Dust climatology from spaceborne remote sensing observations

Antonis Gkikas

Assistant Researcher

Research Centre for Atmospheric Physics and Climatology

Academy of Athens

ACADEMY OF ATHENS

Outline

01 Introduction

02 MIDAS development

03 Global and regional dust climatologies

04 Global and regional dust trends

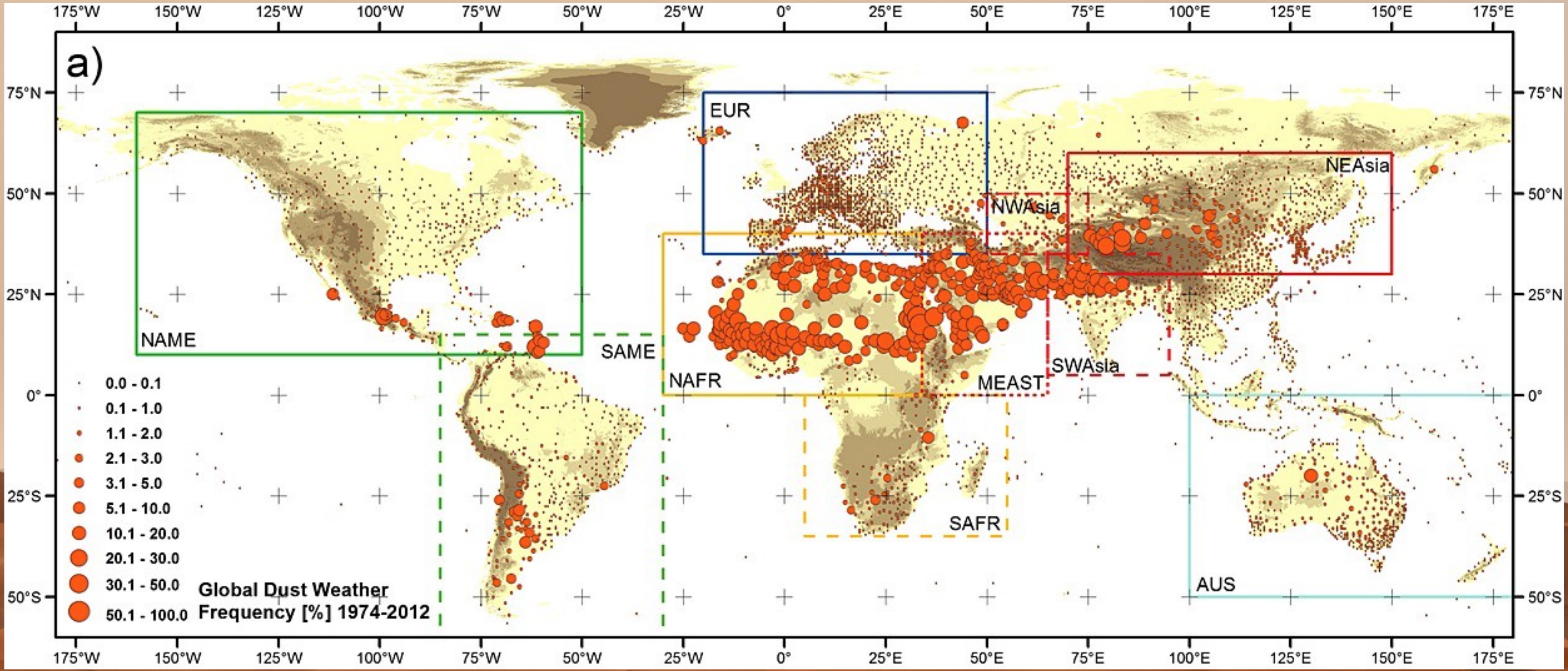
05 MIDAS dataset exploitation

06 MIDAS upgrade and upcoming activities

Introduction

Dust within the Earth-Atmosphere system

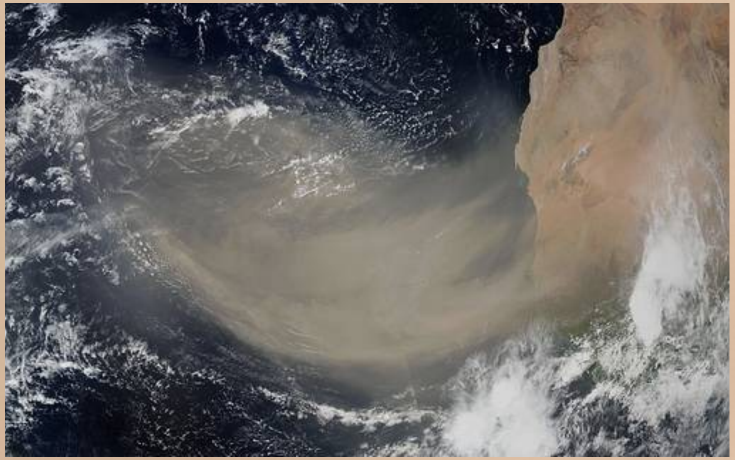
Dust “belt”



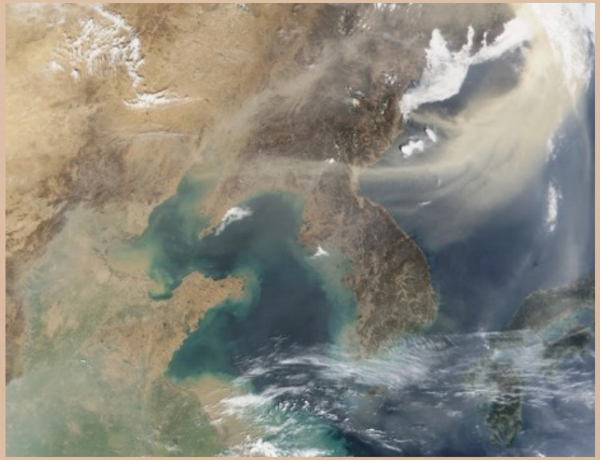
Shao et al. (2013)

Dust transport over downwind areas

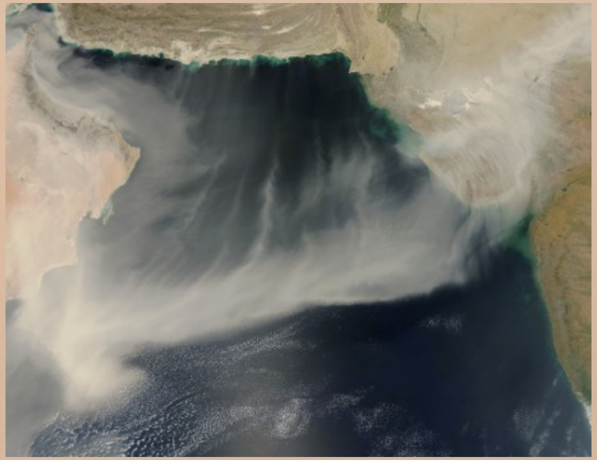
Atlantic



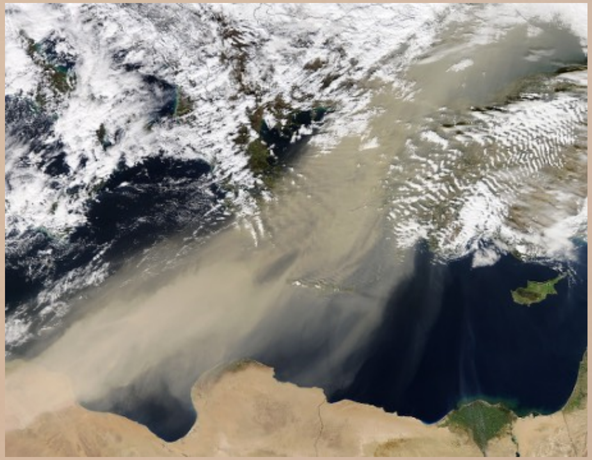
Pacific



Arabian Sea



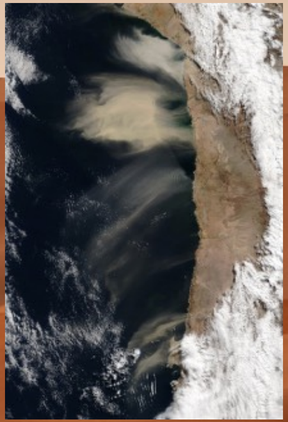
Mediterranean



Patagonia

Namibia

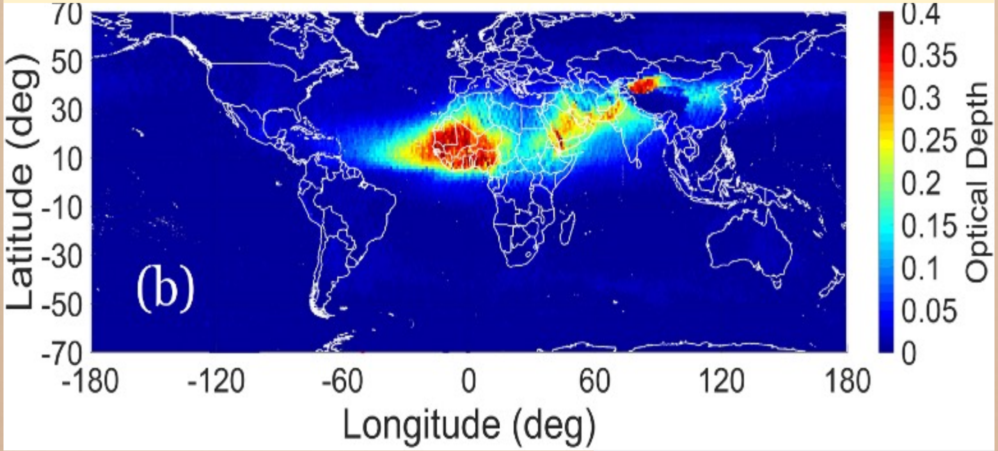
Chile



Australia

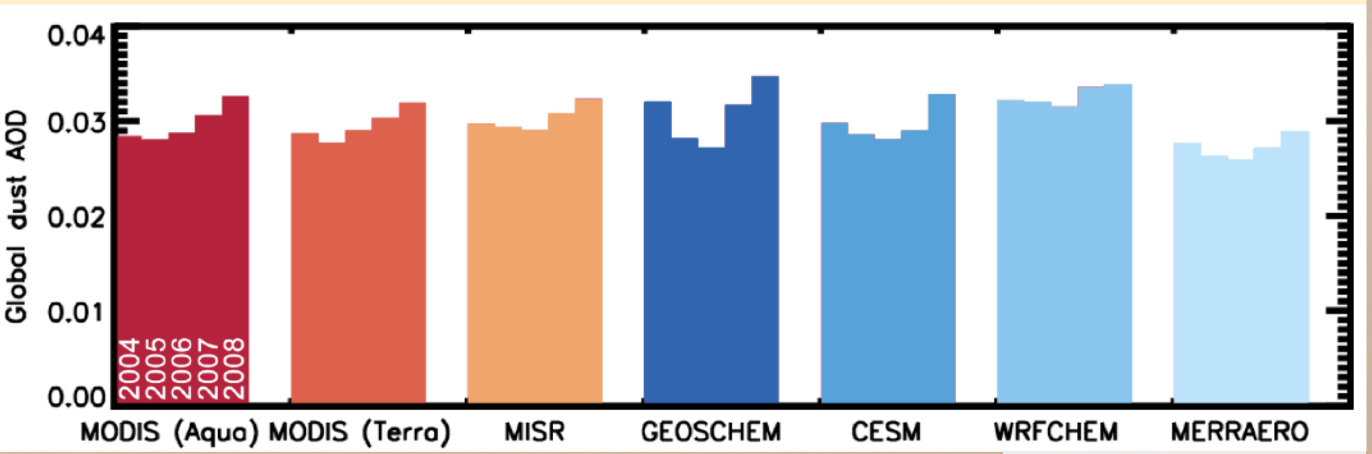
Dust monitoring from space

LIVAS-CALIPSO



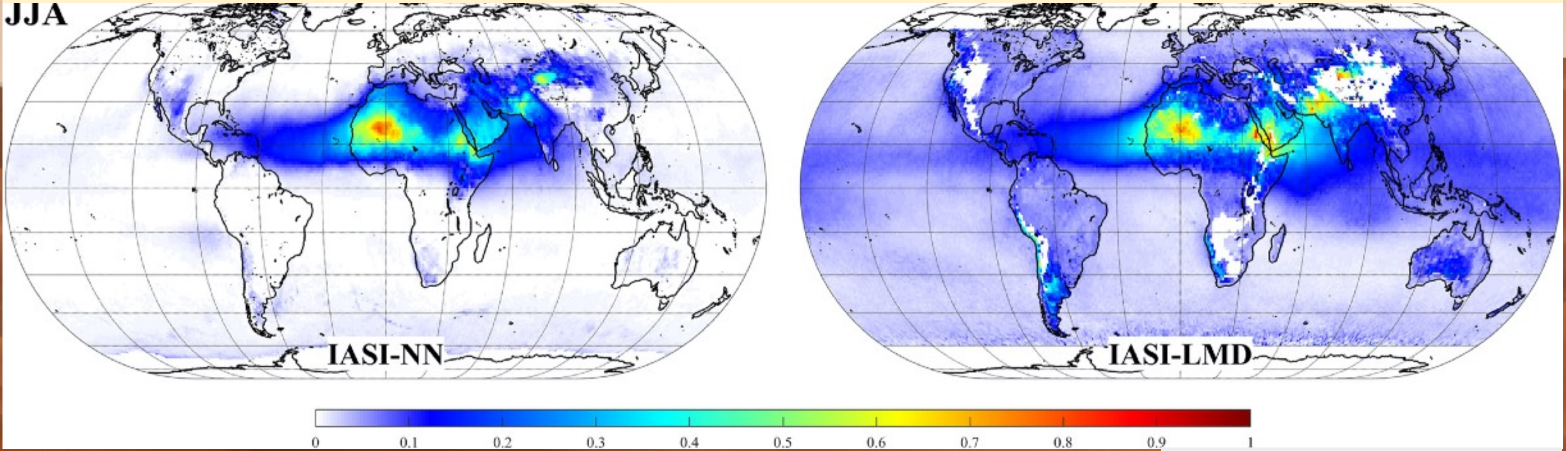
Amiridis et al. (2015)

Passive spaceborne retrievals & models



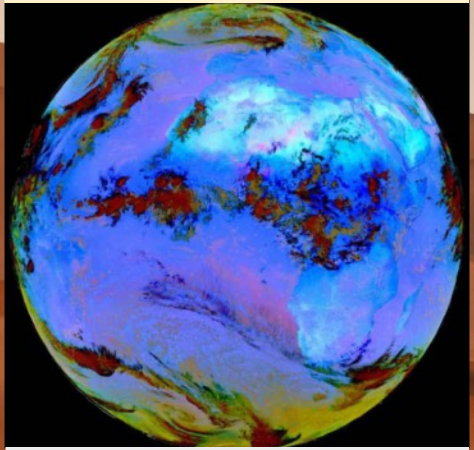
Ridley et al. (2016)

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° x 0.1°**)
- **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

Atmospheric Measurement Techniques
Open Access
EGU

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

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

Atmos. Chem. Phys., 22, 3553–3578, 2022
https://doi.org/10.5194/acp-22-3553-2022

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

Atmos. Chem. Phys., 21, 16499–16529, 2021
https://doi.org/10.5194/acp-21-16499-2021

Atmospheric Chemistry and Physics
Open Access
EGU

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

Stavros-Andreas Logothetis[1], Vasileios Salamalikis[1], Antonis Gkikas[2], Stelios Kazadzis[3,4], Vassilis Amiridis[2], and Andreas Kazantzidis[1]

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.

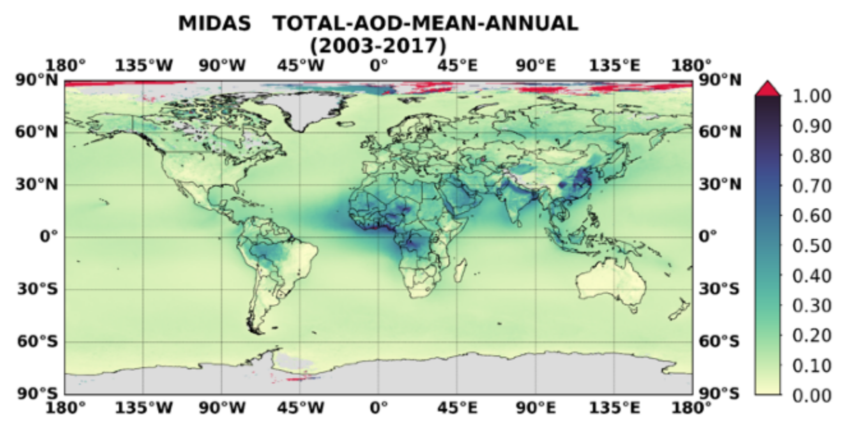
inDust

MIDAS development

Gkikas, A., Proestakis, E., Amiridis, V., Kazadzis, S., Di Tomaso, E., Tsekeri, A., Marinou, E., Hatzianastassiou, N., and Pérez García-Pando, C.: ModIs 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

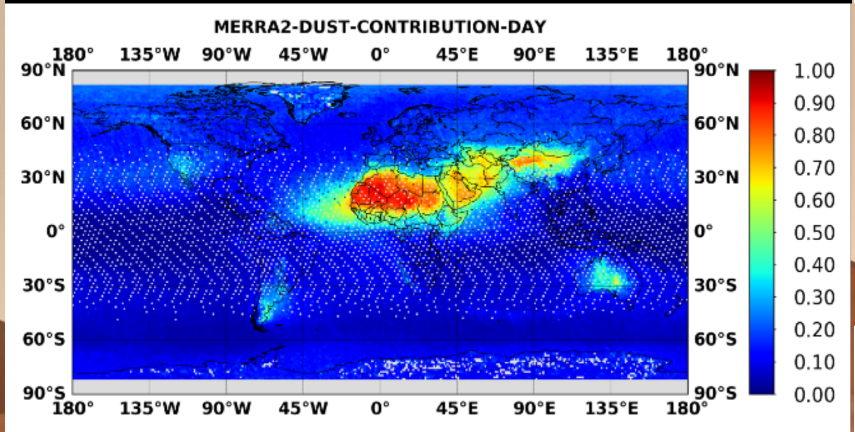
MODIS-Aqua AOD_{550nm}



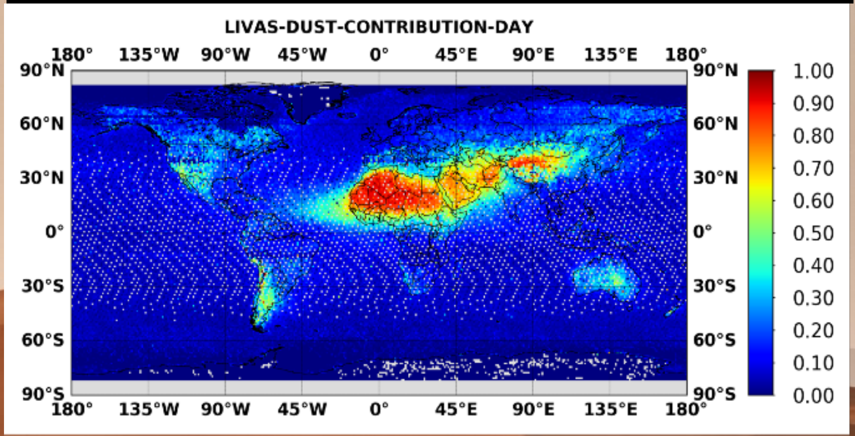
Derivation of MIDAS DOD [MODIS-MERRA-2]

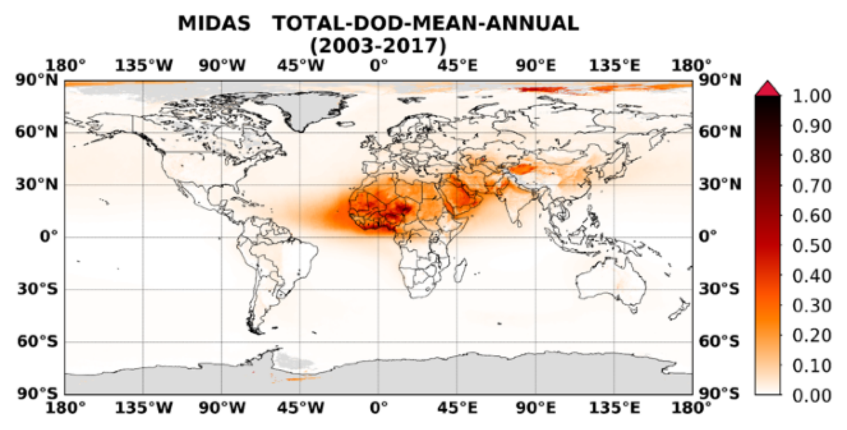
Evaluation of MDF vs LDF

MERRA-2 Dust Fraction (MDF)



LIVAS Dust Fraction (LDF)





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

MIDAS DOD_{550nm}

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

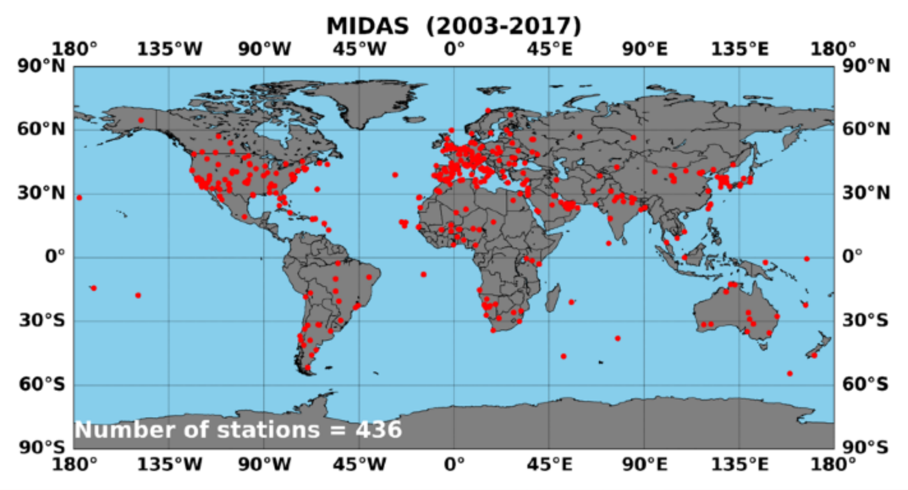
$$DOD_{MIDAS} = AOD_{MODIS} * MDF$$

Derivation of MIDAS DOD from MODIS AOD Level 2 retrievals

Evaluation versus AERONET [Global metrics]

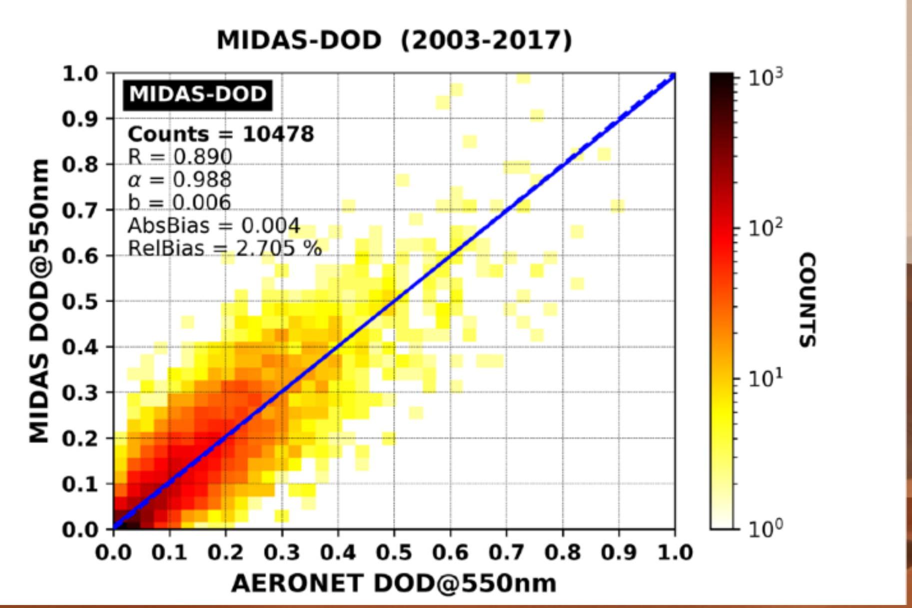
AERONET data

- ➢ 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

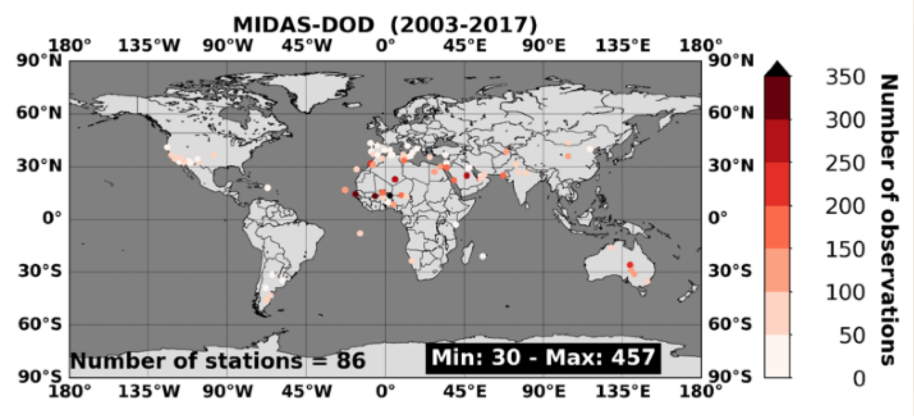
- ➢ Selection of records when $\alpha_{440\text{-}870nm} \leq 0.75$ (predominance of coarse aerosols) and $SSA_{675nm} - SSA_{440nm} > 0$ (dust discrimination from sea-salt particles)
- ➢ SSA: decreasing absorptivity for increasing wavelengths in the visible spectrum in pure or dust-rich environments (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



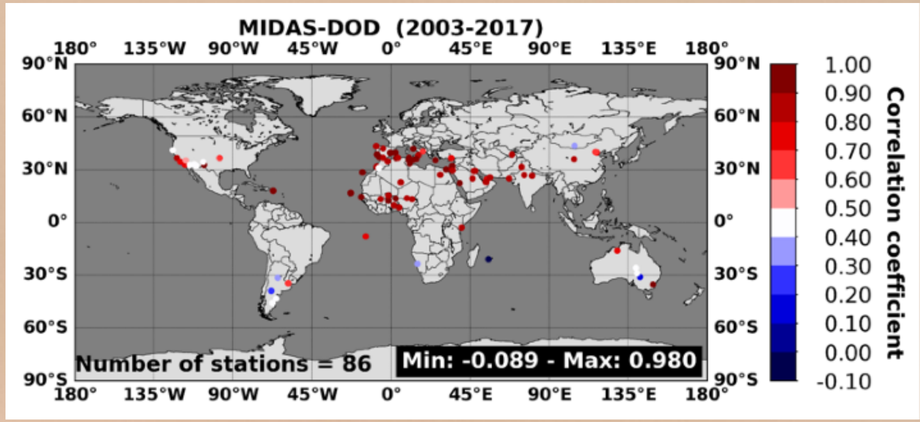
Evaluation versus AERONET [Stations]

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

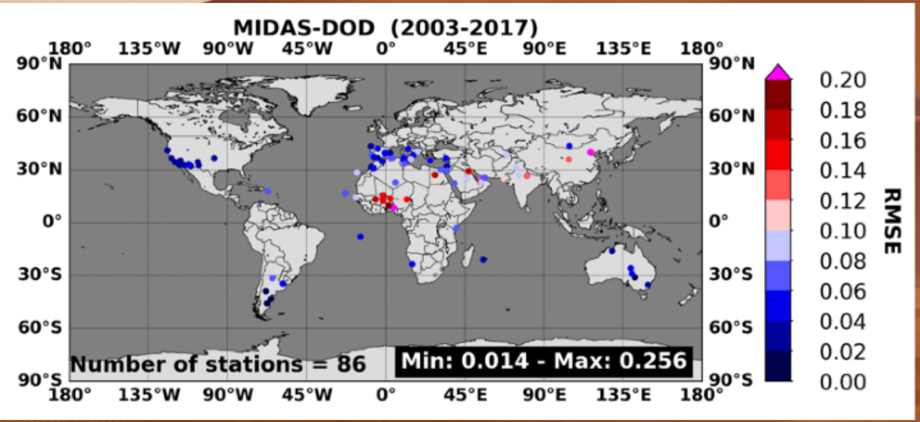
Number of observations



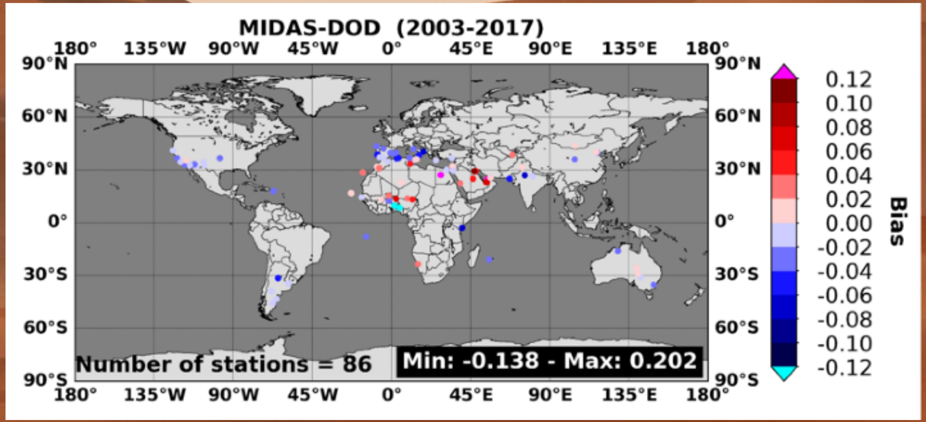
Correlation coefficient



Root-mean-square-error



Bias



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

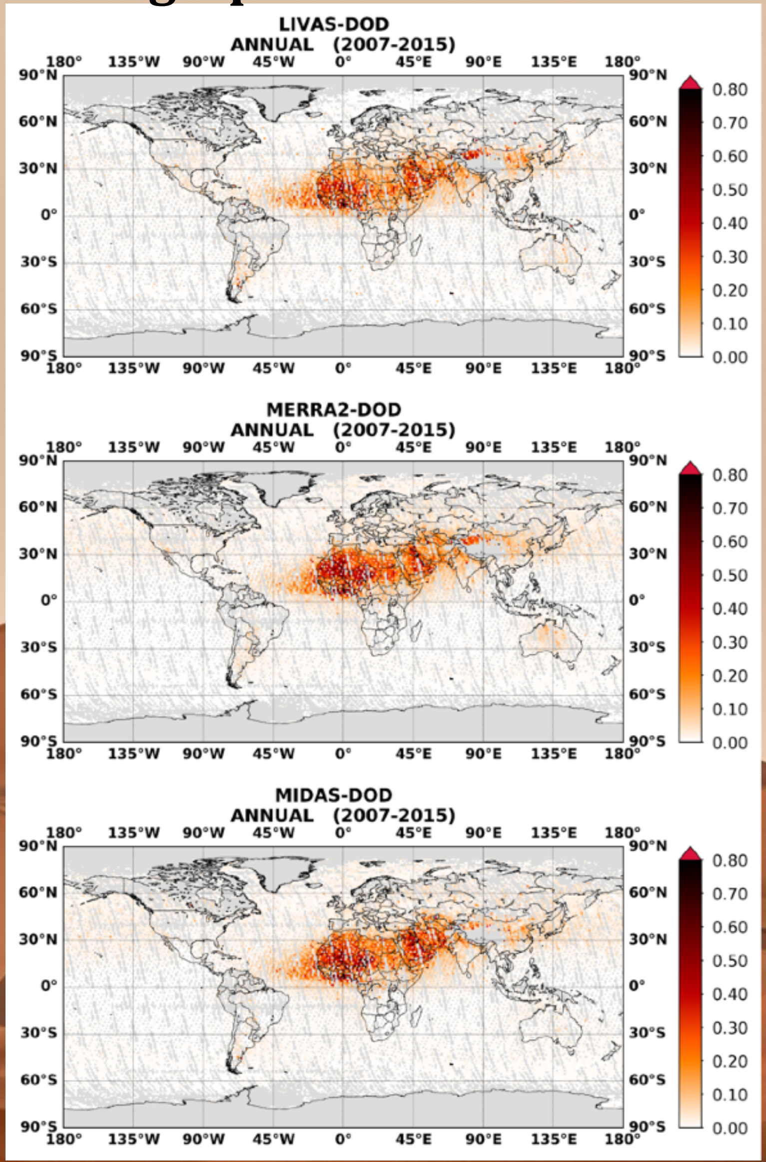
Intercomparison of MERRA-2, LIVAS, MIDAS DODs

Geographical distributions

LIVAS

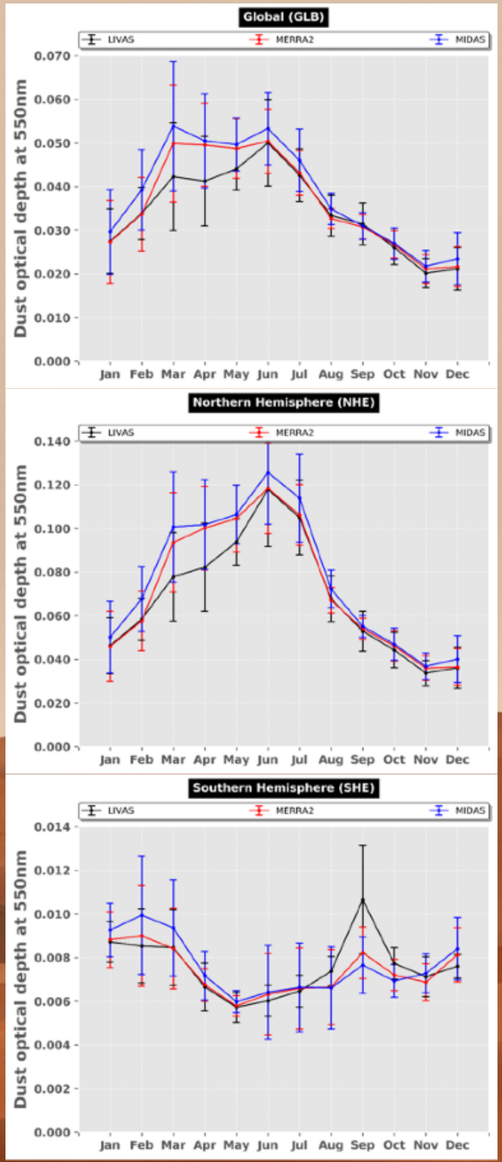
MERRA-2

MIDAS



2007-2015
1°x1°

Intra-annual variation



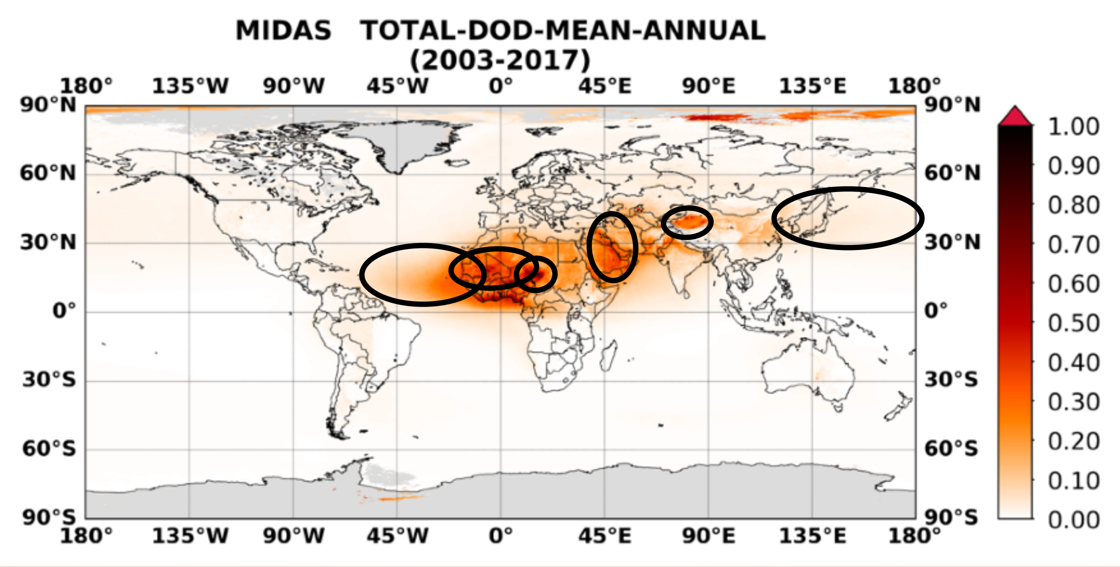
Global
0.029 | 0.031 | 0.033

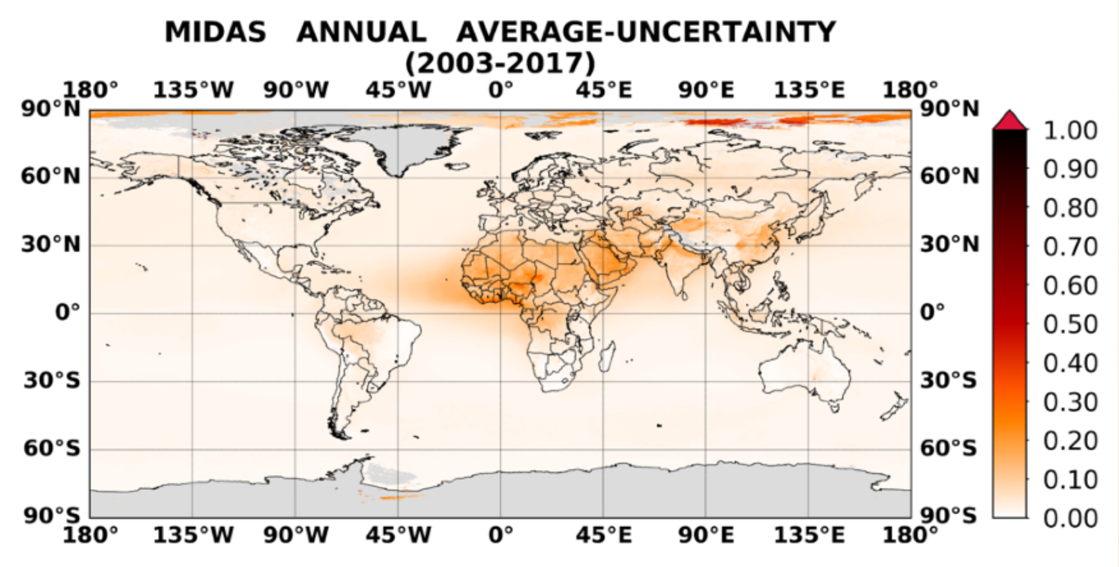
N. Hemisphere
0.051 | 0.056 | 0.060

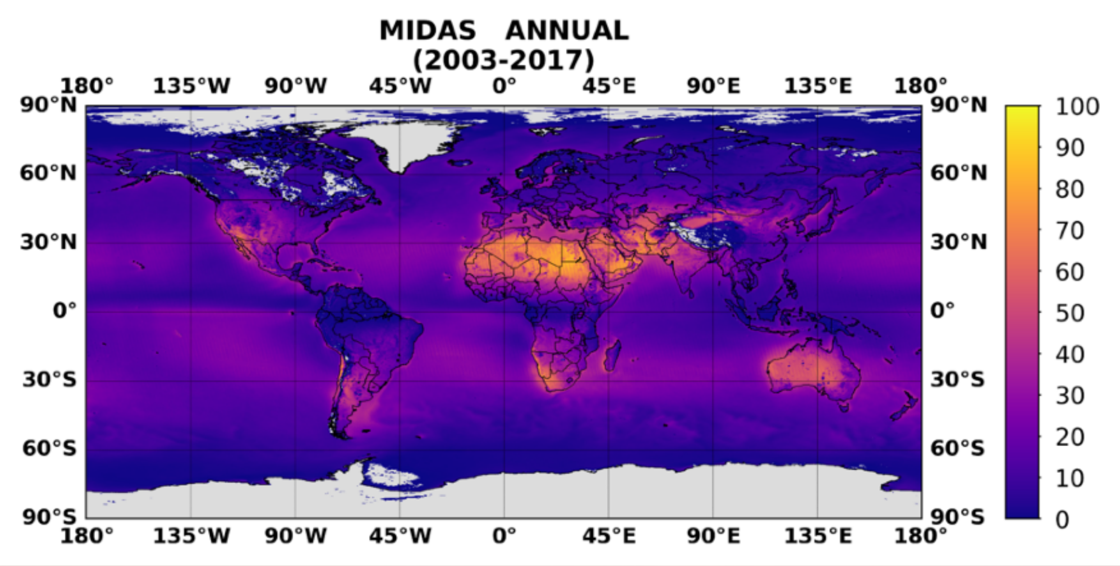
S. Hemisphere
0.008 | 0.008 | 0.008

LIVAS
MERRA-2
MIDAS

MIDAS DOD annual global patterns

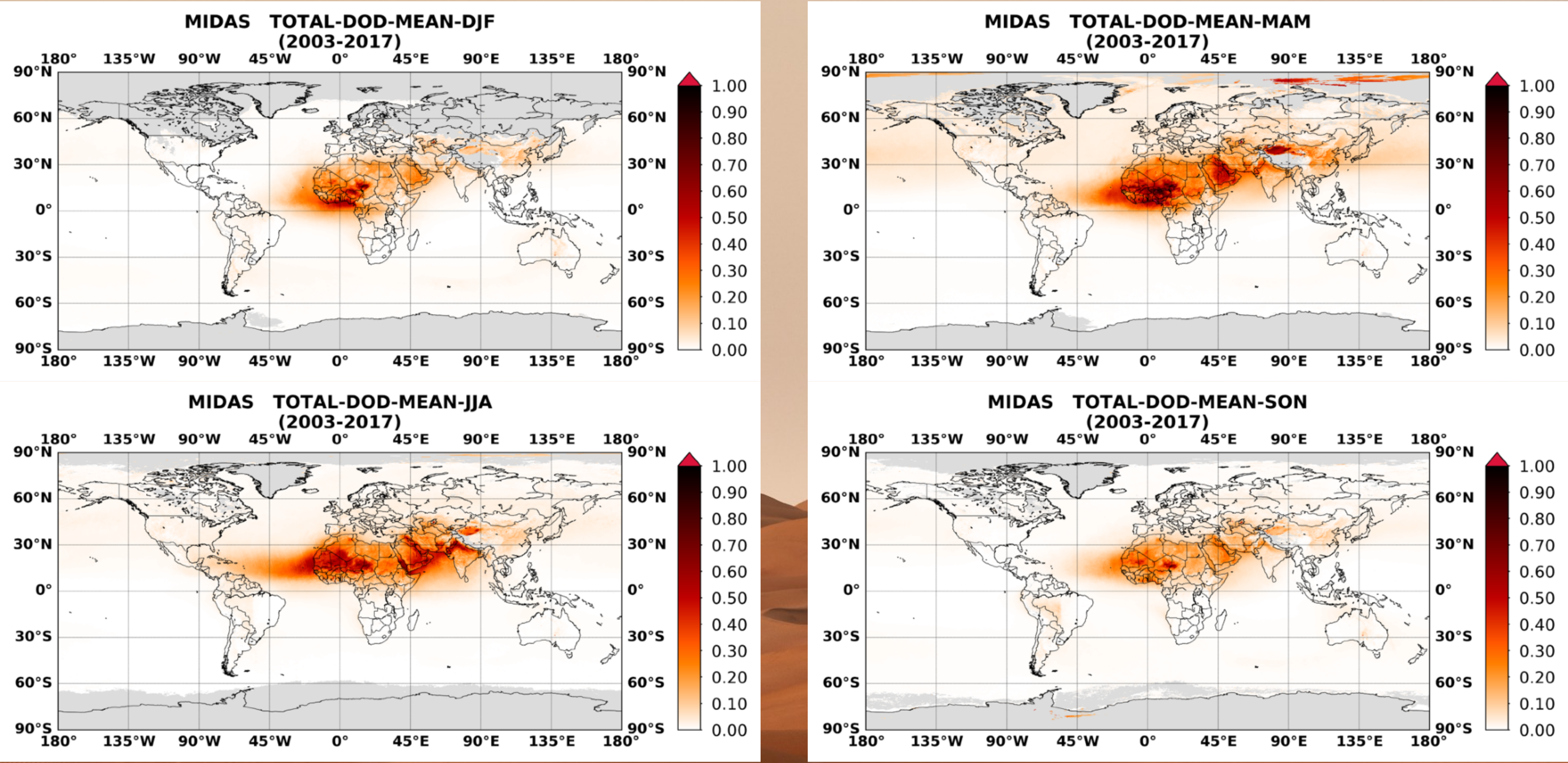






- Maximum DODs up to ~1.2 in the Bodélé Depression (northern Lake Chad)
- Moderate-to-high DODs are recorded in the W. Sahara, Middle East and the Taklamakan Desert
- Dust transport over the Atlantic and Pacific Oceans
- Average of DOD uncertainties (up to 0.5) scales with DOD
- MIDAS DOD availability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

MIDAS DOD seasonal global patterns



Global and regional dust climatologies

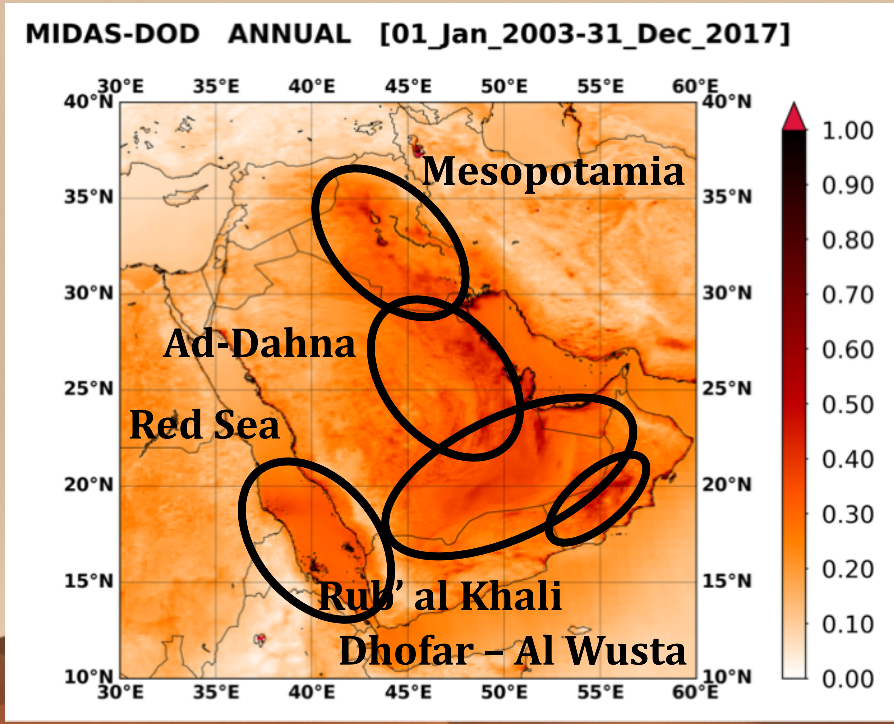
Gkikas, A., Proestakis, E., Amiridis, V., Kazadzis, S., Di Tomaso, E., Marinou, E., Hatzianastassiou, N., Kok, J. F., and García-Pando, C. P.: Quantification of the dust optical depth across spatiotemporal scales with the MIDAS global dataset (2003–2017), Atmos. Chem. Phys., 22, 3553–3578, https://doi.org/10.5194/acp-22-3553-2022,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

HARMONIA

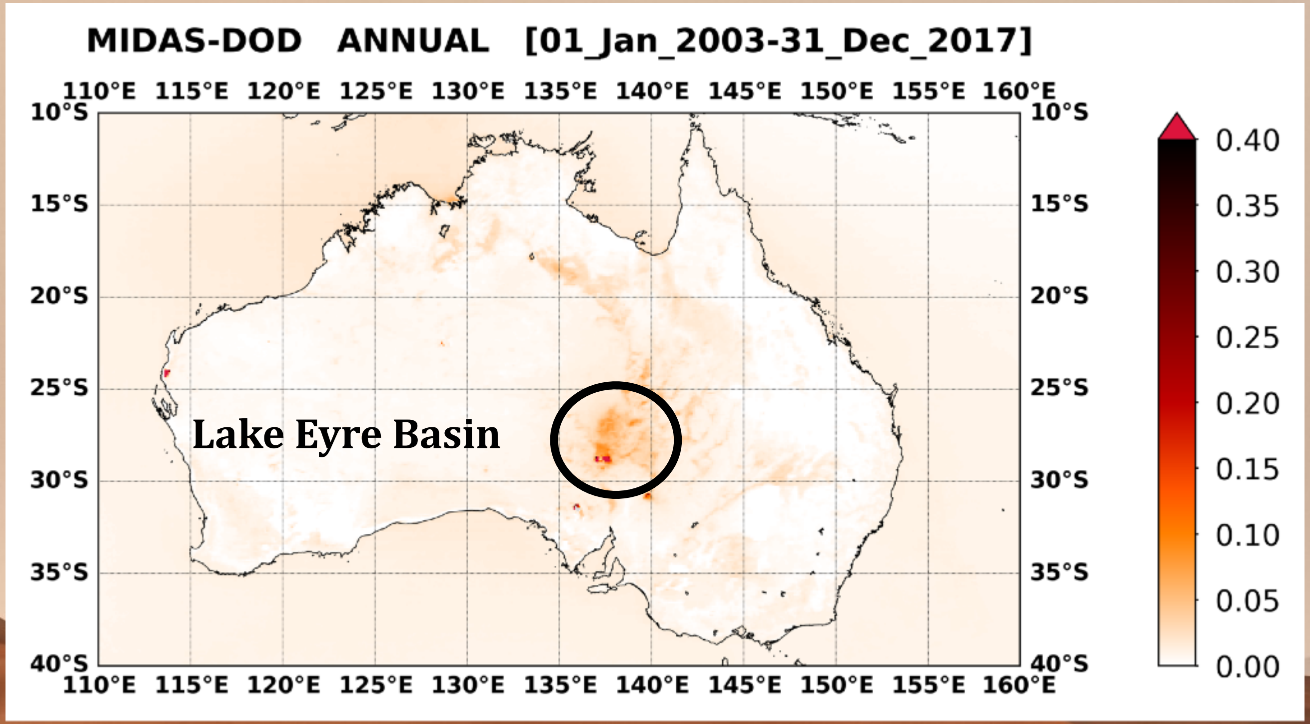
cost
EUROPEAN COOPERATION
IN SCIENCE & TECHNOLOGY

Focus on dust sources and downwind areas

Middle East

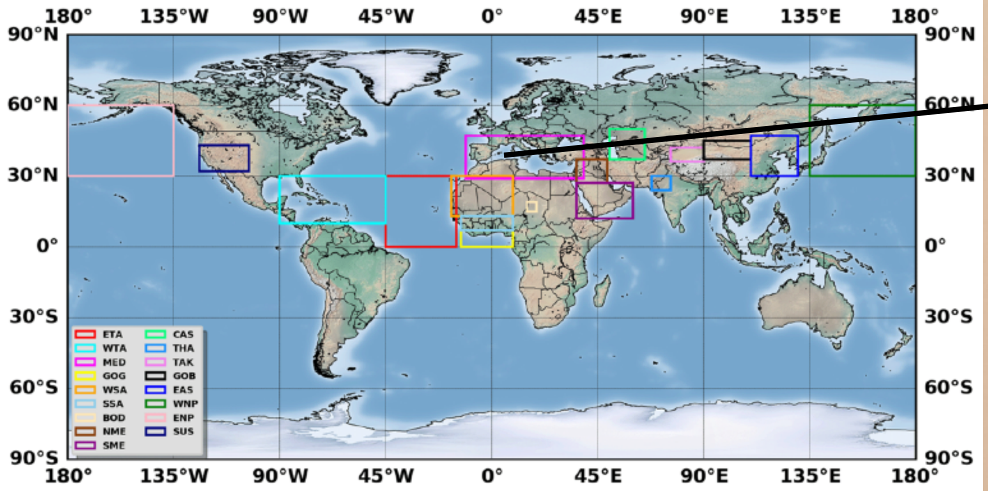


Australia



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

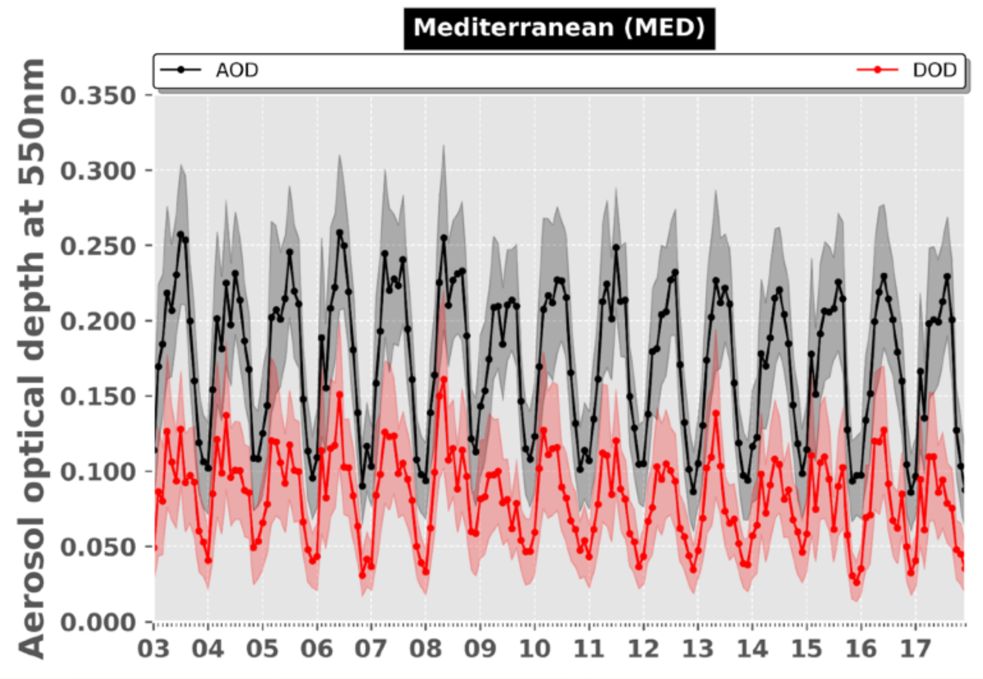
Interannual and intra-annual DOD variability

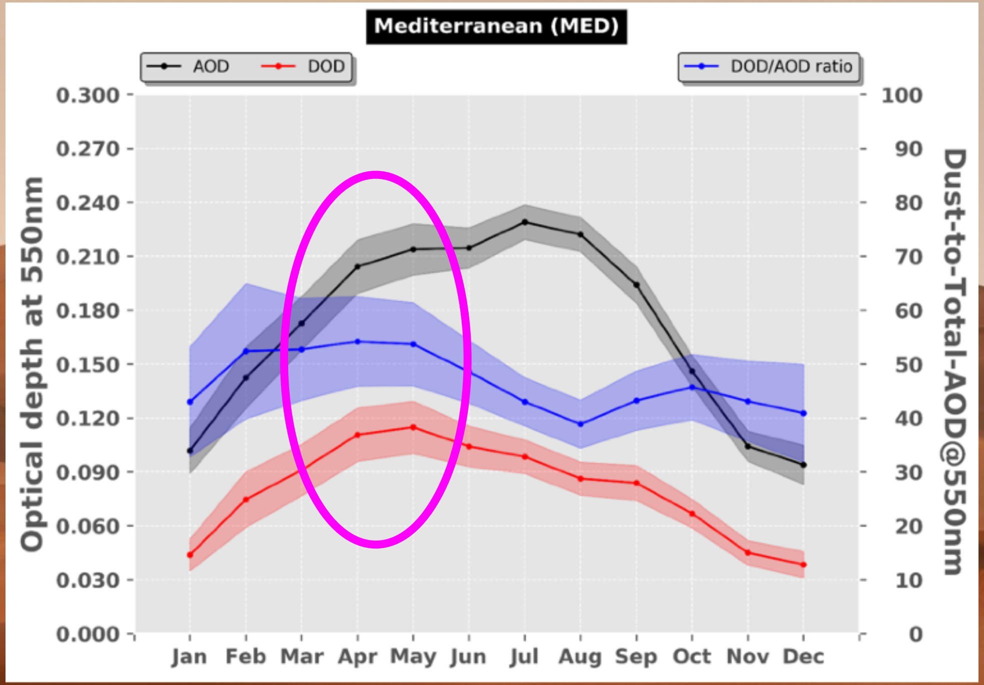


Mediterranean

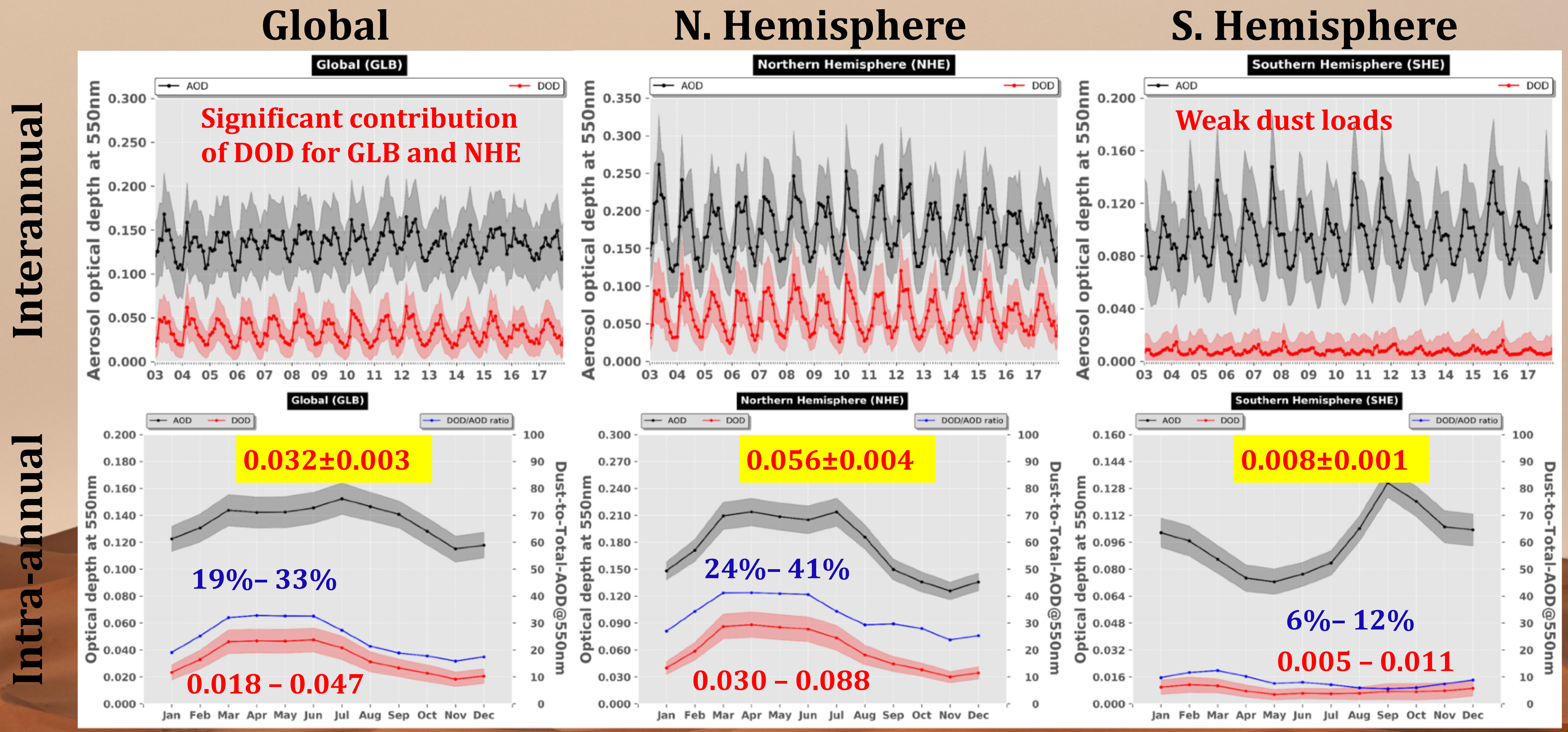
AOD | DOD | DOD-AOD ratio

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





Temporal variation of global and hemispherical averages



AOD | DOD | DOD-AOD ratio

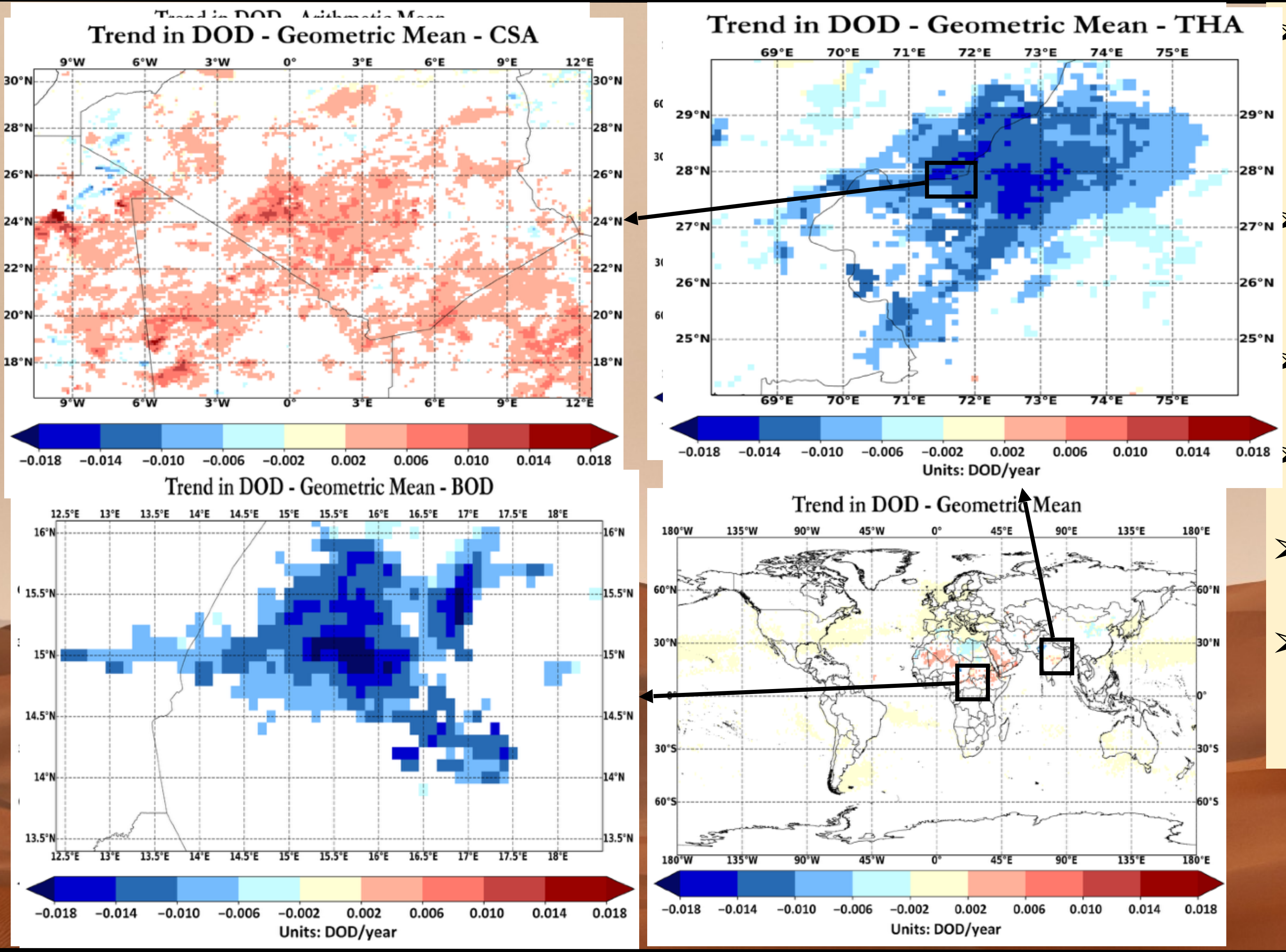
Global and regional dust trends

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]

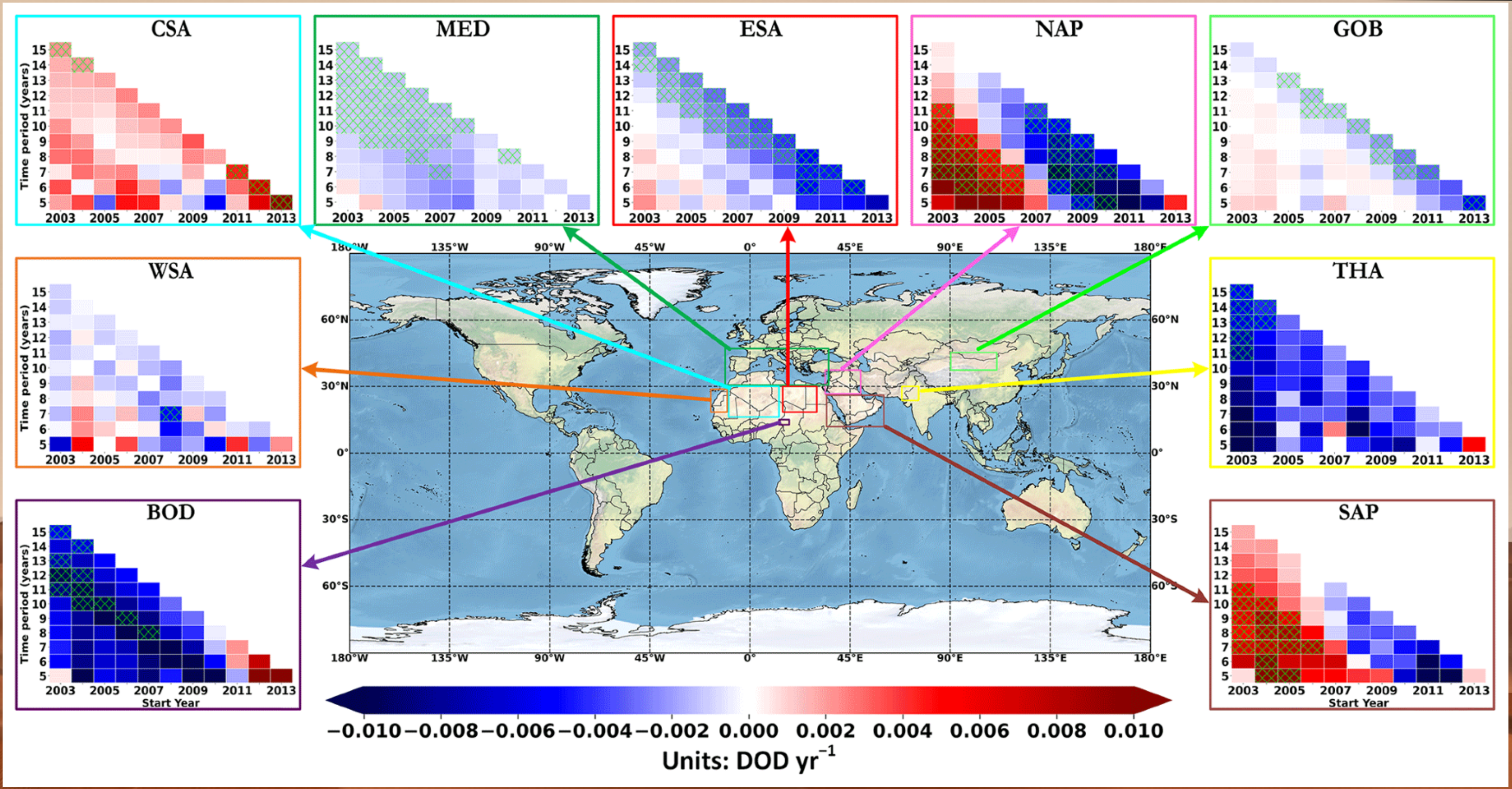
0.1° x 0.1°

1° x 1°



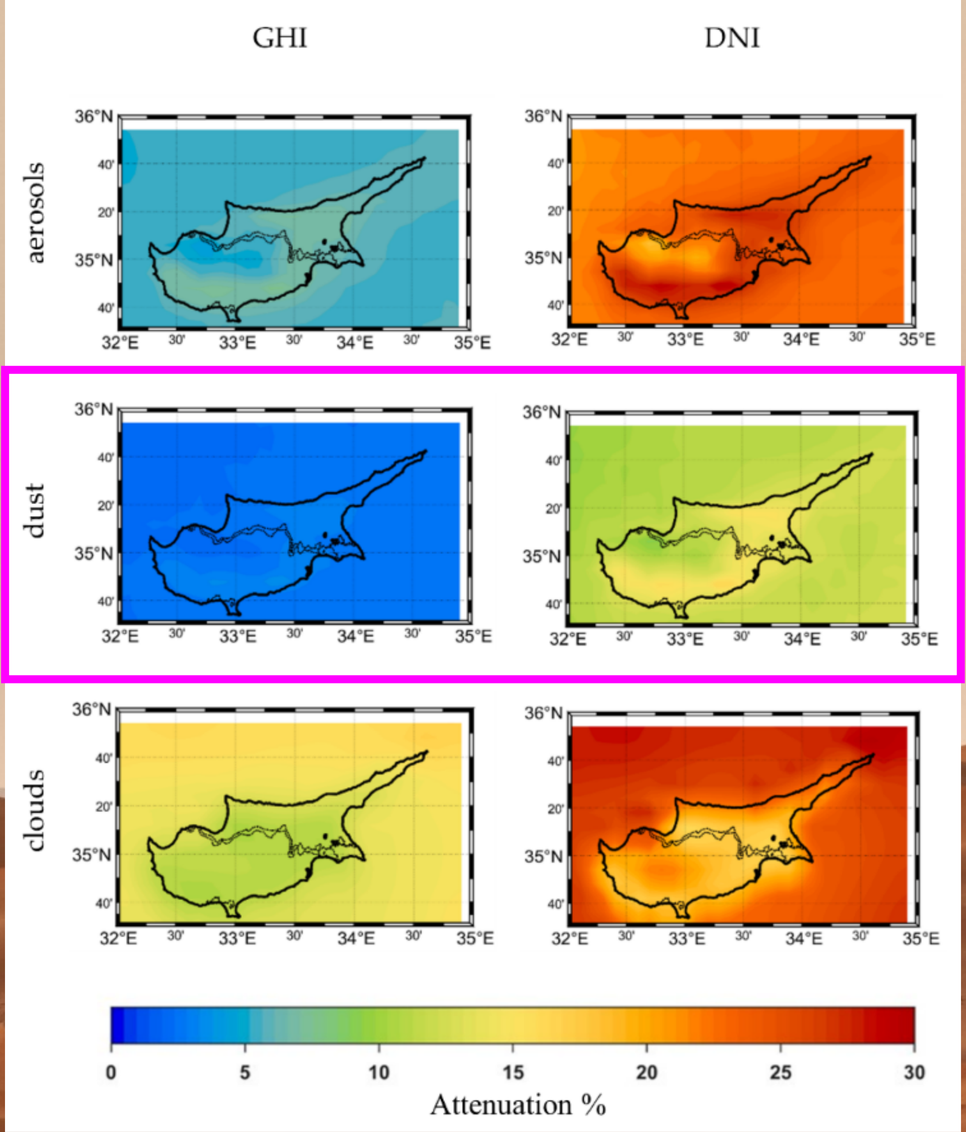
- ➢ Calculation of monthly arithmetic and geometric averages when at least 6 days are available at each grid-cell
- ➢ Trends of deseasonalized DODs when at least 5 out of 15 years are available (Hsu et al., 2012)
- ➢ 95% confidence level (Weatherhead et al., 1998)
- ➢ Maximum **positive trends** in the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

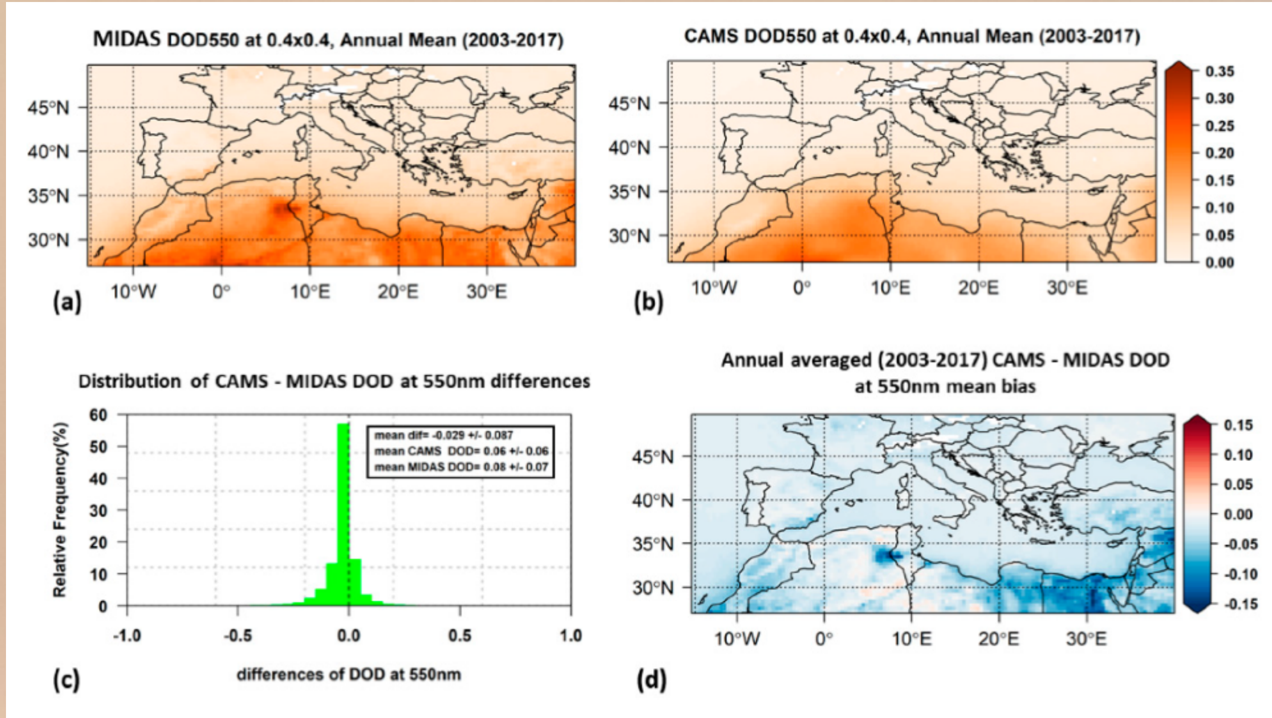
Dust trends in regions of interest

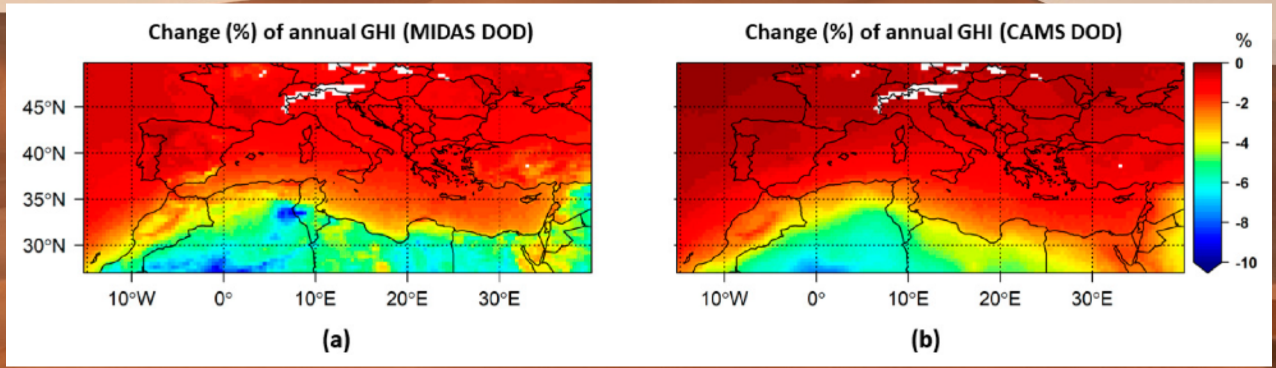


MIDAS dataset exploitation

Radiative effects



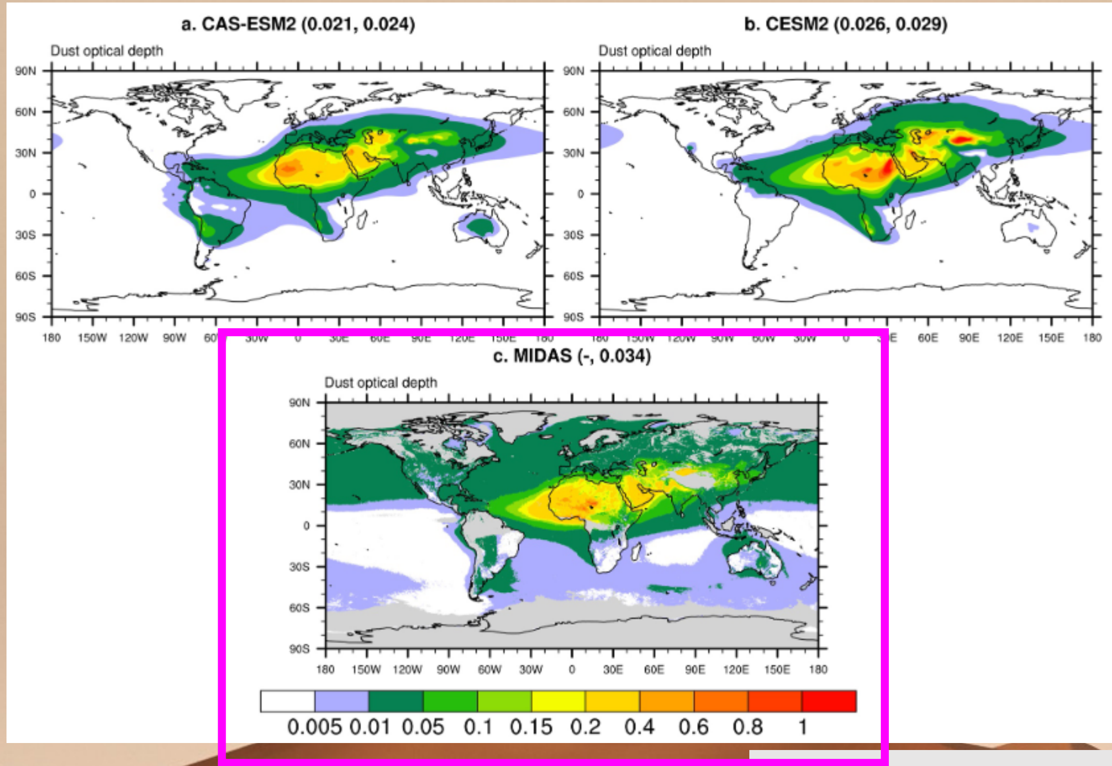




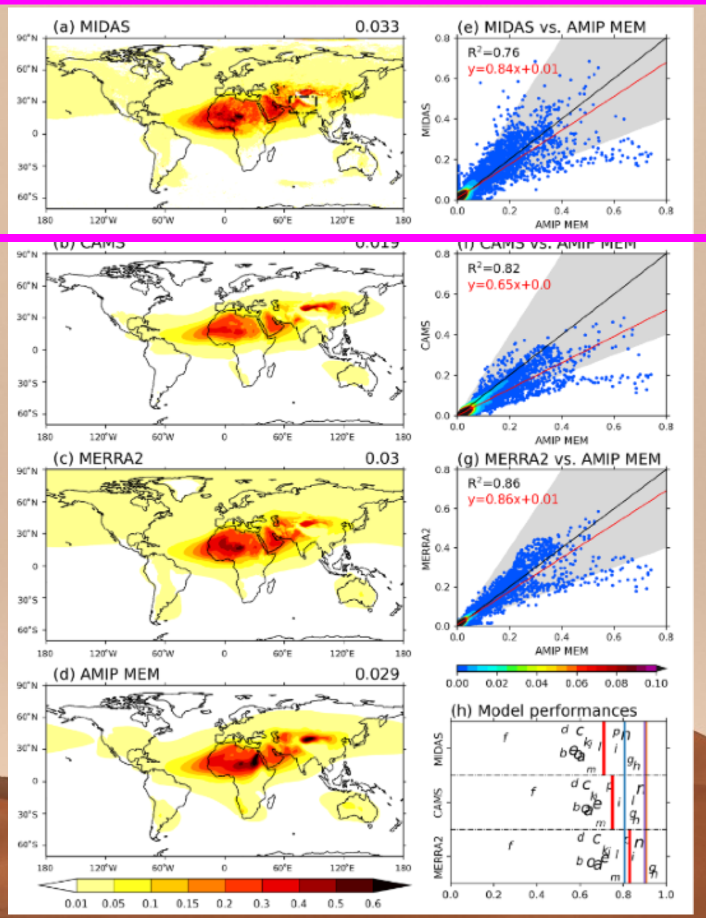
Fountoulakis et al. (2021)

Papachristopoulou et al. (2022)

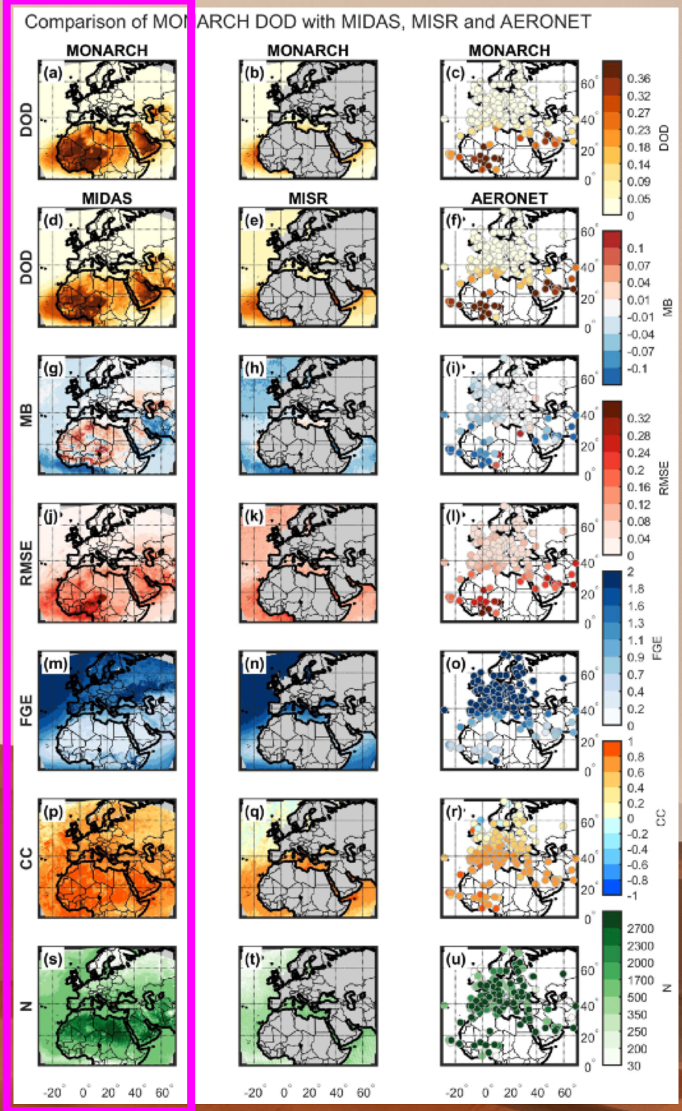
Model evaluation



Wu et al. (2021)



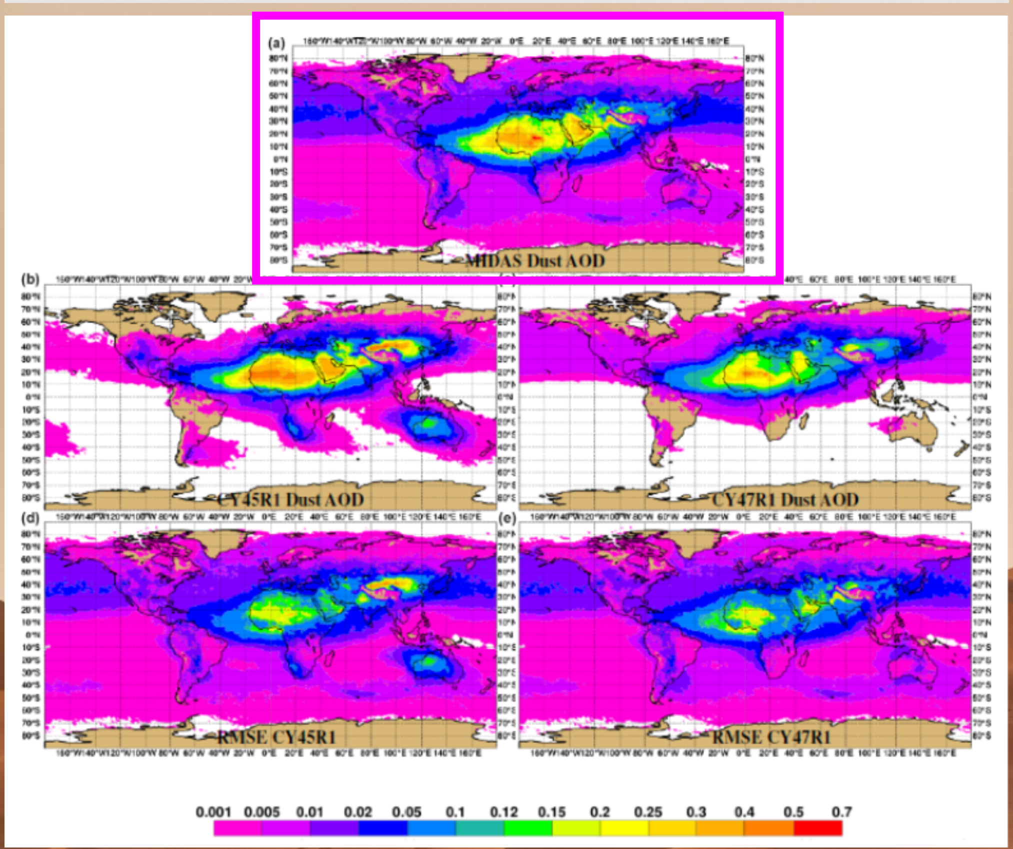
Zao et al. (2022)



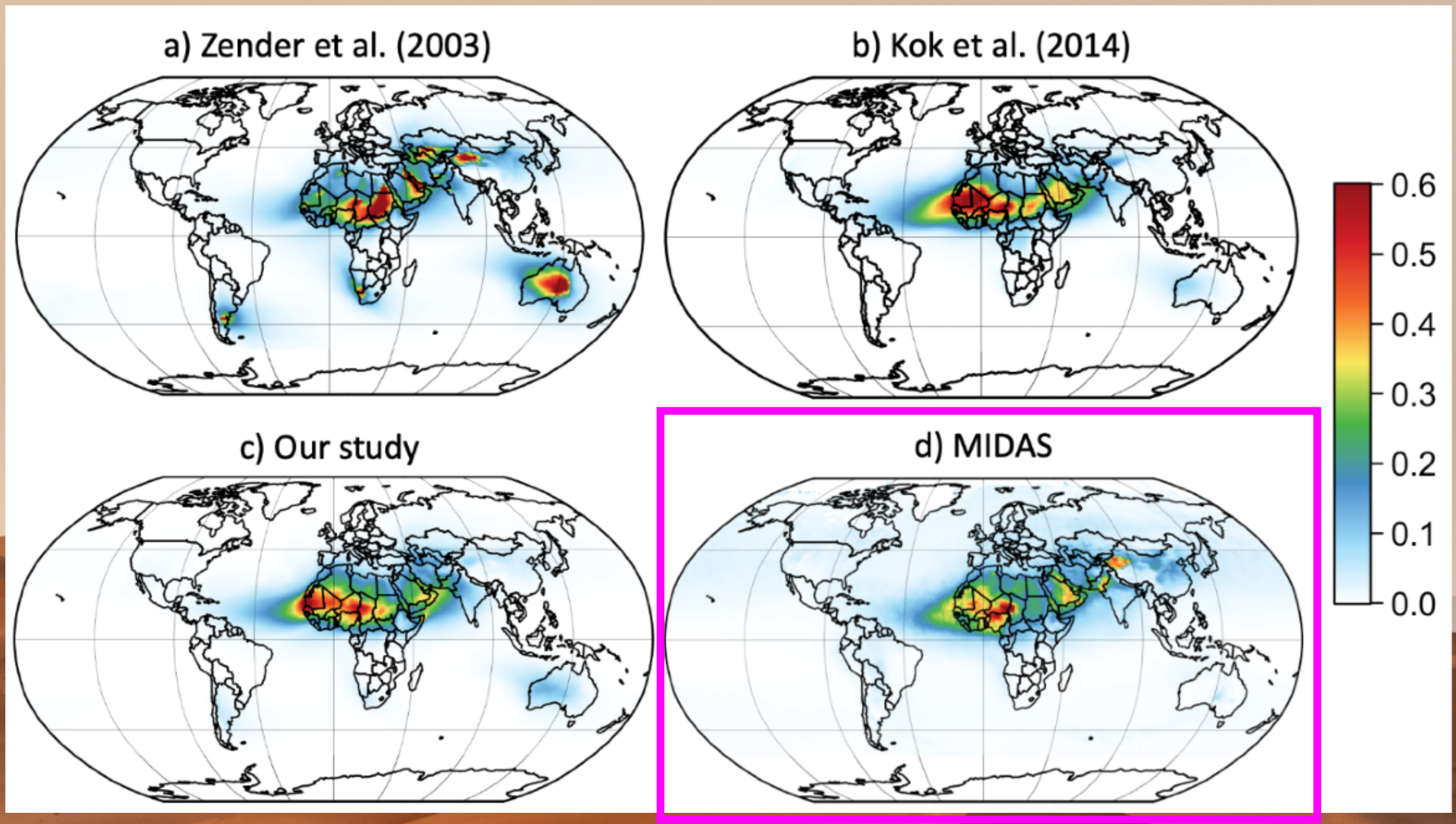
Mytilinaios et al. (2023)

Model evaluation

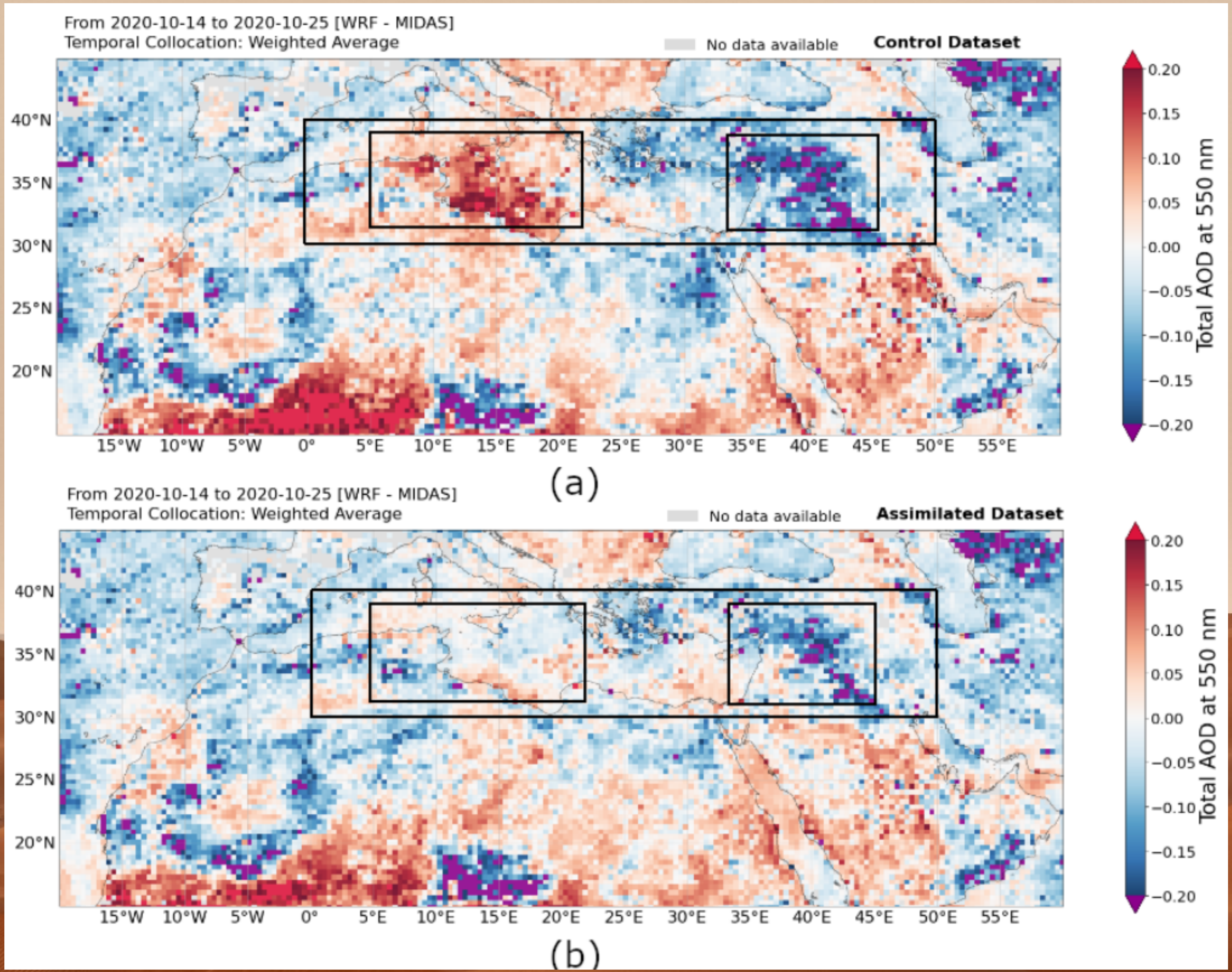
Remy et al. (2022)



Leung et al. (2023)

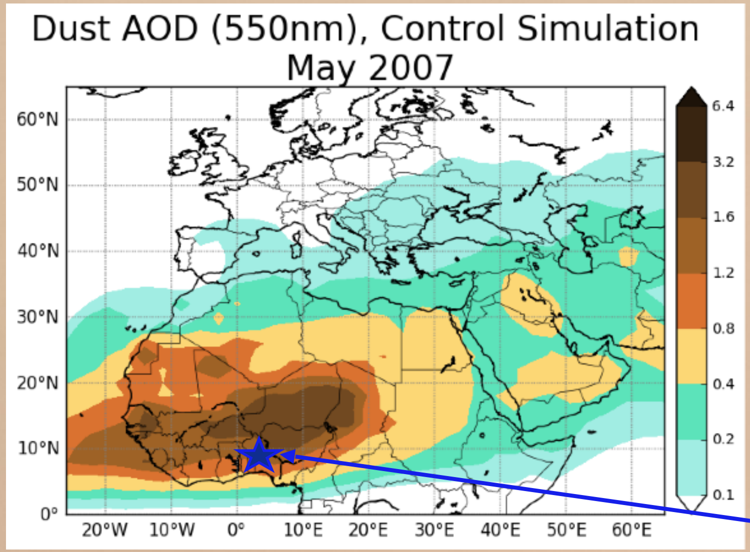


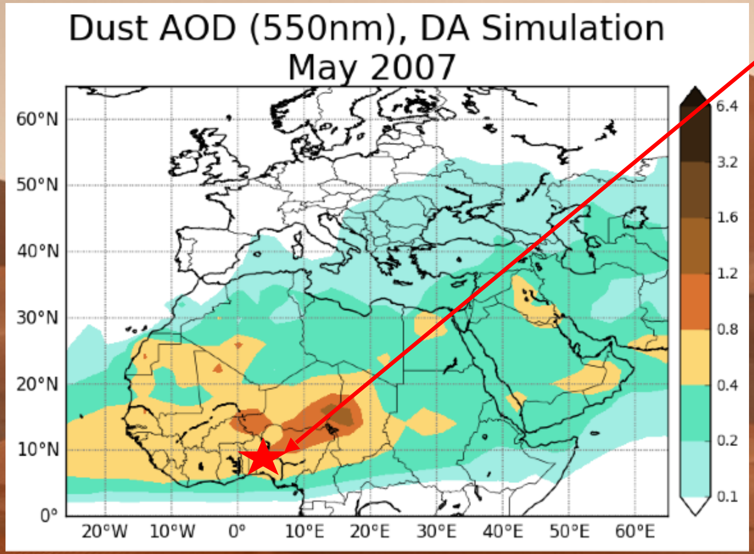
Model evaluation



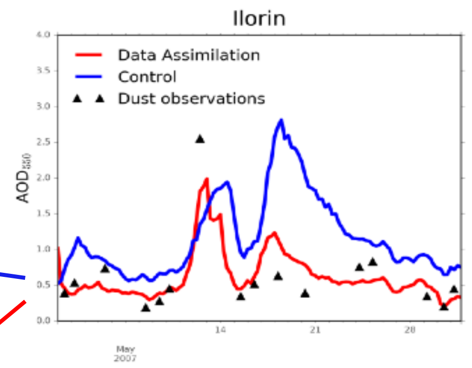
Kiriakidis et al. (2023)

MIDAS assimilation in the MONARCH model



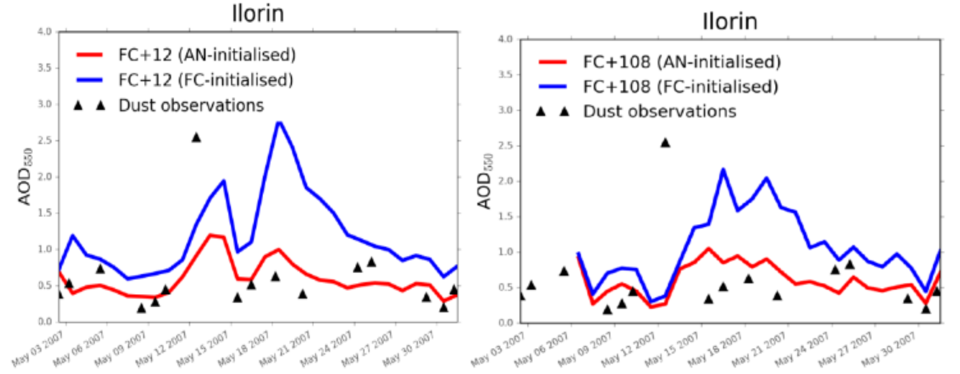


Control | DA | Observations



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)

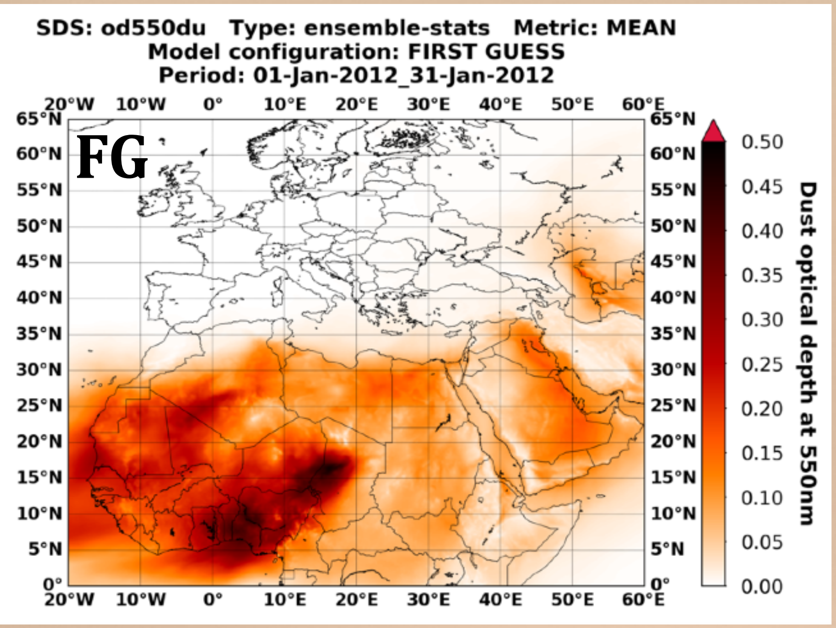
Di Tomaso et al. (2017)

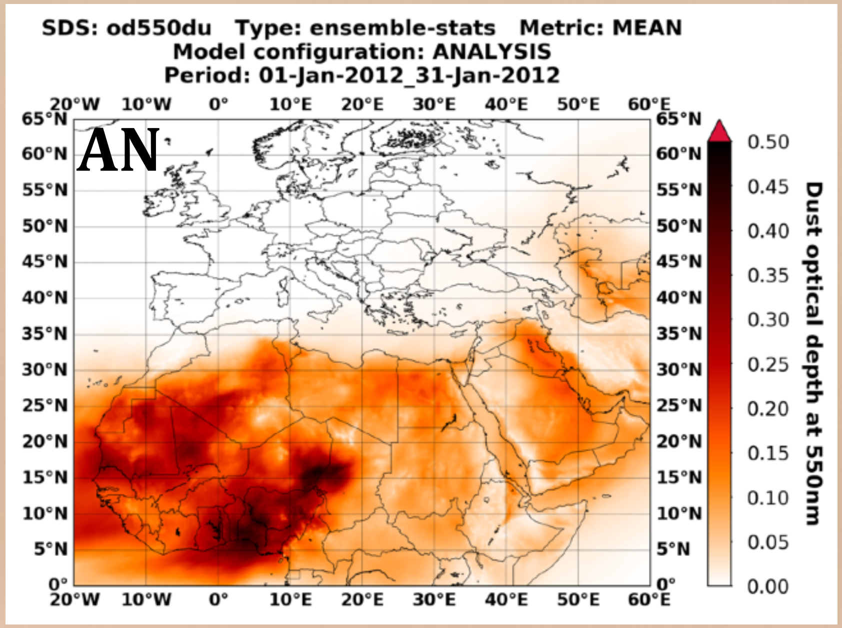
MIDAS provides an improved data set for data assimilation applications

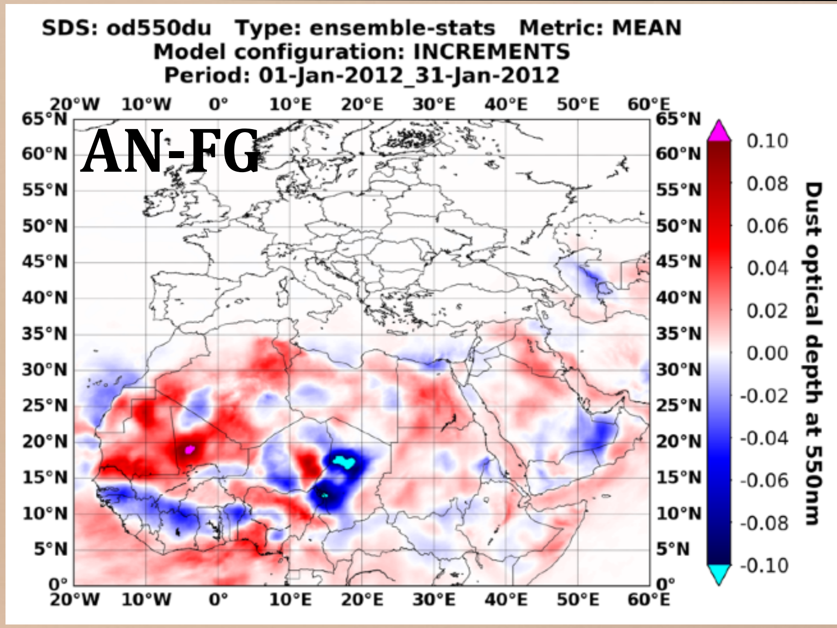
MIDAS

- 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

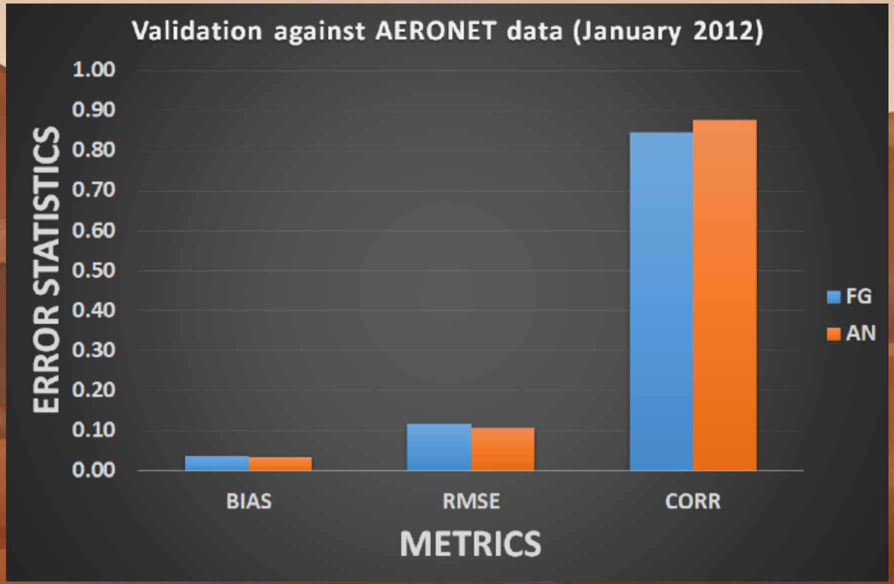
MIDAS assimilation: First test [January 2012]





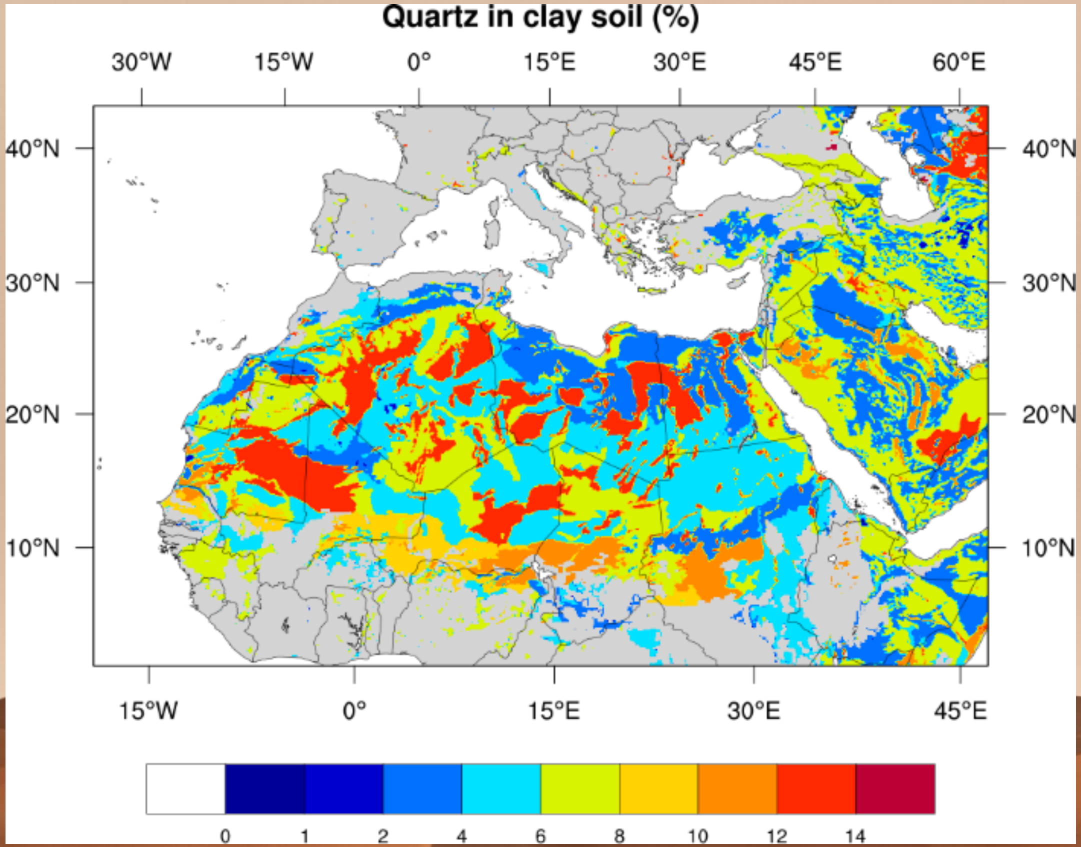


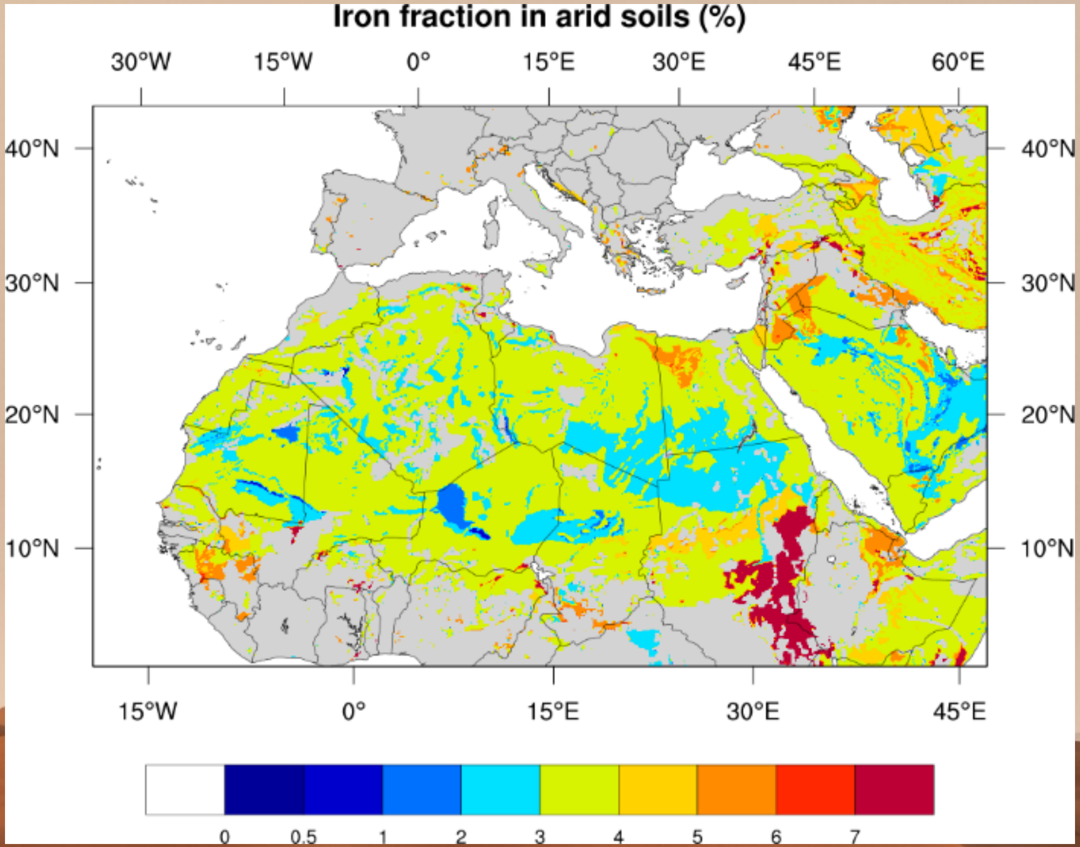
Evaluation against AERONET SDA retrievals



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

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

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° x 0.1°) 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.

Preview

MIDAS Dataset

Structure of the repository

The files are provided in netCDF4 format. The folders are organized in years and grid

Publication date: November 8, 2020

DOI: DOI 10.5281/zenodo.4244106

Keyword(s): dust, aerosol, MODIS, MERRA-2, CALIPSO

Grants: European Commission:

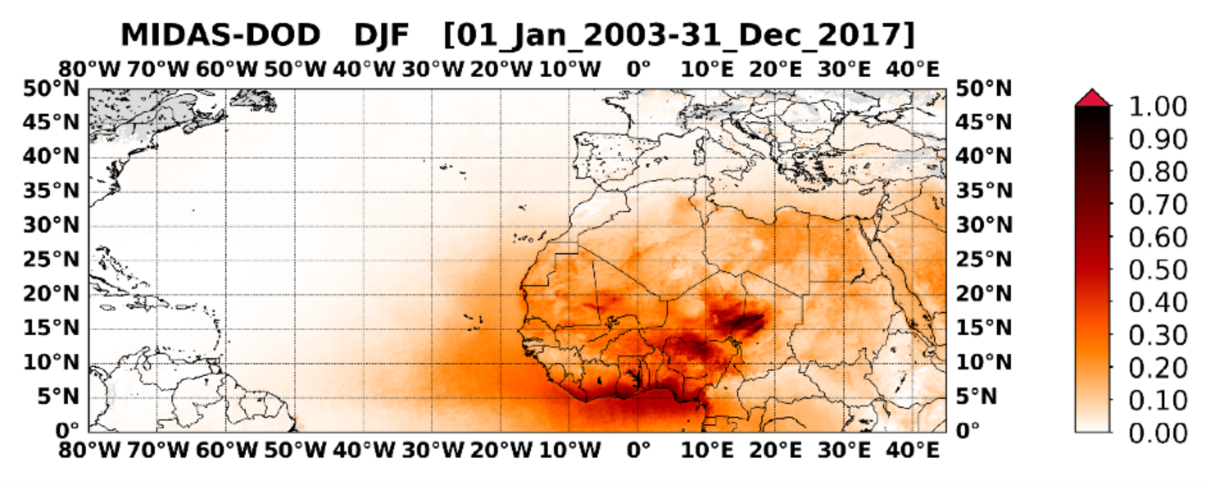
- DUST-GLASS - Improving global dust prediction and monitoring through data assimilation of satellite-based dust aerosol optical depth (749461)

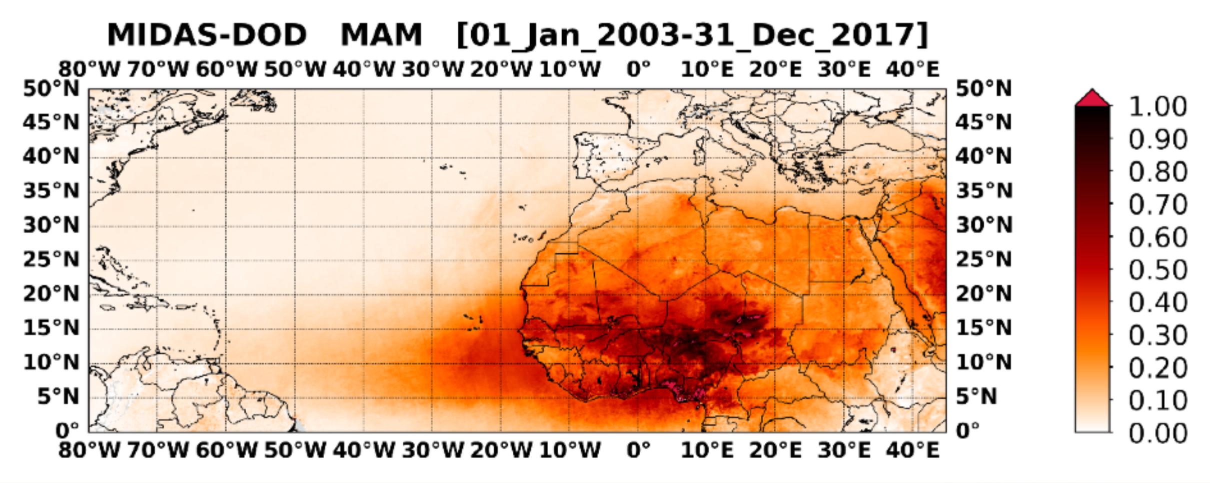
Communities: NOA: ReACT

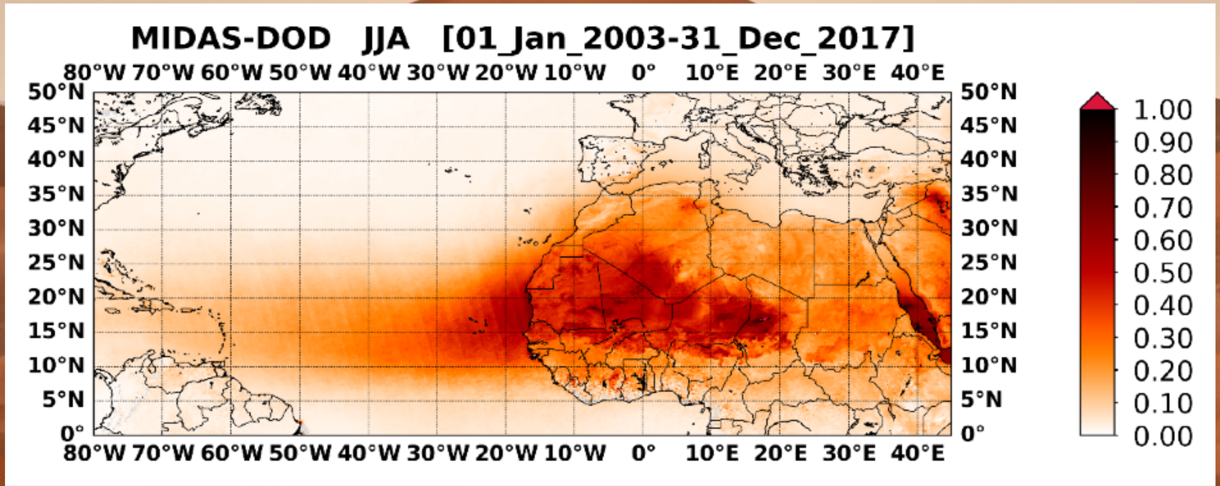
https://zenodo.org/record/4244106

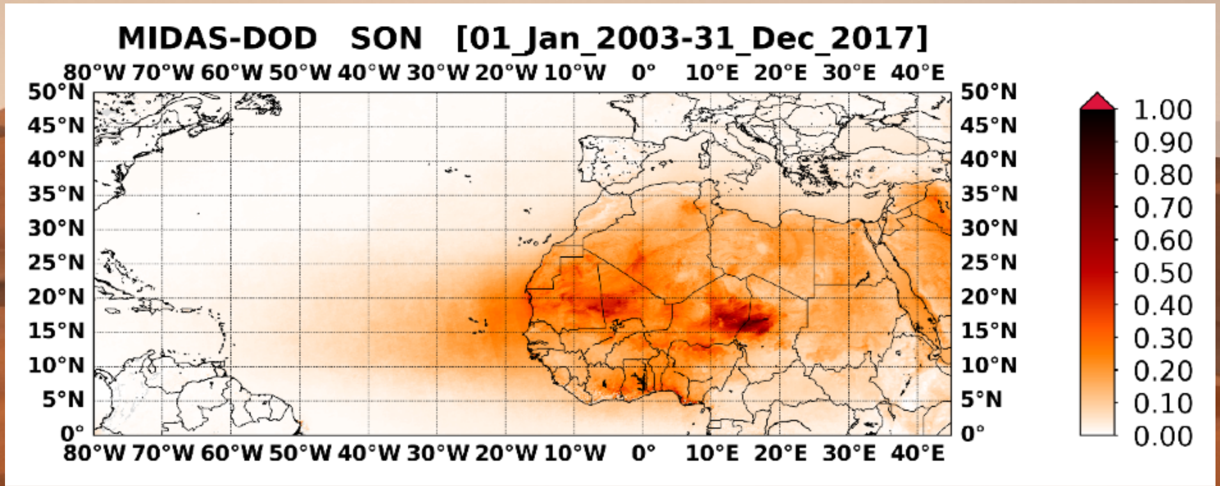
MIDAS DOD seasonal global patterns

Sahara – Tropical Atlantic Ocean – Mediterranean

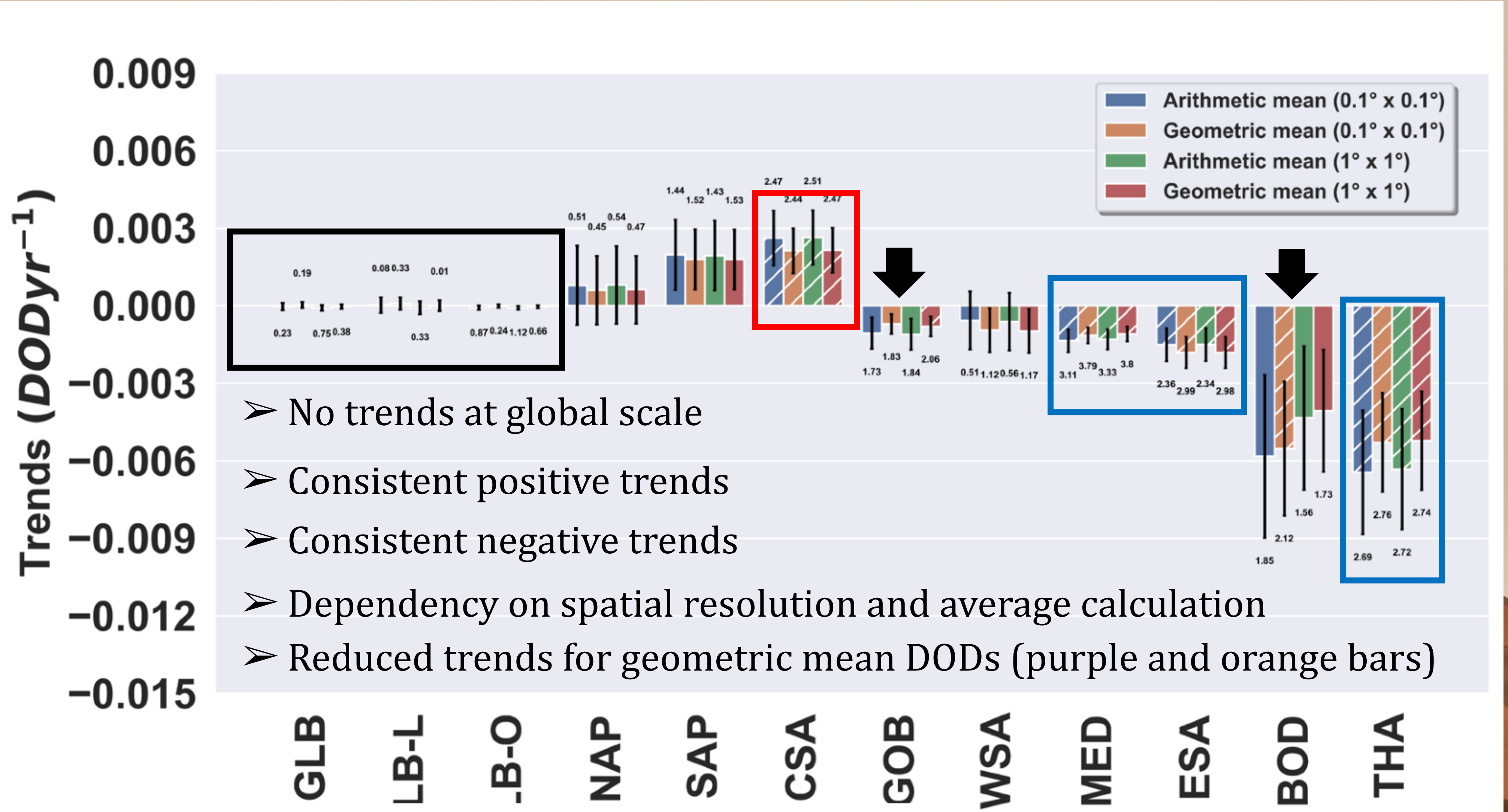








Global and regional trends [2003-2017]



- ➢ 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: $|\omega/\sigma_\omega| > 2$ (95% confidence level)

➢ ➢ Error | ➢ Hatched bars: statistical significant trends rend

Dust sources identification