A model of dust episode impact on surface solar irradiance

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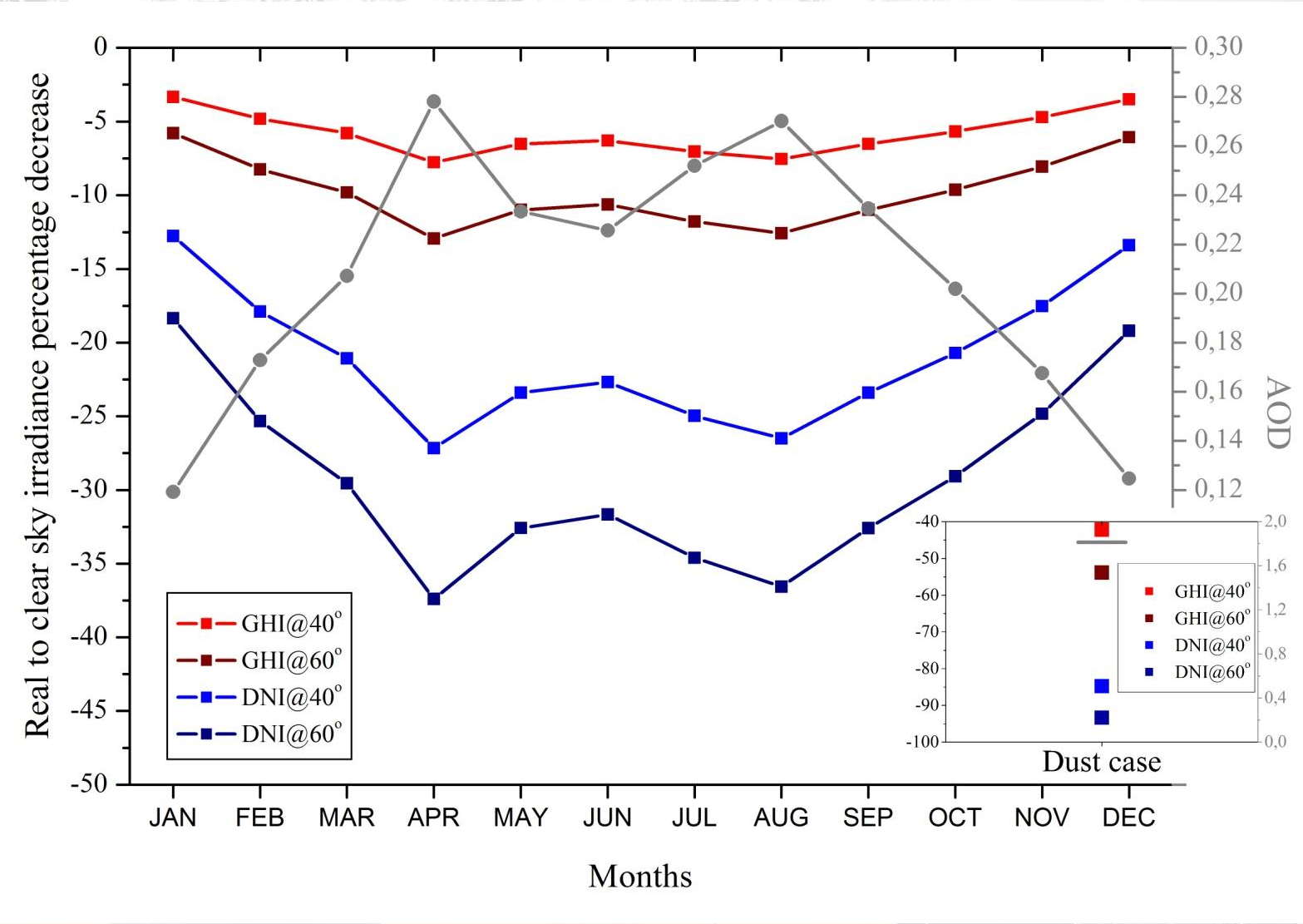
Introduction

- Solar energy potential is sensitive to the presence of clouds which attenuates the solar radiation measured at the surface. Various **large photovoltaic installations have been built at places with minimum cloudiness** over southern Europe and northern Africa. Here, aerosols play an important role on the solar radiation reaching the Earth's surface, especially for the direct normal irradiance (DNI).

- In preparation for the Horizon 2020 consortium project GEO-CRADLE for coordinating and integrating state-of-the-art Earth observation (EO) activities in North Africa, the Middle East, and the Balkans, we report on the findings of a study to assess the impact of dust aerosol outbreaks on DNI (and the global and diffuse horizontal irradiances GHI & DHI) and hence on solar power generation.

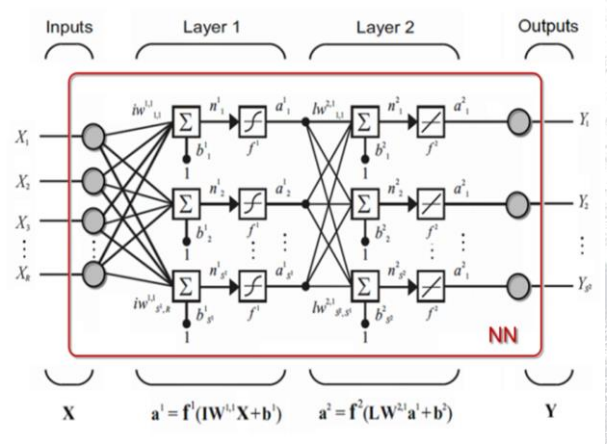
- We calculated spectrally-integrated DNI and GHI from a state-of-the-art modelling system developed by the solar energy applications project (www.solea.gr) during the evolution of an extreme dust outbreak period on the 1/2/2015.

Aerosol impact on radiation



Mean monthly, clear sky GHI and DNI % decrease in Athens, Greece for various solar angles together with the aerosol optical depth (AOD) (in grey). The inset shows values for the extreme dust outbreak on the 1/2/2015.

The SOLEA Project



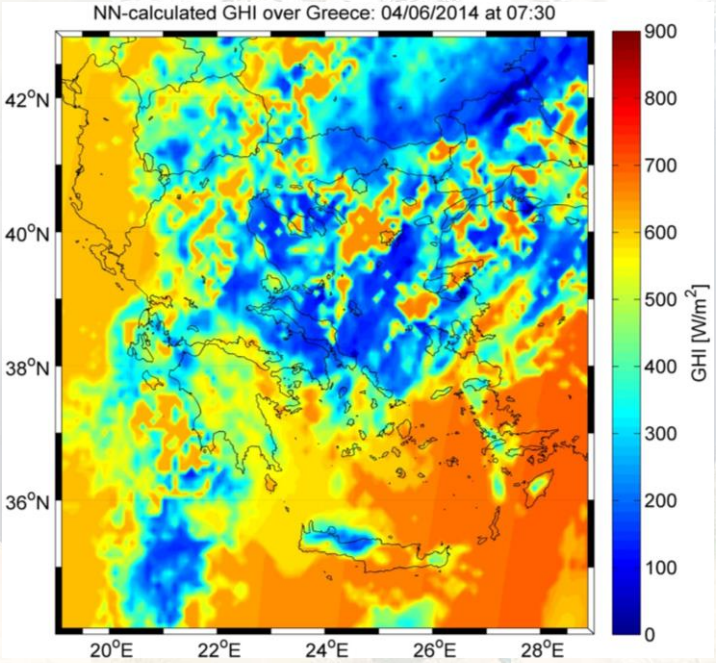
- SOLEA is a new research project for the development of SOLar Energy Applications (**solea.gr**) based on solar irradiance spectra produced from a operational system that uses a synergy of neural networks (NN), radiative transfer (RT) simulations and real-time satellite retrievals.

- NN is trained on a large-scale (2.5 million record) look-up table (LUT) of clear and cloudy sky RT simulations (generated by a bank of PCs running in parallel for over 3-months) to convert satellite cloud and aerosol products directly into solar radiation spectra.

- Surface spectra for the DNI, GHI and DHI are produced at high resolution (1nm, 0.05 degrees, 15-min) using input data acquired from MODIS & AERONET (aerosol) and from the SEVIRI onboard the MSG3 satellite (cloud).

- The RT-NN solver is capable of producing maps of spectrally-integrated GHI of the order of 10^4 to 10^5 pixels within 1-minute and with relative errors less than 20% of libRadtran-simulated values [Taylor et al 2016, JQSRT 168:176-192].

- Local or regional maps of the total DNI, GHI and DHI provide the capability needed to serve high precision solar power applications. The inclusion of cloud and aerosol effects means that this approach is ideal for correct assessments of solar power operational loads [Kosmopoulos et al 2016, Energy 93, 1918-1930].



State-of-the-art Methodology

i. the effects of clouds and aerosol on the solar radiation spectrum at the surface are included directly to provide accurate solar energy estimates

ii. the satellite retrievals are of high temporal (15-min) and spatial resolution (0.05 degrees) enabling production of precise and large-scale, nowcast maps

iii. the trained NNs are much faster than RT simulations and enable real-time capability

iv. in each pixel, the full DNI, GHI and DHI spectrum is generated at high spectral resolution (0.5 nm)

v. our high-speed calculation system has been validated against 10,000 simulated results in over 0.5 million pixels (so far for Europe and the Mediterranean)

vi. the system is continuously evolving and being fine-tuned with the outputs being monitored and validated to ensure their accuracy and quality.

Clear sky inputs

SZA	2:2:88
SSA	0.6:0.1:1
O3	250:20:450
AOD	0:0.05:1.5
H2O	0.5:0.5:3.5
AEX	0.2:0.6:2

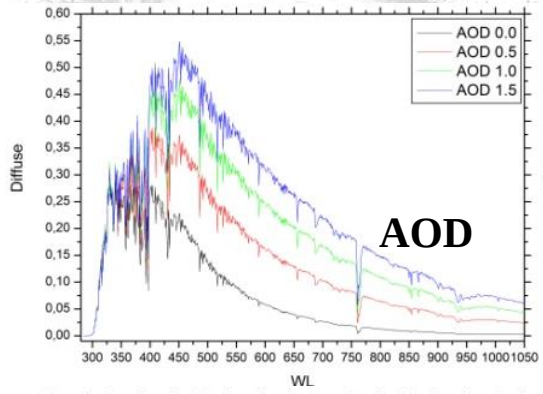
Cloudy inputs

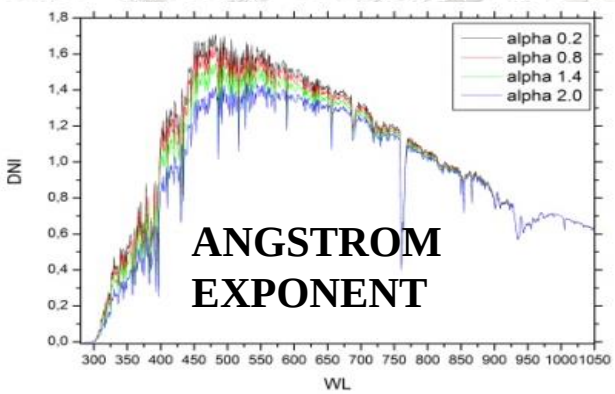
SZA	2:2:88
O3	250:20:450
WCOT	0:1:30
ICOT	0:1:30

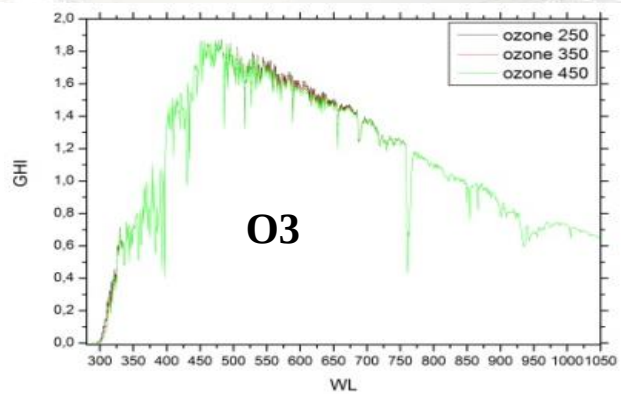
Total

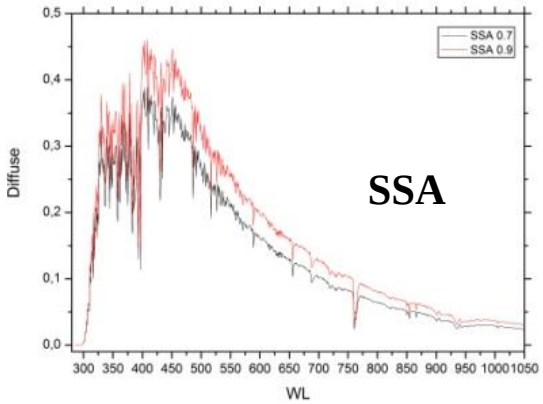
2.565.684 radiative transfer simulated output files

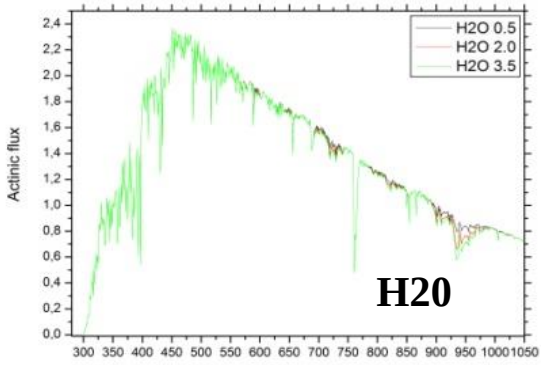
Dependence of spectral flux on input parameters

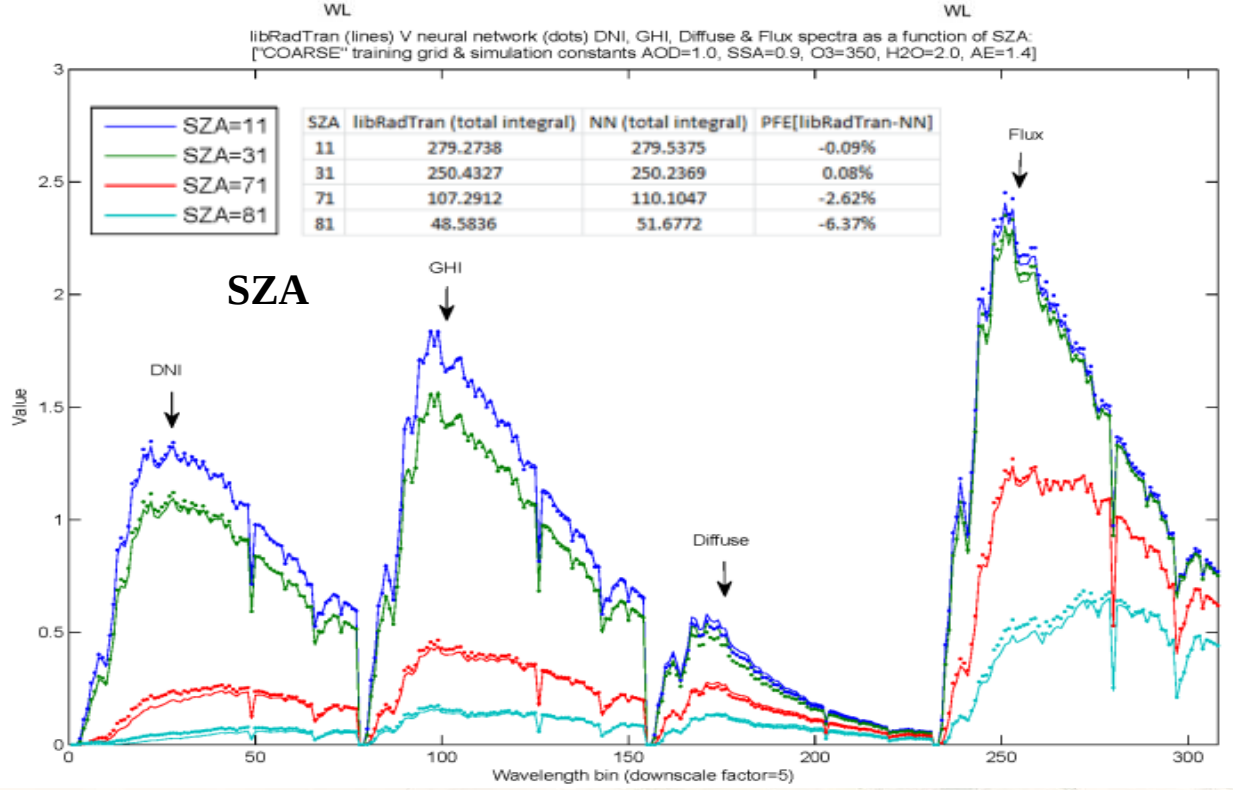






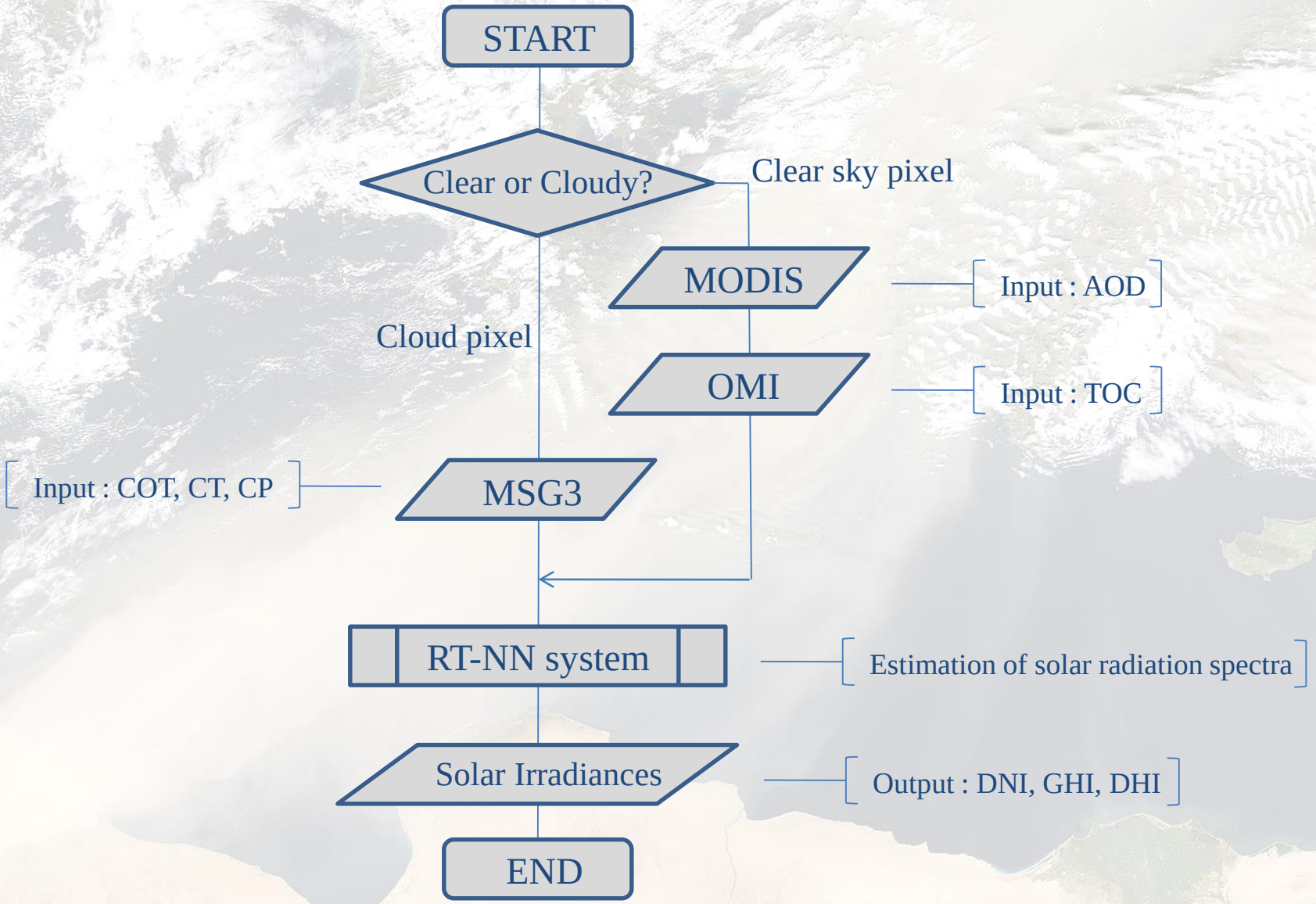




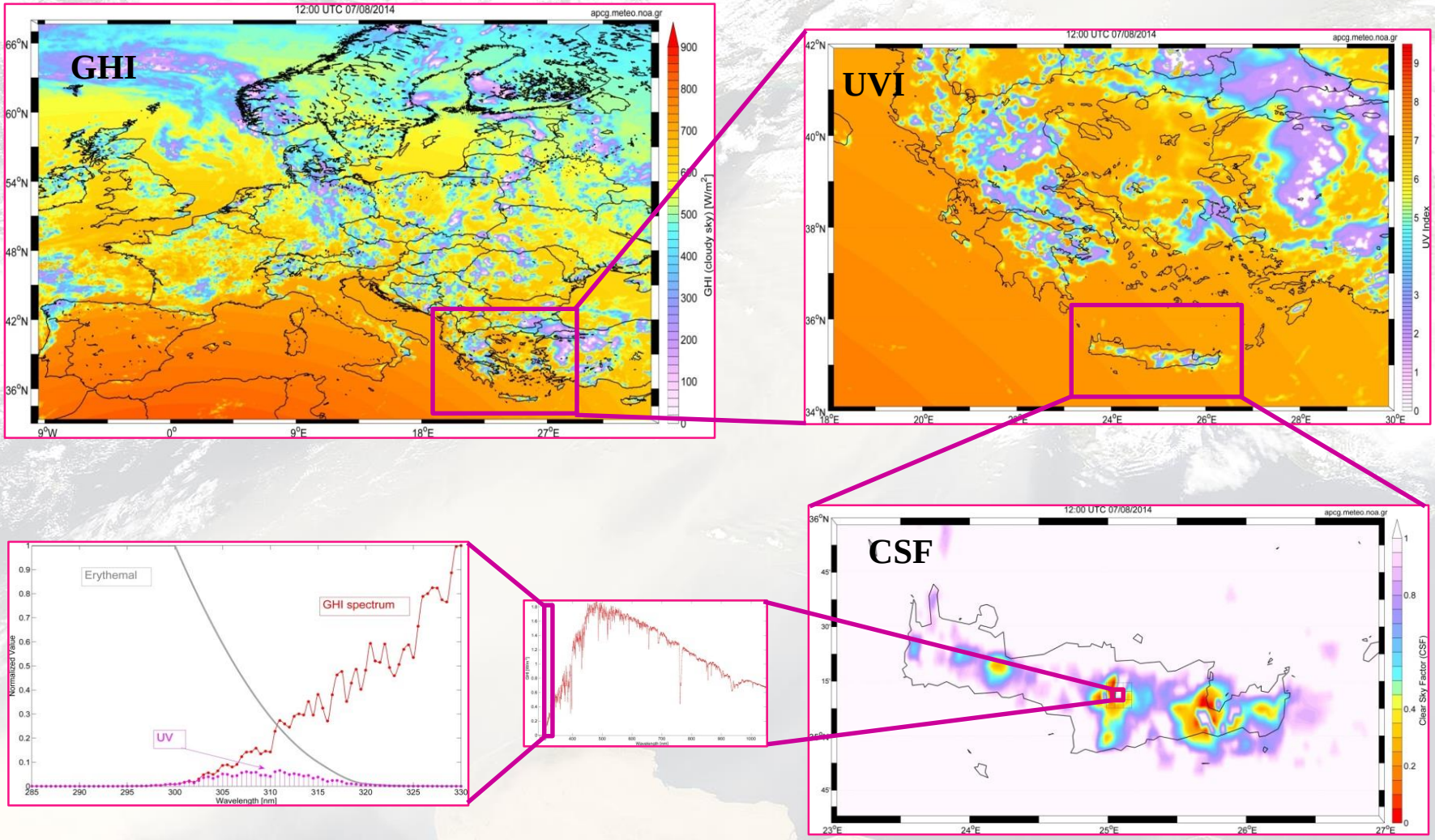


SZA	libRadTran (total integral)	NN (total integral)	PFE[libRadTran-NN]
11	279.2738	279.5375	-0.09%
31	250.4327	250.2369	0.08%
71	107.2912	110.1047	-2.62%
81	48.5836	51.6772	-6.37%

The SOLEA Project



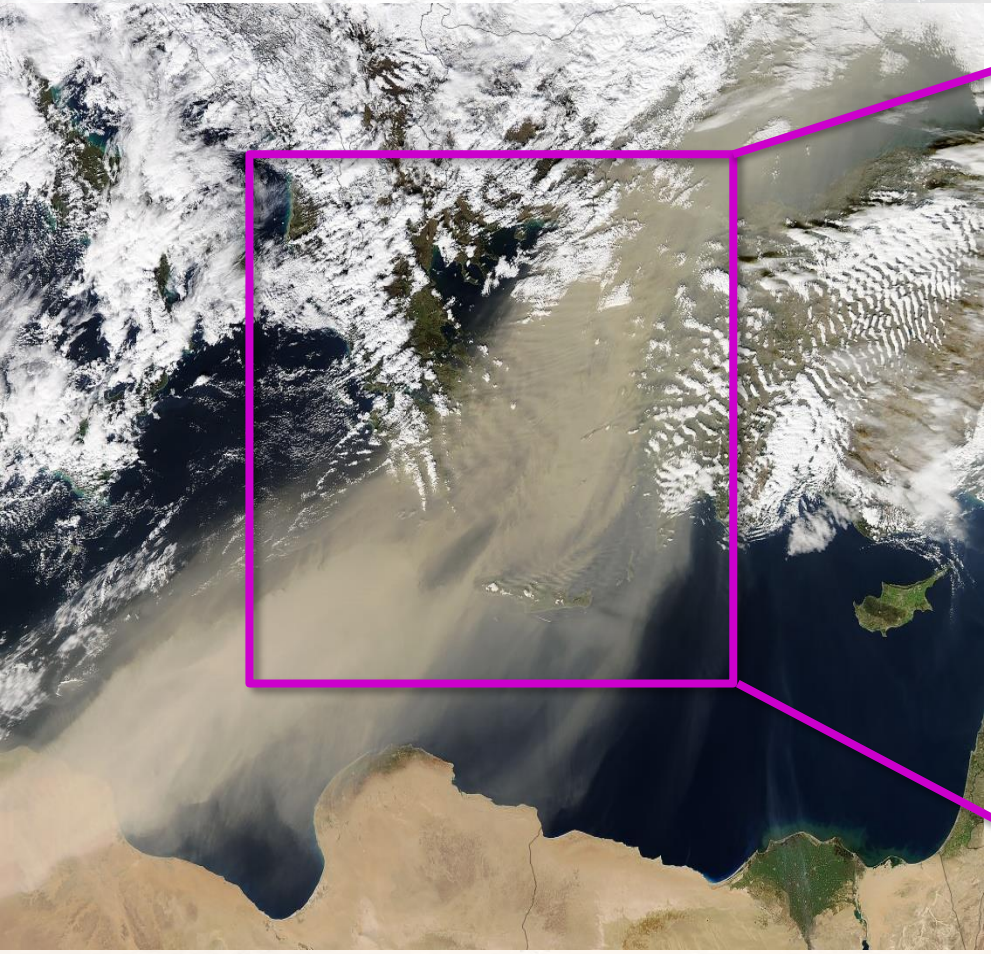
The SOLEA Project

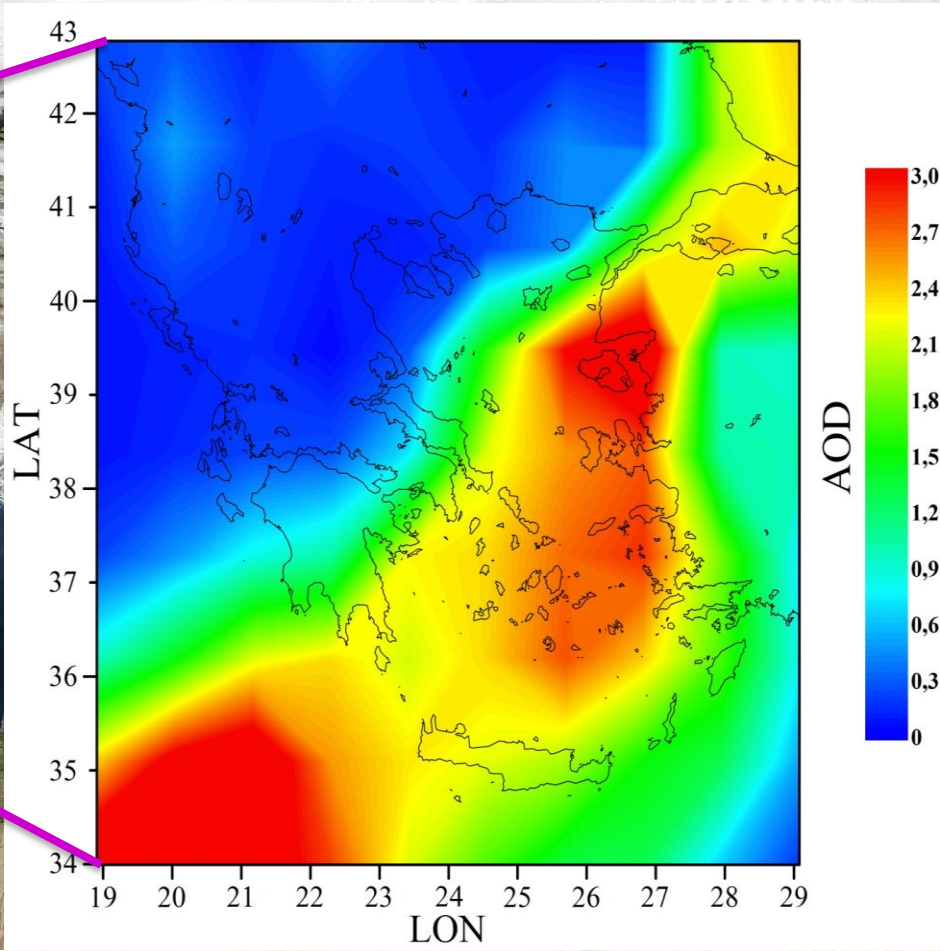


A zoom sequence showing a selection of the solar energy products. Going clockwise: the GHI for Europe, the UV index for Greece, the clear sky factor on the island of Crete, the insolation spectrum in a single pixel, and finally, the spectrally-weighted UV radiation spectrum.

Extreme dust event – 1/2/2015

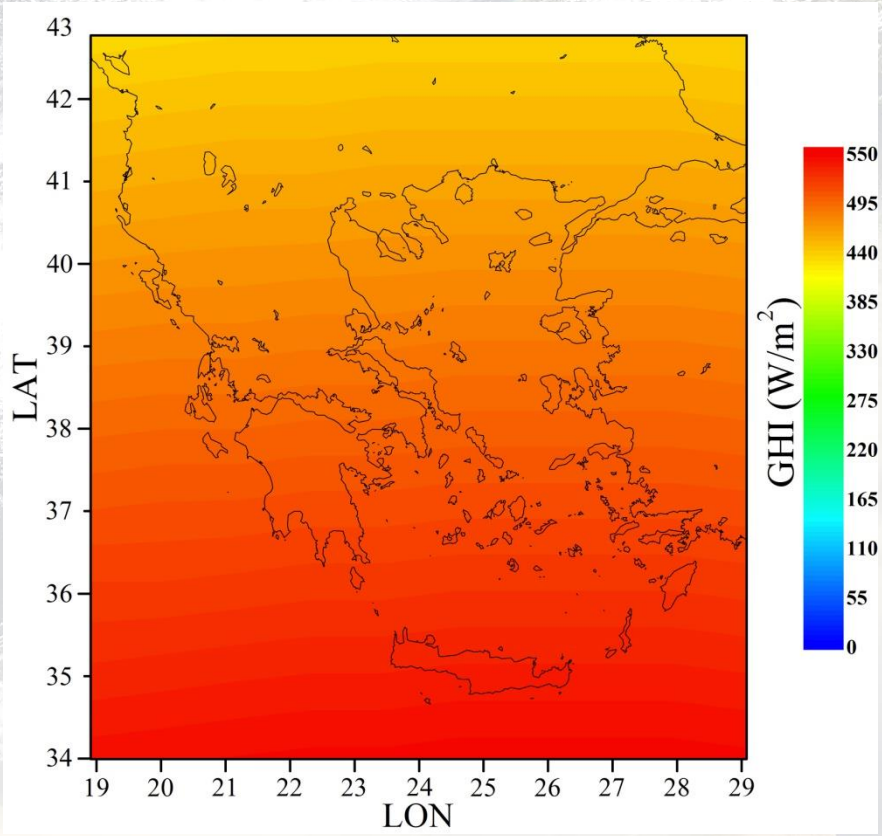
- **MODIS** data (AOD @ 550nm)
- Spatial resolution: **1º x 1º**
- Temporal resolution: ≈ **1 value per day**
- AOD max values ≈ **3.5**



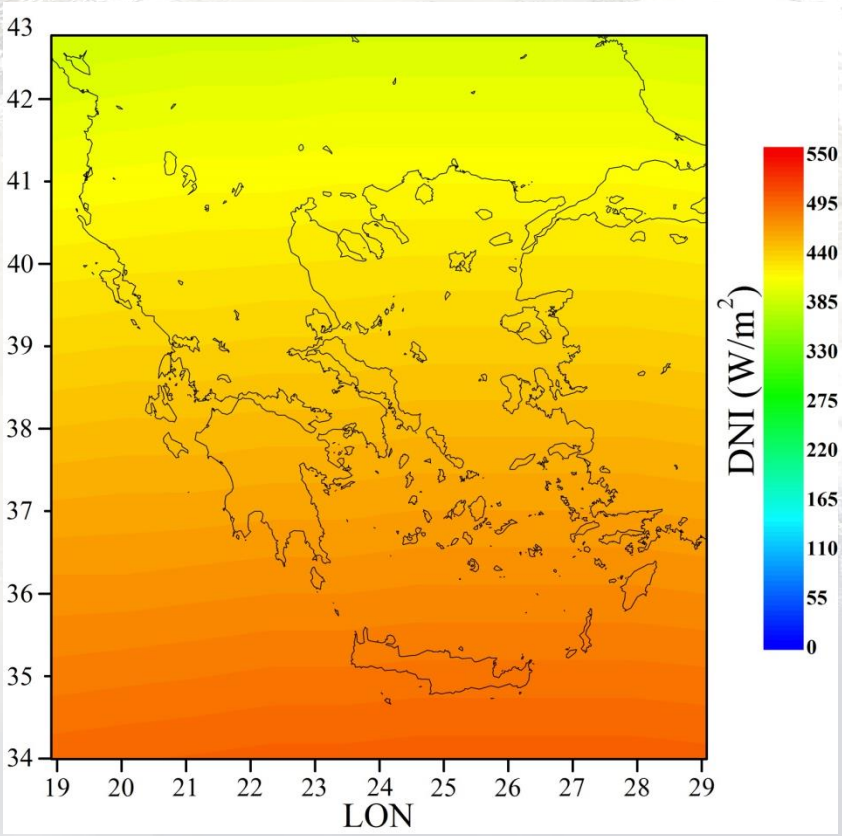


Surface solar irradiance without dust

- **Global Horizontal Irradiance**



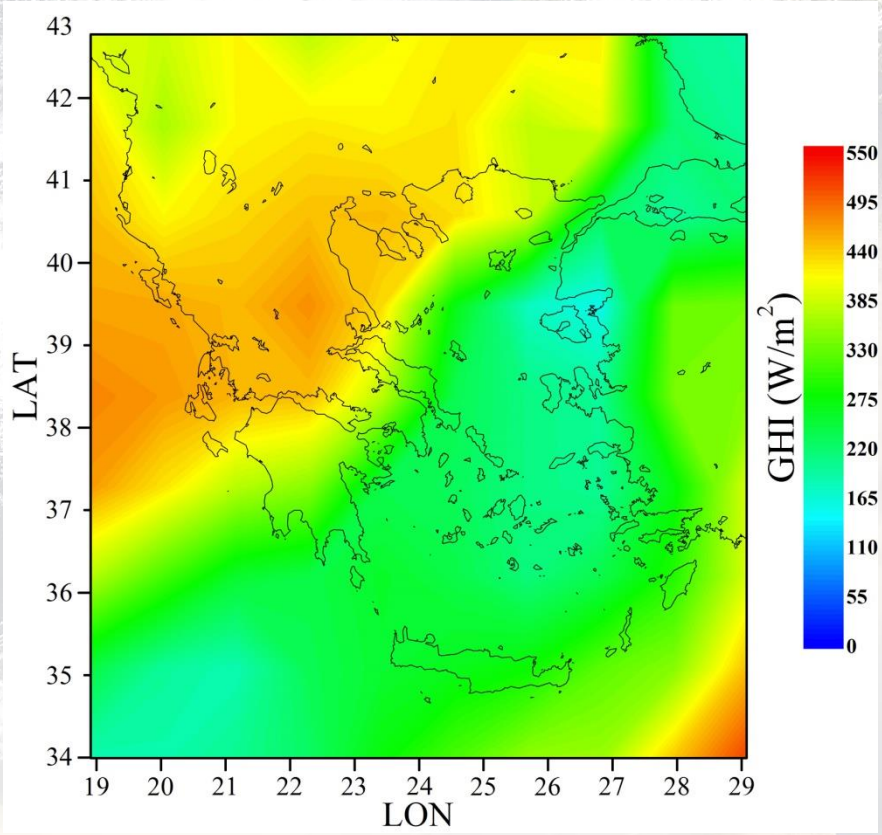
- **Direct Normal Irradiance**



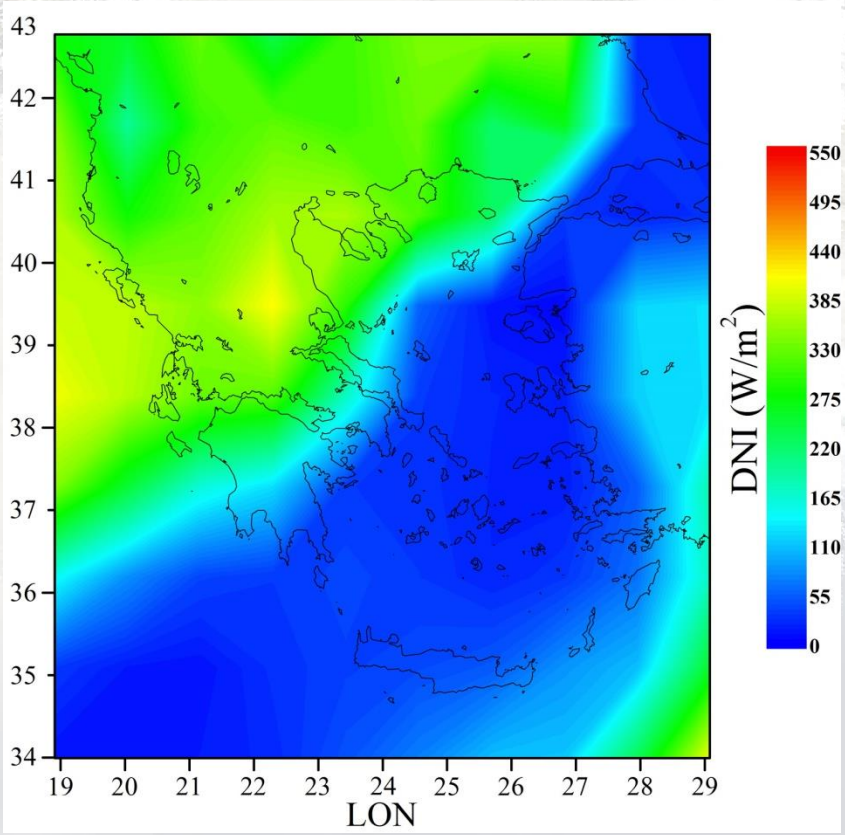
Input data: SZA @ local noon (1/2/2015)

Surface solar irradiance with dust

- **Global Horizontal Irradiance**



- **Direct Normal Irradiance**

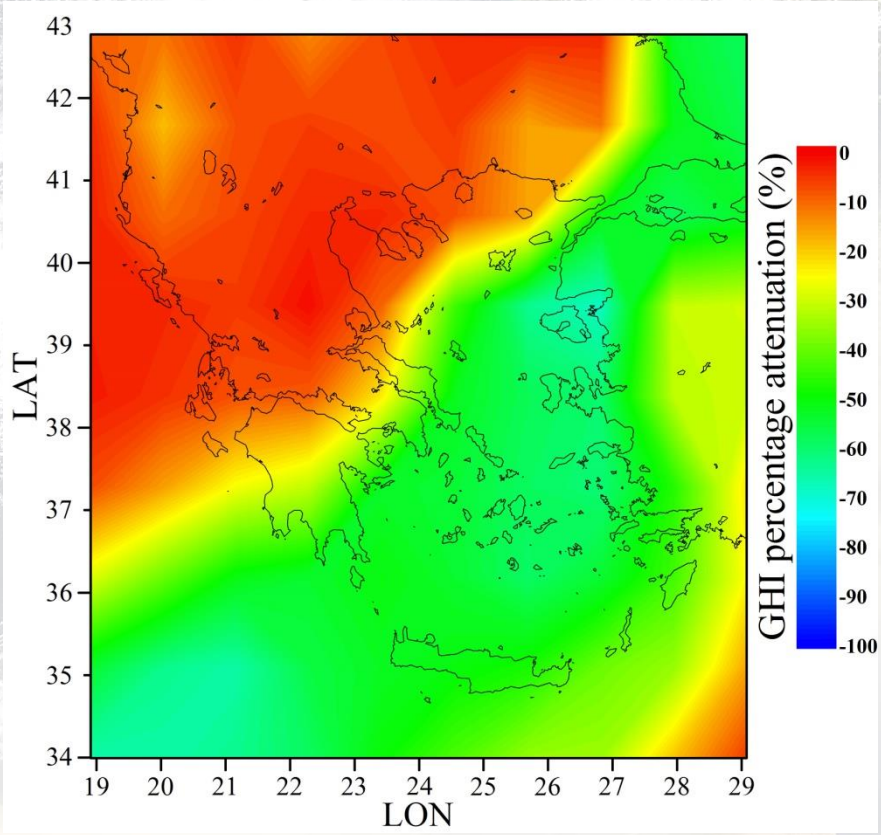


Input data: SZA @ local noon (1/2/2015)

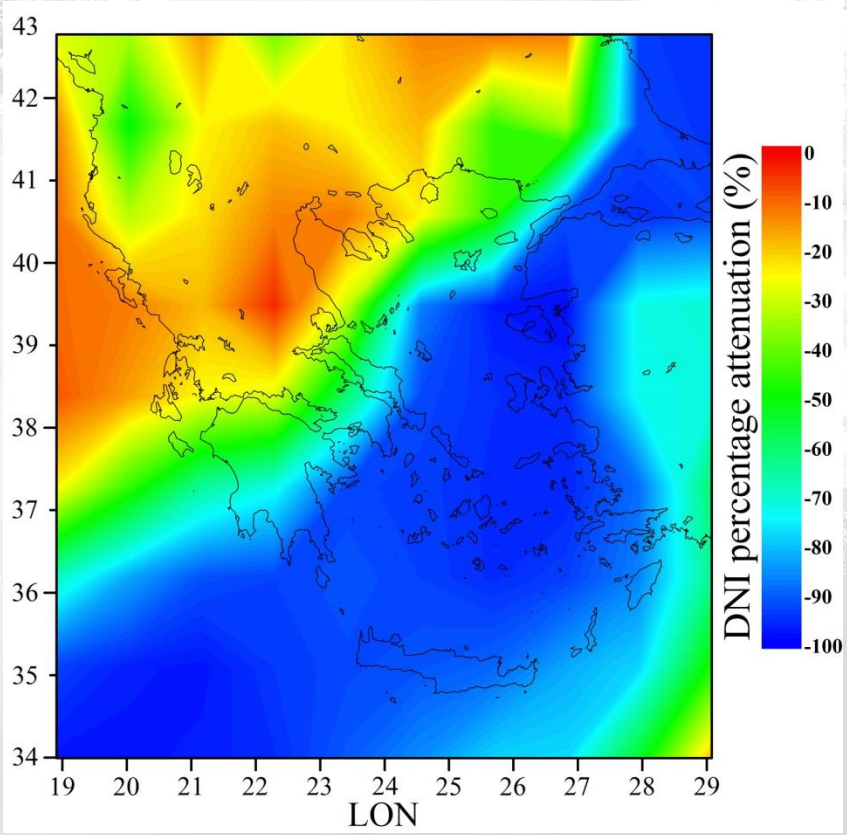
AOD @ 550 nm

Dust episode impact

- **Global Horizontal Irradiance**



- **Direct Normal Irradiance**



Attenuation: GHI ≈ 30 – 70 % (reduction)

DNI ≈ 70 – 100 % (reduction)

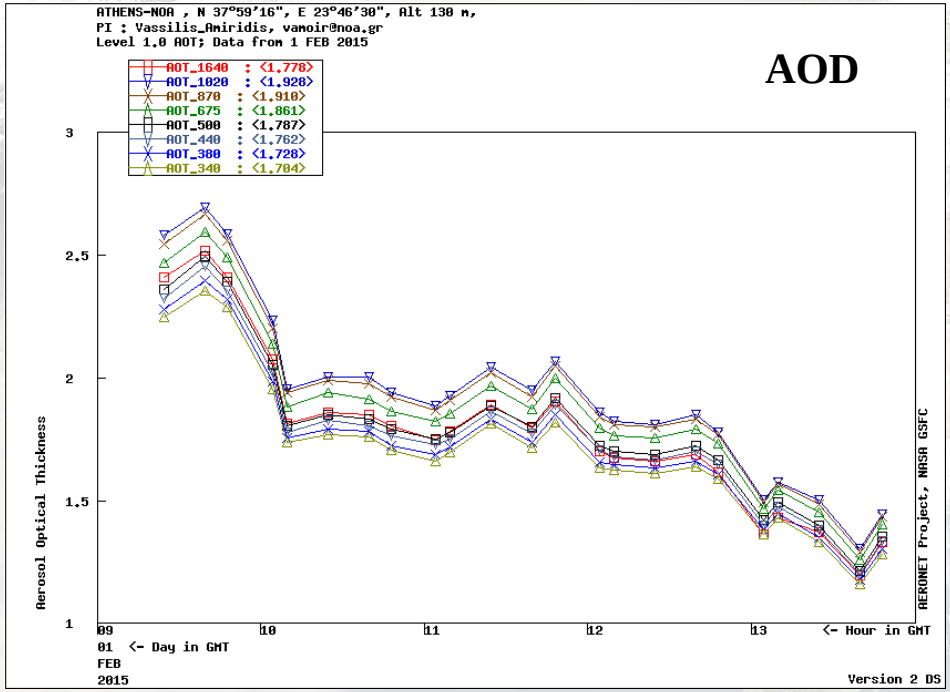
Detection of the dust episode at the Athens station (AERONET)

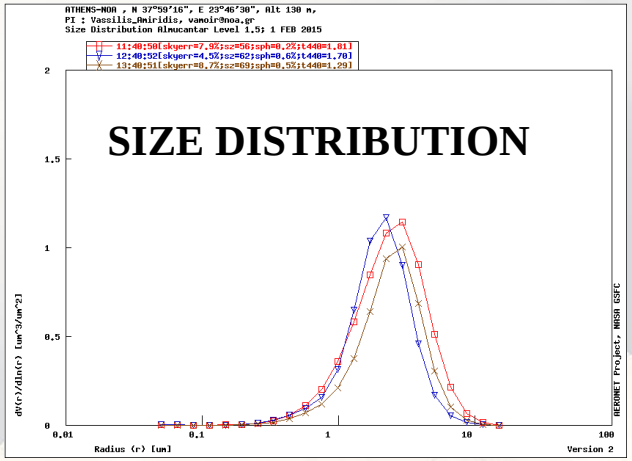
- **AERONET** data (AOD) can flag up events (a substantial increase of aerosol was observed on 1/2/2015 and its optical properties were consistent with dust)

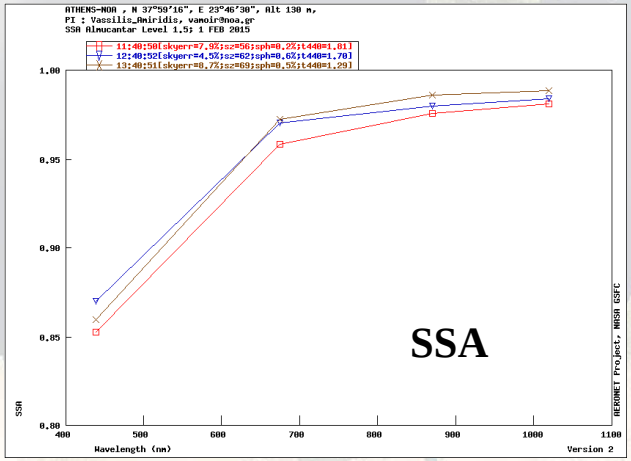
- The temporal resolution of AERONET AOD measurements is very high (≈ 1 per 10 minutes)

- But, the spatial resolution of AERONET is low due to the low global density of stations

- Classical signature of mineral dust aerosol



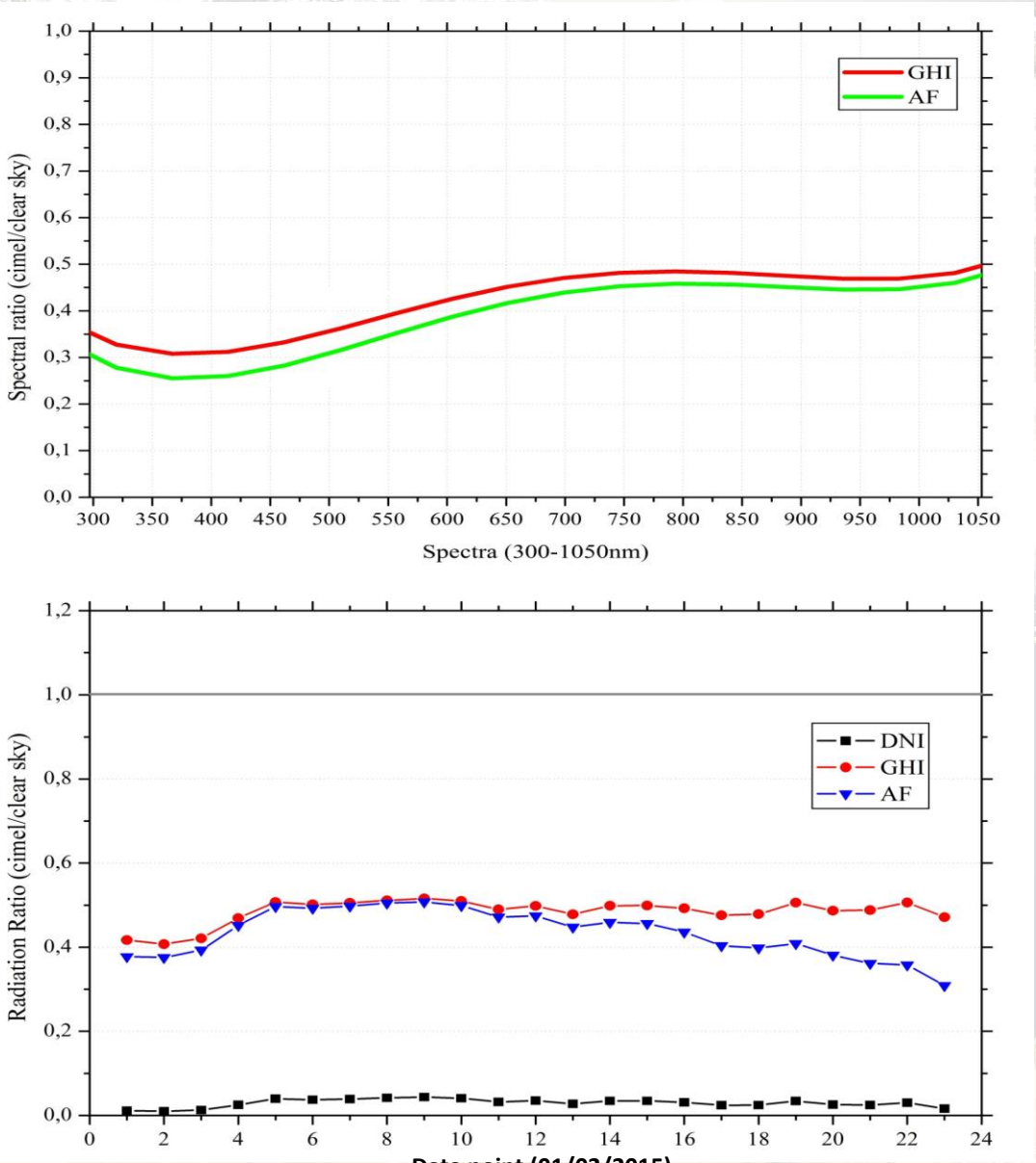




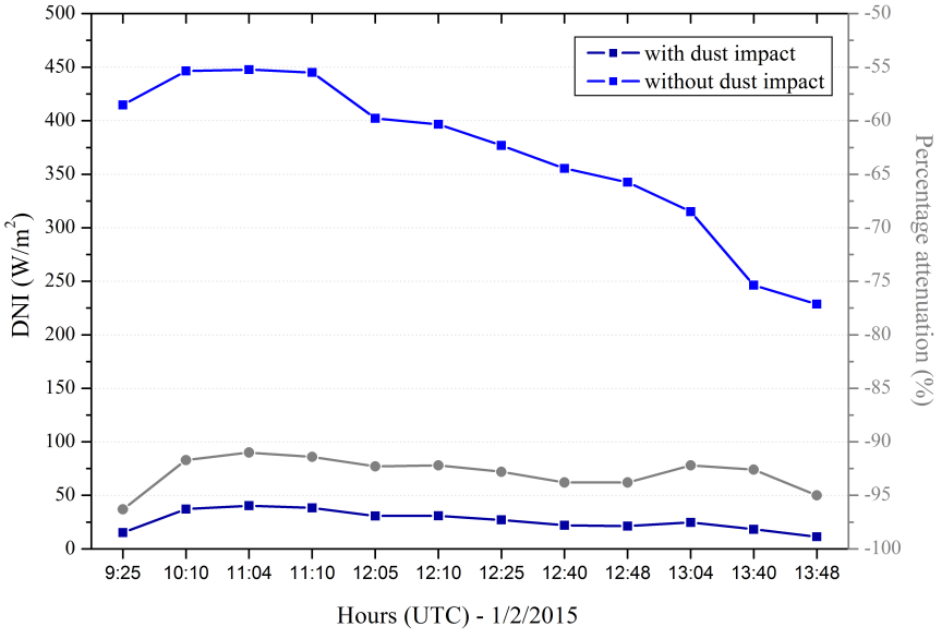
Spectral impact at the Athens station (AERONET)

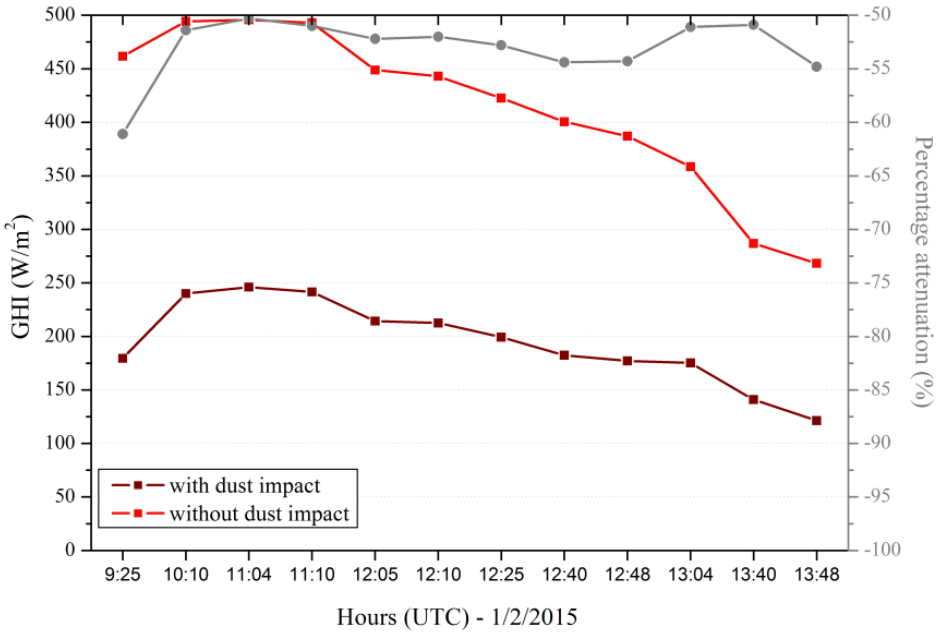
- Higher impact in the **UV region** (UVA ≈ 400 nm)

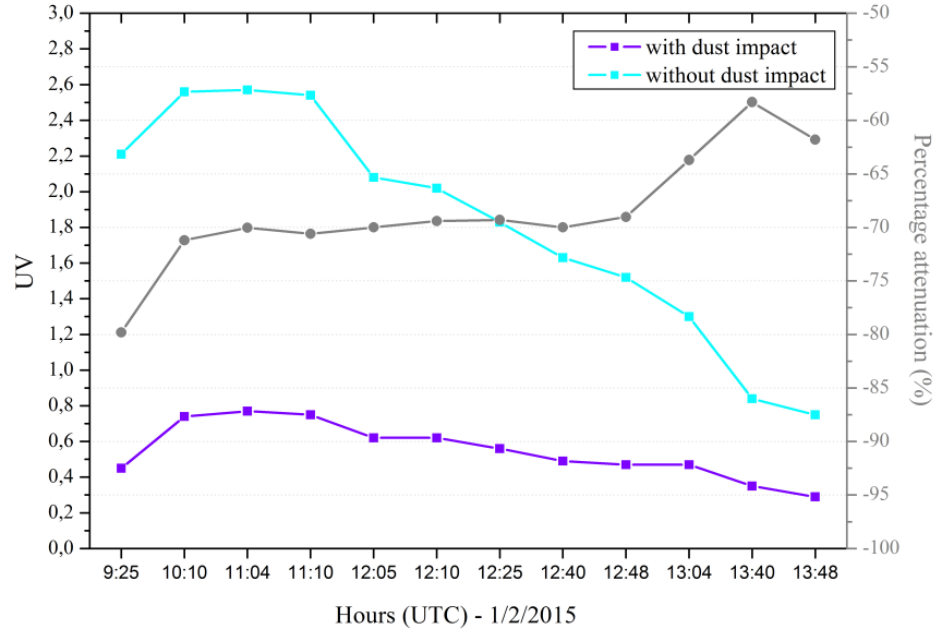
- Attenuation: UV **≈ 68 %**
  VIS ≈ 60 %
  IR ≈ 54 %

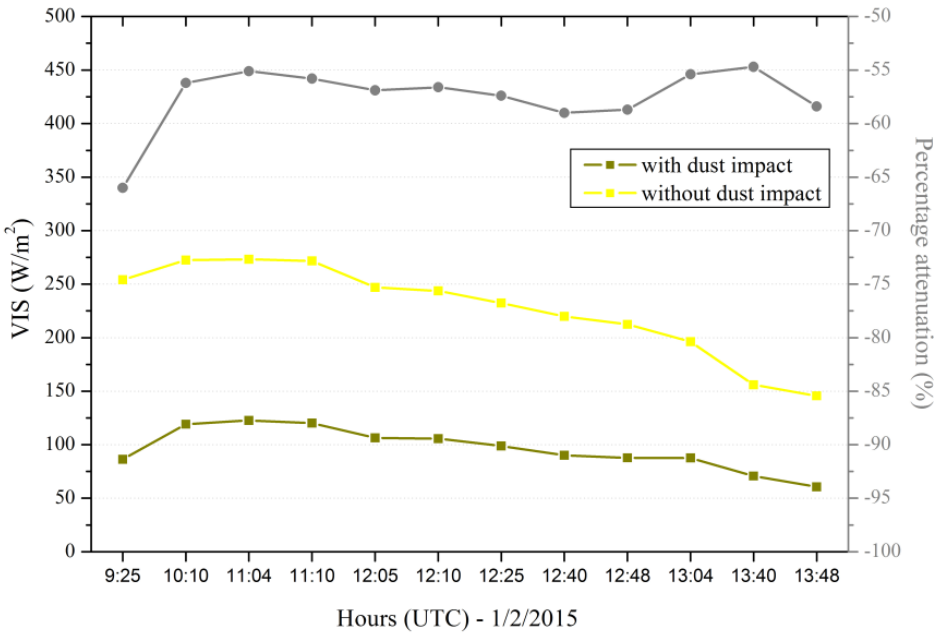


Modeled irradiance impact at the Athens station (AERONET)







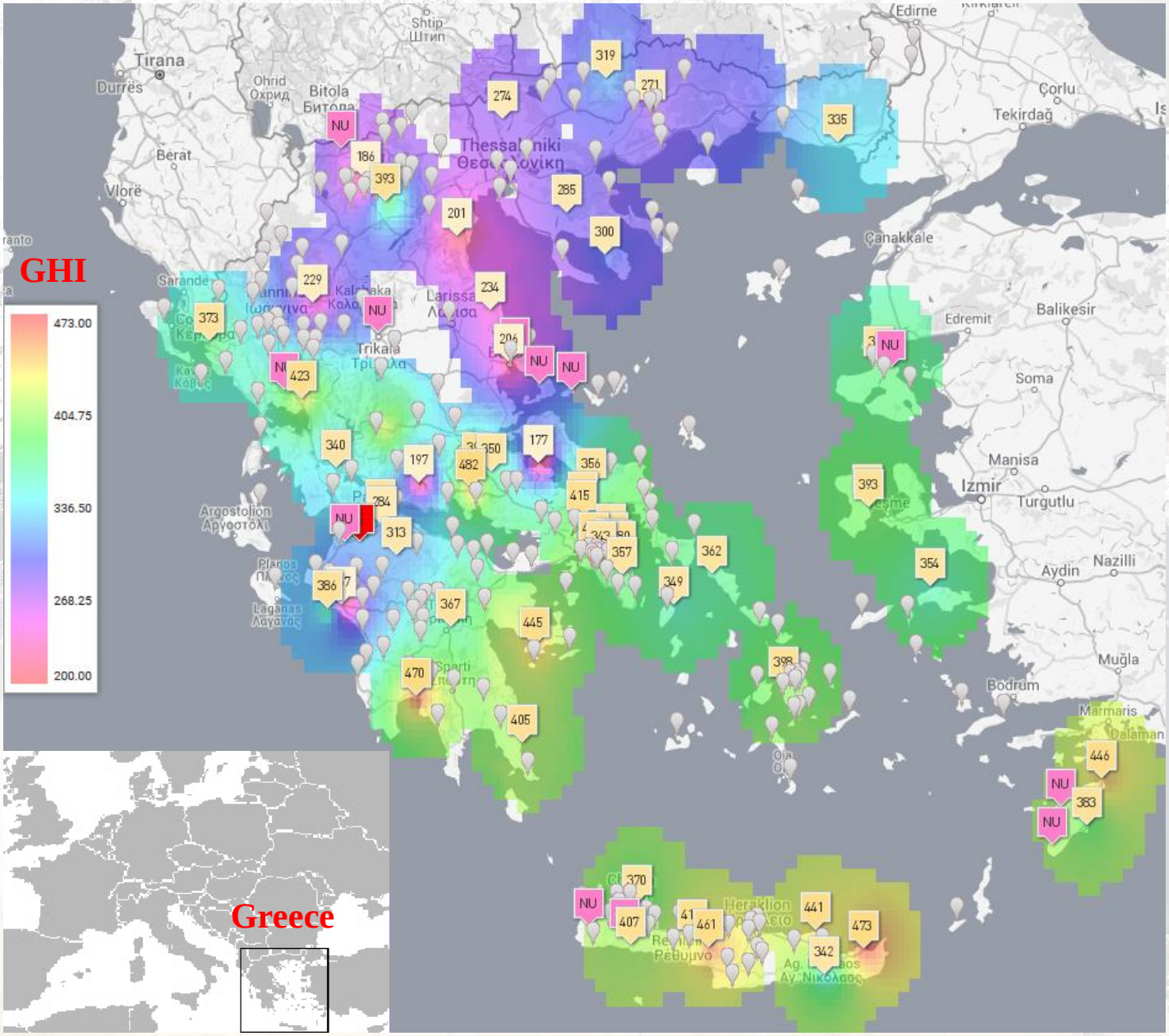


Some Improvements being Implemented by SOLEA

- **MODIS** for increasing the daily spatial coverage of AOD
- **AERONET** for interpolation/forecasting of accurate spot measurements of AOD

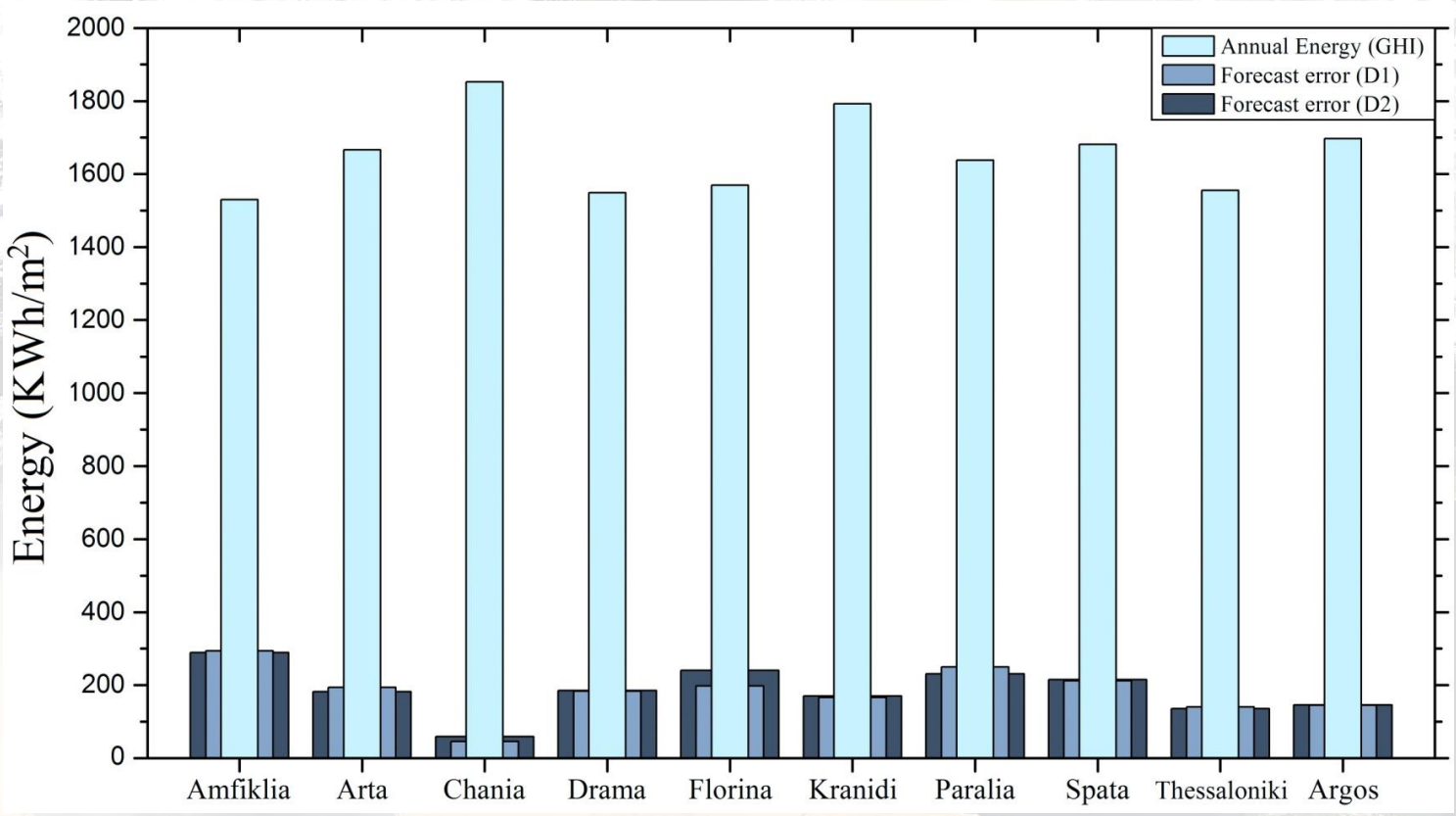
- **METEOSAT** for retrieval of dust AOD at high temporal resolution **(15 min)**
- **NOA network** for precision ground-based validation of GHI, DNI, DHI & UV

NOA network (http://stratus.meteo.noa.gr/front)



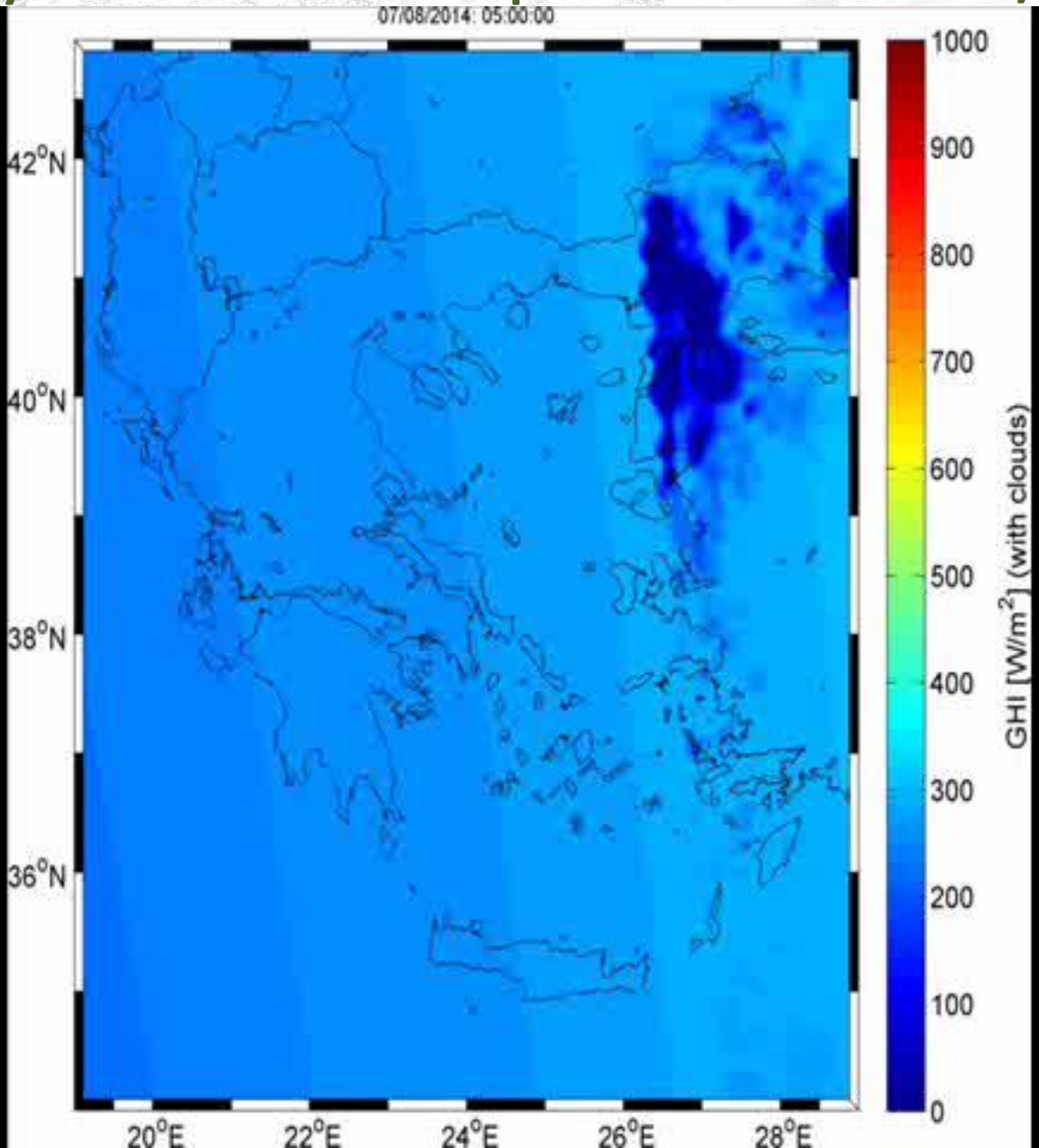
Annual solar energy potential

- The total energy potential for each ground station is found to range from 1.5 to 1.9 MWh/m^2 with aerosols and cloudiness causing increments in the MM5 forecast error of the order of 10%.



Kosmopoulos et al (2016), Energy 93, 1918-1930

The SOLEA approach to derive surface solar irradiance directly from satellite cloud products from MSG-3/SEVIRI



Major Applications & Contribution to Emerging Technology

- **Location studies** for the placement of SCP plants and CPV installations with reference to **climatological time series** of the total DNI, GHI and DHI calculated on the hourly, daily, monthly and seasonal timescales

- **Large-scale** (regional) and **precise solar energy calculations** to assist Public Authorities in **energy planning** policy

- Supporting the work of **various scientific communities** (marine, biology, medical, agricultural, climate change and physics of the atmosphere) by providing real time solar energy and UV product input

- Provision of specialized data of high spectral precision for private and public sectors dealing with **health protection** (e.g. DNA and/or cataract damage, sun protection and anti-ageing agents), **energy consumption** and **solar energy exploitation** (e.g. **emerging technologies**: artificial photosynthesis, solar biofuel storage involving cyanobacteria and phytoplankton blooms).

- Application of the SOLEA system to data from satellite (MODIS, MSG, etc) demonstrates that the speed-up offered by the NN makes **real-time mapping** of solar energy for nowcasting purposes **feasible**.

- The fast and accurate NN solvers presented here facilitate studies of the **impact of aerosol and cloud parameters on solar irradiance spectra** at the local, regional or global scale.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