Dust aerosols in the Greek area and their effect on surface solar irradiance

Papachristopoulou K.[1,2*], Kosmopoulos P.[3], Gkikas A.[2], Amiridis V.[2], Hatzaki M.[1] and Kazadzis S.[4,3]

1 National and Kapodistrian University of Athens, Department of Geology and Geoenvironment, Athens, Greece

2 Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens (IAASARS/NOA), Greece;

3 Institute for Environmental Research and Sustainable Development, National Observatory of Athens (IERSD/NOA), Greece

4 Physikalisch Meteorologisches Observatorium Davos, World Radiation Center (PMOD/WRC), Switzerland

*corresponding author e-mail: kpapachr@phys.uoa.gr

Abstract: Dust aerosols through their interaction with solar radiation perturb the radiation budget of the Earth–atmosphere system. The broader Greek area is frequently affected by dust outbreaks originating across North Africa where the largest desert area (Sahara) of the planet is located. Under favorable meteorological conditions, dust loads are transported over Greece with decreasing intensities northwards. This latitudinal gradient has been revealed from several studies relying on aerosol optical depth (AOD) observations, since pure dust optical depth (DOD) databases are rare. In the current study, we are using: (i) the Copernicus Atmospheric Monitoring Service modeling and reanalysis providing total and per aerosol types AODs, including dust (2003-2017, 0.4º x 0.4º) and (ii) a recently developed MODIS DOD dataset (2003-2017, 0.1º x 0.1º, DUST-GLASS project), in which spaceborne AODs and reanalysis DOD-to-AOD ratios from MODIS-Aqua and MERRA-2, respectively, are jointly processed. The key objectives of this work are: (i) the comparison of the DOD at 550nm data, derived from the two databases, (ii) the comparison of the DOD trends over the broader Greek area since 2004 and (iii) the calculation of the dust direct radiative effects (DREs) on the shortwave radiation based on simulations of the libRadtran Radiative Transfer Model.

1 Introduction

Aerosols interactions with the incoming solar (shortwave, SW) radiation are affecting the Earth-atmosphere radiation budget. Aerosols directly interact with SW radiation through scattering and absorption (direct radiative effects – DREs). Among aerosol particles, dust is the most abundant and the Sahara Desert is one of the digest dust sources on the planet, affecting mostly the southern European countries.

Greece is often affected by dust particles and various studies have shown the geographically expected gradient in dust aerosol contribution to total aerosol optical depth, showing larger contribution in Southern Greek areas than Northern ones (Gkikas et al. 2016, Koukouli et al. 2010).

The aim of this study is to quantify the mean seasonal dust DRE on the SW radiation for the broader Greek region using the synergy of a radiative transfer model and Dust aerosol Optical Depth (DOD) as input from the broadly used data base of CAMS and the newly developed MIDAS dust product (Gkikas et al. 2021).

2 Data and Methodology

2.1 Data

Dust loads utilized in this study in terms of Dust aerosol Optical Depth (DOD) at 550nm is Copernicus Atmospheric Monitoring Service (CAMS) reanalysis dataset and the recently developed MIDAS (Gkikas et al. 2021) DOD dataset. Also, the MODIS-Aqua Aerosol Optical Depth (AOD) at 550nm was utilized which is provided alongside with MIDAS DOD database, as it was used for the construction of the aforementioned database using also DOD/AOD ratios from MERRA-2 reanalysis. The study area is the broader Greek area (34º to 42º North and 19º to 29º East) and the time period of the study is limited to 2003-2017 which is MIDAS data availability.

CAMS DOD reanalysis data were collected with a spatial resolution of 0.4º x 0.4º. The temporal resolution of CAMS data is 3hours and the mean DOD from 12:00 and 15:00 UTC was calculated as the representative CAMS DOD daily value, in order to synchronize the two datasets (Aqua satellite overpass over Greece is around 13:00 UTC). MIDAS dataset provides daily DOD values, to a fine spatial resolution of 0.1º x 0.1º in a global scale. For the study area, the data were re-gridded to a coarser spatial resolution of 0.4º x 0.4º and collocated with CAMS dataset. The choice for the upscale from the original fine spatial resolution of MIDAS was based on the limited data availability (below 50%) due to cloud coverage and spatial coverage of the satellite.

2.2 Methodology

The comparison of the DOD (550nm) values from the two databases was performed with the daily synchronous and collocated values. Also, annual means and monthly means for all years were calculated, and from the de-seasonalized monthly means for every year DOD linear trends were also derived for both datasets.

In order to calculate the dust Direct Radiative Effects (DREs) on the shortwave radiation LibRadtran (Mayer and Kylling, 2005) Radiative Transfer Model (RTM) runs were performed. RTM runs were made using as input seasonal means of DOD values for every grid point of both datasets and the corresponding aerosol free runs were also made for the same atmospheric and astronomical conditions. In order to calculate the relative contribution of dust from MIDAS dataset to the overall attenuation from total aerosol loads, RTM simulations for MODIS AOD seasonal means were performed as well. For RTM simulations including aerosols, apart from the input of DOD values at the 550nm and MODIS AOD, for the other dust and total aerosol optical properties (Ångström exponent and Single Scattering Albedo) climatological values (Raptis et al. 2020) were used. For both aerosol free and total aerosol/dust included runs, ozone seasonal values were used as input, calculated from OMI daily satellite retrievals.

3 Results

3.1 CAMS – MIDAS comparison of the DOD

In Figure 1 the comparison of DOD (550nm) values from CAMS and MIDAS datasets is presented. Figure 1(a) gives the distribution of the CAMS and MIDAS DOD differences. Those differences were calculated from the co-located and synchronized DOD values (whole study area, all years 2003-2017) for both datasets. MIDAS dataset has greater DOD values with a mean difference of 0.02. Annual average DOD values are in a relatively good agreement between those datasets as depicted in Figure 1(b), ranging from 0.3 to 0.9 for both DOD datasets. Analyzing also the daily DOD values (not shown) we found a MIDAS DOD overestimation, especially in cases when MODIS detected high AOD in the area related to dust events. At these cases, CAMS DOD does not exceed the maximum value of 2. However, these cases represent less than 0.05% of the total daily ones. The spatial distribution of the difference between those annual averaged DOD values is presented in Figure 1(c). This map shows that these differences are close to zero for almost all the study area.

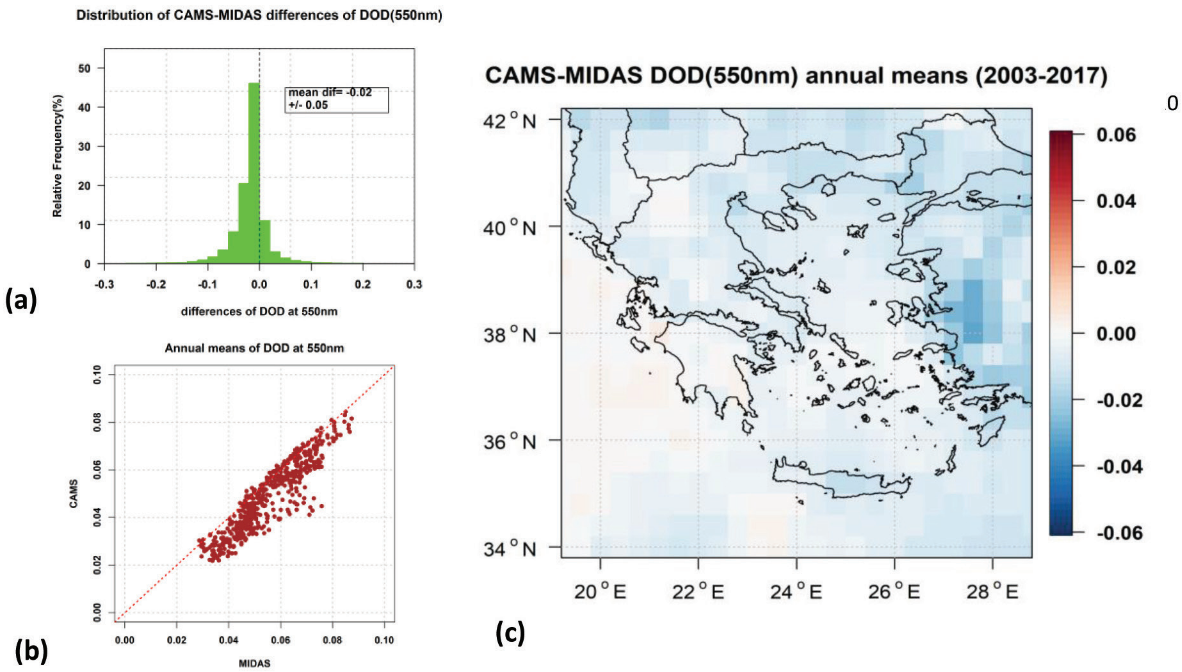

Fig. 1. (a) The distribution of the DOD (550nm) differences and **(b)** scatterplot of DOD (550nm) annual means from CAMS and MIDAS datasets (2003-2017). **(c)** The spatial distribution of CAMS-MIDAS DOD (550nm) annual mean (2003-2017) differences.

3.2 CAMS – MIDAS DOD at 550nm trends

In Figure 2 is depicted the spatial distribution of DOD at 550nm changes per decade. De-seasonalized monthly means were calculated for every grid point for both datasets and linear regression was performed in order to compute the linear trends and their statistical significance was assessed by the t-test with 95% confidence interval. For CAMS data, the changes of DOD values per decade are almost zero everywhere in the study area and those values are not statistically significant as well. In contrasts, for MIDAS dataset an overall decline of DOD values was computed, which is statistically significant at the 95% confidence interval for the majority of the grid points (marked grid points on the map). The greater tendency was found for the area south east of the island of Crete, with a statistically significant (p-value<0.05) decline up to 0.04 per decade for DOD at 550nm. The trend difference is directly linked with the fact that CAMS DOD has an upper limit of around 2 on a daily DODs while for MIDAS this limit is much higher. In our understanding CAMS DOD, that is based mostly in a modeling aspect, fails to identify high dust intrusion events captured by MIDAS (MODIS). These events are less often during the more recent period leading to this difference in the two trends.

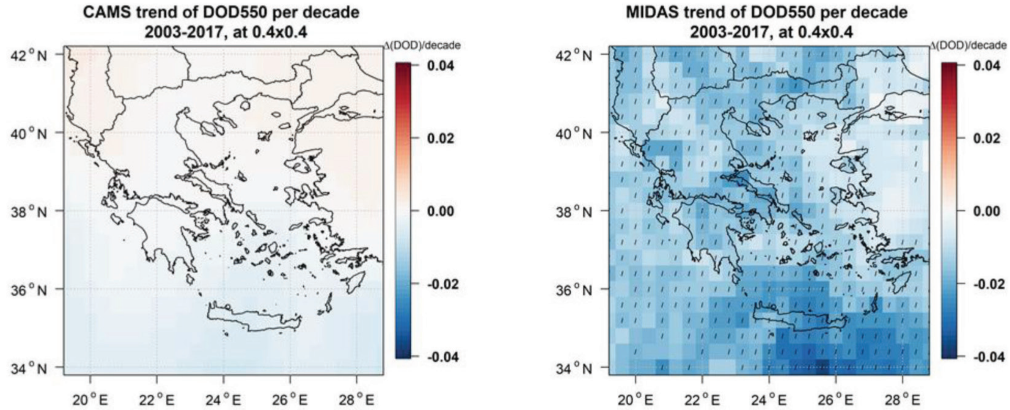

Fig. 2. Spatial distribution of decadal changes of DOD at 550nm over the broader Greek area from CAMS and MIDAS datasets (2003-2017).

3.3 CAMS – MIDAS dust DREs on shortwave radiation

The surface Direct and Global components of SW irradiance were calculated using as input to RTM simulations the seasonal and annual means of DOD from both CAMS and MIDAS datasets, for the average local noon solar zenith angle for each season and location. Also, aerosol free simulations were performed with the same atmospheric and astronomical conditions and the Dust Modification Factor (DMF) was calculated, as the ratio of dust included and aerosol free results, for both SW irradiance components.

For all seasons and for annual means, the results reveal the latitudinal gradient of DMF following the same spatial pattern of the DOD spatial distribution over Greek area, for both datasets. Southern regions having greater DOD values, with spring to be the season with the greatest mean DOD at 550nm values among seasons up to ~0.14 for CAMS and ~0.16 for MIDAS dataset for spring season. The maximum mean spring value of CAMS DOD reduced by 12.1% and 3.3% the Direct and Global irradiances respectively, on average for spring season. The maximum mean spring value of MIDAS DOD reduced by 13.1% and 3.7% the Direct and Global irradiance respectively, on average for spring season. Figure 3 summarizes the mean spring DMF as computed from both datasets for Direct and Global solar irradiance components, and it is also clear from this Figure that aerosols affect much more the Direct than the Global (Direct plus Diffuse) irradiance as the theory suggests. For Direct component the DMF ranges from 0.87 to 0.96 and for Global component ranges from 0.96 to 0.99, as mean values for spring season.

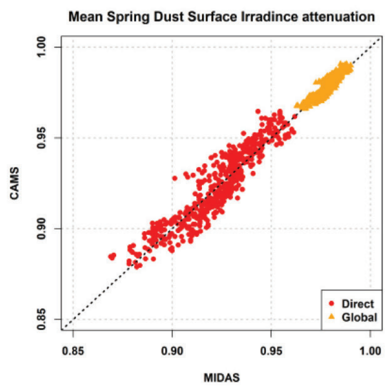

Fig. 3. Mean spring Direct and Global irradiance attenuation attributed to DOD (550nm) from CAMS and MIDAS datasets. Solar irradiances have been calculated for the average local noon solar zenith angle for each season and location.

3.4 MIDAS DOD contribution to total aerosol attenuation

In this section, we will focus on MIDAS dataset. In order to calculate the dust contribution relatively to total aerosol load in surface SW irradiance attenuation, RTM simulations were also made for MODIS AOD (550nm) seasonal means. Results for spring season and Direct SW irradiance component are presented in Figure 4. Figure 4(a) gives the percentage of mean attenuation due to MODIS AOD and Figure 4(b) gives the percentage of mean attenuation due to MIDAS DOD. Figure 4(c) is giving the percentage of dust contribution relatively to total aerosol loads in surface Direct irradiance attenuation, as means values for spring season, and these values were calculated from the results of the two aforementioned figures. The latitudinal gradient of dust contribution to irradiance attenuation is prominent. For northern areas dust contribution to SW irradiance attenuation ranges from 30% to 40% and for central areas is around 45%. For the southern part of the study area, dust contribute from 50% up to 65%.

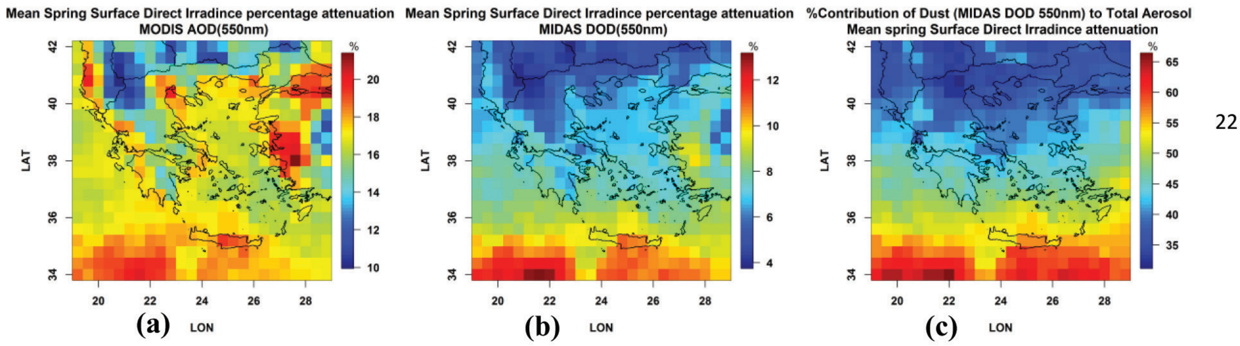

Fig. 4. Percentage of mean spring surface Direct SW irradiance attenuation due to (a) MODIS AOD and (b) MIDAS DOD at 550nm. (c) Percentage of mean spring contribution of dust to surface Direct SW irradiance attenuation relative to total aerosol loads. Solar irradiances have been calculated for the average local noon solar zenith angle for each season and location.

4 Conclusions

In this study, two DOD databases were exploited and the effect of dust to incoming surface solar irradiance was examined through the synergies of DOD datasets and RTM simulations. Our findings for the broader Greek area could be summarized as follows:

- For the study area, CAMS slightly underestimate DOD, compared to MODIS derived MIDAS DOD.
- CAMS DOD trends are negligible compared to statistically significant (p-value<0.05) DOD decline calculated from MIDAS DOD dataset up to 0.04 per decade for south east of Crete island.
- The greatest seasonal mean DOD values were found in spring season, up to ~0.14 for CAMS and ~0.16 for MIDAS dataset for the southern broader Greek area, with corresponding Direct and Global irradiance reductions up to 12.1% and 3.3% for CAMS DOD, and up to 13.1% and 3.7% for MIDAS DOD.
- The dust contribution to mean surface SW irradiance attenuation during spring season compared to total aerosol attenuation for:
  - northern parts of the study area ranges from 30% to 40%
  - central is around 45%
  - southern ranges from 50% up to 65%.

These quantitative results are of particular interest for Greece, a country with an increase share on solar energy exploitation systems.

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