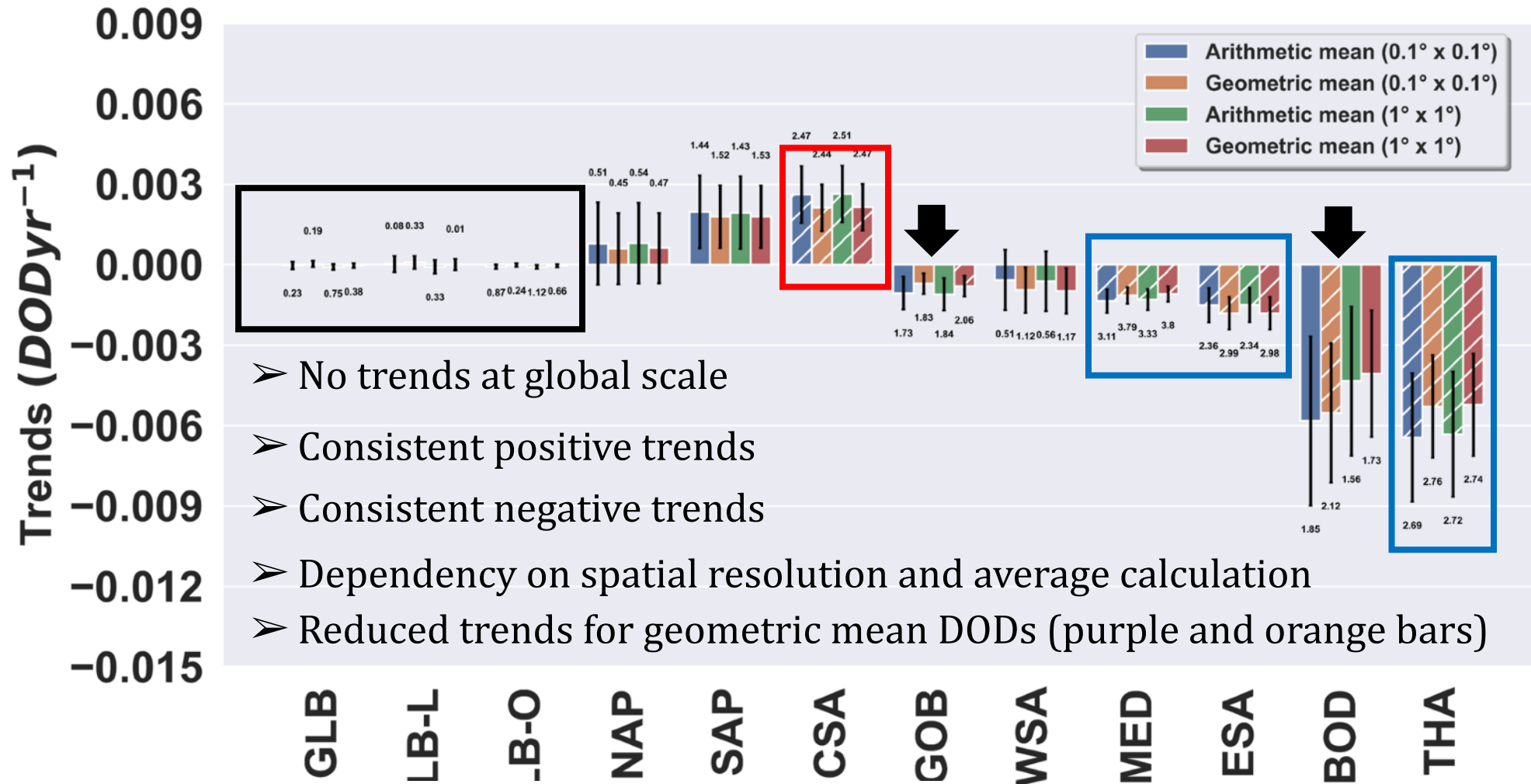
MIDAS-DOD JJA [01\_Jan\_2003-31\_Dec\_2017]



MIDAS-DOD SON [01\_Jan\_2003-31\_Dec\_2017]



# Global and regional trends [2003-2017]

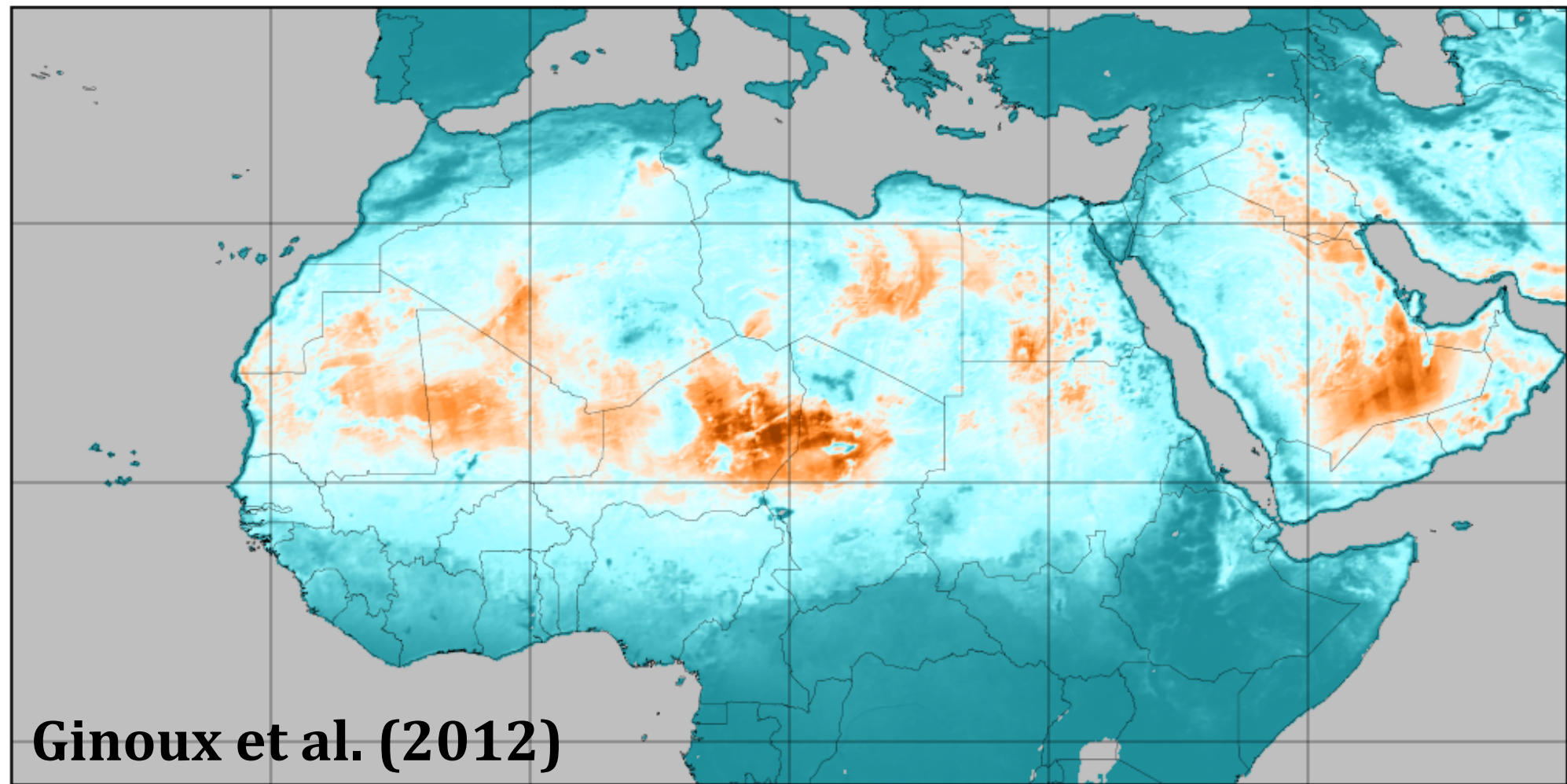


- No trends at global scale
- Consistent positive trends
- Consistent negative trends
- Dependency on spatial resolution and average calculation
- Reduced trends for geometric mean DODs (purple and orange bars)

- Numbers above bars:  $|t_0/\sigma| > 2$  (95% confidence level)
- Error bars: statistical significant trends

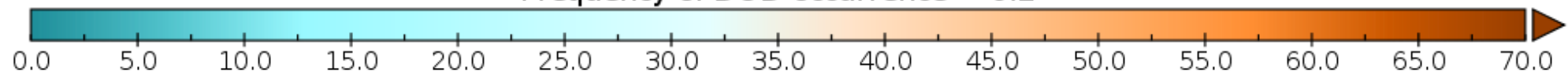
rend

# Dust sources identification



**Ginoux et al. (2012)**

Frequency of DOD occurrence > 0.2



Data Min = 0.0, Max = 71.7