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Introducing the Solar Radiation and Energy Laboratory of the Eratosthenes' Centre of Excellence: Overview of Activities †

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Abstract: A brief overview of the newly established Solar Radiation and Energy Laboratory of the Eratosthenes' Centre of Excellence is provided. The laboratory focuses on fundamental research and practical applications related to solar radiation levels, radiative transfer modeling, and atmospheric effects. The laboratory's goal is to establish a scientific foundation that will support some of the most important sectors of the EU and Cyprus Smart Specialization Strategy, including energy, tourism, health, and agriculture, and become a reference point for the Eastern Mediterranean, Middle East, and North African region. Finally, some preliminary results concerning solar radiation climatology and a system for clear-sky ultraviolet index forecast over Cyprus are presented.

Keywords: solar radiation monitoring; solar energy; ultraviolet radiation; radiative transfer modeling; climate; forecasting

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1. Introduction

Cyprus exhibits the greatest duration of sunlight among European countries. Throughout the year, the daily percentage of sunshine duration ranges from approximately 60% in winter to as high as 90% during summer [1]. This abundant sunshine duration, combined with the dry climate, especially during summer, positions Cyprus as one of the regions with the greatest solar energy potential in Europe [2]. However, despite the considerable solar potential, the integration of solar energy into the electricity mix remains relatively low, accounting for only 4.51% in 2020 [3]. Moreover, although greenhouse gas emissions in Cyprus have shown a decreasing trend since the 1970s, there has been an uptick in emissions over the past five years [4]. As a result, the Cyprus Electricity Authority had to pay EUR 183 million for greenhouse gas emission rights in 2022, marking a 150% increase compared to the penalty imposed in 2021 [3]. To address these challenges, Cyprus has set its sights on increasing the share of renewable energy sources from 13.9% in 2020 to 22.9%

by 2030 [5]. Effective harnessing of solar radiation for energy purposes can play a crucial role in achieving this goal.

Furthermore, Cyprus experiences high levels of ultraviolet (UV) radiation, with UV index values reaching up to 10 during the summer months [6]. While UV radiation is essential for vitamin D synthesis, overexposure can lead to harmful health effects such as erythema, eye damage, and an increased risk of skin cancer [7]. However, despite the high levels of UV radiation, a significant portion of the Cypriot population, particularly those with lower educational backgrounds, do not adhere to appropriate protective measures when exposed to the sun [8]. Additionally, a recent study found that 69.3% of a sample of 2594 individuals in Cyprus had inadequate levels of 25(OH)D [9], indicating a need for a better strategy to promote optimal sun exposure behaviors and benefit the public health system of Cyprus.

To address these issues, the Eratosthenes Centre of Excellence (https://eratosthenes.org.cy/, accessed on 22 August 2023) (ERATOSTHENES CoE), in collaboration with advanced partners from the National Observatory of Athens (NOA) and Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center (PMOD/WRC), established the ERATOSTHENES Solar Radiation and Energy Laboratory (ESEL) as part of the Excelsior EU project (https://excelsior2020.eu/, accessed on 22 August 2023). This laboratory aims to contribute to the above needs and conduct research in this field. This paper provides an overview of the research activities and presents some preliminary results of the conducted research.

2. Overview of Research Directions and Instrumentation

The activities of ESEL are diverse, encompassing both fundamental research and applications related to solar radiation levels, radiative transfer modeling, and relevant atmospheric effects. The main scientific directions focus on several key areas:

1. Solar radiation forecasting for energy purposes: ESEL aims to develop the CySENSE system, based on the existing NOA's solar irradiance nowcasting and short-term forecasting system (nextSENSE) [10,11], currently running for a wide domain over Europe and North Africa. The goal is to replicate and optimize the system to meet the specific needs of Cyprus. The CySENSE model utilizes real-time information for cloud optical thickness from the Meteosat Second Generation (MSG) product, aerosol optical properties from the Copernicus Atmosphere Monitoring Service (CAMS), and other atmospheric parameters retrieved from earth observation to nowcast solar irradiance. Furthermore, the model incorporates cloud motion vectors to enable short-term forecasting.
2. Forecasting of spectrally weighted solar radiation products: In addition to solar energy forecasting, ESEL aims to provide nowcasts and forecasts of various spectrally weighted products. These forecasts have applications in fields such as health, tourism (e.g., erythemal UV doses, DNA damage dose, vitamin D production doses), and agriculture.
3. Continuous monitoring of total and ultraviolet (UV) solar radiation levels and their impact: ESEL focuses on the continuous monitoring of total and UV radiation levels and their effects on energy, human health, tourism, and agriculture. The research investigates the interactions between radiation, aerosols, and clouds, and their broader effects on climate.

Currently, the clear sky UV index forecast model has been developed and is undergoing testing, with the remaining forecast and nowcast products expected to be available by the end of 2023.

The Cyprus Solar Network (CSN), a ground-based network of stations for monitoring solar energy and solar ultraviolet (UV) radiation, is also under development. The stations have been selected to cover different geographical areas of the Cyprus Republic territory (Figure 1). The CSN will be used for validation, and will provide near real-time correction of the CySENSE products. It will consist of five stations equipped with sensors, including

pyranometers to measure total solar irradiance and UV radiometers to measure solar UV irradiance. The central station, located in Limassol, will have additional equipment such as a spectral radiometer, serving as the reference instrument for the network. An optical laboratory with a calibration unit will be set up at the reference station for instrument calibration. Table 1 presents a comprehensive list of the instruments that have been acquired. The CSN will complement the nextSENSE assimilation tool and provide real-time data for various health, agriculture, and tourism applications. Moreover, by analyzing CSN measurements alongside high-quality atmospheric measurements from the Cyprus Atmospheric Remote Sensing Observatory (CARO) of the Eratosthenes Centre of Excellence (CoE) [12], the CSN can provide valuable scientific information regarding the radiative effects of aerosols and the impact of changes in aerosols and clouds on Cyprus' regional climate.

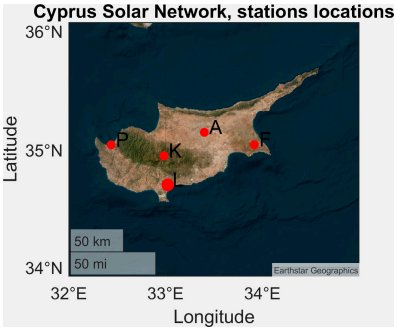

Figure 1. Map of the CSN stations plotted with red circles. The central station in Limassol is denoted with the letter "L", while the rest of the station, from west to east, are the following: "P": Polis Chrysochous, "K": Kyperounta, "A": Athalassa, "F": Frenaros.

Table 1. List of sensors and their locations.

Instrument Type	Instrument Model	Measured Quantity	Location
Pyranometer (x6)	MS-80 EKO EKO Instruments Co., Ltd.	Downwelling total shortwave irradiance (W/m^2)	Limassol (x2, one for global and one for diffuse), other stations (x1)
Pyrheliometer	MS-57 EKO Instruments Co., Ltd.	Direct shortwave irradiance (W/m^2)	Limassol
Pyrgeometer	MS-21 EKO Instruments Co., Ltd.	Downwelling longwave irradiance (W/m^2)	Limassol
UV Radiometer (x5)	SUV-E UVE Radiometer Kipp & Zonen B.V	Erythemal UV irradiance (W/m^2)	All stations (x1)
Spectrophotometer UV/VIS	DMc150 Double Monochromator Bentham Instruments Ltd.	Global spectral (290–500 nm) irradiance ($W/nm \cdot m^2$)	Limassol

3. Results

Some preliminary results concerning the activities of ESEL are presented below. These include a high temporal and spatial resolution solar irradiance climatology for Cyprus and a system for clear-sky UV index forecasting.

3.1. Climatology of Solar Irradiance

The mean monthly integrals of total (GHI) and direct solar irradiance (DNI) for January, April, July, and October for the period 2004–2017 are shown in Figure 2. The climatology is based on simulations of the clear-sky shortwave surface irradiance based on the LibRadtran radiative transfer model [13] using satellite-derived aerosol optical depth from MODIS and climatological values of the ozone and total precipitable water vapor. The effects of clouds were quantified applying the cloud modification factor (CMF) from the CM SAF-SARAH2.1

dataset. The spatial and temporal resolution of the simulations was 0.1 × 0.1 degrees and 15 min, respectively. A full description of the climatology is given in [2]. The monthly integrals range from 250 to 900 MJ/m^2 and 300 to 1000 MJ/m^2 during January and July, for GHI and DNI, respectively.

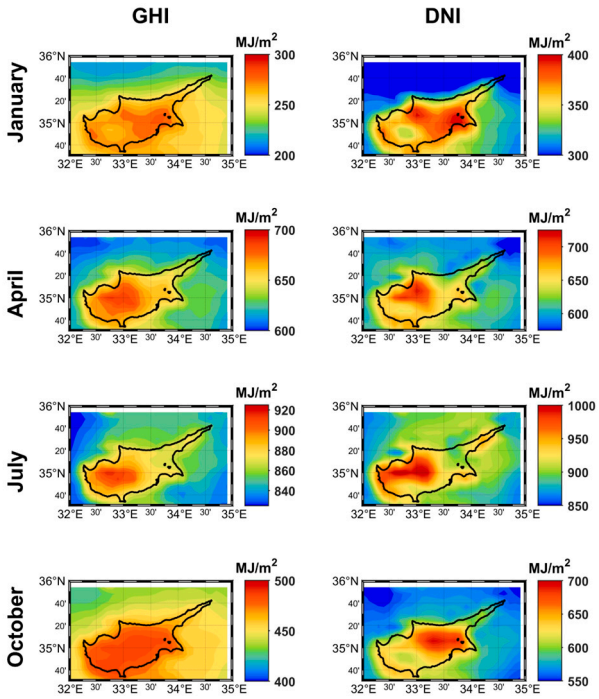

Figure 2. Multiyear mean monthly maps of total and direct all-sky solar irradiance for Cyprus. Adopted from [2].

3.2. Ultraviolet Index Forecast

A system for clear-sky forecasting of the UV index has been developed. The system utilizes the LibRadtran radiative transfer model, which receives forecasts of aerosol properties (aerosol optical depth, single scattering albedo, asymmetry factor) from the CAMS global atmospheric composition forecasts [14], as well as total ozone column forecasts from the Tropospheric Emission Monitoring Internet Service (TEMIS, https://www.temis.nl/index.php, accessed on 22 August 2023). The system provides spectral UV irradiance data (290–400 nm) with a temporal resolution of 1 h for a grid of 0.1 × 0.1 degrees. To obtain UV index values, the UV spectra are convolved with the erythemal action spectrum, which quantifies the relative effectiveness of different wavelengths in causing erythema (skin reddening). Figure 3 illustrates an example of the UV index forecast over Cyprus on 12 May 2023 for three different hours.

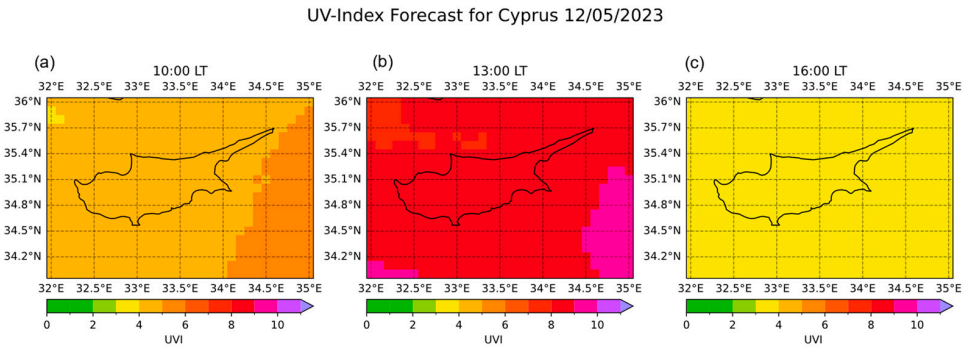

Figure 3. UV index forecast over Cyprus for 10 am (**a**), 13 pm (**b**) and 16 pm (**c**). All times refer to local time.

During noontime, very high UV index levels (8+) are observed, indicating intense UV radiation. Moderate levels (4+) are reported during the morning, and slightly lower levels (3+) are expected in the afternoon. These findings suggest that protective measures against sunburn, in line with the guidelines provided by the World Health Organization, should be implemented for most of the day.

In addition to the maps, hourly forecasts are available for the four major cities of Cyprus: Nicosia, Larnaca, Limassol, and Paphos, as depicted in Figure 4. The forecasts indicate UV index values exceeding 3 from 9 am to 5 pm. During the interval of 11 am to 3 pm, elevated values (6+) are projected, with particularly high values (8+) occurring between 12 pm and 1:30 pm.

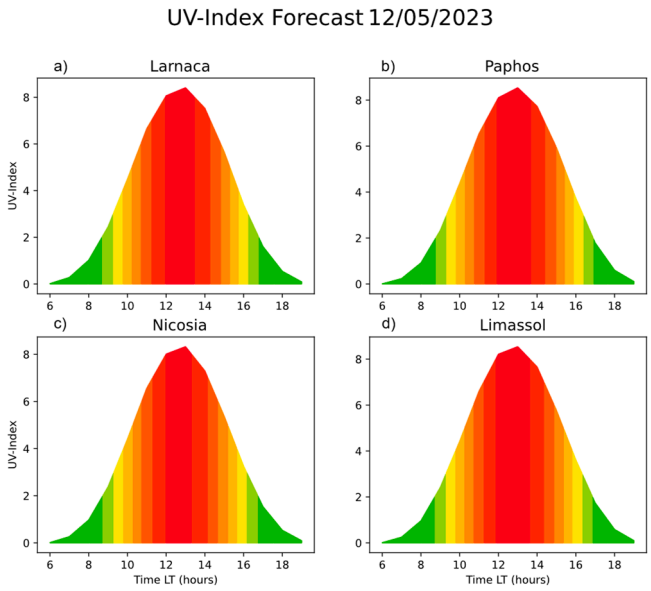

Figure 4. Hourly UV index forecasts for the four major cities of Cyprus: Larnaca (**a**), Paphos (**b**), Nicosia (**c**) and Limassol (**d**).

4. Conclusions

The Solar Radiation and Energy laboratory was established by the Eratosthenes' Centre of Excellence in July 2022 to leverage the potential of solar radiation for applications related to energy, agriculture, health, and tourism. The main scientific directions focus on solar radiation continuous monitoring and forecasting for energy, human health, tourism, and agricultural purposes, and the investigation of radiation–aerosol–cloud interactions and their effects on climate.

To facilitate its work, a network of five measuring stations is being developed, encompassing a central spectroradiometric/calibration station in Limassol, as well as four stations for measuring UV and downwelling shortwave radiation. These measurements will provide valuable insights into solar radiation levels, aiding in the refinement of solar forecasting models through assimilation techniques. The laboratory's ultimate goal is to establish a scientific foundation that will support some of the most important sectors of the EU and Cyprus Smart Specialization Strategy, including energy, tourism, health, and agriculture, and become a reference point for the Eastern Mediterranean, Middle East, and North African region.

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