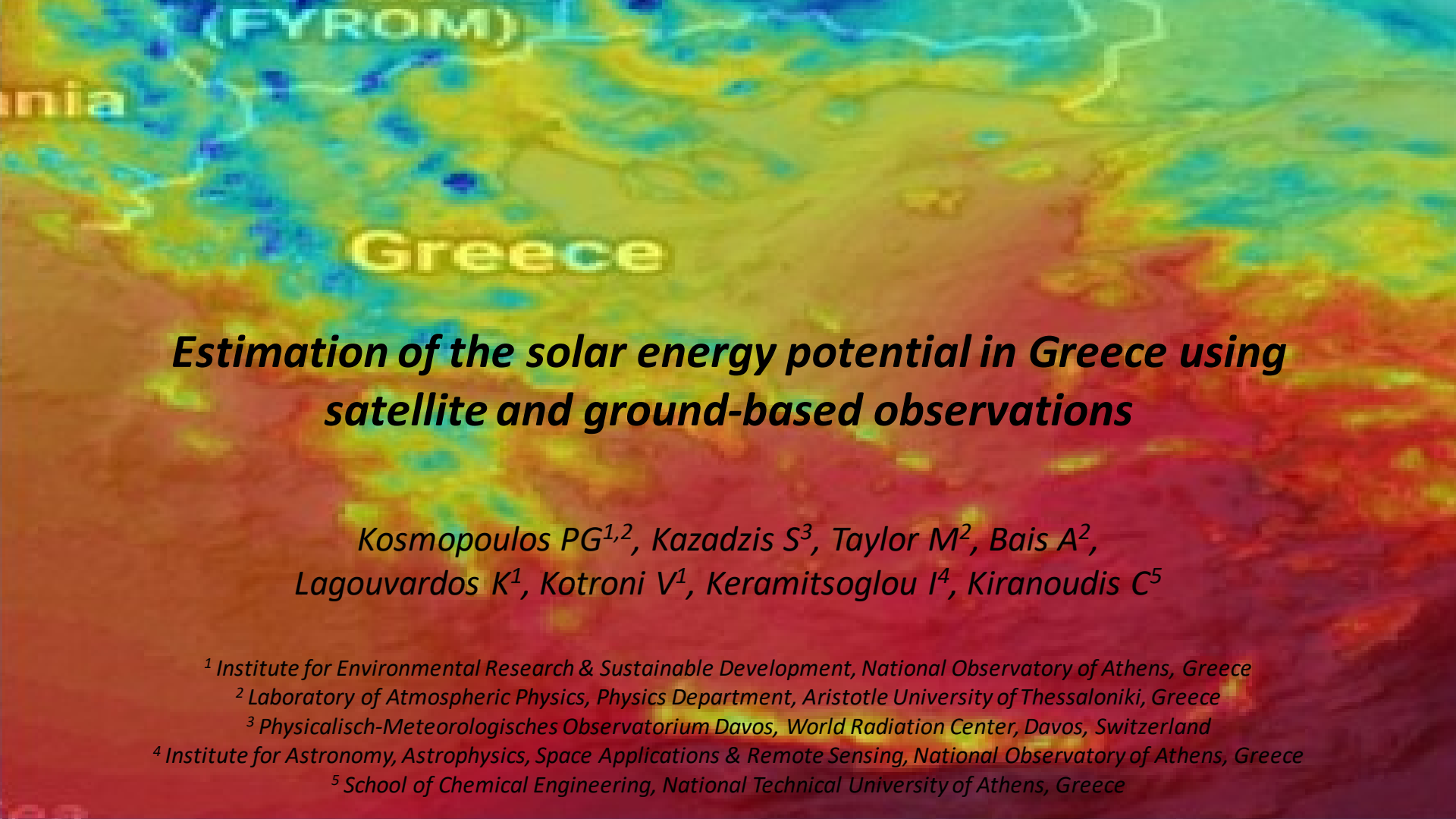

Estimation of the solar energy potential in Greece using satellite and ground-based observations

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Introduction

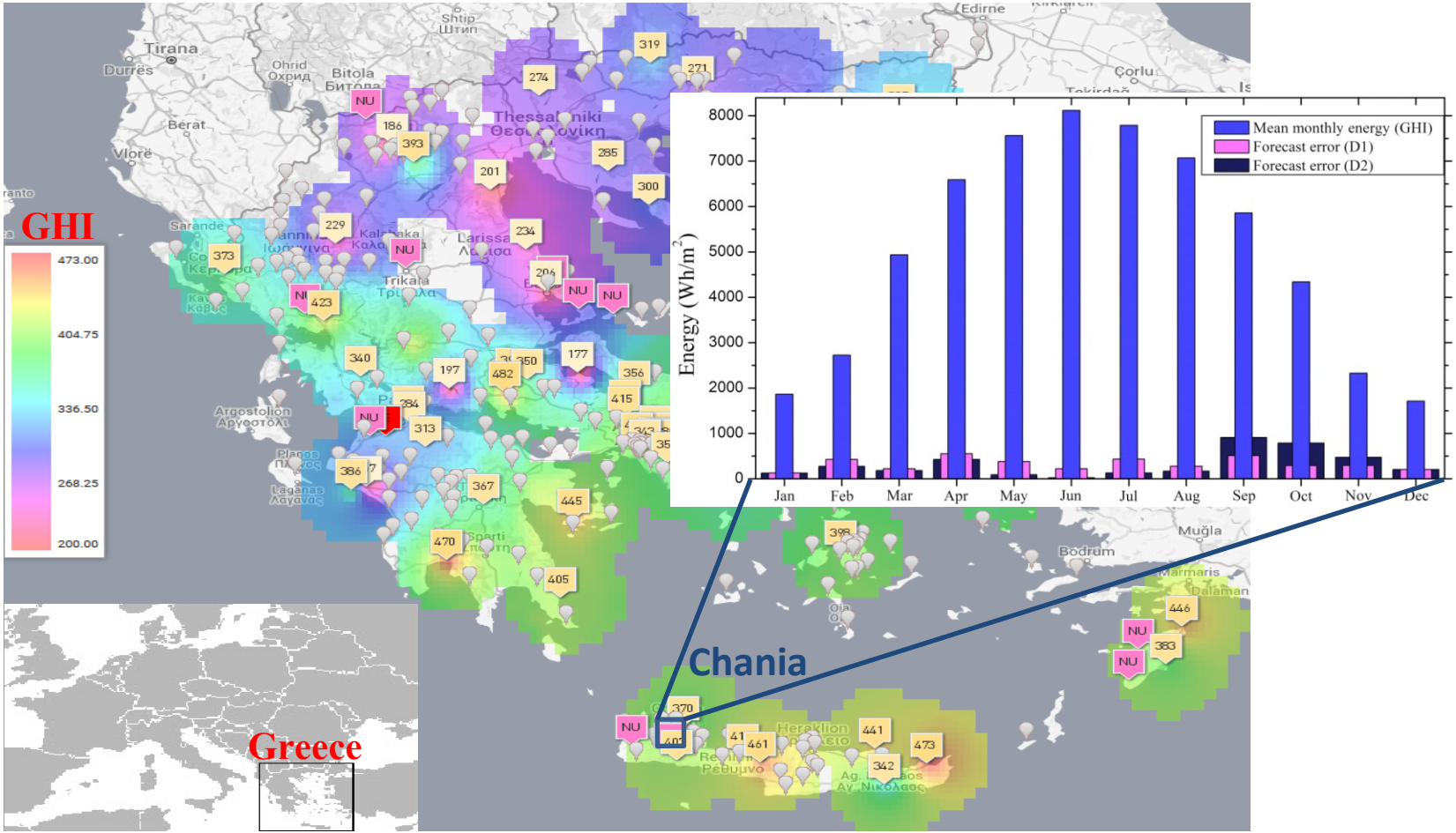
- We report on estimation of the solar energy potential in Greece using satellite- and ground-based observations in conjunction with radiative transfer model (RTM) simulations. Pyranometers of the Hellenic Network for Solar Energy and the National Observatory of Athens provide accurate insolation measurements and are used to verify 1- and 2-day ahead forecasts provided by the mesoscale model MM5.

- We also present a model (www.solea.gr) for generating instantaneous and accurate gridded surface solar radiation spectra and budgets via a synergy of large (2.5M record) RTM look-up tables and neural networks (NN). We demonstrate that NNs fed with cloud inputs retrieved from the Spinning Enhanced Visible and Infrared Imager onboard the Meteosat Second Generation 3 satellite are able to produce maps of the Earth disk at high resolution (1nm, 0.05 x 0.05 degrees, 15-min) and we cross-validate them with other models to guarantee the quality and accuracy of the irradiance products. In addition to this real-time system we created the Solar Atlas of Greece using CM SAF radiation data from EUMETSAT.

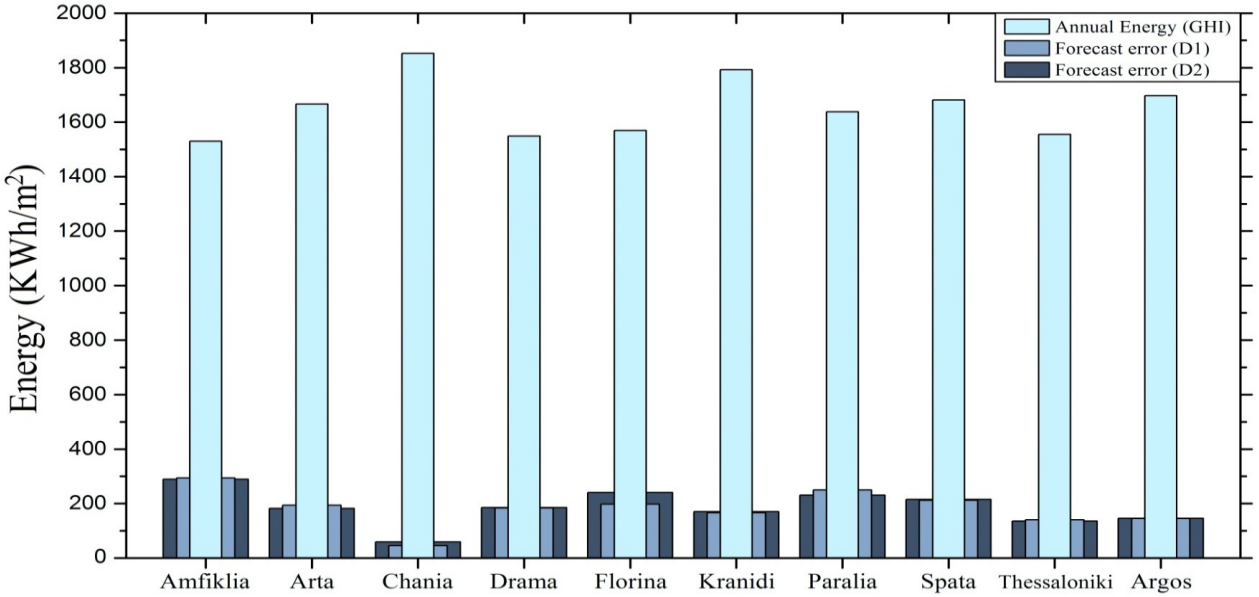
- This operational model is developed in the framework of the ARISTOTELIS project (Hellenic Republic-Siemens settlement Agreement), is one of the main pilot studies of the European project GEO-CRADLE (HORIZON 2020) and its scope is the interconnection of the solar energy applications with potential end users from different countries (North Africa, Middle East, Balkans, etc).

- We show that these complimentary approaches are ideal for correct assessments of the solar energy potential and for providing accurate solar energy applications in real-time.

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



Annual Solar Energy Potential

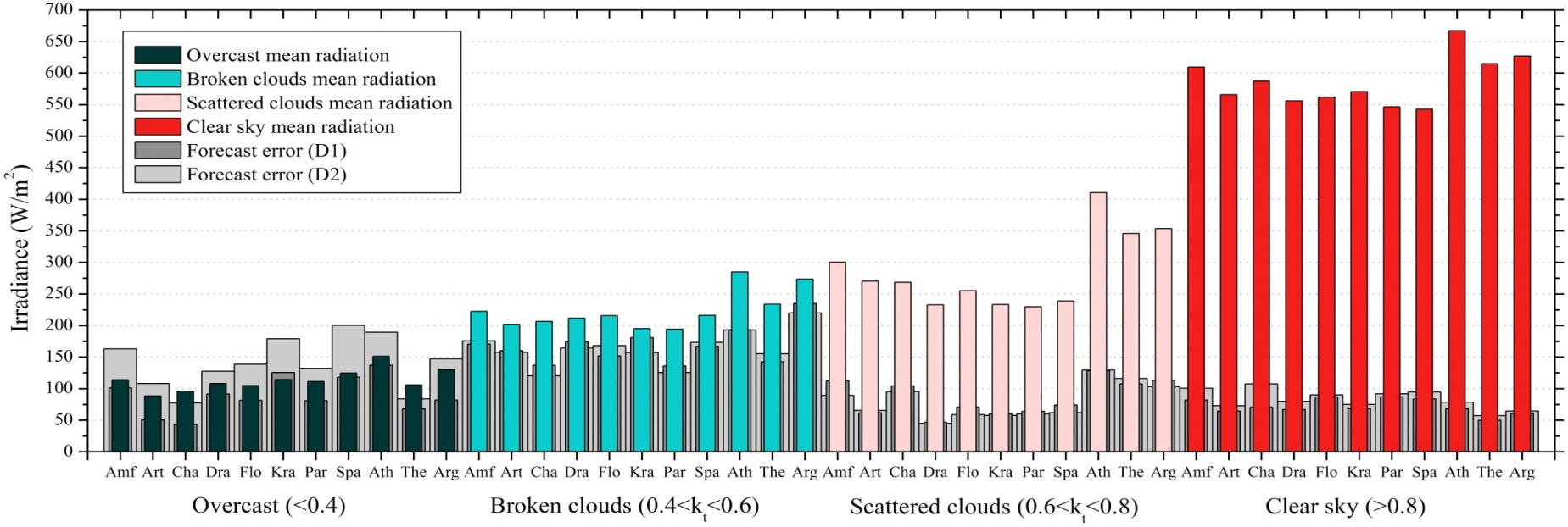


Kosmopoulos et al (2016), Energy 93, 1918-1930

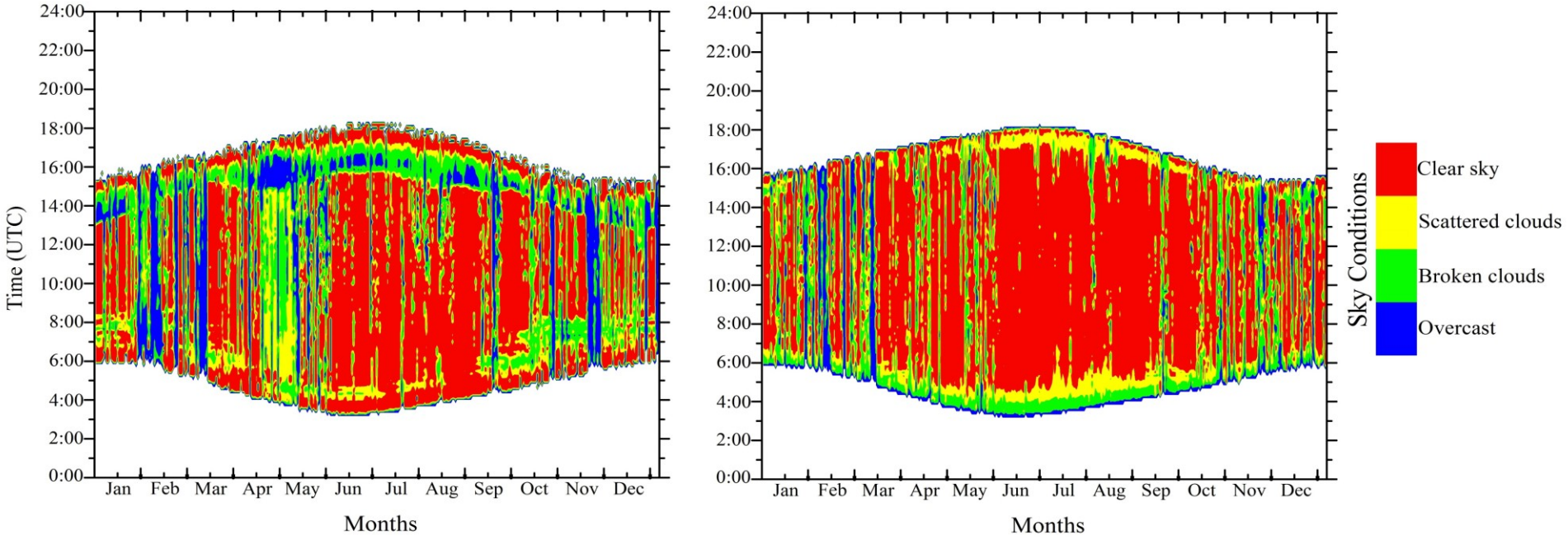
- The total energy potential for each ground station is found to range from **1.5** to **1.9 MWh/m²** with aerosols and cloudiness causing increments in the MM5 forecast error of the order of 10%.

Monthly mean daily energy	(Wh/m²)		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Obs		2054	2452	4437	5408	6096	7455	7170	6491	5169	3614	2217	1789
	AE	D1	140	226	419	901	1050	817	884	725	370	375	198	124
		D2	274	317	407	977	972	795	832	649	340	336	177	133

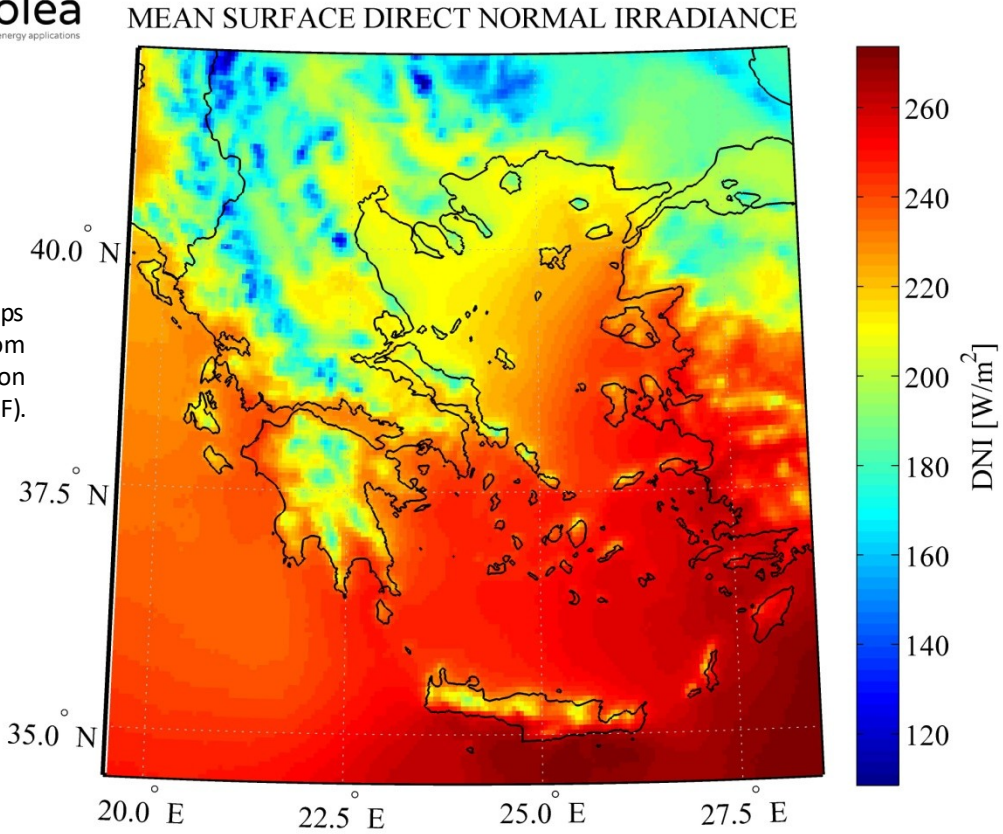
Clouds Classification Impact



Recording cloud impact



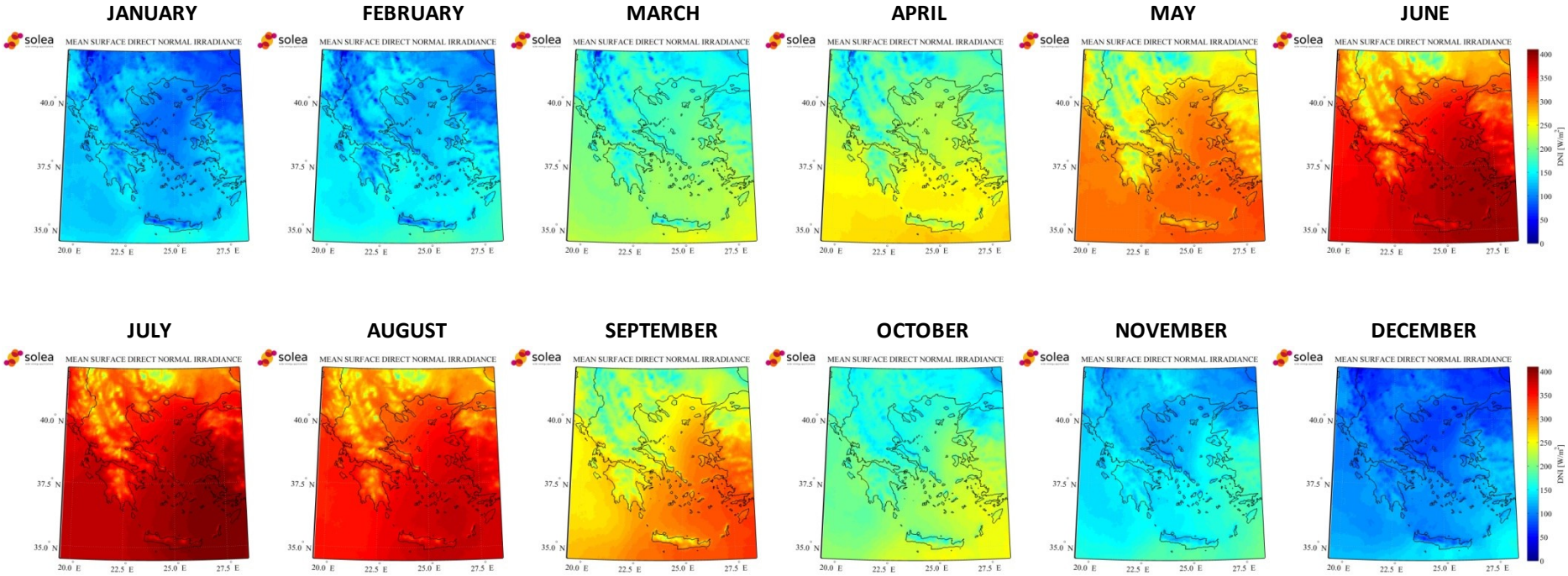
Solar Atlas for PV & CSP installations



- The mean climatological maps (1999-2013) are based on data from EUMETSAT's Satellite Application Facility on Climate Monitoring (CM SAF).

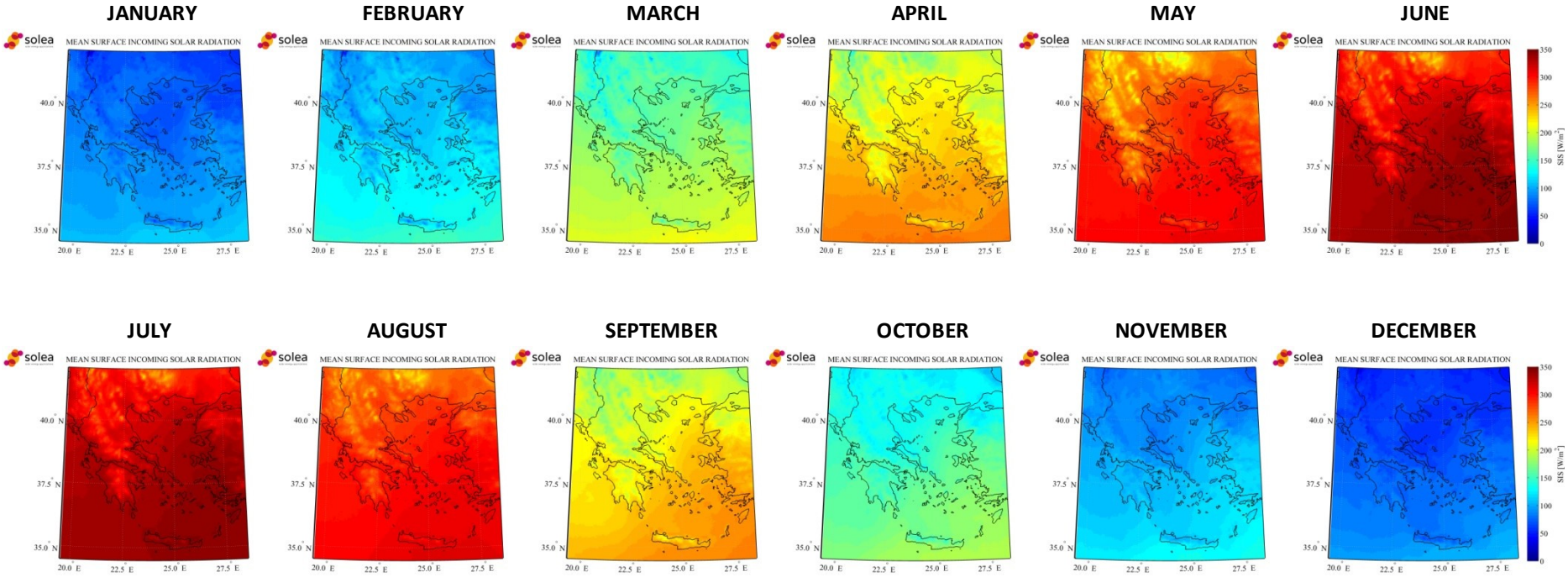
- Optimum locations for CSP & PV installations using solar Atlas energy maps

Mean monthly climatological maps of DNI



➢ The mean monthly solar energy maps are based on a 15-year complex and highly variable climatology taking into account the clouds and aerosols impact on **Direct Normal Irradiance** and **Global Horizontal Irradiance** (**DNI** and **GHI** respectively), while the spatial resolution is almost 5 km, maximizing the exploitative value of the solar energy technologies.

Mean monthly climatological maps of GHI



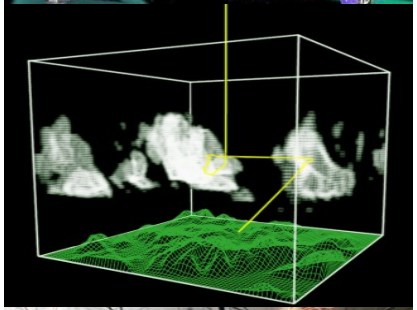
➢ The **Direct Normal Irradiance** applies to Concentrated Solar Plant (CSP) installations while the components of the **Global Horizontal Irradiance** (in terms of Surface Incoming Solar radiation ,SIS) applies to Photovoltaic (PV) installations.

DOI: 0.5676/EUM_SAF_CM/SARAH/V001

The Solar Energy Estimation Model
Technical Background

Satellite Data

Radiative Transfer models



Neural networks

➢ The real-time operational system uses a synergy of neural networks (NN), radiative transfer (RT) simulations and real-time satellite retrievals (MSG/SEVIRI, CAMS).

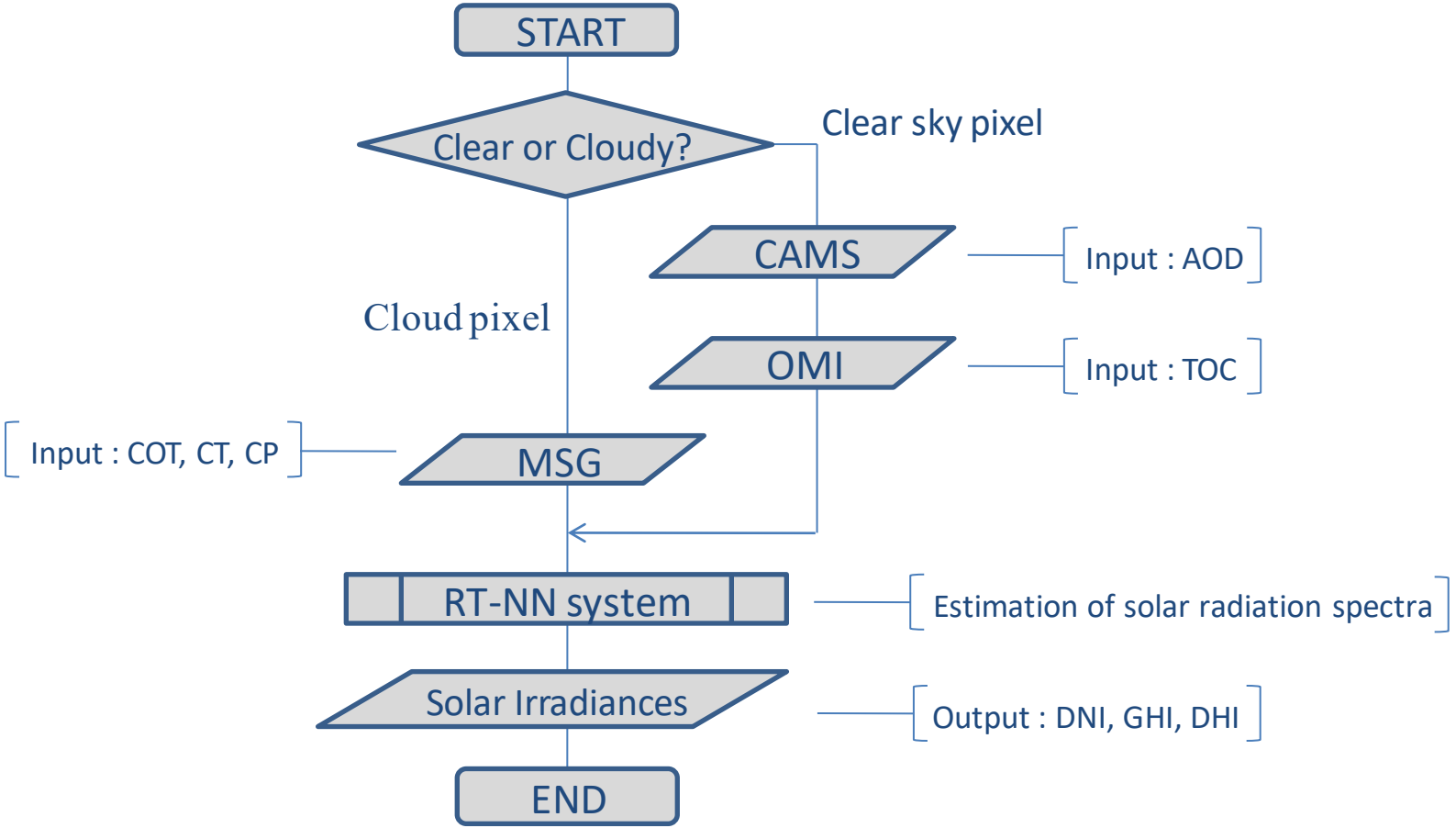
➢ Surface irradiances are produced at high resolution (1nm, 0.05 degrees, 15-min) in real time. The RT-NN solver is capable of producing maps of spectrally-integrated DNI and GHI of the order of 10^4 to 10^5 pixels within 1-min.

Precise assessment of solar energy

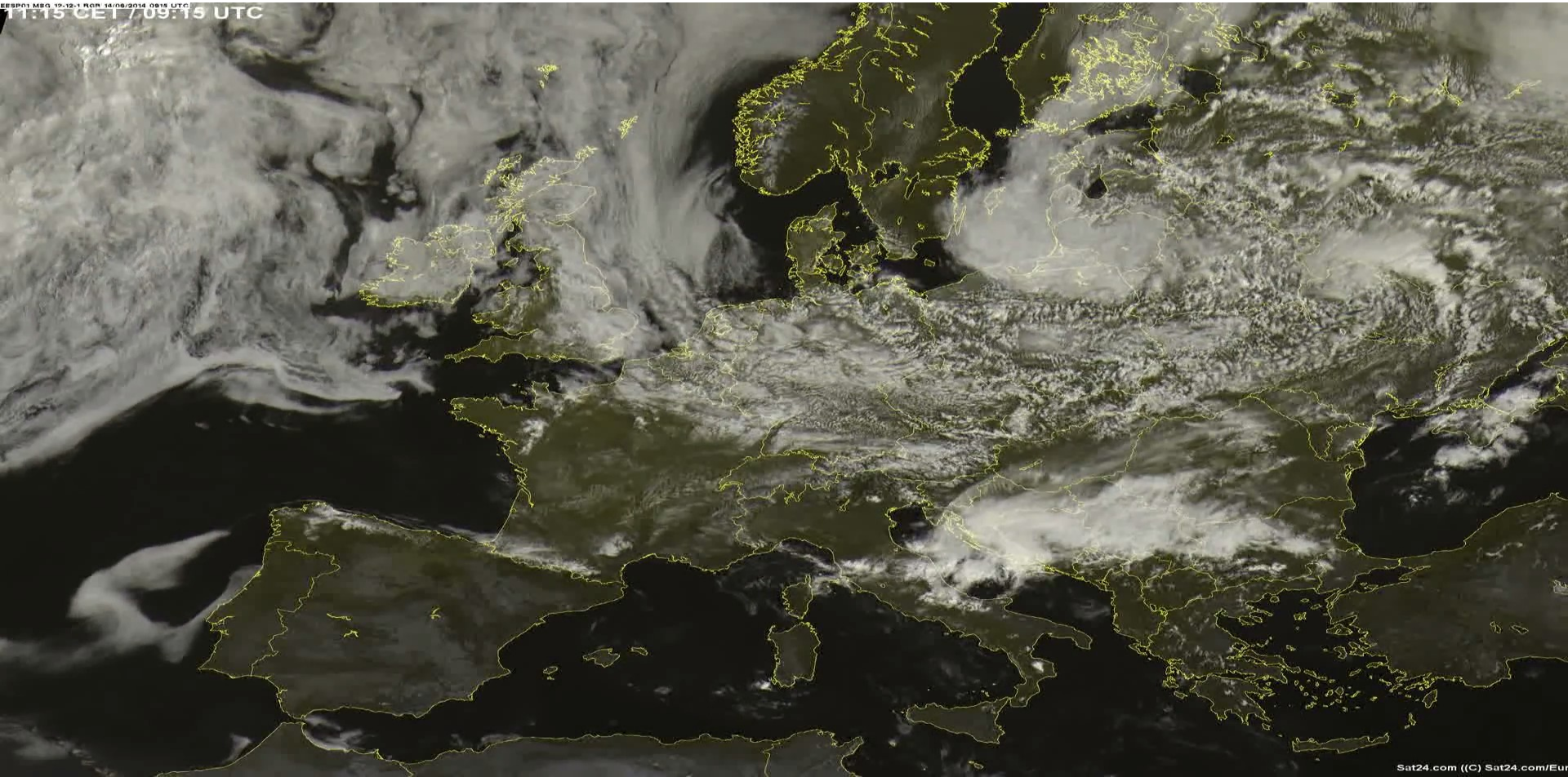
➢ Local or regional maps of the total irradiances provide the capability needed to serve high precision solar power applications for energy planning.

➢ NN is trained on a large-scale (2.5 million record) look-up table (LUT) of clear and cloudy sky radiative transfer simulations to convert satellite cloud and aerosol products directly into solar radiation spectra.

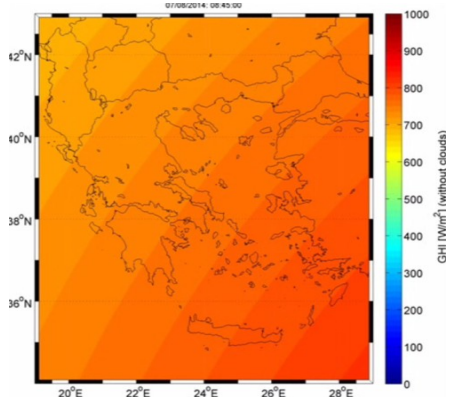
The Solar Energy Estimation Model



Input Data from MeteoSat & CAMS

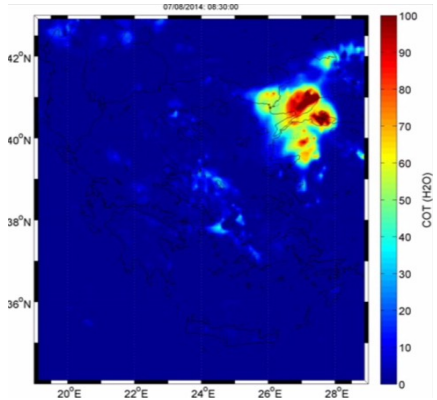


Clouds impact

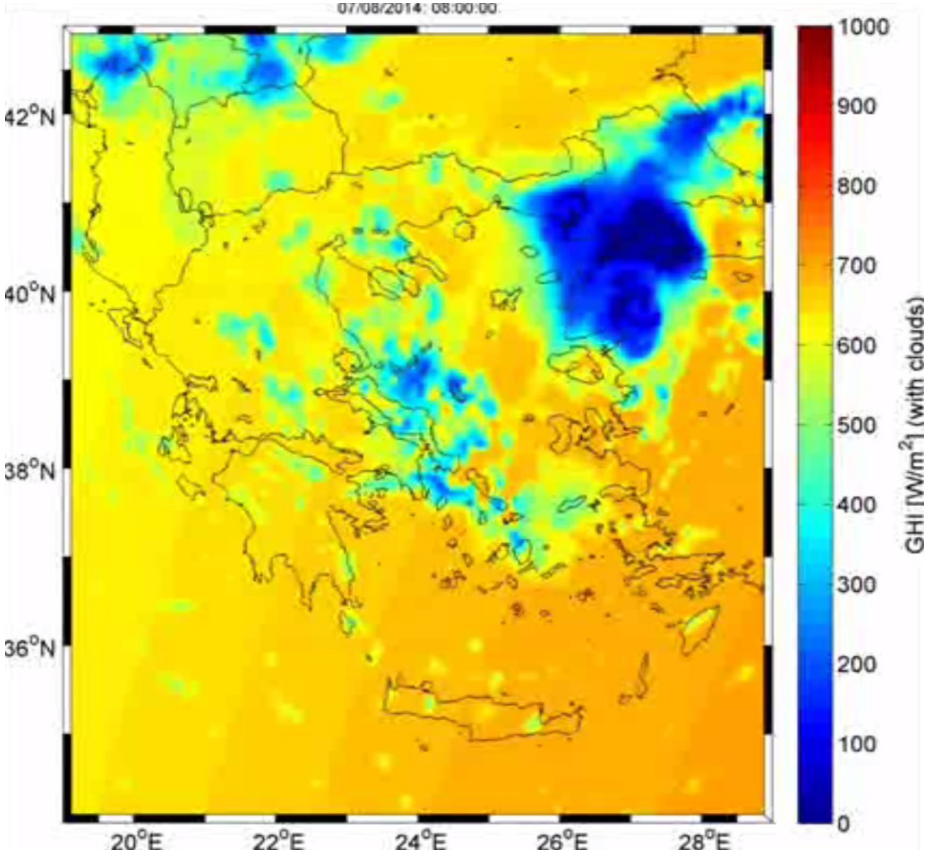


Without clouds

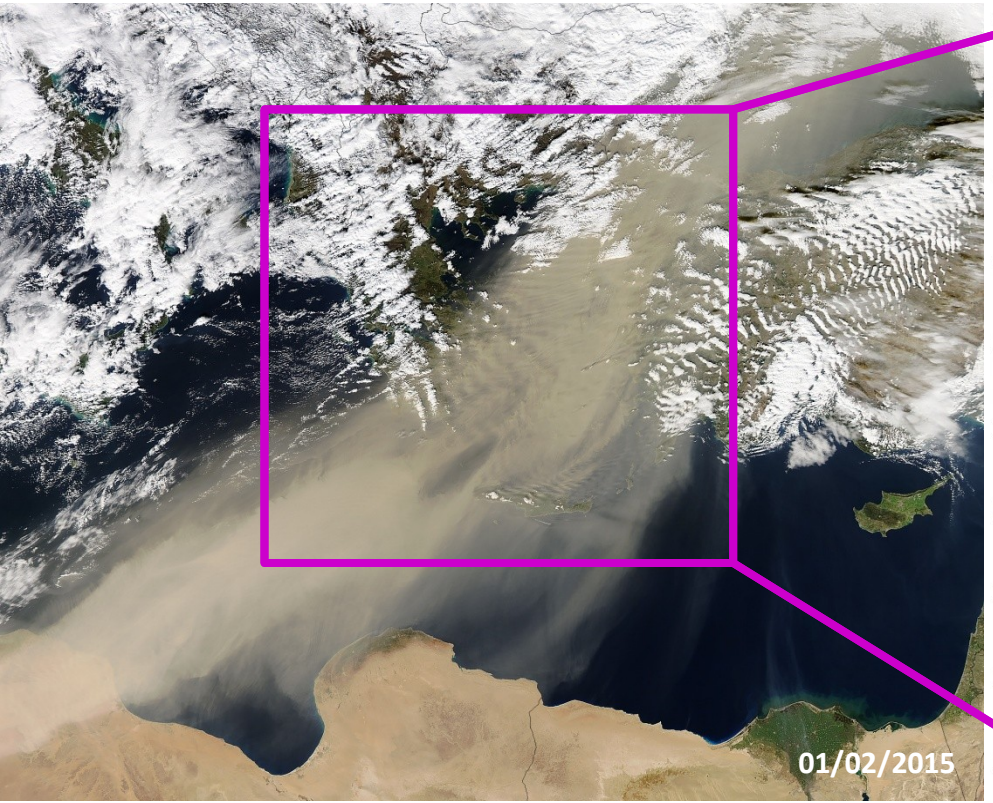
Clouds

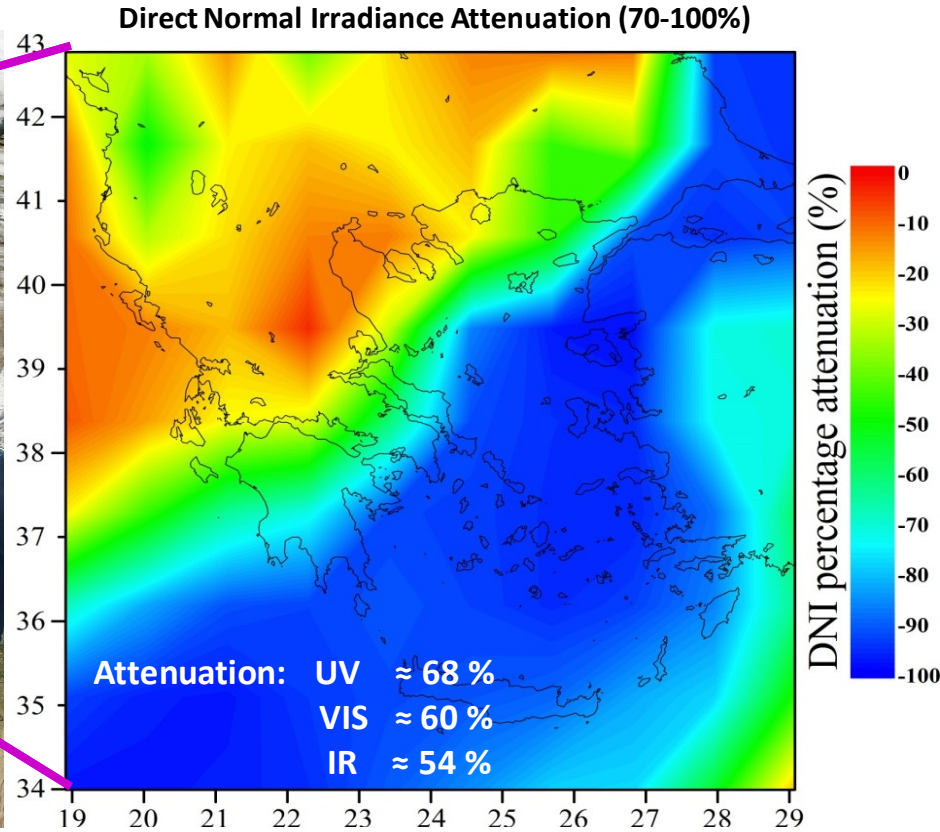


Global Horizontal Irradiance



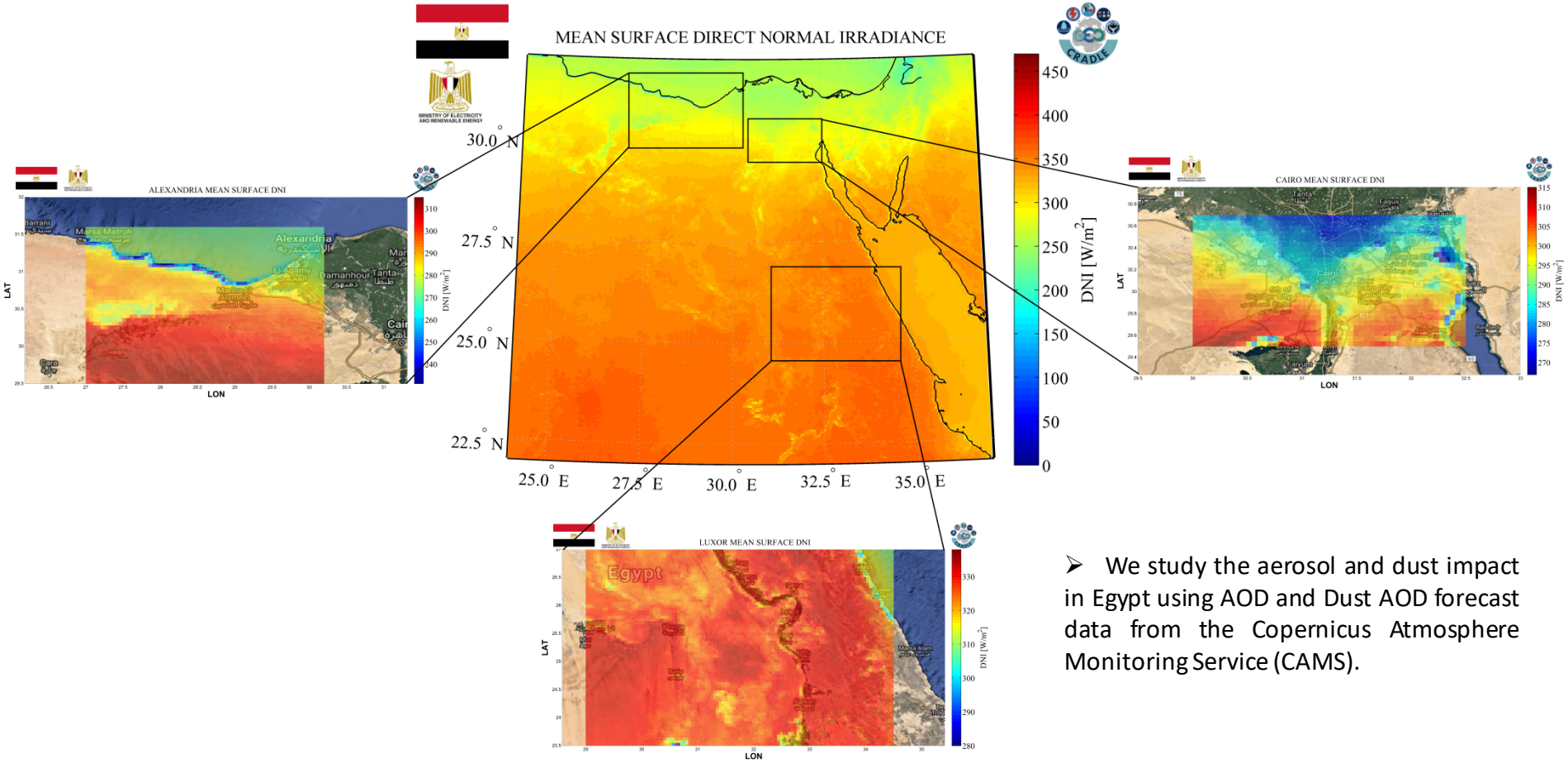
Aerosols impact





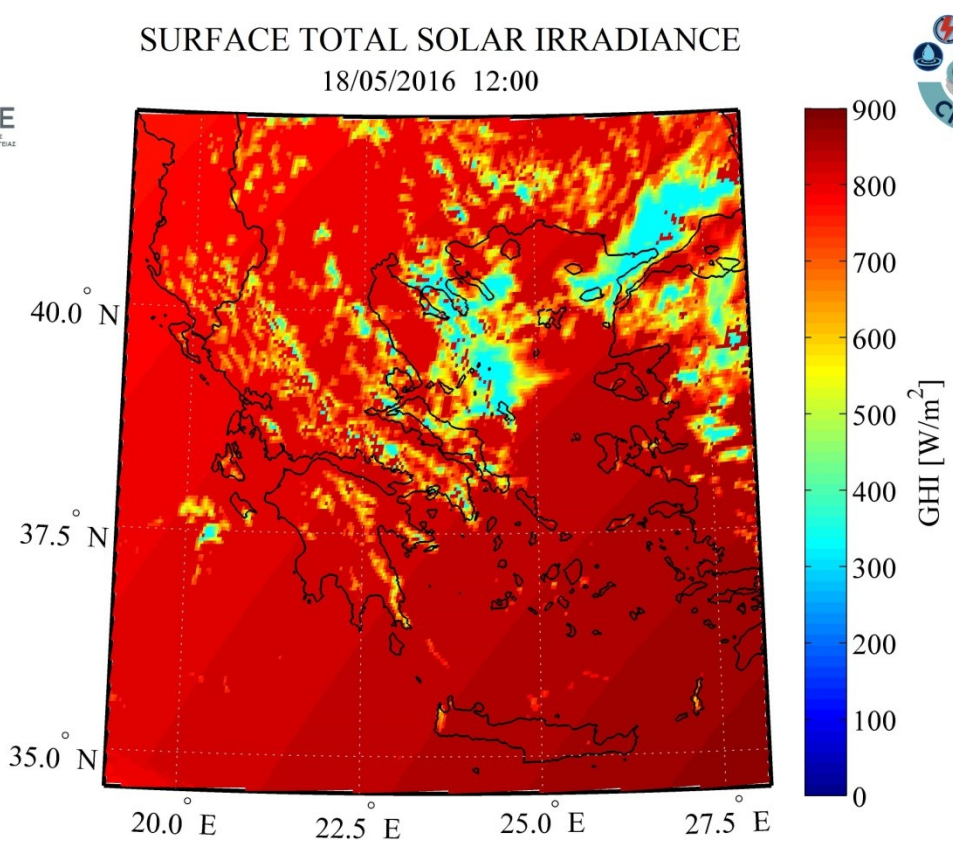
- The inclusion of cloud and aerosol effects means that this approach is ideal for correct assessments of solar power operational loads.

Aerosols impact (Egypt pilot study)

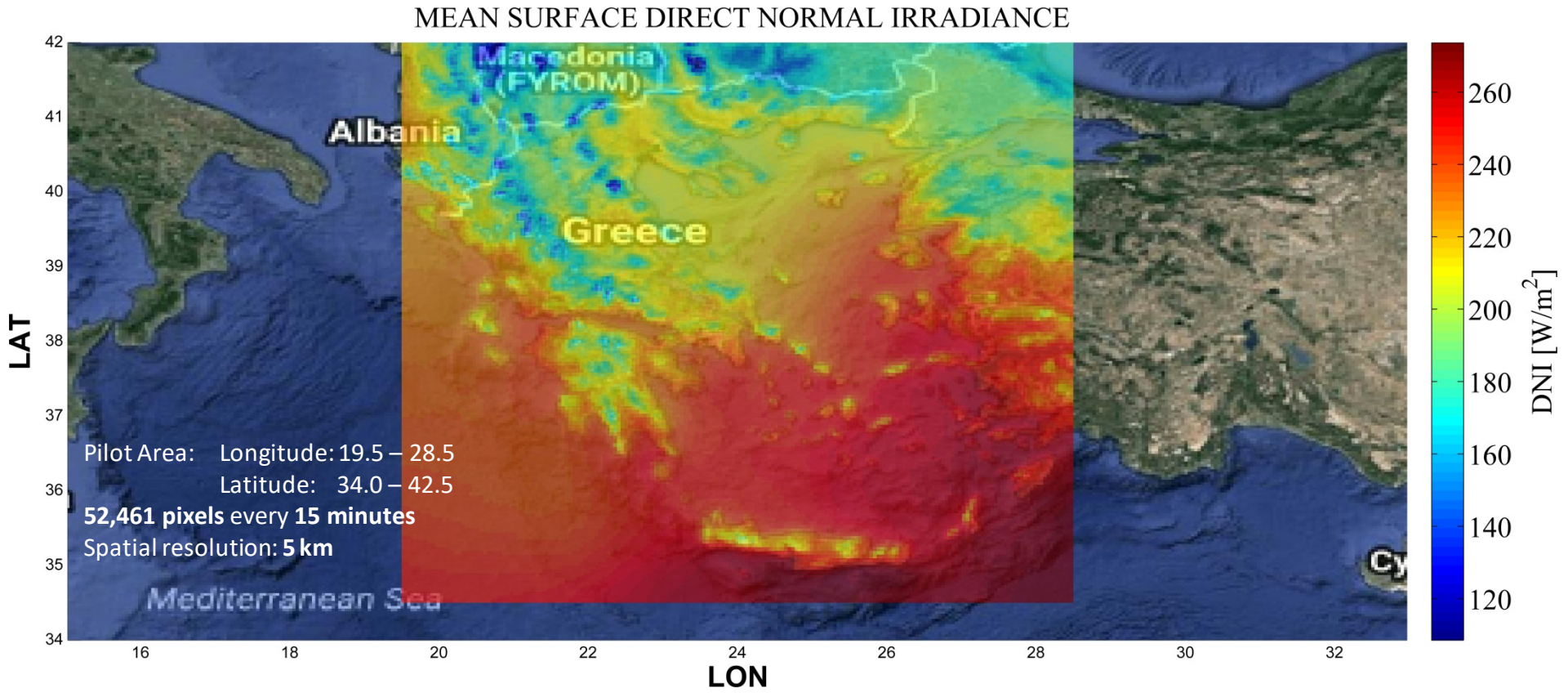


- We study the aerosol and dust impact in Egypt using AOD and Dust AOD forecast data from the Copernicus Atmosphere Monitoring Service (CAMS).

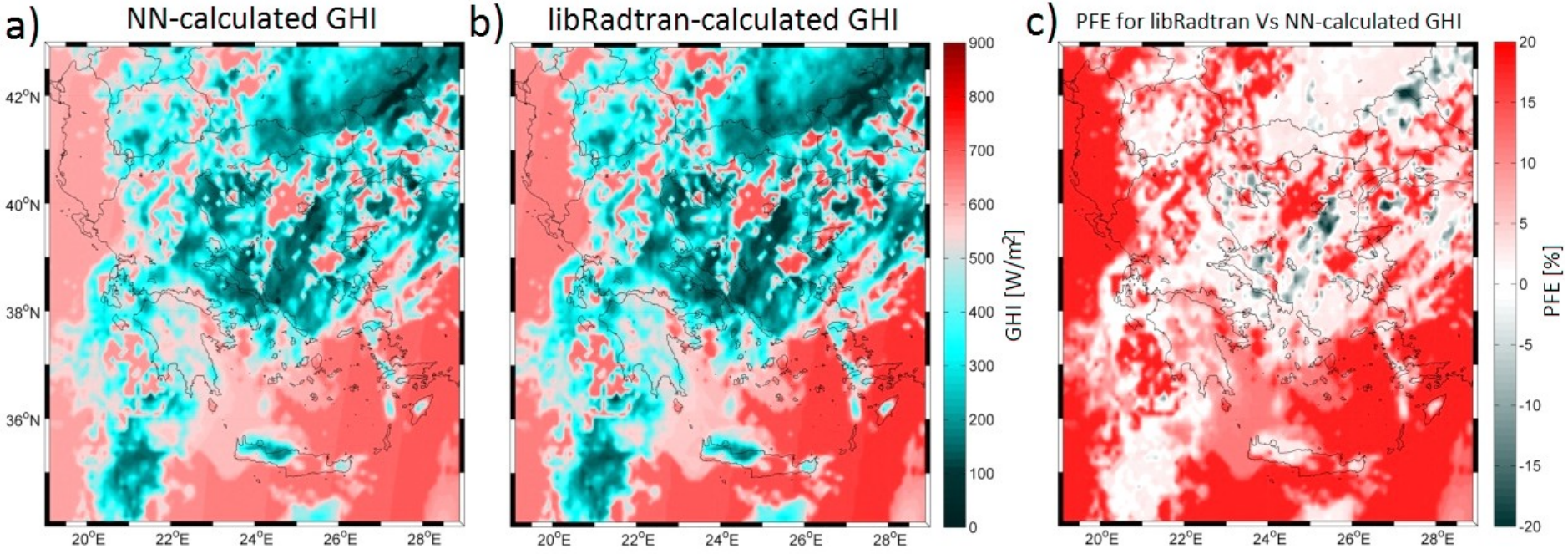
Nowcasting application



Advanced products



Operational accuracy of products

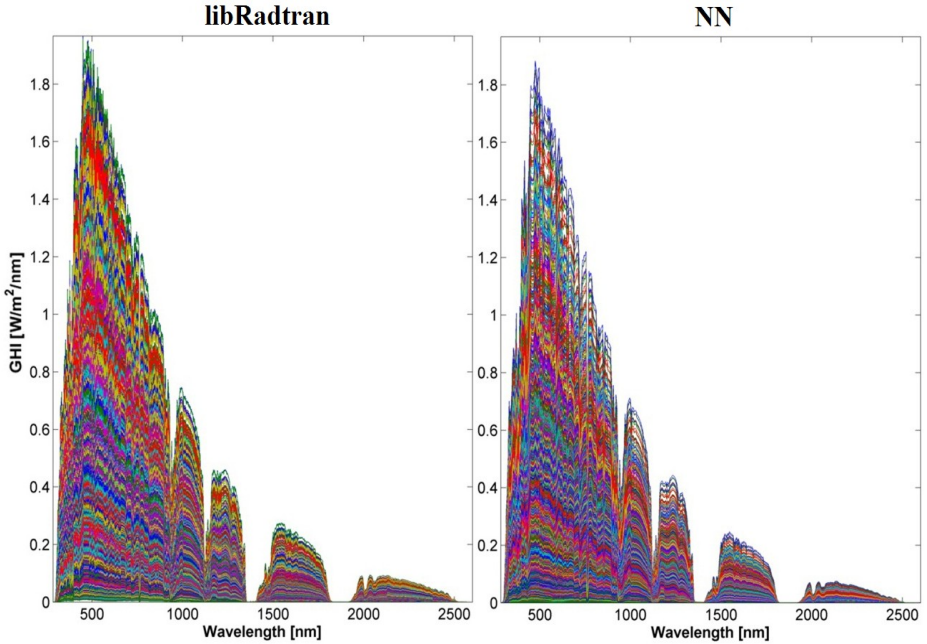


t ≈ 1 minute

t ≈ 8 days

$$\mathrm{PFE} = \frac{(t_i - y_i)}{t_i} \times 100\%$$

Spectral accuracy of products



Major Applications & Contribution to Emerging Technology

This developed system is ideal for:

- realistic assessment of solar energy potential
- provision of solar energy applications of high precision in real time
- solar potential forecasts for energy planning

Products

- ✓ Real time nowcasts and short-term forecasts of:
  - cloud cover
  - gridded spectra over the Earth disc
  - gridded solar potential
  - health and environmental UV radiation impact measures
- ✓ Continental and local maps of solar products

Applications

- **Location studies** for the placement of CSP plants and CPV installations
- **Large-scale** and **precise solar energy calculations** to assist Public Authorities in **energy planning** policy
- Supporting the work of **various scientific communities**
- Provision of specialized data of high spectral precision for private and public sectors dealing with **health protection**, **energy consumption** and **solar energy exploitation**

References

P.G. Kosmopoulos, S. Kazadzis, M. Taylor, H.M. El-Askary, P. Raptis, I. Keramitsoglou, C. Kiranoudis, 2016. Estimation of the solar energy potential in Egypt by developing high resolution solar Atlas and nowcasting service in real time. AGU Fall Meeting, San Fransisco, USA, 12-16 December 2016.

M. Taylor, P.G. Kosmopoulos, S. Kazadzis, I. Keramitsoglou, C.T. Kiranoudis, 2015. Neural network radiative transfer solvers for the generation of high resolution solar irradiance spectra parameterized by cloud and aerosol parameters. *Journal of Quantitative Spectroscopy & Radiative Transfer, 168, pp 176-192*

P.G. Kosmopoulos, S. Kazadzis, K. Lagouvardos, V. Kotroni, A. Bais, 2015. Solar Energy prediction and verification using operational model forecasts and ground-based solar measurements. *Energy, Vol. 93, DOI: 10.1016/j.energy.2015.10.054, pp 1918-1930.*

PG. Kosmopoulos, M. Taylor, S. Kazadzis, 2015. The SOLEA Project: nowcasting solar energy spectra and UV products. *15th European Meteorological Society (EMS) Annual Meeting & 12th European Conference on Applications of Meteorology (ECAM), Sofia, Bulgaria, 7-11 September 2015.*

M. Taylor, P.G. Kosmopoulos, S. Kazadzis, I. Keramitsoglou, C.T. Kiranoudis, 2015. A machine learning approach to derive surface solar irradiance spectra directly from satellite. *15th European Meteorological Society (EMS) Annual Meeting & 12th European Conference on Applications of Meteorology (ECAM), Sofia, Bulgaria, 7-11 September 2015.*

P.G. Kosmopoulos, M. Taylor, S. Kazadzis, 2016. A model of dust episode impact on surface solar irradiance. *International Skynet Workshop, Rome, Italy, 2-4 March 2016.*

P.G. Kosmopoulos, M. Taylor, S. Kazadzis, 2016. Solar energy potential nowcasting and forecasting services in real time. Invited talk at the *Independent Power Transmission Operator (IPTO or ADMIE), Athens, Greece, 15 April 2016.*

P.G. Kosmopoulos, S. Kazadzis, M. Taylor, A. Bais, K. Lagouvardos, V. Kotroni, I. Keramitsoglou and C. Kiranoudis, 2016. Estimation of the solar energy potential in Greece using satellite and ground-based observations. *13th International Conference on Meteorology, Climatology and Atmospheric Physics, COMECAP 2016, Thessaloniki, Greece, 19-21 September 2016.*

Thank you