Clouds and aerosol effects on solar energy in Cyprus

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Motivation:

- **Deployment of renewable energy resources** is essential towards **to mitigation of climate change**.
- **Cyprus plans to drastically increase the share of renewable energy sources from 13.9% in 2020 to 22.9% in 2030. (Mesimeris et al., 2021)**
- **Solar energy exploitation systems** are one of the main pillars for this effort in Cyprus due to the **high solar energy potential** of the island, with
  - sunshine durations (daily percentage) from ~ 60% in winter up to ~ 90% in summer (Kassem et al., 2020; Jacovides et al., 1993)
  - cumulative annual global horizontal irradiance (GHI) of 6700 – 7300 MJ/m^2 (Kalogirou et al.,2017; Pashiaridis et al., 2017)

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Motivation:

- For such rare cloudy conditions at Cyprus, and especially in summer, **aerosols** play a key role in the formulation of the levels of surface solar radiation (SSR) (Jacovides et al., 1993), with **dust** particles have a significant impact to SSR, as desert dust is frequently transported over Cyprus, either from North Africa or from Middle East (Achilleos et al., 2020; Mamouri, R.-E. et al., 2016)

- So, accurate measurements of aerosol optical properties are necessary, in addition to information for clouds, in order to accurately **model SSR in Cyprus**.

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Aim of the study:

- to highlight the **role** of **aerosols**, with special focus on **dust** aerosols, in the production of solar energy in Cyprus, using the recently developed high quality and high resolution **ModIs Dust AeroSol (MIDAS)** dust climatology (Gkikas et al., 2021)

- to investigate the spatial and the temporal **variability** of the effects of aerosols, dust and clouds on **GHI**, of interest mainly for photovoltaic systems (**PVs**) and Direct Normal Irradiance (**DNI),** of interest mainly for Concentrating Solar Power systems (**CSP**).

- To create a 14-year **climatology** of the DNI and GHI, using high quality satellite aerosol and cloud products. [added value: SSR has been simulated using satellite high resolution retrievals of Aerosol Optical Depth (AOD) instead of climatological or assimilated AOD]

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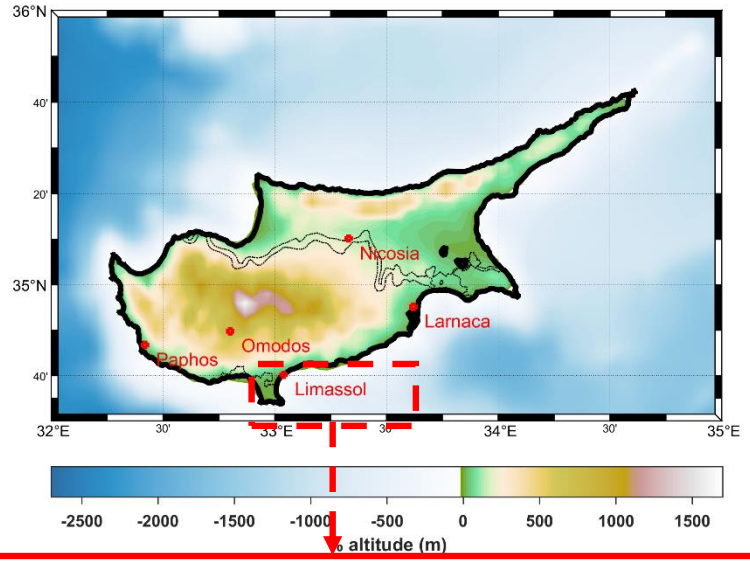
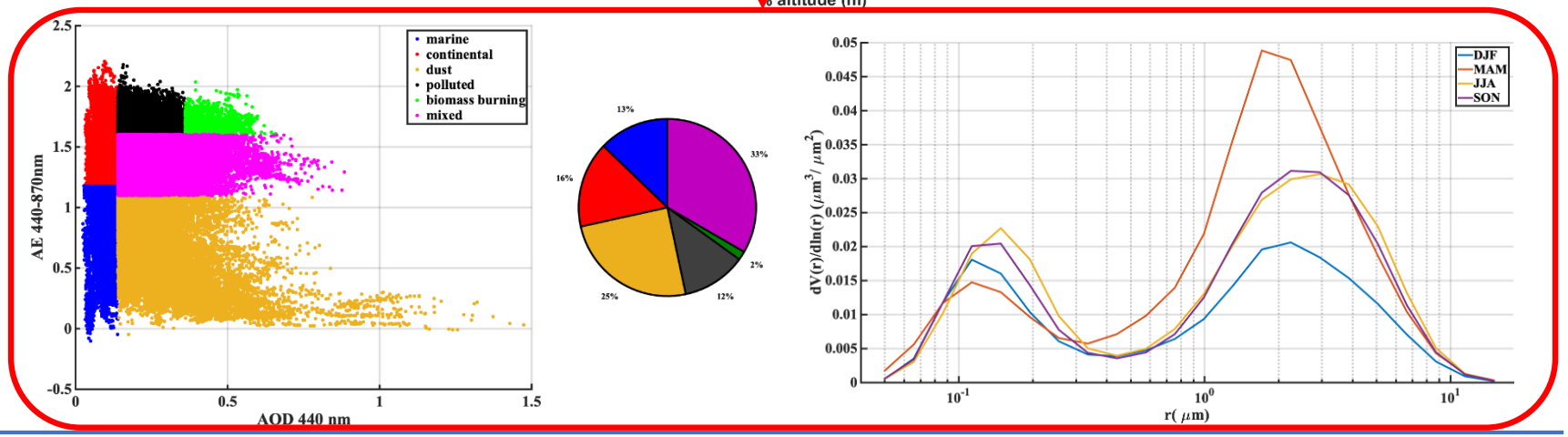
Aerosols in Cyprus (ground based retrievals):

- Dust is a significant fraction of the aerosol mixture in Cyprus
- In AERONET measurements at Limassol (in 2010-2020) the dominant type in the aerosol mixture was dust (~25%)
- Large amount of course particles in spring





Ground based measurements:
Level 1.5 and 2.0, Version 3 AERONET retrievals of aerosol optical properties (2010-2020), using measurements by the CIMEL sun photometer which is operating at Cyprus University of Technology (CUT-TEPAK) in Limassol.

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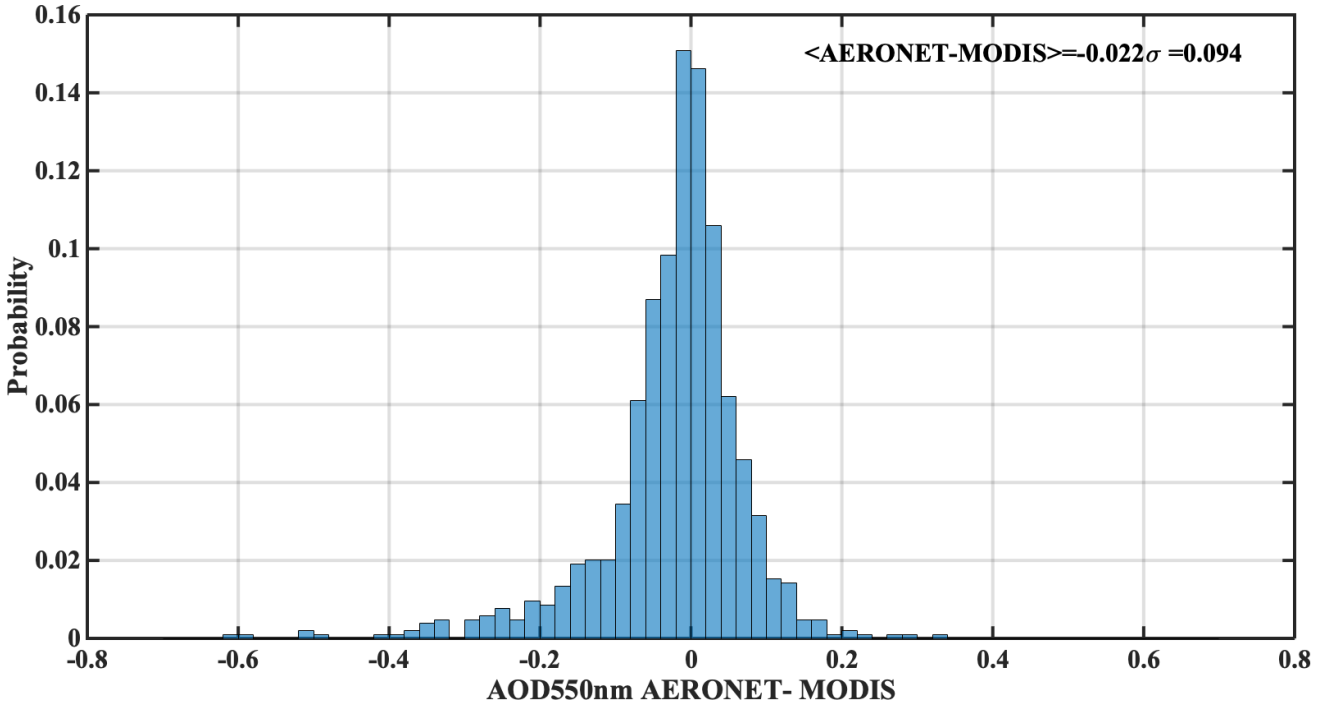
Ground based VS satellite data:

Since long-term continuous AERONET retrievals in Cyprus are available only for Limassol, Aerosol optical Depth (AOD) and Dust Optical Depth (DOD) at 550 nm (hereon AOD and DOD) from **MIDAS (Gkikas et al., 2021)** data set were used for the study of aerosol variability on a wider spatial scale.



Features of the ModIs Dust AeroSol (MIDAS) dataset:

- MODIS- Aqua columnar aerosol optical depth (AOD) at 550 nm
- Columnar dust optical depth (DOD) at 550 nm
- Spatial/Temporal resolution: 0.1° x 0.1° / Daily
- Spatial coverage: Global (both over land and ocean)
- Temporal availability: 2003 – 2017 (15 years)

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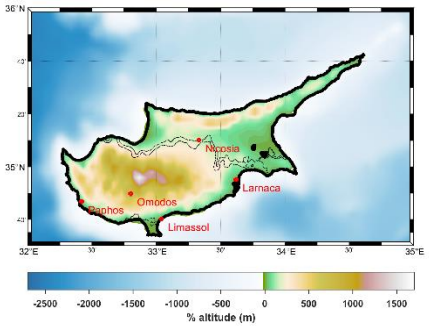
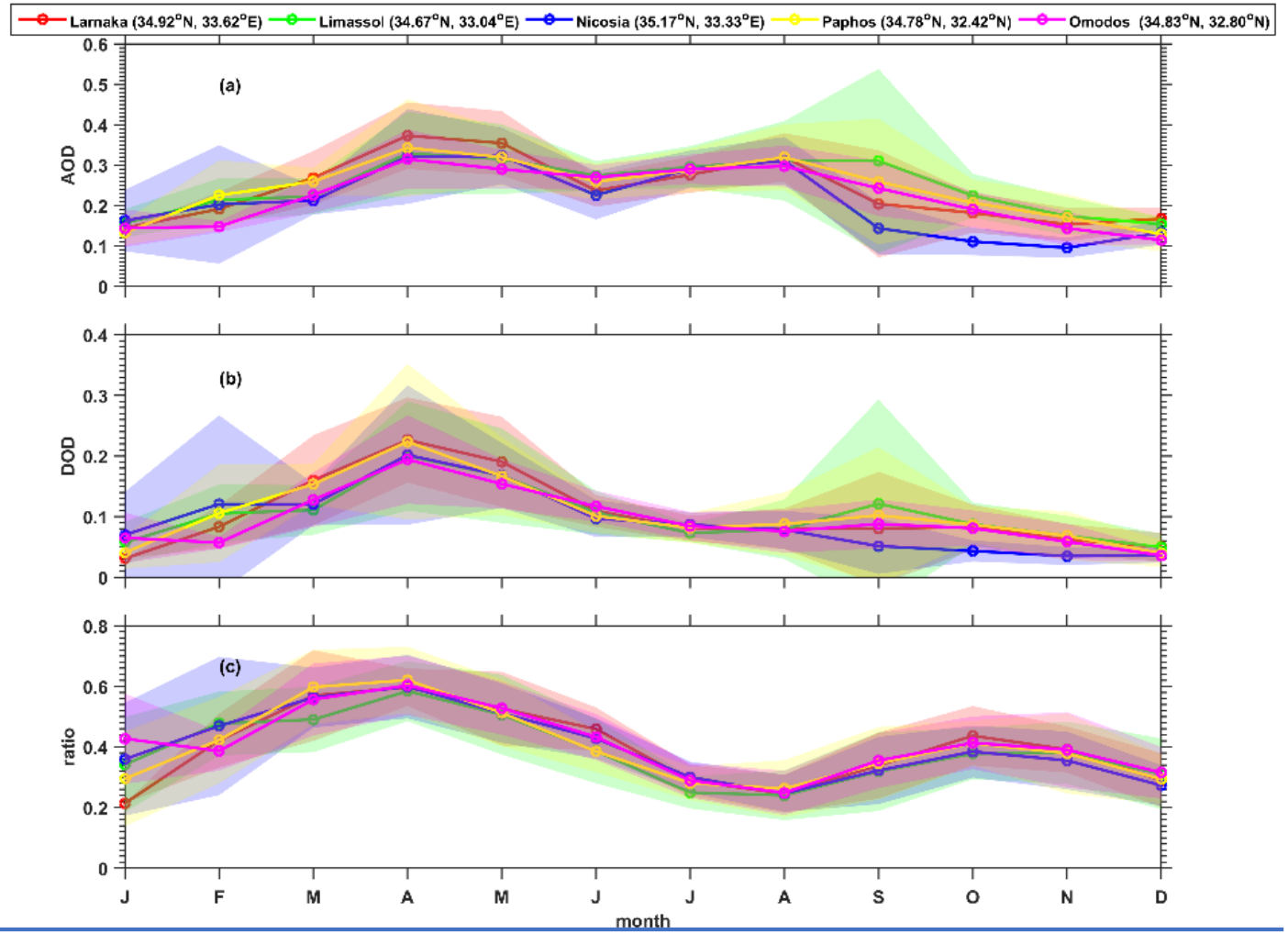
Aerosols in Cyprus (satellite retrievals):

- Maximum AOD values in spring and summer (0.3 and 0.25 respectively)
- Maximum of dust contribution to aerosol mixture in spring, with secondary maximum in autumn
- Dust transfer from North Africa and Middle East is frequent, especially in spring with average DOD values 0.15-0.2





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Climatological study of solar energy:

Aerosol optical depth (**AOD**) and Dust Optical Depth (**DOD**) from **MODIS/MIDAS** (Gkikas et al., 2021)

Climatological **water vapor**, **ozone**, **SSA**, **Angstrom exponent**, etc

LUT of spectra (290 – 3000 nm) corresponding to different conditions – radiative transfer simulations from Uvspec libRadtran (Emde et al., 2016)

Integrated shortwave (SW) irradiances in timesteps of 1h for 2004-2017

Attenuation by **clouds** from **CMSAF-SARAH2** (Pfeifroth et al., 2017)

- Climatology of **GHI** and **DNI** on 0.1x0.1 grid
- Study the effects of clouds, aerosols and dust on the production of solar energy

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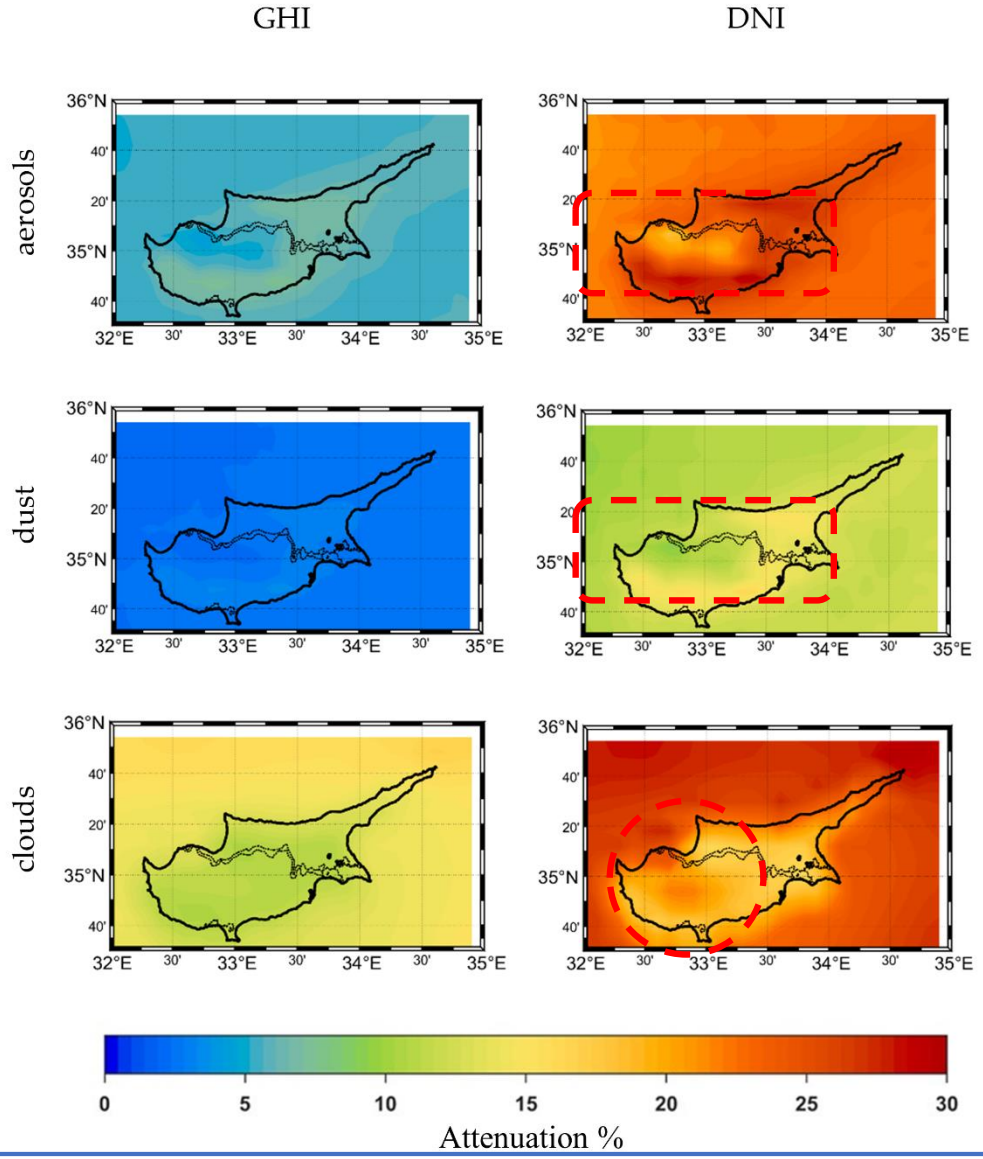
Geographical distribution of GHI and DNI attenuation by aerosols, dust and clouds:

For GHI:

- 5-10% attenuation due to aerosols
- 30-40% of the overall attenuation by aerosols due to dust
- 12-14% attenuation due to clouds

For DNI:

- 15-35% attenuation due to aerosols
- 30-50% of the overall attenuation by aerosols due to dust
- 22-25% attenuation due to clouds



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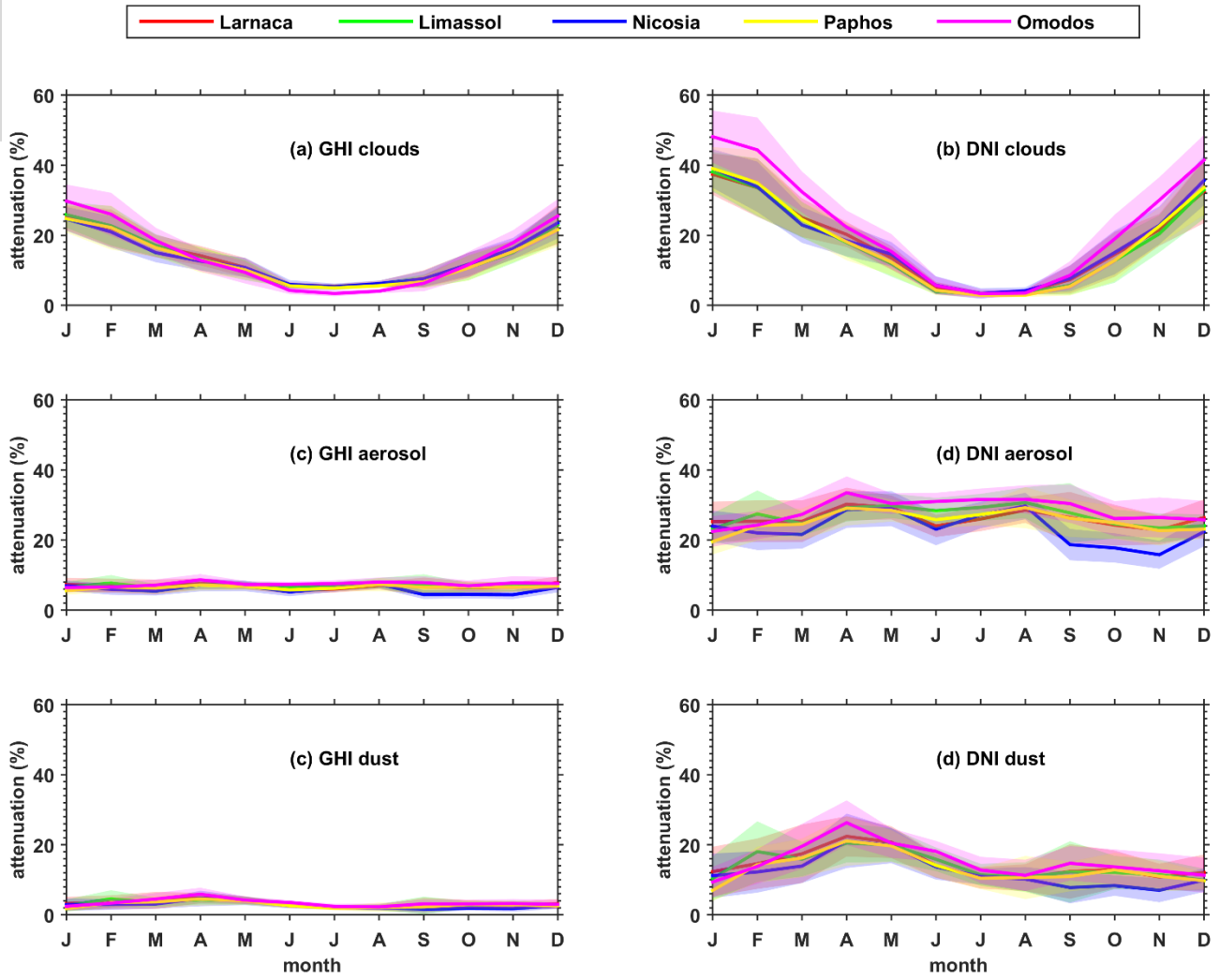
Monthly averages of GHI and DNI attenuation by aerosols, dust and clouds:

In winter:
25-30% GHI attenuation and 35-50% DNI attenuation by clouds

In summer:
- GHI attenuation by clouds and aerosols practical the same
- DNI attenuation by aerosols is 7-8 times stronger than this by clouds
- DNI attenuation by dust is 3 times stronger than this by clouds



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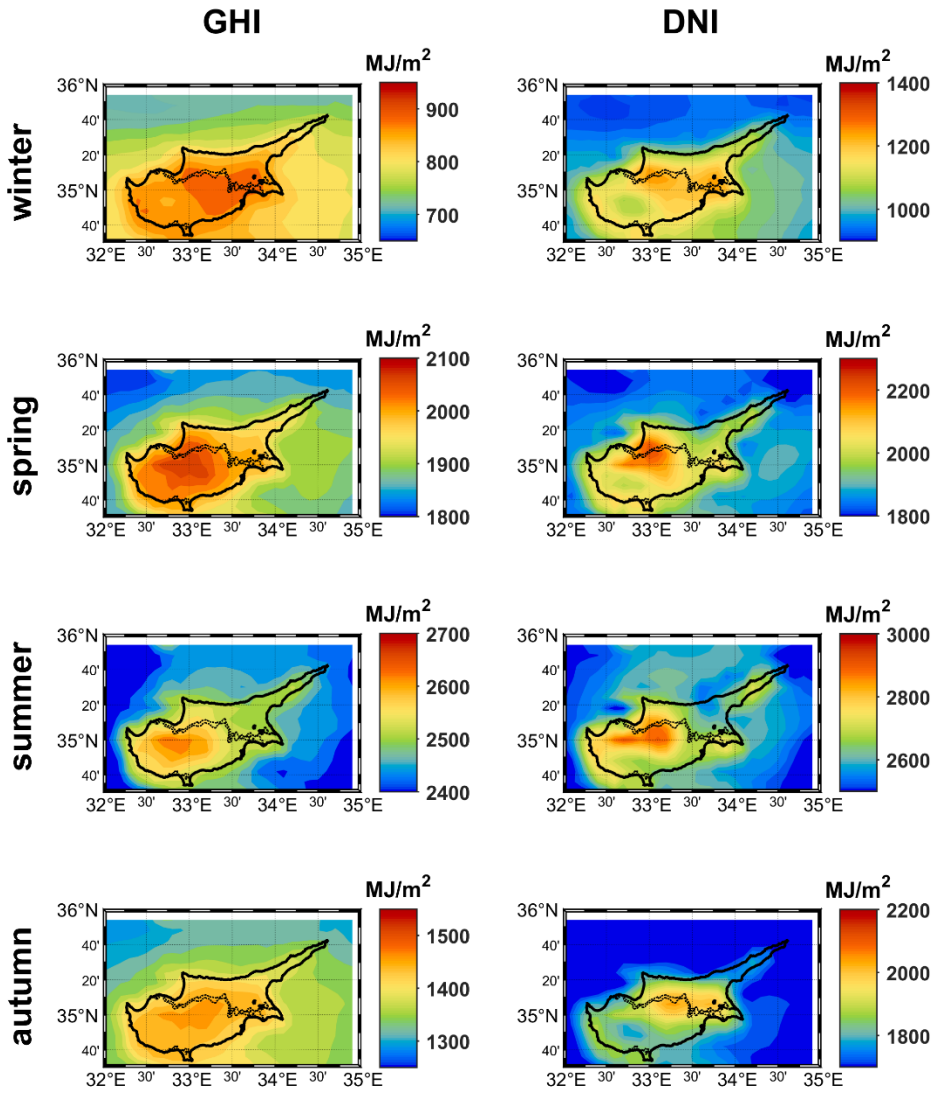
Seasonal integrals of GHI and DNI in Cyprus:

Despite the small geographical extent of Cyprus, Troodos Mountains seem to have drastic effect on the spatial variability of solar potential, especially for DNI, with minimum levels at the south slopes and maximum at the north.



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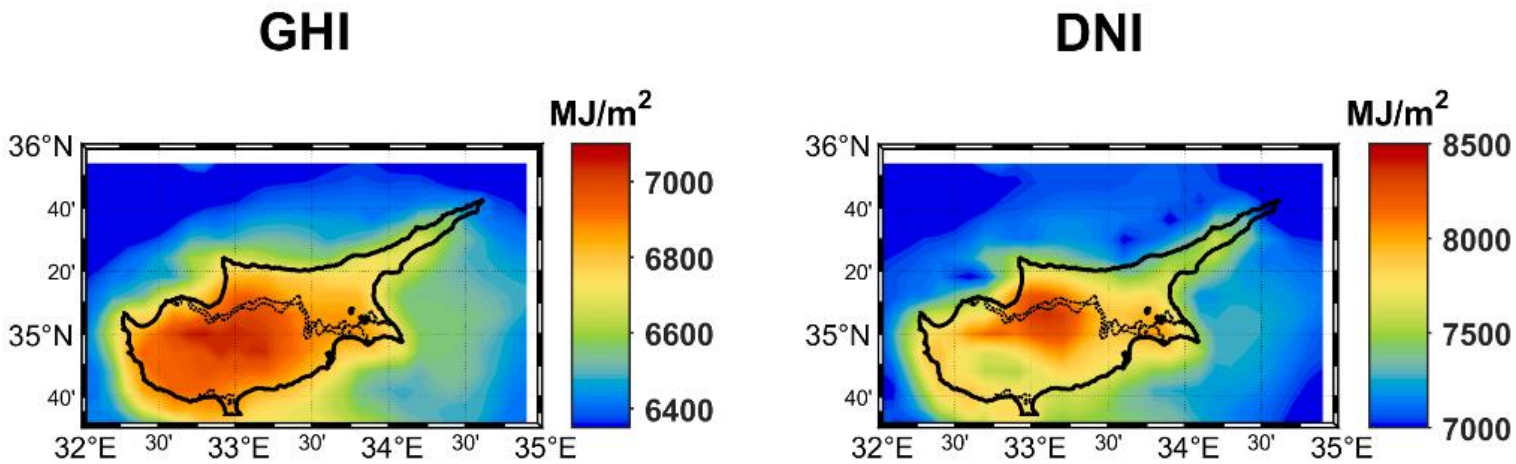
Annual integrals of GHI and DNI in Cyprus:

GHI:
6800-7200 MJ/m^2 , with maximum values at the north slopes of Trodos Mountains

DNI:
7500-8500 MJ/m^2 , with maximum levels slightly shifted to the north relative to GHI



Summary:

- Annual GHI in Cyprus ~ 6800 – 7200 MJ/m^2
- Annual DNI in Cyprus ~ 7500 – 8500 MJ/m^2
- Similar levels of GHI and DNI with Malta and Andalusia, Spain – highest in Europe (Yousif et al., 2013; Moreno-Tejera et al., 2016)
- Main factors attenuating surface solar radiation are clouds and aerosols
- The role of dust is very significant
- Dust contributes ~25% in the aerosol mixture (~50% in spring)

Find more information for this study in the recent published paper:

remote sensing

MDPI

Article

Effects of Aerosols and Clouds on the Levels of Surface Solar Radiation and Solar Energy in Cyprus

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Thank you for your attention!

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