



UV Index monitoring and forecasting in Cyprus: the effect of ozone, aerosols and clouds

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Abstract. Surface ultraviolet (UV) radiation is strongly influenced by clouds, aerosols, and total column ozone, making accurate operational forecasting challenging in regions with highly variable atmospheric conditions. This study evaluates UV Index (UVI) variability and forecasting over Cyprus using more than one year of observations from a five-station ground-based monitoring network. Spectral measurements from a Bentham spectroradiometer were combined with broadband UV observations, all-sky imagery, AERONET aerosol measurements, and satellite ozone products to evaluate the regional Cyprus Erythral Radiation Forecasting System (CERYFOS) and the Copernicus Atmosphere Monitoring Service (CAMS) corresponding product. Ground-based observations showed a strong seasonal cycle across Cyprus, together with regional differences associated with altitude and local atmospheric variability, particularly at the mountainous Kyperounda station. Both forecasting systems reproduced observed UVI well under typical atmospheric conditions. For the all sky conditions, CERYFOS and CAMS achieved RMSE values of 0.72 and 0.60 UVI, respectively, decreasing to 0.47 and 0.40 UVI under clear-sky cases. In contrast, performance deteriorated under cloudy conditions, with RMSE increasing to 1.65 and 1.12 UVI, respectively, identifying cloud representation as a major source of forecast uncertainty. Ozone-related uncertainties generally produced relatively small UVI deviations, whereas aerosol errors became increasingly important under enhanced aerosol loading, as particularly evident during the 23–24 July 2025 wildfire, underestimated aerosol loading resulted in forecast errors exceeding 4 UVI units. These results demonstrate the importance of accurate cloud and aerosol representation and coordinated ground-based observations for improving operational UVI forecasting in the Eastern Mediterranean.

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1 Introduction

Solar ultraviolet (UV) radiation represents a small part of the incoming solar spectrum but exerts a significant influence on atmospheric chemistry and biological processes (Barnes et al. 2023). The flux of UV radiation at the Earth's surface depends on several atmospheric and environmental factors, including solar zenith angle (SZA), total column ozone (TOC), cloud cover,

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aerosol optical properties, surface albedo, and altitude (McKenzie et al., 2007; Bais et al., 2014; Bais et al., 2019). Variations in these parameters can substantially modify surface UV levels on both regional and global scales, while interactions between ozone recovery and climate change continue to influence long-term UV radiation trends (Bais et al., 2019). To communicate the resulting UV levels and associated health risk to the public in a simple, consistent form, the World Health Organization (WHO) and World Meteorological Organization (WMO) introduced the UV Index (UVI) as a standardized indicator of erythemally weighted surface UV, with values of 8-10 classified as “very high” and over 11 as “extreme” (Fioletov et al., 2010; WHO, 2002).

Among the atmospheric factors controlling surface UV, TOC is the principal absorber of UVB radiation, whereas clouds and aerosols introduce substantial short-term variability (Kazadzis et al., 2009; Park et al., 2017; Bernhard et al., 2023). The high spatiotemporal variability of clouds makes their representation one of the main challenges in operational UV forecasting, with uncertainties in cloud properties contributing substantially to short-term forecast errors (Calbó et al., 2005; Fountoulakis et al., 2024, 2025). Under cloud-free conditions, aerosol amount and optical properties become increasingly important, with their effects governed mainly by aerosol optical depth (AOD), single scattering albedo (SSA), asymmetry parameter (asy), and the Ångström exponent (AE) (Kazadzis et al., 2007; Fountoulakis et al., 2019; Kosmopoulos et al., 2021; Papachristopoulou et al., 2022; Zhao et al., 2024). Under high aerosol loading, aerosol attenuation can substantially modify, and in some cases partly offset, the UV enhancement associated with low TOC (Di Sarra et al., 2002; Fountoulakis et al., 2016; Fragkos et al., 2016; Raptis et al., 2021). Recent studies report significant positive long-term trends in surface solar UV radiation that are mainly driven by changes in aerosols and/or cloudiness (Fountoulakis et al., 2021; Schmalweiser et al., 2026). Thus, accurate representation of clouds, aerosols, and ozone is critical not only for reliable short-term prediction of surface UV radiation, but also to estimate its long-term variability and trends in the models.

These interactions are particularly relevant in the Eastern Mediterranean basin, a region characterized by high solar irradiance, long sunshine duration, and frequent aerosol transport from North Africa and the Middle East (Nisantzi et al., 2015; Papachristopoulou et al., 2022; Karami et al., 2024; Charalampous et al., 2026; Papetta et al., 2026). Cyprus provides a particularly suitable environment for investigating UV variability, combining consistently high UV exposure (Jacovides et al., 2006; Fragkos et al., 2024) with atmospheric conditions influenced by transported desert dust (Charalampous et al., 2026), local and regional pollution (Bimenyimana et al., 2023; Christodoulou et al., 2023), and variable cloud cover (Fountoulakis et al., 2021). Previous studies combining ground-based and satellite observations with radiative transfer modelling (RTM) have characterized ozone and solar-radiation variability over the island and demonstrated the occurrence of very high and extreme UVI levels, particularly during JJA (Charalampous et al., 2023; Fragkos et al., 2023, 2024). This radiation environment also has important public-health implications. While UVB exposure promotes cutaneous vitamin D synthesis, excessive UV exposure increases the risk of sunburn, photo ageing, ocular damage, and skin cancer (Zerefos et al., 2023). Despite the high ambient UV levels and sunshine duration in the Eastern Mediterranean, vitamin D deficiency remains prevalent, with inadequate 25-hydroxyvitamin D levels reported in nearly 70% of a Cypriot sample (Xyda et al., 2022). This apparent “vitamin D paradox”, associated with factors including sun-avoidance behaviour, sunscreen use, and predominantly indoor lifestyles



(Kyriakaki & Fragkoulis, 2019; Xyda et al., 2022), highlights the health implications of both insufficient and excessive UV exposure and reinforces the need for reliable, spatially resolved UV information.

Recent developments in operational UV forecasting have demonstrated the potential of combining Earth-observation products, atmospheric composition datasets, and RTM to provide near-real-time and short-term UVI predictions over large spatial domains (Kosmopoulos et al., 2021; Fountoulakis et al., 2025). The reliability of these products depends strongly on the quality of the atmospheric input parameters, particularly ozone, aerosols, and clouds, making high-quality ground-based UV observations essential for their independent evaluation and improvement (Lakkala et al., 2020; Fountoulakis et al., 2020, 2025; Klotz et al., 2025). Such observations require rigorous calibration and maintenance procedures, traceability to international standards, and well-characterized measurement uncertainties (Gröbner et al., 2005; Hülsen et al., 2016; Fountoulakis et al., 2020). Spectral UV measurements performed with double-monochromator spectroradiometers provide reference-quality observations because of their high spectral accuracy and low stray-light interference (Bernhard & Seckmeyer, 1999; Gröbner et al., 2005; Fountoulakis et al., 2020). Although operational UV products from services such as the Copernicus Atmosphere Monitoring Service (CAMS) are increasingly available, comprehensive evaluations under Eastern Mediterranean conditions remain limited. At the global scale, the recent CAMS Cy48R1 upgrade showed strong correlation with observations ($R=0.82$) and fractional gross error (FGE) of 0.30 against 38 reference stations, while the positive bias, expressed by the modified normalized mean bias (MNMB) increased from 2% to 6% following changes affecting AOD, thick clouds, and stratospheric ozone (Eskes et al., 2024). Given the strong regional variability of these atmospheric components, their individual contributions to UVI forecast uncertainty have not yet been systematically quantified across Cyprus.

The Cyprus Solar Network (CSN) (Fragkos et al., 2023), operated as part of the Solar Radiation and Energy Laboratory (ESEL) (Charalampous et al., 2025), provides a unique observational basis for such an evaluation. Following more than two years of continuous operation, the CSN provides high-resolution ground-based measurements from five stations strategically distributed across Cyprus to capture differences in atmospheric, altitudinal, and geographical conditions. While these measurements provide high-quality point observations, a finite number of stations cannot fully resolve the spatial variability of surface UV radiation across the island, highlighting the complementary role of numerical modelling and spatial forecasting in areas without direct observations. Accordingly, this study evaluates the performance of the operational CAMS and regional CERYFOS UVI forecasting systems over Cyprus under both all-sky and clear-sky conditions, using collocated spectral and broadband UV observations as the validation reference. Attention is given to the characterization, calibration traceability, and uncertainty of the ground-based instruments, followed by an assessment of the roles of clouds, AOD, TOC, and solar geometry in driving model–measurement differences. Through this combined observational and modelling framework, the study aims to quantify the performance and principal uncertainty sources of operational UVI forecasting over Cyprus and to assess its ability to represent the spatial variability of surface UV radiation across the island. Specifically, Section 2 describes the observational datasets, forecasting systems, and evaluation methodology. Section 3 first characterizes the observed temporal and spatial variability of UVI across the Cyprus monitoring network, followed by the evaluation of CERYFOS and CAMS under all-sky, cloudy, and clear-sky conditions. The roles of cloud representation, total column ozone, and aerosol optical



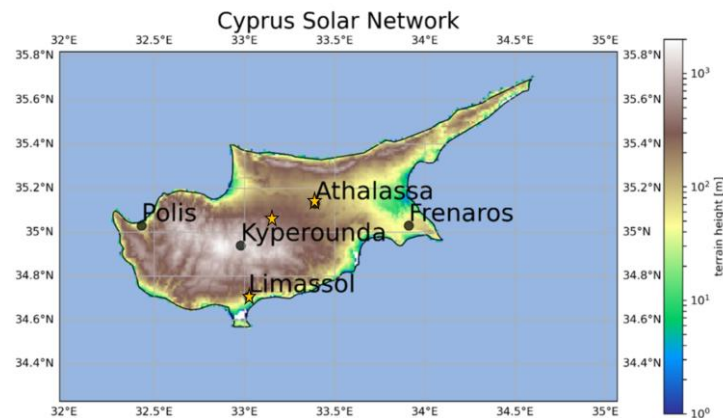
100 depth in the forecast differences are then examined, including a dedicated analysis of the July 2025 wildfire smoke event. The
main findings and implications for operational UV forecasting in the Eastern Mediterranean are summarized in Sect. 4.

2 Data and Methods

2.1 Study Area and UV Monitoring Network

Cyprus, an island nation in the Eastern Mediterranean, is characterized by elevated solar irradiance levels, prolonged sunshine
105 duration, and frequent aerosol transport events originating from North Africa and the Middle East (Nisantzi et al., 2015;
Papachristopoulou et al., 2022). The region experiences strong seasonal variability in atmospheric conditions, marked by
relatively cloud-free “summers” and episodic dust intrusions that significantly alter atmospheric optical properties and surface
radiation levels (Fountoulakis et al., 2021). These distinct environmental conditions make Cyprus a well-suited natural
laboratory for investigating ultraviolet (UV) radiation variability and validating operational UV forecasting frameworks.

110 The present study utilizes ground-based measurements from a UV monitoring network consisting of five stations strategically
distributed across the island (Fig. 1). Developed under the framework of the Cyprus Solar Network (CSN) initiative, this
infrastructure supports long-term monitoring of solar radiation and atmospheric processes in the Eastern Mediterranean basin
(Fragkos et al., 2023). In addition to the UV monitoring stations, three CIMEL CE318 sun-photometers operating within the
AERONET framework provide measurements of aerosol optical properties at Limassol (LIM), Nicosia (NIC) and Agia Marina
115 Xyliatou (AMX). As presented in Table 1, the network's geographical footprint captures a diverse array of microclimates and
environmental typologies, spanning coastal, inland, rural, urban, and high-altitude mountainous settings.



120 **Figure 1: Geographical distribution of the Cyprus UV monitoring network. Black circles indicate the five UV monitoring stations equipped with SUV-E radiometers, while yellow stars denote the locations of the three CIMEL CE318 sun-photometers participating in the AERONET network (Limassol, Nicosia and Agia Marina Xyliatou).**

Table 1: Geographical coordinates, elevation, and environmental classifications of the five UV monitoring stations and the three CIMEL stations.



Station	Latitude (°N)	Longitude (°E)	Altitude (m)	Environment	Instrumentation
Athalassa (ATHA)	35.14	33.40	162	Inland urban	SUV-E UV radiometer, GHI pyranometer
Frenaros (FRN)	35.04	33.92	78	Eastern rural/coastal	SUV-E UV radiometer, GHI pyranometer
Kyperounda (KYP)	34.95	32.98	1332	Mountainous	SUV-E UV radiometer, GHI pyranometer
Polis (POL)	35.04	32.44	21	Western coastal	SUV-E UV radiometer, GHI pyranometer
Limassol (LIM)	34.68	33.04	31	Southern coastal urban	SUV-E UV radiometer, Bentham DMc150 spectroradiometer, CIMEL CE318 sun-photometer, broadband radiation station (GHI, DHI, DNI), all-sky camera
Agia Marina Xyliatou (AMX)	35.04	33.06	535	Rural inland / forested	CIMEL CE318 sun-photometer (AERONET)
Nicosia (NIC)	35.14	33.38	181	Inland urban	CIMEL CE318 sun-photometer (AERONET)

Among the monitoring sites, the Athalassa (ATHA) station is situated in the inland urban area of Nicosia at an altitude of 162 m above sea level (a.s.l.), whereas the Limassol (LIM) station monitors the southern coastal-urban zone. Western and eastern coastal-rural gradients are captured by the Polis (POL) and Frenaros (FRN) stations, respectively. Lastly, the Kyperounda (KYP) station is positioned in the Troodos mountainous region at 1332 m a.s.l., providing the elevation gradient necessary to isolate and investigate altitude-related enhancements in surface UV radiation. Collectively, this spatial distribution allows for a systematic breakdown of both temporal and spatial UV radiation variability under highly contrasting atmospheric states, including localized variations driven by cloud cover, regional meteorology, and heterogeneous aerosol loading.

2.2 Ground-Based Measurements

2.2.1 Bentham Spectroradiometer

Reference spectral UV measurements were conducted using a double-monochromator Bentham DMc150 spectroradiometer (Bentham Instruments Ltd., Reading, UK; <https://www.bentham.co.uk/products/components/product/dmc150-double-monochromator-37/>, last access: 4 August 2026) operating at the Solar Radiation and Energy Laboratory (ESEL) in Limassol, Cyprus. ESEL or LIM provides continuous, high-quality observations of solar radiation and related atmospheric properties in the Eastern Mediterranean, including spectral and erythral ultraviolet radiation, broadband solar irradiance, aerosol optical properties, and cloud cover (Charalampous et al., 2025). The Bentham spectroradiometer records global spectral irradiance from 280 to 600 nm, spanning the ultraviolet and part of the visible spectrum and serves as the primary reference standard for the CSN (Fragkos et al., 2023; Charalampous et al., 2025). As a double-monochromator system, it offers high spectral resolution and low stray light, enabling the accurate retrieval of biologically effective UV; such instruments are regarded as the reference standard for spectral UV measurements and are traceable to the European QASUME reference (Gröbner et al., 2005, 2006).



The Bentham DMc150 measures global spectral irradiance using a sequential wavelength-scanning double-monochromator configuration. Solar radiation is collected by a weatherproof entrance optic equipped with a cosine-response diffuser mounted horizontally on the rooftop measurement platform. The collected radiation is transferred to the spectroradiometer, where it passes through the entrance slit and the two monochromator stages. Each monochromator employs diffraction gratings to spectrally disperse the incoming radiation, while the entrance, intermediate, and exit slits define the spectral bandpass and suppress radiation outside the selected wavelength interval. The double-monochromator configuration provides particularly effective rejection of stray light, which is essential in the UVB region where solar irradiance is several orders of magnitude lower than at longer wavelengths. The spectrally selected radiation is detected using a photomultiplier tube (PMT), whose high sensitivity enables reliable detection of the low irradiance levels encountered at the shortest UV wavelengths. The system sequentially scans the spectrum from 280 to 600 nm, with measurements recorded at 0.25 nm wavelength intervals. This optical configuration provides the spectral resolution, wavelength selectivity, and low stray-light performance required for accurate determination of biologically effective UV radiation (Bernhard and Seckmeyer, 1999; Gröbner et al., 2005). To guarantee long-term stability, traceability, and network-wide data consistency, the Bentham spectroradiometer follows a defined quality assurance, maintenance, and calibration protocol. Its absolute calibration is maintained through regular irradiance calibrations using Schreder CMS 200W quartz-halogen lamps, which are directly traceable to the primary irradiance scale of the Physikalisch-Technische Bundesanstalt (PTB) in Germany. The lamps are pre-aged and certified for precise operational geometry, and are deployed in the field using a Schreder KS-J1011 portable calibrator to provide a highly stable absolute spectral irradiance reference. To account for long-term instrumental drift and photomultiplier sensitivity shifts, absolute irradiance calibrations are repeated on a monthly schedule. Drawing on historical field intercomparisons and established literature for equivalent double-monochromator configurations (Bernhard & Seckmeyer, 1999; Gröbner et al., 2005; Hülsen et al., 2016), the expanded uncertainty of the Bentham spectral UV measurements is estimated to be well within $\pm 5\%$ for SZAs below 70° . Spectral scans were processed using the latest calibration coefficients and quality-control procedures prior to the calculation of erythemally weighted irradiance and UVI values. Consequently, the Bentham spectral dataset serves as the absolute benchmark in this study for cross-evaluating the network's broadband sensors and validating the operational UVI forecast models (Fountoulakis et al., 2020).

In this study, the measured spectral irradiance was weighted with the standardized erythral action spectrum (CIE, 1998) and integrated over the ultraviolet wavelength range to obtain the erythemally weighted irradiance. The UV Index (UVI) was then derived in accordance with World Health Organization (WHO, 2002) and World Meteorological Organization (WMO, 2021) guidelines:

$$E_{er} = \int E(\lambda) S_{er}(\lambda) d\lambda, \quad (1)$$

where E_{er} is the erythemally weighted irradiance (in W m^{-2}), $E(\lambda)$ is the measured spectral irradiance (in $\text{W m}^{-2} \text{nm}^{-1}$) and $S_{er}(\lambda)$ is the CIE erythral weighting function. The UVI was subsequently calculated according to the internationally adopted definition:

$$UVI = 40 \cdot E_{er}, \quad (2)$$



where the factor of $40 \text{ m}^2 \text{ W}^{-1}$ converts erythemally weighted irradiance expressed in W m^{-2} into the dimensionless UV Index scale.

180 2.2.2 Broadband UV Radiometers

The CSN additionally includes broadband SUV-E from Kipp and Zonen (Delft, Netherlands) radiometers installed at the five monitoring stations presented in Fig. 1. The instruments continuously measure erythemally weighted ultraviolet irradiance (UVE) and provide high-temporal-resolution UVI observations suitable for operational monitoring and forecasting applications (Charalampous et al., 2025). The SUV-E radiometers measure UVE irradiance directly through an optical filter
185 combination designed to approximate the CIE erythral action spectrum. The instrument output voltage is converted to erythemally weighted irradiance using calibration coefficients provided by the manufacturer. To account for deviations between the actual spectral response of the instrument and the ideal erythral response, spectral mismatch corrections are applied as a function of solar zenith angle and total column ozone. These correction factors are derived from radiative transfer simulations and are provided as lookup tables accompanying the instrument calibration. The UVI is subsequently calculated
190 from the corrected erythemally weighted irradiance using the standard definition given in Eq. (2). Following the application of the spectral mismatch correction, the corrected UVE measurements are converted to UVI and used for operational monitoring and forecast evaluation across the Cyprus UV monitoring network. The resulting UVI values are produced at the native temporal resolution of the measurements and were used throughout the present study for the evaluation of spatial UV variability across Cyprus and for comparison with forecast products.

195 The SUV-E radiometers were supplied with calibration certificates traceable to the Dutch national metrology institute (VSL B.V.). According to the manufacturer specifications, the calibration uncertainty ($k = 2$) of the instruments is $\pm 2.4\%$. Since broadband UV radiometers exhibit deviations between their actual spectral response and the ideal erythral action spectrum, spectral mismatch corrections were applied following the methodology proposed by the instrument manufacturer (Lamy et al., 2021). The SUV-E radiometers were characterized by instrument-specific mean sensitivity coefficients, expressed in $(\text{W} \cdot \text{m}^{-2})$
200 $\cdot \text{V}^{-1}$, of 26 for LIM, 29 for ATHA, 38 for FRN, and 32 for both KYP and POL. These coefficients convert the measured voltage signal into erythemally weighted irradiance. To account for the dependence of the instrument response on solar geometry and ozone absorption, SZA and TOC dependent correction matrices derived from radiative transfer simulations were subsequently applied. The correction matrices cover SZAs from 0° to 70° and TOC values from 260 to 400 DU. The application of these correction matrices reduces spectral mismatch errors from approximately -12% to 5.2% , depending on atmospheric conditions.
205 Routine validation procedures, including regular instrument inspections, consistency tests, and intercomparisons against the Bentham spectroradiometer, were performed throughout the measurement period to ensure measurement stability and minimize instrumental deviations. Although a full uncertainty propagation analysis considering all uncertainty sources (e.g., calibration uncertainty, cosine response, spectral mismatch, temperature dependence, and angular response) has not yet been completed, the overall uncertainty of the SUV-E measurements is estimated by the manufacturer to remain on the order of 5%
210 for SZAs below 70° . For the intercomparison, the different native temporal resolutions of the instruments (1 min for the SUV-



E and 15 min for the Bentham) were accounted for by temporally aggregating the measurements to hourly values using a ± 5 min window centred on each hourly timestamp. The resulting 3,708 paired hourly observations showed strong agreement, with a mean bias (SUV-E – Bentham) of -0.063 UVI, a normalized mean bias of -2.0% , an RMSE of 0.340 UVI, and a coefficient of determination of ($R^2 = 0.986$). The regression slope of 0.982 and intercept of -0.008 UVI further indicate close
215 correspondence between the two instruments, with only a small overall underestimation by the SUV-E relative to the Bentham reference. These results provide additional support for the reliability and consistency of the broadband UV dataset.

2.2.3 Aerosol - CIMEL

Aerosol optical properties used in this study were obtained from CIMEL CE 348NE (Paris, France) sun/sky photometer observations operating within the Aerosol Robotic Network (AERONET) (Holben et al., 1998; Holben et al., 2001). The
220 primary aerosol observations were acquired at the Cyprus Atmospheric Remote Sensing Observatory National Facility (CARO NF) (Ene et al., 2024) of the Eratosthenes Centre of Excellence in Limassol (34.677° N, 33.0375° E), which is co-located with the ESEL radiation monitoring infrastructure.

Additional aerosol observations were obtained from the Nicosia (NIC) and AMX AERONET stations. The NIC station, located at the Cyprus Atmospheric Observatory on the Athalassa campus of the Cyprus Institute (CAO-Nicosia) (Yukhymchuk et al.,
225 2022), approximately 1.7 km from the Athalassa UV station and at a similar altitude (181 m a.s.l.), and is therefore representative of the aerosol conditions at ATHA. The AMX station (Peletidou et al., 2023; Charalampous et al., 2026), located in the rural background environment of central Cyprus at 535 m a.s.l., is minimally affected by local anthropogenic emissions and is considered representative of regional background aerosol conditions over the Eastern Mediterranean. The combined use of the LIM, NIC and AMX observations allows the investigation of coastal-urban, inland-urban and regional background
230 aerosol variability across Cyprus.

All three stations are equipped with CIMEL sun photometers operating within the AERONET framework. The LIM station hosts a CE318 sky/lunar sun photometer operating continuously since 2010, performing direct solar irradiance and sky-radiance measurements at multiple spectral bands centered at 340 , 380 , 440 , 500 , 675 , 870 , 937 , 1020 , and 1640 nm with a field of view of 1.2° . The AMX station are equipped with a CE318NE sun photometer operating continuously since 2015 and
235 performing direct sun measurements in the spectral range between 340 and 1020 nm, together with sky-radiance observations in almucantar and principal plane geometries. The NIC station is likewise equipped with a CE318NE sun photometer and has provided nearly continuous observations since February 2019.

Direct sun observations are processed to retrieve spectral aerosol optical depth (AOD), which serves to characterize the column-integrated atmospheric loading during the validation period and isolate the exact contribution of aerosol-induced
240 attenuation to UVI forecast uncertainties under clear-sky conditions. Throughout this analysis, we utilize the standardized AERONET Version 3 retrieval dataset (Sinyuk et al., 2020). Because Level 2.0 (fully quality-assured) data were not yet fully processed for the entirety of our recent study period, Level 1.5 cloud-screened and quality-controlled data were utilized for



those specific windows, after applying supplementary manual inspections to ensure the absolute exclusion of cloud-contaminated outliers.

245 2.2.4 All-Sky Imager

Local cloud conditions were monitored using an ASI-16 All-Sky Imager (EKO Instruments, Tokyo, Japan) operating continuously at the LIM station since 2023 as part of the ESEL infrastructure (Charalampous et al., 2025). The instrument utilizes a high-resolution camera coupled with a hemispherical fisheye lens to acquire 180° sky images at a 1 min temporal resolution, enabling high-frequency monitoring of local cloud conditions. In the present study, the all-sky images were used to identify periods during which the solar disk and its immediate vicinity were unobstructed by clouds. Therefore, the term “clear-sky” used here does not necessarily imply a completely cloudless sky, clouds could be present elsewhere in the hemispherical field of view, provided that they did not obstruct the Sun. For example, an observation was classified as clear-sky when (i) no clouds were visible across the sky or (ii) clouds were present in other parts of the sky but the solar disk remained unobstructed. Conversely, observations for which a cloud obscured or crossed the solar disk were excluded from the clear-sky subset. No additional angular-distance filter around the Sun was applied. Therefore, clouds located close to, but not directly obscuring, the solar disk may still be included in the clear-sky subset, and potential cloud-edge enhancement effects cannot be completely excluded. This image-based cloud-screening protocol provides an objective ground-truth filter, classifying the coincident UV measurements into distinct “clear-sky” and “all-sky” subsets. Segregating the dataset in this manner allows for a rigorous, decoupled evaluation of both the CAMS and CERYFOS forecasting systems, isolating aerosol-induced forecast errors from the highly dynamic uncertainties associated with cloud-induced radiation attenuation (Kazantzidis et al., 2012).

2.3 Satellite-based Total Column Ozone

Since ground-based total column ozone (TOC) measurements are not currently available within the Cyprus UV monitoring network, satellite-derived ozone products were utilized to characterize regional ozone variability. The primary ozone dataset was obtained from the Ozone Monitoring Instrument (OMI) onboard NASA’s Aura satellite (Levelt et al., 2006, 2018). OMI is a nadir-viewing hyperspectral sensor that measures backscattered solar radiation in the ultraviolet and visible spectral regions, providing daily global observations of atmospheric ozone and other key trace gases at a high spatial resolution of up to 13km × 24km at nadir. In this work, we utilized the Version 3 OMI ozone overpass products, which implement the updated TOMS-V8 total ozone algorithm to provide highly stable TOC retrievals alongside ancillary atmospheric and surface parameters critical for UV radiative transfer applications (Bhartia, 2007; McPeters et al., 2015). Previous analyses over Cyprus based on long-term OMI observations demonstrated that these satellite products reproduce the expected seasonal variability of ozone and UV radiation over the region, providing consistent estimates of TOC across the major urban centers of the island (Charalampous et al., 2023). This climatological analysis showed that mean TOC values over Cyprus range approximately between 277 and 342 DU throughout the annual cycle, with maximum values observed during MAM (March–May) and



275 minimum values during SON (September–November). This seasonal pattern is consistent with the large-scale stratospheric
circulation and transport associated with the Brewer–Dobson circulation (Weber et al., 2022). Importantly, Charalampous et
al. (2023) also identified a non-linear inverse relationship between TOC and erythemally weighted UV radiation over Cyprus,
yielding a local radiation amplification factor (RAF) of approximately 1.1 under clear-sky conditions. This value is in good
agreement with previous studies examining the sensitivity of erythral UV radiation to changes in total ozone under
280 Mediterranean and mid-latitude conditions (Di Sarra et al., 2002; Antón et al., 2015) and is consistent with the established
dependence of surface erythral UV radiation on TOC (Madronich et al., 1998; Bais et al., 2015). These findings demonstrate
the sensitivity of surface UV radiation to variations in TOC over Cyprus and therefore support the importance of accurately
characterizing ozone when evaluating UVI forecasts over the region.

2.4 CERYFOS UVI forecasting

285 The Cyprus Erythral Radiation Forecasting System (CERYFOS) is a regional UV forecasting platform developed through
the collaboration of the Eratosthenes Centre of Excellence, the National Observatory of Athens, and the Physikalisch-
Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC). The system provides hourly forecasts of the
UV Index (UVI) over Cyprus for the current and following day with a spatial resolution of $0.1^\circ \times 0.1^\circ$. The operational
forecasting framework and its real-time spatial mapping products are publicly accessible to researchers and the general public
290 via the interactive UVI Nexus Hub web application (<https://uvinexushub.eratosthenes.org.cy/web/>, last access: 4 August 2026)
maintained by the Eratosthenes Centre of Excellence (Charalampous et al., 2024).

The underlying deterministic forecasting framework relies on rigorous radiative transfer simulations performed via the
libRadtran software package (Mayer & Kylling, 2005; Emde et al., 2016). Clear-sky UVI calculations are executed by
combining prognostic atmospheric composition datasets with localized geographical coordinates and algorithms that dictate
295 surface-level solar geometry. To characterize atmospheric attenuation, the model ingests daily forecast arrays of total column
ozone, spectral aerosol optical properties, surface albedo, and high-resolution topographic indices. The radiative transfer
equation is solved using DISORT (Buras et al., 2011) with six streams and delta-M scaling enabled. The extraterrestrial solar
spectrum is specified using the atlas_plus_modtran spectrum. Simulations are performed over 289–401 nm, with the output
spectrally interpolated over 290–400 nm at 0.5 nm resolution. Standard AFGL mid-latitude atmospheric profiles are used to
300 describe the vertical structure of the atmosphere, with the mid-latitude summer and mid-latitude winter profiles selected
according to season. The main libRadtran settings and atmospheric inputs used in CERYFOS are summarized in Table 2.

Prognostic aerosol optical variables are derived from the Copernicus Atmosphere Monitoring Service (CAMS) global
atmospheric composition forecasts (Inness et al., 2019). The aerosol input set includes AOD at 340 and 380 nm, single
scattering albedo (SSA), asymmetry parameter(asy), and Ångström exponent (AE). In the radiative transfer configuration, the
305 aerosol spectral dependence is represented using the Ångström formulation, while SSA and asymmetry factor are prescribed
as scaling parameters controlling aerosol absorption and forward scattering. The radiative transfer simulations are performed



over 289–401 nm and spectrally interpolated to 290–400 nm at 0.5 nm resolution, covering the erythemally relevant UV range used for UVI calculation.

TOC forecasts are initialised using the TEMIS near-real-time product, which assimilates GOME-2 total ozone observations in a chemistry-transport model (Eskes et al., 2003; van der A et al., 2010, 2015). GOME-2 retrievals agree with ground-based Brewer and Dobson measurements to within about 1 % at mid-latitudes (Loyola et al., 2011), and the 1–3-day TEMIS forecasts show RMS differences of about 3 % relative to the observations (Eskes et al., 2003). Surface elevation is taken from a high-resolution DEM, with an altitude correction of 2 % km⁻¹ (NOAA, 1981).

To generate operational all-sky forecasts, the clear-sky UVI is modified using Cloud Modification Factors (CMFs) derived from a regional configuration of the Weather Research and Forecasting model (WRF-ARW v4.5.1; Skamarock et al., 2019). The CMF is defined as the ratio of all-sky to clear-sky surface shortwave irradiance and is computed hourly at 2 km × 2 km resolution from the forecast cloud fields, including liquid water path and ice water content (Deneke et al., 2008; Taylor et al., 2016). The CMF fields are interpolated onto the 0.1° × 0.1° CERYFOS grid and applied to the clear-sky UVI. In the current operational configuration, the broadband shortwave CMF is applied directly to the UVI, without a spectral conversion to a UV-specific CMF. Because clouds attenuate UV radiation less efficiently than broadband solar radiation, owing to enhanced multiple scattering between cloud layers and the Rayleigh-scattering atmosphere, UV CMFs are generally larger than their shortwave counterparts, with a dependence on SZA and cloud optical properties (Staiger et al., 2008). This simplification may therefore overestimate cloud attenuation in the UV and lead to an underestimation of the all-sky UVI.

In the present study, the CERYFOS forecast fields are comprehensively evaluated against the collocated spectral and broadband UV observations from the Cyprus UV monitoring network under both all-sky and clear-sky conditions. Emphasis is placed on quantifying how errors in cloud field estimates, shifting aerosol loads, ozone anomalies, and solar geometry propagate into the final regional forecast uncertainties.

Table 2: Main input parameters and settings used for the CERYFOS clear-sky libRadtran simulations.

Parameter	Configuration	Source / reference
Radiative transfer model	UVSPEC, libRadtran v2.0.5	Mayer and Kylling (2005); Emde et al. (2016)
Solver	DISORT, 6 streams	Buras et al. (2011)
Atmospheric profile	AFGL Midlatitude Summer (Mar–Nov); Midlatitude Winter (Dec–Feb)	Anderson et al. (1986)
Total column ozone	Daily forecast TOC	TEMIS
Aerosol optical depth	AOD at 340 and 380 nm	CAMS
Ångström parameters	α and β derived from AOD340 and AOD380	Ångström (1929)
Single-scattering albedo	SSA at 340 nm	CAMS



Asymmetry parameter	ASY at 340 nm	CAMS
RT wavelength range	289–401 nm	
Spectral output	290–400 nm; 0.5 nm step	
Solar geometry	Date, time, latitude and longitude	

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2.5 CAMS forecasted UVI and Ozone

Operational UVI forecasts from the CAMS were integrated into this analysis as an independent global benchmark. Implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) as part of the European Union's Copernicus Programme, CAMS provides continuous global analyses and prognostic fields of atmospheric composition, including reactive gases, aerosols, greenhouse gases, and surface solar radiation (Flemming et al., 2017; Inness et al., 2019; Peuch et al., 2022; Rémy et al., 2019). The CAMS service delivers operational forecasts for both clear-sky and all-sky configurations at hourly intervals, with lead times extending up to five days. During the study period, the forecast products were available on a global $0.4^\circ \times 0.4^\circ$ grid. The specific model fields extracted for this study are the UV biologically effective dose rate and the UV biologically effective dose rate under clear-sky conditions, both archived as integrated irradiances in units of Wm^{-2} . These radiative outputs are calculated within the ECMWF Integrated Forecasting System (IFS) by weighting the spectral solar irradiance against the standard erythral action spectrum (CIE, 1998). To ensure direct compatibility with our ground-based network observations and regional model outputs, these raw dose rates (Eery) were converted into the dimensionless UVI following standard WMO protocols via the linear scaling relationship (2) the present study, prognostic local noon UVI values, were extracted from the CAMS operational grid for the coordinates of the five stations in the Cyprus UV monitoring network and cross-evaluated against our collocated spectral and broadband measurements. To diagnose the precise physical drivers of model bias, the corresponding CAMS TOC forecasts were also extracted and validated against spaceborne OMI satellite observations. This parallel validation isolates and quantifies the exact contribution of prognostic ozone initialization errors to downstream UVI forecast uncertainties. The core of the CAMS atmospheric engine relies on the Integrated Forecasting System for Composition (IFS-COMPO), which tightly couples a comprehensive atmospheric chemistry transport model with a data-assimilation numerical weather prediction framework (Eskes et al., 2024). The system combines prognostic simulations and assimilated observations of key atmospheric constituents and radiative parameters, including aerosols, TOC, trace gases, water vapour, cloud properties, and meteorological fields, to provide physically consistent forecasts of atmospheric composition and surface radiative fluxes. During the operational model configuration relevant to this study, these included aerosol optical depth observations from MODIS, PMAp, and VIIRS, as well as ozone observations from MLS, OMI, OMPS, GOME-2, and TROPOMI, together with satellite observations of additional atmospheric constituents. The assimilation of these observations, alongside the meteorological observations used by the IFS, provides a physically consistent initial state for the subsequent five-day atmospheric composition forecasts.

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To further investigate the role of ozone in the UVI forecast differences over Cyprus, CAMS TOC forecasts were additionally compared with OMI satellite observations. This comparison provides an indication of the extent to which differences in prognostic ozone may contribute to the observed UVI forecast errors. The CAMS global forecasting system undergoes routine independent evaluation against a wide range of surface-based, aircraft, balloon, remote-sensing, and satellite observations, with results reported through regular Evaluation and Quality Assurance activities (Eskes et al., 2024). Nevertheless, forecast performance can vary regionally and under challenging aerosol and cloud conditions. Independent evaluation over Cyprus is therefore particularly relevant because of the region's frequent dust transport, high aerosol variability, and strong seasonal solar radiation.

2.6 UVI Forecast Evaluation

The performance of the CERYFOS and CAMS UV forecasting systems was evaluated using collocated observations from the Cyprus UV monitoring network under both all-sky and clear-sky conditions. Forecasted UVI values were spatially collocated with each monitoring station by selecting the model grid point nearest to the station coordinates. This procedure was applied independently to the CERYFOS and CAMS grids, which have different horizontal resolutions, and no spatial interpolation between neighboring grid cells was performed. The extracted model values were subsequently compared with the corresponding ground-based measurements. The Bentham spectroradiometer operating at the LIM reference station was used as the primary reference dataset for model evaluation and to investigate the spatial variability of UV radiation over Cyprus. To ensure consistency between observations and forecasts, temporal matching procedures were applied according to the native temporal resolution of each dataset. Both CERYFOS and CAMS provide UVI forecasts at hourly intervals, whereas the ground-based instruments operate at higher temporal resolutions, with the SUV-E radiometers recording measurements every minute and the Bentham spectroradiometer performing spectral scans every 15 min. Ground-based observations were matched to each hourly forecast timestamp using a ± 5 min temporal window. For the SUV-E radiometers, all available 1 min measurements within this window were averaged to obtain a representative observational value, whereas the nearest available Bentham observation within the same ± 5 min window was selected. The Bentham requires approximately 3 min to scan the UV spectral range from 280 to 400 nm relevant to the UVI calculation, while a complete scan from 280 to 600 nm requires approximately 10 min. Therefore, averaging the higher-frequency SUV-E measurements within the temporal window provides a value representative of the irradiance conditions surrounding the Bentham UV scan and partly accounts for short-term variability occurring while the spectrum is acquired sequentially. This procedure minimizes temporal mismatches while ensuring consistent model-measurement comparisons despite differences in the native sampling frequencies of the observational datasets. For the investigation of spatial and temporal UV variability across Cyprus, local-noon UVI values were used to minimize differences associated with solar geometry and to provide a common reference time across all monitoring stations. The corresponding local-noon forecast values from CERYFOS and CAMS were compared with the temporally matched ground-based observations described above. The Bentham spectroradiometer operating at the LIM reference station was used as the primary reference dataset for the model evaluation and as the LIM measurement in the analysis of spatial UV



variability across the network. To characterize the spatial variability of surface UV radiation across Cyprus, local-noon UVI measurements from the five monitoring stations were analysed. Spatial variability was quantified for each day using the coefficient of variation (CV), calculated as the ratio of the standard deviation to the mean local-noon UVI across the five stations:

$$CV = 100 \cdot \left(\frac{\sigma}{\mu} \right), \quad (3)$$

where σ and μ denote the daily standard deviation and mean of the local-noon UVI measurements, respectively. In addition, day-to-day variability was assessed using the daily UVI change:

$$\Delta UVI = UVI_{(t)} - UVI_{(t-1)}, \quad (4)$$

from which the mean daily change, mean absolute daily change, standard deviation, and maximum positive and negative daily excursions were derived for each station. These metrics were used to investigate the influence of local atmospheric conditions, altitude, and topography on the temporal stability of surface UV radiation across the monitoring network.

For the forecast evaluation, the temporally collocated hourly observations and forecasts were compared under both all-sky and clear-sky conditions. The ± 5 min matching criterion described above was applied consistently to both forecasting systems. This relatively narrow temporal window was selected to reduce differences associated with rapidly changing solar and atmospheric conditions, particularly in the presence of clouds, while retaining sufficient observational coverage for a statistically evaluation. Clear-sky conditions were identified using observations from the ASI-16 all-sky imager operating continuously at the LIM station. Only measurements classified as cloud-free were included in the clear-sky analyses, while the complete dataset was retained for the all-sky evaluation. This separation enabled the isolation of aerosol- and ozone-related forecast uncertainties from the dominant effects of cloud attenuation.

To investigate the influence of clouds on surface UV radiation and forecast performance, the Cloud Modification Factor (CMF) was used. The *CMF* is defined as:

$$CMF = \frac{UVI_{all-sky}}{UVI_{clear-sky}}, \quad (5)$$

where $UVI_{all-sky}$ represents the UV Index under actual atmospheric conditions and $UVI_{clear-sky}$ represents the corresponding cloud-free UV Index. CMF values close to unity indicate negligible cloud attenuation, whereas lower values correspond to increasing reductions in surface UV radiation caused by clouds. Monthly and seasonal CMF analyses were performed using both the WRF-derived CMFs employed within the CERYFOS forecasting framework and CMFs calculated directly from CAMS UV forecasts.

To investigate the contribution of total column ozone (TOC) uncertainty to UVI forecast performance, the TOC fields used by the two forecasting systems were evaluated independently against OMI satellite observations. Specifically, the TEMIS TOC forecasts used as input to CERYFOS and the prognostic CAMS TOC fields were compared directly with OMI-derived TOC. OMI was used solely as an independent reference for evaluating the forecast ozone fields, no additional UVI calculations were performed using OMI TOC as input. Since continuous ground-based TOC measurements were not available over Cyprus during the study period, the available OMI observation for each day was used as the daily reference and compared with the



corresponding hourly TEMIS and CAMS forecast values for that day. This approach enables an assessment of the differences
in TOC between each forecasting dataset and the independent satellite observations, while accounting for the lower temporal
resolution of the OMI dataset. The influence of aerosols was investigated through comparisons between CAMS AOD380
forecasts and AERONET observations at LIM. In addition, AERONET observations from NIC and AMX were used to
investigate the spatial variability of aerosol loading across Cyprus. The NIC station, located approximately 1.7 km from the
Athalassa UV station at a similar altitude, was used to relate aerosol conditions to the Athalassa UV measurements, while
AMX was used as a regional background reference.

Aerosol information in both CERYFOS and the operational CAMS UV forecasting system originates from the CAMS global
atmospheric composition forecasting framework. In CERYFOS, CAMS-derived AOD at 340 and 380 nm is used to
characterize the spectral dependence of aerosol extinction through the Ångström formulation, while single-scattering albedo
(SSA) and the asymmetry parameter (ASY) at 340 nm are used to describe aerosol absorption and scattering, respectively. The
operational CAMS UV forecasting system similarly incorporates prognostic aerosol information from the CAMS global
forecasting system. However, the two UV forecasting frameworks differ in their radiative transfer implementation and in the
way the aerosol optical properties are incorporated into the UV calculations. Therefore, differences between CERYFOS and
CAMS UVI forecasts cannot be attributed solely to clouds and ozone but may also reflect differences in the implementation
of aerosol optical properties within the respective radiative transfer schemes.

Forecast performance was quantified using the mean bias error (MBE), median bias, standard deviation (Std) of the forecast–
observation differences, mean absolute error (MAE), root mean square error (RMSE), and the squared Pearson correlation
coefficient (R^2). For N collocated forecast–observation pairs, the individual forecast error was defined as

$$ei = Fi - Oi, \quad (6)$$

where Fi and Oi represent the forecasted and observed values, respectively. The MBE, median bias, standard deviation, MAE,
and RMSE were calculated as

$$MBE = \frac{1}{N} \sum_{i=1}^N (ei), \quad (7)$$

$$Median\ bias = median(ei), \quad (8)$$

$$Std = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (ei - \bar{e})^2}, \quad (9)$$

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (ei)^2}, \quad (10)$$

$$MAE = \frac{1}{N} \sum_{i=1}^N |ei|, \quad (11)$$

Here, denotes the $\bar{e}$ mean forecast error. The linear association between forecasted and observed values was quantified using
the Pearson correlation coefficient (r), with $R^2=r^2$. In addition, forecast agreement was evaluated as the percentage of cases
falling within predefined absolute and relative error thresholds. For UVI, thresholds of ± 0.5 and ± 1.0 UVI and relative
thresholds of $\pm 5\%$, $\pm 10\%$, $\pm 20\%$, and $\pm 30\%$ were considered. Relative differences (RD) were calculated as:



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$$RD_i = \frac{F_i - O_i}{O_i} \times 100, \quad (12)$$

A positive value means overestimation, and a negative value means underestimation. The percentage of cases within each relative threshold was subsequently calculated based on the absolute relative difference.

For the AOD evaluation, thresholds of ± 0.02 , ± 0.05 , ± 0.10 , and ± 0.20 AOD units and relative thresholds of $\pm 5\%$, $\pm 10\%$, $\pm 20\%$, and $\pm 30\%$ were applied. The statistical metrics were calculated separately for the all-sky, cloudy, and clear-sky subsets,
460 where applicable.

3 Results and Discussion

3.1 Observed UVI variability

This section characterizes the temporal and spatial variability of surface UVI across Cyprus. The analysis first examines the temporal evolution of UVI at the LIM reference station using the Bentham spectroradiometer and subsequently extends to the
465 five-station broadband monitoring network to assess spatial and day-to-day variability across the island. Spatial differences in aerosol loading are also considered as a potential contributor to the observed regional variability. Finally, the WRF-derived CMF is examined to provide model-based context for the seasonal and spatial cloud conditions represented within CERYFOS. Together, these analyses establish the observational framework for interpreting the forecast performance and its dependence on atmospheric conditions in the following sections.

470 3.1.1 Spectral UV observations: Bentham

To characterize the temporal variability of surface UV radiation over Cyprus, we first examine the ground-based UVI observations from the monitoring network, using the Bentham spectroradiometer at the LIM station as the spectral reference. This observational characterization provides the basis for assessing the temporal and spatial variability of UVI across the network and subsequently for evaluating the regional CERYFOS and global CAMS forecasting systems. The analysis is
475 restricted to local-noon conditions to reduce variability associated with the diurnal evolution of the SZA and to facilitate comparison of measurements obtained under similar solar geometries. For each day, local noon was defined as the time of minimum SZA, and the Bentham measurement closest to this time was selected within a maximum time difference of ± 5 min. During the study period, the local-noon SZA ranged from a minimum of approximately 12° in June to a maximum of approximately 59° in December. Figure 2 shows the local-noon UVI measured by the Bentham spectroradiometer between
480 October 2024 and September 2025. The complete observational record is shown together with the subset of measurements acquired when the solar disk was unobstructed by clouds, as determined independently from the co-located ASI-16 all-sky imagery. In the following, these observations are referred to as clear-sky measurements. This definition refers specifically to the absence of cloud obstruction along the solar direction and does not require the entire sky hemisphere to be cloud free,



clouds may therefore be present outside the vicinity of the solar disk and may still influence the diffuse component of surface
485 UV irradiance.

The local-noon measurements exhibit the expected annual cycle, with the highest UVI occurring during JJA and the lowest values during DJF. Under clear-sky conditions, local-noon UVI frequently reached approximately 9–10.5 between June and August 2025, whereas values of approximately 1–3 were observed during DJF. The seasonal evolution is primarily driven by changes in solar elevation and the resulting atmospheric optical path, while seasonal and short-term variations in TOC,
490 aerosols, and clouds further modulate surface UV irradiance, thereby changing atmospheric transmission. The largest reductions in the all-sky record generally coincide with cloud-affected conditions. Variability is also evident within the clear-sky subset, demonstrating that an unobstructed solar disk alone does not imply constant atmospheric transmission. Under these conditions, variations in aerosol optical properties and total column ozone, together with changes in solar geometry, can contribute to the observed variability in surface UVI.

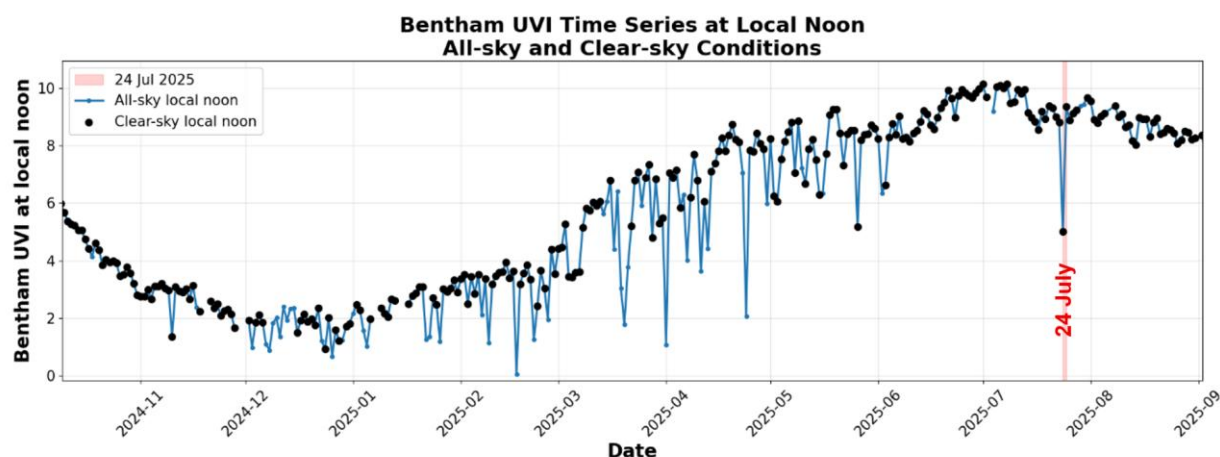


Figure 2: Local-noon UV Index (UVI) measured by the Bentham spectroradiometer at the Limassol station from October 2024 to September 2025. The blue line represents measurements under all atmospheric conditions, while the black markers indicate measurements for which the solar disk was identified as unobstructed by clouds using the co-located ASI-16 all-sky imager. The red shaded area highlights the measurement on 24 July 2025, following the wildfire event that occurred in Cyprus on 23 July 2025.

The comparison between all-sky and clear-sky observations provides insight into the factors controlling UV variability. The largest departures between the two datasets occur during cloudy conditions, when cloud attenuation can substantially reduce surface UV radiation. In addition, several periods characterized by reduced UVI under cloud-free conditions are evident. Since these observations were independently verified as cloudless by the all-sky camera, the reductions likely reflect variations in
505 atmospheric composition, with enhanced aerosol loading representing a potential contributing factor. Such episodes are common in the Eastern Mediterranean and are frequently associated with Saharan dust transport, regional haze, or biomass-burning aerosols. These events provide useful test cases for evaluating the ability of forecasting systems to represent aerosol-related UV attenuation.



A distinct reduction in clear-sky UVI was observed on 24 July 2025, highlighted by the red shaded area in Fig. 2, following a wildfire that started in Cyprus on 23 July 2025. The fire affected an area of approximately 105 km², while the main fire-affected area and associated smoke plume extended to within approximately 12.5 km of the LIM station. The event resulted in the presence of biomass-burning aerosol in the vicinity of the measurement site, providing an opportunity to examine the response of surface UV radiation to enhanced aerosol loading under unobstructed-Sun conditions. On 24 July, the Bentham spectroradiometer measured a local-noon UVI of approximately 5.5, considerably lower than the values exceeding 9 observed during surrounding clear-sky JJA periods. The corresponding ASI-16 image (Fig. S1) confirms that the solar disk was unobstructed by clouds at the time of the measurement, although clouds may have been present elsewhere in the sky. The observed reduction therefore cannot be explained by direct cloud obstruction of the solar disk and coincided with the presence of wildfire smoke in the region, suggesting a substantial contribution from enhanced aerosol loading to the attenuation of surface UV radiation. This event illustrates the sensitivity of surface UV radiation to short-term changes in atmospheric aerosol loading and demonstrates the value of combining spectral UV measurements with independent cloud information when interpreting UVI variability.

3.1.2 Cyprus Broadband UV Monitoring Network

Although Cyprus covers a relatively small geographical area, differences in elevation, topography, and local atmospheric conditions introduce measurable spatial variability in surface UV radiation. Figure 3a presents the daily local-noon UVI measured across the five monitoring stations during the high-insolation period of 2025. The co-located Bentham and SUV-E measurements are both shown for LIM, while Fig. 3b presents the corresponding CV across the five stations, calculated using the Bentham measurements as the LIM reference. The definition and calculation of the CV are provided in Sect. 2.6. The stations exhibit strong temporal coherence, following a common seasonal evolution driven primarily by changes in solar geometry and large-scale atmospheric conditions. On many days, local-noon UVI values at the low-elevation stations are closely grouped, whereas KYP frequently records higher values. Located in the Troodos Mountains at 1332 m a.s.l., KYP is the highest station in the network and regularly reaches or exceeds UVI 10 during JJA. The systematically higher UVI observed at KYP is consistent with the expected altitude dependence of surface UV irradiance, resulting from the reduced molecular atmospheric column above the station and potentially from differences in the aerosol column relative to the low-elevation sites. Quantification of the relative contributions of molecular and aerosol extinction to this altitude effect would, however, require dedicated radiative-transfer calculations and vertically resolved aerosol information and is beyond the scope of the present observational analysis.



Daily Local-Noon UVI and Spatial Variability Across Cyprus Stations

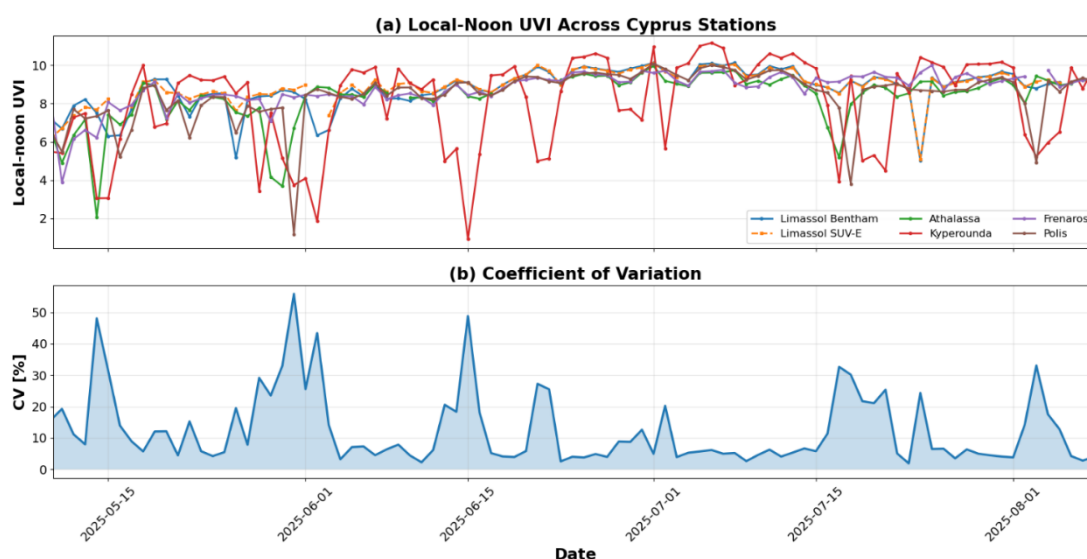


Figure 3: Spatial and temporal variability of local-noon UV Index (UVI) across the Cyprus UV monitoring network during the high-insolation period of 2025. (a) Daily local-noon UVI measured at Limassol (Bentham spectroradiometer and SUV-E radiometer), Athalassa, Kyperounda, Frenaros, and Polis. (b) Daily coefficient of variation (CV) of local-noon UVI across the five monitoring stations. The Bentham measurements were used to represent Limassol in the CV calculation, thereby avoiding double weighting of the co-located Limassol observations. Higher CV values indicate greater spatial dispersion of local-noon UVI across the network.

The spatial CV (Fig. 3b) remains low during periods when the station measurements evolve coherently. Considering days for which the range in local-noon UVI across the CSN was ≤ 1 UVI, the median CV was 3.92%, with 90% of cases exhibiting CV values below 5.37%. This indicates relatively small spatial dispersion in local-noon UVI across the network during periods of coherent station behaviour. Part of this persistent spatial variability is associated with the systematic difference between the high-elevation KYP station and the lower-elevation sites. Superimposed on this background variability are distinct episodes during which the CV exceeds 30% and, on individual days, approaches 50%. Inspection of Fig. 3a shows that several of these peaks coincide with pronounced departures at KYP relative to the other stations. The mountainous location of KYP makes the site particularly susceptible to local atmospheric variability, including orographically influenced cloud conditions, however, UVI measurements alone cannot unambiguously separate the contributions of clouds, aerosols, and other atmospheric factors to individual events. The remaining stations generally show smaller departures from the common temporal evolution, although isolated large reductions are also observed at individual low-elevation sites.

The close correspondence between the co-located LIM Bentham and SUV-E measurements provides an additional indication that the observed network variability is predominantly associated with spatial differences in atmospheric conditions rather than instrumental differences. The two instruments reproduce the same temporal evolution over most of the period, consistent with the quantitative instrument intercomparison presented in Sect. 2.2.2.



In addition to spatial variability, the day-to-day variability of local-noon UVI was examined to characterize the temporal persistence of the observations and, importantly, to assess how rapidly changing conditions may affect the predictability of UVI at individual stations. The day-to-day UVI change and associated metrics are defined in Sect. 2.6 and summarized in Table 3. Mean daily changes remain close to zero at all stations, as expected over a period containing both increasing and decreasing UVI. The mean absolute daily change and its standard deviation therefore provide more informative measures of the magnitude of short-term variability. The LIM Bentham measurements exhibit a mean absolute day-to-day change of 0.61 UVI and a standard deviation of 1.02 UVI. The co-located SUV-E shows a similar temporal behaviour, with a slightly smaller mean absolute change of 0.52 UVI, further supporting the temporal consistency between the two independent measurement systems. Among the other stations, FRN exhibits the lowest day-to-day variability, with a mean absolute change of 0.43 UVI and a standard deviation of 0.69 UVI. ATHA shows intermediate variability comparable to that observed at LIM. KYP exhibits the largest sustained day-to-day variability in the network, with a mean absolute daily change of 1.08 UVI and a standard deviation of 1.64 UVI, together with individual changes ranging from -6.51 to $+5.69$ UVI. POL also exhibits large isolated changes, including the largest positive and negative single-day excursions in the dataset ($+7.43$ and -6.73 UVI, respectively), although its overall variability is less persistently elevated than at KYP. These results demonstrate that similar seasonal UVI evolution across the island does not imply equivalent short-term variability at individual sites.

From a forecasting perspective, this distinction is important. Stations characterized by larger day-to-day variability present a more demanding forecasting environment because relatively rapid changes in local atmospheric conditions must be represented accurately to reproduce the observed UVI. In particular, the enhanced variability observed at KYP suggests that UVI forecasts at the mountainous site may be more sensitive to errors in the representation of local atmospheric conditions than forecasts for the more temporally stable low-elevation stations. The observational variability characterized here therefore provides an important context for interpreting the station-dependent performance of the CERYFOS and CAMS forecasts examined in the following sections.

Table 3: Statistical metrics of day-to-day local noon UV Index (UVI) variations recorded across the Cyprus solar monitoring network stations. Day-to-day change is defined as Eq (4), where positive and negative values indicate an increase and decrease, respectively, relative to the preceding day. Maximum increase and maximum decrease represent the largest positive and negative day-to-day changes, respectively, while maximum absolute change represents the largest change irrespective of direction.

Station	Mean/Median Day-to-Day Change [UVI]	Mean/Median Absolute Day-to- Day Change [UVI]	Std. Dev. Day- to-Day Change [UVI]	Maximum Increase [UVI]	Maximum Decrease [UVI]	Maximum Absolute Change [UVI]
Limassol Bentham	-0.01/0.02	0.61/0.35	1.02	5.96	4.99	5.96
Limassol UVE	+0.03/0.02	0.52/0.31	0.83	3.99	3.50	3.99



Athalassa	-0.02/0.01	0.52/0.31	0.82	5.06	4.33	5.06
Frenaros	-0.02/0.03	0.43/0.24	0.69	2.89	4.98	4.98
Kyperounda	-0.02/0.02	1.08/0.67	1.64	5.69	6.51	6.51
Polis	-0.02/0.02	0.52/0.27	0.94	7.43	6.73	7.43

Spatial variability in aerosol loading represents an additional factor that may contribute to UVI differences across the network. To examine this, local-noon AOD380 from three AERONET stations was considered, with simultaneous AOD and UVI observations: LIM, NIC and AMX. Aerosol loading was highly correlated among the three sites (Spearman $\rho = 0.78\text{--}0.89$) and decreased from the coast towards the rural interior. Median AOD380 was 0.24 at LIM, 0.23 at NIC and 0.20 at AMX, and the median differences relative to LIM were -0.01 for NIC and -0.05 for AMX. The larger difference at AMX reflects its background character and higher elevation rather than the aerosol conditions at ATHA. Local-noon UVI at Athalassa was systematically lower than at LIM, with a median difference of -0.41 UVI (-7% , interquartile range -0.59 to -0.24).

Since the aerosol loading at Nicosia and LIM is very similar on average, the systematic UVI offset cannot be attributed to aerosol differences. It is more likely related to the higher latitude of Athalassa (approximately 0.5° north of LIM) and the associated larger solar zenith angles, and to calibration differences between the Bentham spectroradiometer and the broadband radiometers. On a day-to-day basis, however, the UVI differences vary consistently with the Nicosia – LIM AOD differences (Spearman $\rho = -0.43$, excluding 24 July 2025), indicating that episodic local aerosol differences do modulate the spatial UVI distribution. This was most pronounced during the wildfire event of 24 July 2025, when local-noon AOD380 reached 1.33 at LIM but remained at 0.28 at Nicosia and 0.19 at AMX (Fig. 12a).

The coexistence of lower AOD in the inland region and higher UVI is qualitatively consistent with reduced aerosol attenuation of surface UV radiation. The observed offset therefore does not provide evidence for a direct quantitative relationship between the spatial AOD gradient and the corresponding UVI difference. Instead, it indicates that spatial differences in aerosol loading coexist with the observed regional UVI differences and may represent one of several contributing factors. Differences in elevation, local cloud conditions, ozone, and other atmospheric characteristics may also influence the spatial UVI distribution. The relative importance of these factors cannot be isolated from this observational comparison alone.

Overall, the network observations demonstrate that surface UVI over Cyprus is spatially coherent on many days but can exhibit substantial local variability. The largest and most frequent short-term departures occur at the mountainous KYP station, emphasizing the influence of local topography and cloud variability, while systematic differences in aerosol loading may additionally contribute to the contrast between inland and coastal locations. These observational characteristics provide important context for the subsequent evaluation of the UVI forecasting systems, since stations exhibiting greater spatial and day-to-day atmospheric variability are expected to present a more challenging forecasting environment.

To investigate the cloud-related processes responsible for the temporal and spatial variability observed across the Cyprus UV monitoring network, CMFs derived from the Weather Research and Forecasting (WRF-ARW v4.5.1) model runs for the same period with observations were analysed. The CMF is defined as the ratio between all-sky and clear-sky irradiance conditions,



with values close to unity indicating negligible cloud attenuation and lower values corresponding to increasing cloud influence on surface UV radiation. Figure 4 presents the monthly mean local-noon CMF values for the six monitoring locations, while Fig. 5 illustrates the corresponding seasonal geographical distribution across Cyprus. The CMF climatology reveals a pronounced seasonal cycle that closely follows the behavior observed in the ground-based UVI measurements (Figs. 2 and 3). Across all stations, the lowest CMF values occur during DJF, indicating enhanced cloud attenuation associated with the increased frequency of synoptic weather systems affecting the eastern Mediterranean. In contrast, JJA is characterized by CMF values approaching unity, reflecting the predominance of persistent clear-sky conditions and limited cloud influence on surface UV radiation. The monthly climatology shown in Fig. 4 highlights both the common seasonal behaviour and the influence of local topography. During the DJF, mean local-noon CMF values range between approximately 0.77 and 0.88. KYP consistently exhibits the lowest values, reaching monthly means of 0.77 during February, while the low-altitude stations generally remain between 0.83 and 0.88. During MAM, CMF values gradually increase at all sites, reaching 0.90–0.95 at most stations by May. The highest values occur during JJA, when the coastal and lowland stations frequently reach monthly mean CMFs of 0.99–1.00, indicating nearly cloud-free conditions during the local-noon period. SON (September, October and November) represents a transition back towards more variable atmospheric conditions, with CMF values gradually decreasing from September through November.

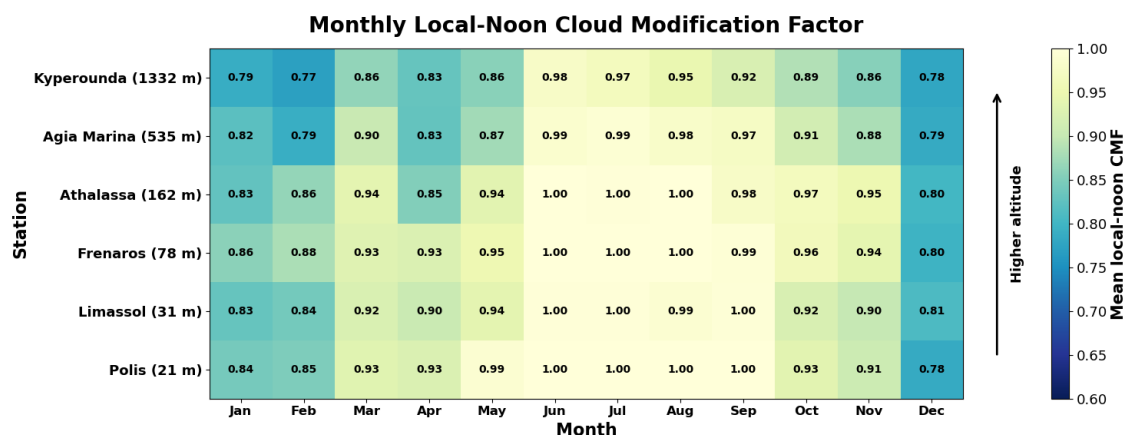


Figure 4: Heatmap matrix showing the monthly mean local noon Cloud Modification Factors (CMFs) derived from the WRF numerical weather prediction model across the monitoring stations. A CMF value of 1.00 denotes completely clear-sky state, while lower values isolate localized cloud masking dynamics.

The spatial patterns presented in Fig. 5 illustrate the seasonal variability of the WRF-derived CMF used within the CERYFOS forecasting system. As these fields represent modelled rather than observed cloud conditions, they should be interpreted as an indication of the spatial and seasonal cloud-related attenuation represented by WRF, their performance is evaluated separately in Sect. 3.2. During DJF (Fig. 5a), lower CMF values are simulated over much of Cyprus, with the lowest values occurring over parts of the mountainous interior. During MAM (Fig. 5b), the simulated cloud attenuation weakens, although differences between the Troodos region and the surrounding lower-elevation areas remain apparent. JJA (Fig. 5c) exhibits the highest and



most spatially homogeneous CMF values, approaching unity over large parts of the island, while lower values persist over the Troodos region. During SON (Fig. 5d), the model indicates increasing cloud-related attenuation relative to JJA, particularly over the mountainous interior.

The lower modelled CMF over the Troodos region is qualitatively consistent with the enhanced day-to-day UVI variability observed at KYP (see Table 3), suggesting that spatially heterogeneous cloud conditions may contribute to the variability at this mountainous site. However, given that the CMF fields are model-derived, this correspondence should be interpreted cautiously and does not provide direct observational attribution of the UVI variability to cloud processes. Overall, Fig. 5 provides an overview of the seasonal and spatial cloud attenuation represented by WRF and subsequently incorporated into the CERYFOS all-sky UVI forecasts.

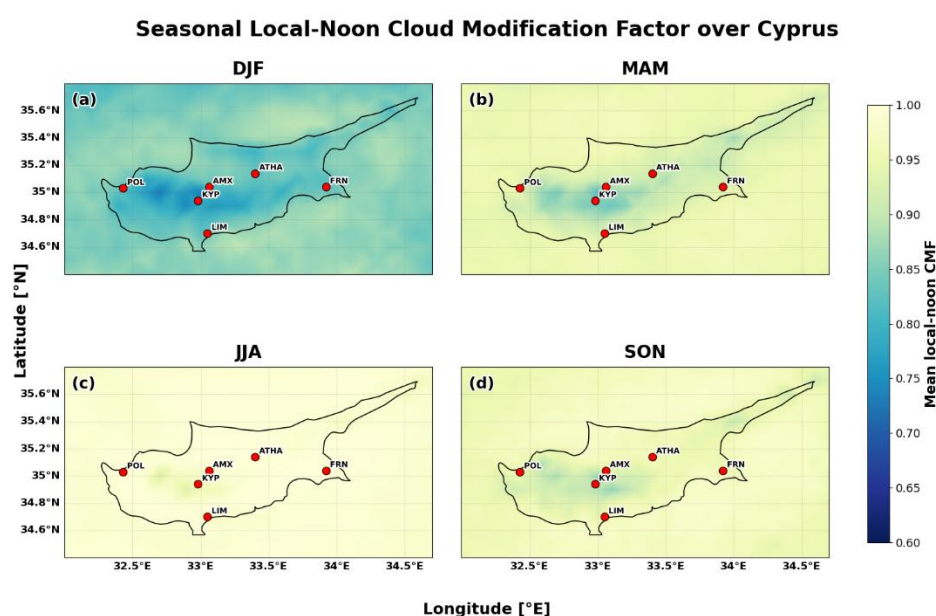


Figure 5: Seasonal maps of the mean local noon Cloud Modification Factor (CMF) over Cyprus derived from the WRF weather prediction model for: (a) DJF, (b) MAM, (c) JJA, and (d) SON. The spatial patterns illustrate the transition from stronger cloud attenuation during DJF to predominantly clear-sky conditions during JJA, with lower CMF values over the Troodos mountain region.

3.2 UVI Forecast Evaluation

3.2.1 Overall Performance

Having characterized the spatial and temporal variability of surface UV radiation across Cyprus, the performance of the operational CERYFOS and CAMS forecasting systems was subsequently evaluated against ground-based observations. The detailed evaluation was performed at the LIM station using measurements from the Bentham spectroradiometer, which serves as the spectral reference instrument of the monitoring network. Model performance was assessed for the complete all-sky dataset and separately for cloudy and clear-sky conditions. The sky-condition classification was derived independently from



the co-located ASI-16 all-sky imager rather than from the modelled cloud fields. As defined in Sect. 2.2.4, observations were classified as clear-sky when the solar disk was unobstructed by clouds and as cloudy when clouds obstructed the solar disk. The clear-sky and cloudy samples therefore constitute complementary subsets of the corresponding all-sky evaluation dataset. Figure 6 presents scatterplot comparisons between forecast and measured UVI for CERYFOS and CAMS under these three observational sky-condition categories.

Both forecasting systems reproduce the observed UVI variability reasonably well when the complete all-sky dataset is considered (Figs. 6a and 6d). CERYFOS yields a mean bias of -0.07 UVI, an RMSE of 0.72 UVI, and an R^2 of 0.94 , whereas CAMS shows a mean bias of -0.01 UVI, an RMSE of 0.60 UVI, and an R^2 of 0.96 . The small overall biases indicate limited systematic deviations when all atmospheric conditions are considered, while the lower RMSE and higher R^2 obtained for CAMS indicate somewhat better overall agreement with the Bentham observations.

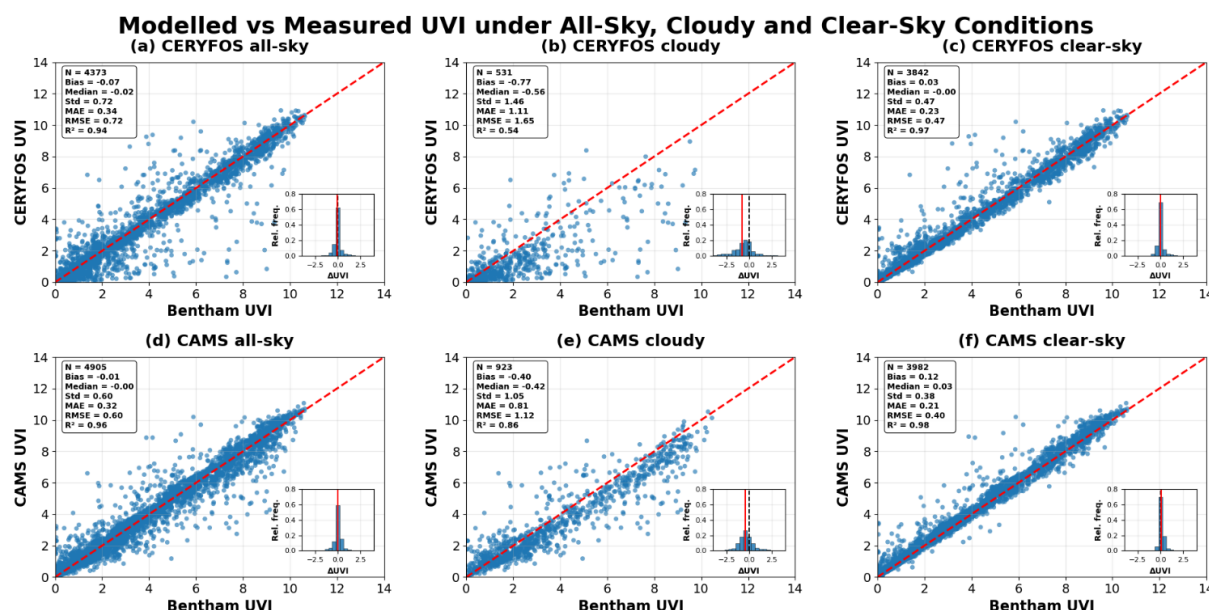


Figure 6: Comparison between modelled and measured local-noon UV Index (UVI) values at the Limassol station under different sky conditions. Panels (a–c) show the performance of the CERYFOS forecasting system and panels (d–f) the corresponding performance of the CAMS forecasting system. Comparisons are presented for all-sky (a,d), cloudy (b,e), and clear-sky (c,f) conditions. The red dashed line denotes the one-to-one relationship. Insets show the normalized frequency distribution of model–measurement differences (Δ UVI). Statistical metrics including sample size (N), bias, median bias, standard deviation, RMSE, and correlation coefficient (R) are provided in each panel.

The separation according to observed sky conditions reveals a pronounced dependence of forecast performance on cloud occurrence. Under clear-sky conditions (Figs. 6c and 6f), both systems show close agreement with the Bentham measurements. CERYFOS yields a mean bias of $+0.03$ UVI, an RMSE of 0.47 UVI, and an R^2 of 0.97 , while CAMS yields a mean bias of $+0.12$ UVI, an RMSE of 0.40 UVI, and an R^2 of 0.98 . The substantially reduced scatter under clear-sky conditions indicates that both forecasting systems reproduce surface UVI more consistently when direct cloud obstruction of the solar disk is absent. Remaining differences under these conditions are more directly associated with the representation of clear-sky radiative



controls, including solar geometry, TOC, aerosol optical properties, and surface characteristics. In contrast, forecast performance deteriorates substantially under cloudy conditions (Figs. 6b and 6e). For CERYFOS, the mean bias decreases to
690 -0.77 UVI, the RMSE increases to 1.65 UVI, and R^2 decreases to 0.54 . CAMS also exhibits reduced performance under cloudy conditions, although the degradation is less pronounced, with a mean bias of -0.40 UVI, an RMSE of 1.12 UVI, and an R^2 of 0.86 . The predominantly negative model–measurement differences indicate that both systems tend to predict lower UVI than observed during cloud-affected periods, with the effect being considerably stronger for CERYFOS. This behaviour points to cloud occurrence, timing, spatial representativeness, and cloud optical properties as important sources of uncertainty in the
695 operational forecasts. In particular, the stronger negative bias of CERYFOS suggests that its treatment of cloud attenuation contributes importantly to the forecast error under these conditions. This may reflect uncertainties in the simulated cloud occurrence, timing, and spatial distribution, as well as limitations in the representation of cloud effects on UV radiation. In particular, no UV-specific correction for multiple scattering within clouds is currently applied in the CERYFOS cloud treatment, which may contribute to discrepancies between the predicted and observed UVI under cloudy conditions. The
700 evaluation demonstrates that the largest forecast uncertainties are associated with cloudy conditions, whereas both systems perform substantially better when the solar disk is unobstructed. CAMS provides better statistical performance for the complete all-sky dataset and particularly for the cloudy subset, while the differences between the two systems are comparatively small under clear-sky conditions. Additional agreement statistics, including the fraction of forecasts falling within selected and relative UVI thresholds, are provided in Table S1.

705 To investigate whether forecast performance depends on solar geometry, model–measurement differences were additionally analysed as a function of SZA. Median and relative UVI differences, together with their interquartile ranges, were calculated for discrete SZA intervals under both all-sky and clear-sky conditions (Figs. S2–S3). For both forecasting systems, the median differences remain close to zero across the investigated SZA range, indicating no pronounced systematic dependence of the forecast bias on solar elevation. In contrast, the relative differences (%) exhibit greater variability at larger SZAs, particularly
710 above 60° , as indicated by the widening interquartile ranges. This behaviour should be interpreted in the context of the substantially lower UVI values occurring at large SZAs, for which differences in UVI units can translate into larger percentage differences. Overall, the absence of a corresponding systematic increase in the magnitude of the UVI differences suggests that the apparent increase in relative variability at large SZA does not necessarily represent a substantial deterioration in forecast performance.

715 3.2.2 Cloud Effects on UVI Forecasts

Figure 7 compares the monthly mean local-noon CMF represented in the CERYFOS and CAMS UV forecasts over LIM. Here, CMF is calculated consistently for both forecasting systems as the ratio of all-sky to the corresponding clear-sky forecast UVI, providing a common measure of the cloud-induced modification of surface UV radiation. For CERYFOS, the cloud effect originates from the WRF-derived cloud fields used within the forecasting framework, whereas the CAMS CMF reflects the
720 cloud representation within the ECMWF forecasting system. Thus, unlike the spatial analysis of the WRF-derived CMF



presented previously, the Fig. 7 directly compares the effective cloud attenuation represented in the final UVI forecasts of the two systems.

Both forecasting systems exhibit a clear seasonal cycle, with lower monthly mean CMF during the cloudier part of the year and values approaching unity during JJA. CERYFOS CMF ranges from 0.81 in December to 1.00 in June, July, and September, while CAMS ranges from 0.78 in February to 0.97 in August and October. Between June and September, CERYFOS CMF remains between 0.99 and 1.00, whereas CAMS ranges between 0.94 and 0.97, indicating relatively weak mean cloud attenuation during the JJA period in both systems. Lower CMF values occur mainly during DJF and early MAM, indicating a stronger modelled influence of clouds on local-noon UV radiation. The monthly differences between the two systems are relatively small, ranging from -0.05 to $+0.06$ in CMF (Fig. 7b). CERYFOS generally produces higher CMF values than CAMS, with positive differences in eight months and the largest differences occurring in February and September ($+0.06$). This indicates weaker cloud attenuation in CERYFOS relative to CAMS during these months. Conversely, CAMS produces higher CMF values in January (-0.03) and October (-0.05), while the two systems show essentially identical monthly mean CMF in March. Overall, the relatively small differences in the monthly means indicate that CERYFOS and CAMS reproduce a broadly similar seasonal pattern in cloud modification of local-noon UV radiation. However, agreement in monthly mean CMF does not necessarily imply comparable performance for individual cloud-affected situations, as demonstrated by the substantially larger model–measurement differences for cloudy conditions in Fig. 6.

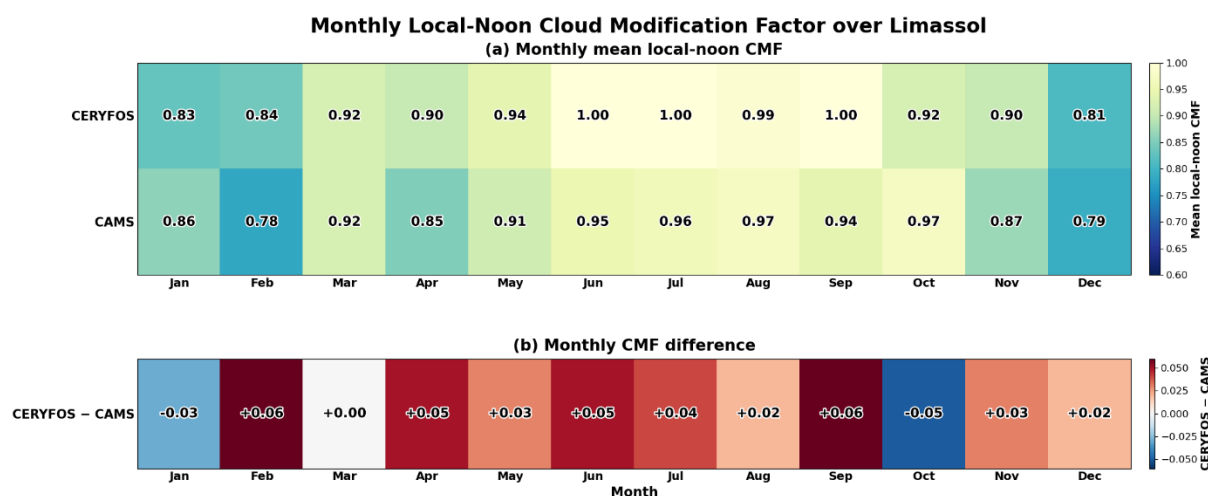


Figure 7: Monthly mean local-noon Cloud Modification Factor (CMF) derived from the CERYFOS and CAMS UV Index forecasting systems over Limassol. Panel (a) shows the monthly mean CMF values for each model. CMF values close to unity correspond to clear-sky or weak-cloud conditions, while panel (b) presents the monthly differences (CERYFOS – CAMS). Positive values (reddish colours) indicate weaker cloud attenuation predicted by CERYFOS relative to CAMS, whereas negative values (bluish colours) indicate stronger attenuation.

The stronger negative bias of CERYFOS under cloudy conditions (-0.77 UVI, compared with -0.40 UVI for CAMS) is consistent with the direct application of the broadband shortwave CMF to the UVI (Sect. 2.4). Since UV CMFs generally exceed shortwave CMFs for the same cloud conditions (Staiger et al., 2008), this approach tends to overestimate cloud



attenuation in the UV, particularly for optically thin and broken clouds. Errors in the WRF cloud fields themselves also contribute, so the relative importance of the two cannot be fully separated with the present dataset.

3.3 Clear-Sky Forecast Evaluation

750 The clear-sky evaluation provides an opportunity to isolate the influence of the principal atmospheric inputs controlling surface ultraviolet radiation. Under cloud-free conditions, forecast errors can be strongly influenced by the representation of TOC and aerosol optical properties, such as the AOD and SSA which determine the magnitude of ultraviolet absorption and scattering within the atmosphere. CERYFOS and CAMS use the same CAMS aerosol information, whereas their treatment and input data for total column ozone differ. Therefore, the performance of the ozone and aerosol input datasets used by the two
755 forecasting systems was assessed independently before examining their influence on the resulting UVI forecasts.

3.3.1 Assessment of Total Column Ozone Fields

TOC represents one of the most important atmospheric parameters governing surface ultraviolet radiation due to its strong absorption within the UV-B spectral region. To evaluate the ozone fields used by the forecasting systems, the TEMIS ozone product employed within CERYFOS and the CAMS ozone forecasts were compared against OMI satellite observations. In the
760 absence of continuous ground-based total column ozone measurements over Cyprus during the study period, OMI was adopted as an independent reference dataset rather than an absolute ground truth. Consequently, the following analysis evaluates the consistency of the TEMIS and CAMS ozone fields relative to the satellite observations, while acknowledging that part of the observed differences may also originate from uncertainties associated with the OMI retrievals themselves. The temporal evolution of daily ozone differences relative to OMI is presented in Fig. S4 in Supplement. Both datasets reproduce the major
765 day-to-day ozone variability observed by OMI throughout the study period. However, TEMIS exhibits substantially larger fluctuations and more frequent departures from the satellite observations, whereas CAMS generally remains closer to the OMI reference. Figure 8 presents the monthly ozone climatology together with the probability density distribution of ozone differences relative to OMI. All datasets successfully reproduce the expected seasonal cycle over Cyprus, characterized by maximum TOC in February and generally elevated values during MAM, followed by a progressive decline towards minimum
770 values in SON. This behaviour is consistent with the known climatology of stratospheric ozone over the Eastern Mediterranean. Although both ozone products capture the annual cycle, systematic differences are evident. TEMIS exhibits an overall positive bias relative to OMI, although the magnitude and direction of the differences vary throughout the year, whereas CAMS exhibits a more consistent negative offset relative to OMI but substantially lower variability than TEMIS. The associated ± 1 standard deviation envelopes indicate enhanced ozone variability during DJF and MAM, reflecting increased atmospheric dynamical
775 activity and ozone transport processes during these seasons.

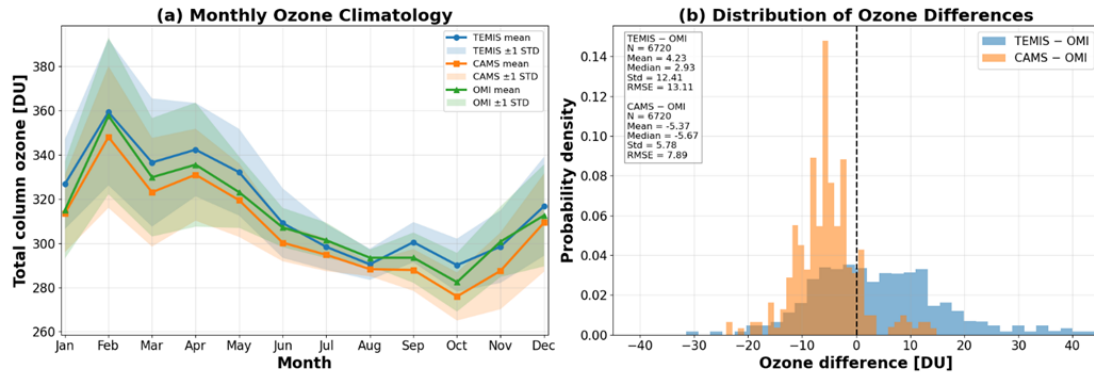


Figure 8: (a) Monthly climatology of total column ozone over Cyprus derived from the satellite-based OMI observations, the CERYFOS/TEMIS ozone fields, and the CAMS ozone model during the study period. Shaded areas represent ± 1 standard deviation for each dataset. All datasets reproduce the expected seasonal ozone cycle, with maximum values during late DJF–MAM and minimum values during SON. (b) Probability density distribution of total column ozone differences relative to the OMI satellite observations, shown as TEMIS – OMI and CAMS – OMI differences. The dashed vertical line indicates zero difference.

The statistical comparison summarized in Table 4 confirms these findings. Relative to OMI, TEMIS exhibits a mean bias of +4.23 DU, a median bias of +2.93 DU, a standard deviation of 12.41 DU and an RMSE of 13.11 DU. Approximately 62.1 % of the TEMIS values remain within ± 10 DU and 89.4 % within ± 20 DU of the satellite observations. In contrast, CAMS displays a mean bias of –5.37 DU, a median bias of –5.67 DU, but a substantially lower standard deviation of 5.78 DU and a RMSE of 7.89 DU, indicating a more consistent, although negative biased, agreement with OMI. Furthermore, 78.8 % of CAMS values fall within ± 10 DU and more than 98 % within ± 20 DU of the OMI observations. The narrower CAMS–OMI distribution shown in Fig. 8b further demonstrates the lower dispersion of the CAMS TOC relative to OMI, despite their systematic negative bias.

Table 4: Statistical comparison of total column ozone fields relative to OMI satellite observations. Reported metrics include mean bias, median bias, standard deviation (Std), RMSE, percentages of retrievals within fixed thresholds (± 5 , ± 10 , ± 15 and ± 20 DU), and percentages within relative thresholds (± 1 %, ± 2 %, ± 5 % and ± 10 %).

Dataset		% within ± 5	% within ± 10	% within ± 15	% within ± 20	% within ± 1 %	% within ± 2 %	% within ± 5 %	% within ± 10 %
TEMIS OMI	–	31.55	62.14	80.25	89.43	19.54	39.52	81.68	96.38
CAMS OMI	–	37.01	78.82	95.71	98.93	23.54	55.19	96.38	100.00

3.3.2 Influence of Ozone Differences on UVI Forecasts

To assess the contribution of ozone-related uncertainties to UV forecast errors, ozone differences relative to OMI observations were compared against the corresponding model–measurement UVI differences (Fig. 9). Positive ozone differences indicate



an overestimation of total column ozone relative to OMI, whereas negative values indicate underestimation. For the CERYFOS forecasts (Fig. 9a–b), the distribution shows a weak tendency towards an inverse association between ozone differences and UVI forecast errors. Positive TEMIS–OMI differences are generally associated with slightly negative UVI biases, consistent with the physical expectation that excess ozone leads to enhanced ultraviolet absorption and consequently lower forecasted UVI values. Conversely, negative ozone differences tend to correspond to small positive UVI biases. Nevertheless, the highest point densities remain concentrated near small UVI differences, while large UVI forecast errors also occur when ozone differences are close to zero. This indicates that ozone differences alone cannot explain the full variability in UVI forecast errors. A similar behaviour is observed for CAMS (Fig. 9c–d). Negative CAMS–OMI ozone differences are associated with a tendency towards positive UVI biases, while positive ozone differences correspond to modest underestimations of UVI. Overall, 82.6 % of the CERYFOS cases and 84.5 % of the CAMS cases exhibit model–measurement differences within ± 0.5 UVI. This relatively high level of agreement is maintained despite ozone differences relative to OMI occasionally exceeding ± 10 DU, suggesting that the observed ozone discrepancies alone do not account for the largest UVI forecast errors.

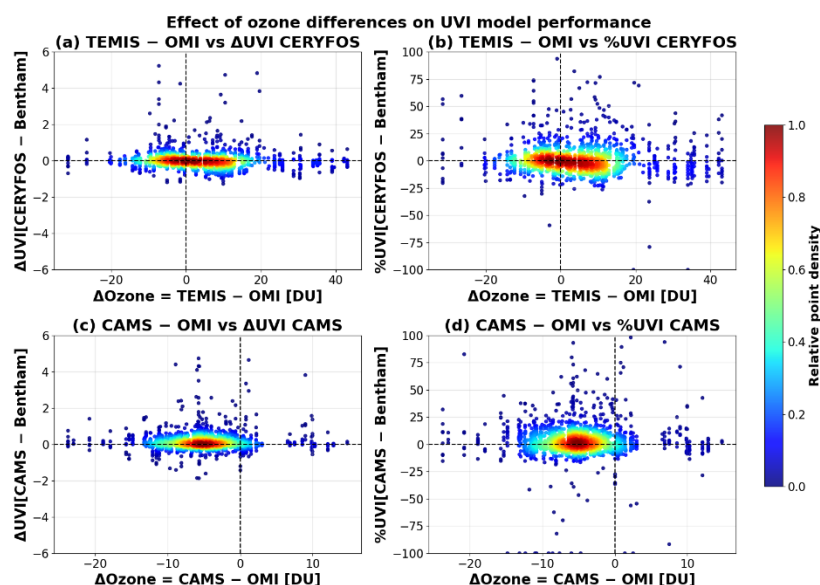


Figure 9: Relationship between ozone differences relative to OMI observations and corresponding UV Index forecast errors. Panels (a–b) show the influence of TEMIS–OMI differences on CERYFOS UVI forecasts, while panels (c–d) show the influence of CAMS–OMI differences on CAMS UVI forecasts. (Δ UVI) and relative ($\%$ UVI) forecast differences are shown separately. Colours indicate relative point density.

The results therefore indicate that differences in the ozone fields relative to OMI are generally associated with relatively small UVI forecast deviations in both forecasting systems. While accurate ozone information remains essential for reliable UV calculations, particularly during periods of anomalously high or low ozone abundance, the observed ozone discrepancies cannot explain the largest forecast errors identified during the study period. Instead, the results suggest that cloud representation and aerosol characterization constitute the dominant sources of uncertainty in UV Index forecasting over Cyprus. Nevertheless,



the interpretation of the ozone statistics should consider the absence of co-located ground-based ozone observations, which limits the assessment to a relative comparison against the OMI satellite product.

3.3.3 Assessment of Aerosol Optical Depth

Aerosols constitute the second major atmospheric factor controlling surface UV radiation under cloud-free conditions. In contrast to ozone, aerosol effects are highly variable in both space and time, particularly over the Eastern Mediterranean basin, where anthropogenic pollution, biomass burning and frequent desert dust intrusions can substantially modify surface UV levels. Since both the CERYFOS and CAMS UV forecasting systems utilize CAMS aerosol fields as input to the radiative transfer calculations, the accuracy of these aerosol products was evaluated against ground-based AERONET observations. Figure 10 presents the monthly climatology of AOD₃₈₀ together with the distribution of CAMS–AERONET differences. The monthly climatology shown in Fig. 10a demonstrates the characteristic seasonal aerosol cycle over Cyprus. Both the CAMS and the ground-based AERONET observations capture enhanced aerosol loading during MAM and JJA and lower AOD values during DJF. The increased aerosol burden during the JJA is primarily associated with frequent Saharan and Middle Eastern dust transport events affecting the Eastern Mediterranean basin. AERONET generally reports slightly higher AOD values than CAMS during periods of elevated aerosol loading, particularly during JJA, suggesting a tendency of CAMS to underestimate the magnitude of some intense aerosol episodes. The associated ± 1 standard deviation envelopes indicate substantially enhanced variability during MAM and JJA, reflecting the episodic nature of dust outbreaks and regional aerosol transport processes.

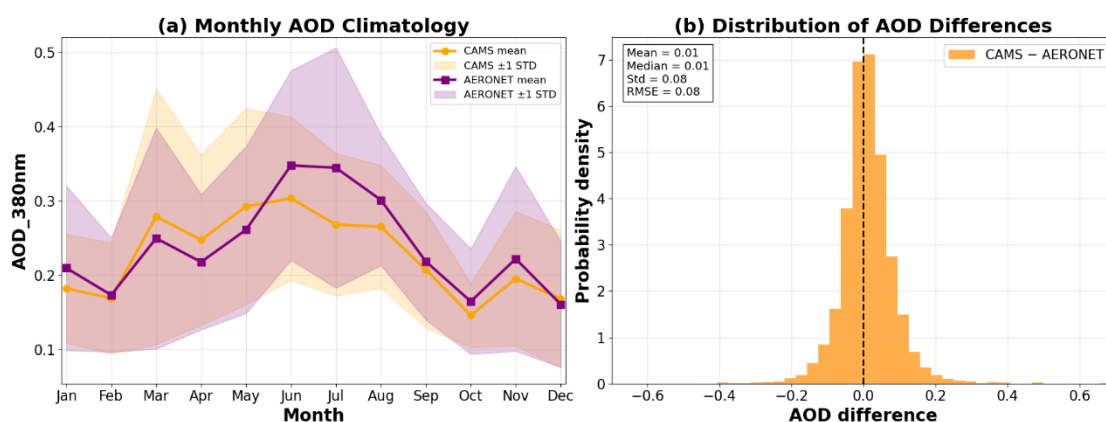


Figure 10: (a) Monthly climatology of aerosol optical depth (AOD) over Cyprus from the CAMS aerosol model and the ground-based AERONET observations during the study period. Shaded areas represent ± 1 standard deviation. Enhanced aerosol loading is observed during MAM and JJA due to increased regional dust transport activity. (b) Probability density distribution of CAMS – AERONET AOD differences. The dashed vertical line indicates zero difference.

Hourly CAMS AOD values were temporally collocated with AERONET observations using a ± 15 min window around each CAMS output time. When multiple AERONET observations were available within the window, their mean was used for comparison. The statistical comparison summarized in Table 5 confirms the overall consistency between the two datasets. The



hourly CAMS–AERONET comparison yields a mean bias of 0.01, a median bias of 0.01 and an RMSE of 0.08. Approximately 62.4 % of all collocations remain within ± 0.05 AOD units, while nearly 87 % fall within ± 0.10 AOD units, demonstrating a generally good representation of aerosol conditions over Cyprus by the CAMS aerosol model. Further insight into model performance is provided by the distribution of CAMS–AERONET differences shown in Fig. 10b. The distribution is strongly centred around zero, indicating only a small positive systematic bias between CAMS and the ground-based observations. Most collocations are concentrated within approximately ± 0.10 AOD units, consistent with the statistical metrics reported in Table 5. Nevertheless, the distribution exhibits broader tails extending towards both positive and negative values, indicating occasional larger CAMS overestimations and underestimations. Despite these individual cases, the relatively narrow distribution and centred around zero (Fig. 10b), together with similar seasonal evolution shown in Fig. 10a, indicated that CAMS provided a generally consistent representation of aerosol loading relative to the available AERONET observations over Cyprus.

Table 5: Statistical comparison of hourly CAMS AOD380 against collocated AERONET observations at Limassol. Reported metrics include mean bias, median bias, standard deviation (Std), RMSE, percentages within fixed thresholds (± 0.02 , ± 0.05 , ± 0.10 and ± 0.20 AOD units), and percentages within relative thresholds (± 5 %, ± 10 %, ± 20 % and ± 30 %).

Dataset		% within ± 0.02	% within ± 0.05	% within ± 0.10	% within ± 0.20	% within $\pm 5\%$	% within $\pm 10\%$	% within $\pm 20\%$	% within $\pm 30\%$
CAMS	–	29.10	62.40	86.99	98.09	12.11	24.24	45.04	63.65
AERONET									

The temporal evolution of CAMS–AERONET differences is presented in Fig. S5. Overall, aerosol CAMS–AERONET differences remain relatively small for most of the study period, although occasional larger positive and negative deviations are observed. The eastern Mediterranean basin is frequently affected by highly variable aerosol conditions associated with desert dust transport, biomass-burning smoke, and other regional aerosol episodes, which can present challenges for aerosol forecasting. Since CAMS aerosol fields are used as input in both the CERYFOS and CAMS UV forecasting systems, errors in the representation can propagate into the corresponding UV calculations and therefore contribute to the clear-sky UVI forecast errors.

Additional analyses of the temporal evolution and seasonal variability of the CAMS–AERONET differences, together with a comparison between the full operational CAMS evaluation period since December 2019 and the study-period subset used for the CERYFOS validation, are provided in the Supplement (Table S2). The study-period subset shows slightly better agreement with AERONET than the longer evaluation period, while remaining broadly consistent with CAMS performance obtained over the longer period. These results indicate that CAMS generally provides an adequate representation of the aerosol conditions used for the UV forecasts, although occasional larger discrepancies are evident.



3.3.4 Assessment of aerosol optical properties

Besides the aerosol load, the effect of aerosols on surface UV depends on how strongly they absorb and in which direction they scatter. These are described by the SSA and the asy. For a given AOD, a lower SSA means more absorption and less UV reaching the surface. The CAMS SSA and asy at 340 nm, the wavelength most relevant to the UVI among those CAMS provides, were therefore evaluated against the AERONET Level 1.5 almucantar inversions at LIM, using the same collocation as for AOD. AERONET inversions are only retrieved from 440 nm upwards, so the AERONET values at 340 nm were extrapolated log-linearly from the retrieved 440 and 675 nm values. The comparison therefore gives an indicative rather than a strict validation of the CAMS UV optical properties.

Table 6 summarises the results. Over all collocations, CAMS reproduces the mean optical properties at 340 nm closely: SSA340 is 0.927 against 0.923 from AERONET (mean bias +0.005, RMSE 0.049), and asy340 is 0.719 against 0.715 (mean bias +0.004, RMSE 0.039). About 49 % of the SSA340 collocations and 58 % of the asy340 collocations agree within ± 0.03 , and 74 % and 81 % within ± 0.05 . The correlations are moderate to low ($r = 0.41$ for SSA340 and 0.25 for asy340). CAMS represents the average optical properties of the regional aerosol mix well but captures only part of their short-term variability. At low aerosol loading, AERONET SSA inversions carry large uncertainties, which is why Level 2 only reports SSA when AOD440 ≥ 0.4 . For that subset ($N = 95$), the correlation for SSA340 rises to 0.68. CAMS underestimates SSA340 by about 0.02 (median -0.014) and asy340 by 0.013, so during high-AOD episodes its aerosol is more absorbing than the observations indicate. The collocations were also grouped by the Ångström exponent (AE) derived from CAMS AOD (AE440–670). This shows that the SSA340 bias depends on aerosol type, for $AE < 0.6$, CAMS SSA340 is 0.861 against 0.883 from AERONET, a bias of -0.021 , and asy340 is overestimated by +0.023, $0.6 < AE < 1.2$: CAMS SSA340 is slightly too high (+0.010) and finally, $AE > 1.2$: CAMS SSA340 is essentially unbiased (-0.003).

The seasonal behaviour follows the same pattern. SSA340 is underestimated in DJF (-0.020), unbiased in MAM (0.000) and overestimated in JJA and SON (+0.013 and +0.023). For the UVI forecasts, this means that during dust events CAMS dust that absorbs too strongly in the UV would tend to make the CERYFOS and CAMS UVI systems underestimate clear-sky UVI. Under mixed and background conditions, the small positive SSA340 bias would lead to a slight overestimate. The largest errors in the aerosol optical properties therefore occur in the episodic dust conditions that also show the largest AOD differences (Sect. 3.3.3).

Table 6: Statistical comparison of hourly CAMS SSA and asymmetry parameter (asy) at 340 nm against collocated AERONET Level 1.5 inversions at Limassol. AERONET values at 340 nm are extrapolated from the retrieved 440 and 675 nm values.

	Mean bias	Median bias	Std	RMSE	r	% within ± 0.03
SSA340	0.005	0.004	0.049	0.049	0.41	49.3
asy340	0.004	0.003	0.039	0.039	0.25	58.3

Previous studies in the Eastern Mediterranean have shown that aerosol absorption is enhanced at UV wavelengths and that extrapolation of SSA from the visible to the UV leads to an overestimation of the UV SSA (Kazadzis et al., 2016; Fountoulakis



et al., 2019). The extrapolated AERONET SSA340 values used here should therefore be regarded as upper estimates, and the positive CAMS SSA340 bias as a lower bound.

3.3.5 Influence of Aerosol Optical Depth Differences on UVI Forecast Performance

To investigate the influence of differences in aerosol loading on forecast performance, CAMS–AERONET AOD differences were compared with the corresponding UVI forecast errors for both forecasting systems (Fig. 11). Positive AOD differences indicate that CAMS overestimates aerosol loading relative to AERONET and is therefore expected to be associated with enhanced UV attenuation and lower forecasted UVI values. Conversely, negative AOD differences are generally associated with positive UVI biases. A physically consistent relationship is evident for both forecasting systems. Cases with positive AOD differences tend to correspond to negative UVI forecast biases, while negative AOD differences are generally associated with positive UVI biases. The highest point density is concentrated near zero AOD and UVI differences, indicating that small aerosol discrepancies are generally accompanied by relatively small UVI forecast errors. The extreme negative AOD differences are primarily associated with the wildfire event of 23–24 July 2025. During this event, CAMS substantially underestimated the aerosol loading observed by AERONET, with CAMS – AERONET AOD differences reaching approximately 1.33 on 24 July. This coincided with positive UVI forecast differences exceeding 5 UVI units, consistent with insufficient aerosol attenuation in both forecasting systems resulting from the substantially underestimated aerosol loading. Compared with the ozone-related differences examined in Sect. 3.3.2, AOD differences are associated with substantially larger UVI forecast deviations in the most extreme cases. While moderate ozone differences are generally associated with UVI deviations below approximately 0.5 UVI units, substantially larger UVI forecast departures occur in association with large AOD differences. Although CAMS shows good overall agreement with the AERONET observations, occasional large discrepancies in aerosol loading can substantially affect the resulting UVI forecasts. Consequently, accurate representation of aerosol loading remains essential for reliable UV forecasting over Cyprus, particularly during episodes of enhanced aerosol concentrations, including dust and biomass-burning events.

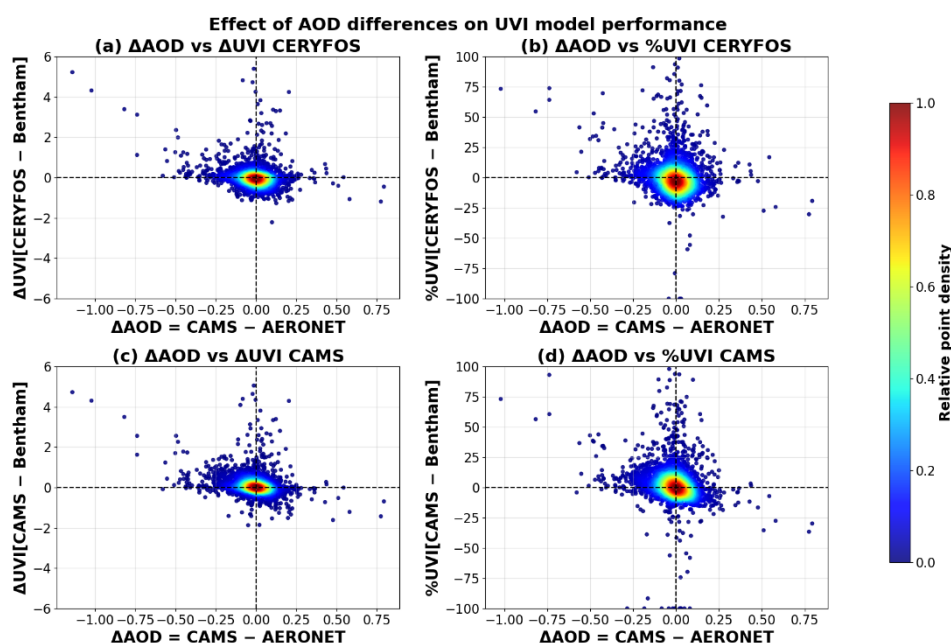


Figure 11: Relationship between CAMS – AERONET AOD380 differences and corresponding UV Index forecast errors. Panels (a–b) show the influence of aerosol differences on CERYFOS UVI forecasts, while panels (c–d) show the corresponding influence on CAMS UVI forecasts. (Δ UVI) and relative (%UVI) forecast differences are shown separately. Positive AOD differences indicate aerosol overestimation by CAMS relative to AERONET, while negative values indicate aerosol underestimation. Colours represent relative point density.

3.3.6 Wildfire Smoke Event: 23–24 July 2025

The influence of extreme aerosol loading on surface ultraviolet radiation is already evident in the long-term Bentham UVI time series presented in Fig. 2, where 24 July 2025 appears as a pronounced reduction in local-noon UVI despite being classified as a clear-sky day. Unlike most low-UVI cases observed throughout the study period, which are primarily associated with cloud attenuation, this event occurred under cloud-free conditions during a major wildfire that affected Cyprus on 23–24 July 2025. The associated smoke plume reached the vicinity of the LIM station, providing an opportunity to evaluate the response of the operational UV forecasting systems under exceptionally high and rapidly evolving aerosol loading. The evolution of aerosol loading, measured UVI, and forecasted UVI during the event is presented in Fig. 12. Prior to the smoke intrusion, aerosol conditions at all three AERONET stations were representative of typical JJA conditions, with AOD380 values generally between approximately 0.3 and 0.6 (Fig. 12a). During 24 July, however, AOD380 at LIM increased rapidly and exceeded 1.4, more than a threefold increase relative to the surrounding days. In contrast, AOD380 remained between approximately 0.2 and 0.4 at both NIC and AMX, indicating that the smoke plume was spatially confined to the Limassol area. The radiative impact of the smoke plume is evident in the UV measurements (Fig. 12b). During the days preceding and following the event, local-noon UVI values measured by the Bentham spectroradiometer were generally around 9–10,



consistent with typical JJA conditions in Cyprus. During the peak smoke intrusion on 24 July, the observed local-noon UVI decreased by approximately 3–5 UVI units to about 5–6, a reduction of approximately 35–45 % relative to the surrounding clear-sky days. The Athalassa measurements showed a considerably weaker reduction, consistent with the much lower aerosol loading recorded at the nearby Nicosia AERONET station (AOD380 of 0.27–0.41, compared with up to about 1.33 at LIM). To quantify the aerosol contribution, supplementary clear-sky libRadtran simulations were performed with the CERYFOS configuration, driven by the LIM AERONET Level 2.0 AOD at 340 and 380 nm and by the SSA and asymmetry parameter from the AERONET inversions for 24 July. Near local noon, the simulations gave UVI values of approximately 6.5–6.7 at LIM, compared with 11.1–11.2 for an aerosol-free and about 10.2 for the aerosol conditions forecast. This corresponds to an aerosol-induced reduction of approximately 33–38 %. For comparison, simulations at Nicosia for the same day gave a reduction of only about 8 %, in agreement with the weaker attenuation observed at Athalassa. The simulated LIM values remain about 1 UVI above the measurements. This residual is likely due to the use of daily-mean SSA and asymmetry values extrapolated from 440 nm to the UV, which do not capture the short-term variability of the plume, and to uncertainties in its vertical distribution. Nevertheless, the simulations show that the observed aerosol loading explains most of the measured UVI reduction, and that forecasts driven by realistic aerosol inputs would have substantially reduced the forecast error during the event.

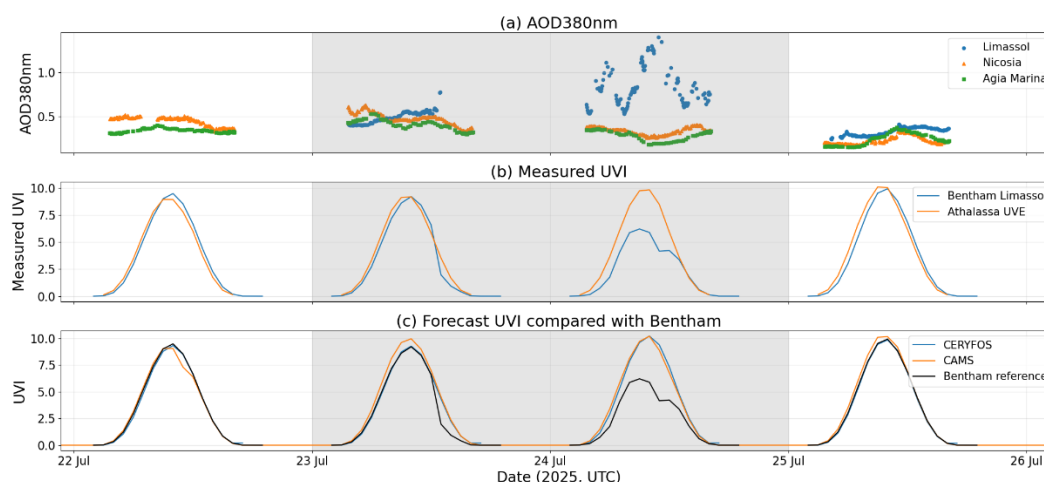


Figure 12: Evolution of aerosol optical depth (AOD380nm), measured UV Index (UVI), and forecasted UVI during the wildfire smoke event of 23–24 July 2025. Panel (a) presents AOD380nm observations from the Limassol (LIM), Nicosia (NIC) and Agia Marina (AMX) AERONET stations. Panel (b) shows measured UVI from the Bentham spectroradiometer at Limassol and the Athalassa SUV-E radiometer. Panel (c) compares CERYFOS and CAMS forecasts against the Bentham reference measurements in Limassol Station. The strong increase in aerosol loading over Limassol on 24 July was associated with a pronounced reduction in observed UVI that was not reproduced by either forecasting system.

The corresponding performance of the forecasting systems is shown in Fig. 12c. Both CERYFOS and CAMS reproduced the observed UVI reasonably well before and after the wildfire episode. During the period of maximum aerosol loading, however, both systems substantially overestimated the measured UVI and failed to reproduce the strong attenuation observed by the



975 Bentham spectroradiometer. Forecasted UVI values remained close to their expected JJA clear-sky levels, consistent with an underrepresentation of the strong local aerosol enhancement observed at LIM in the aerosol fields used by both forecasting systems. Forecast errors exceeded 4–5 UVI units during the most intense phase of the event, representing some of the largest forecast deviations observed during the study period. The largest forecast overestimations coincided with the highest AOD values observed at LIM, whereas substantially smaller forecast deviations were observed at ATHA, where no aerosol enhancement was observed at the nearby NIC station. The temporal relationship between AOD and forecast error for both locations is shown in Fig. S6. Representative all-sky camera images acquired at the LIM station during the event are presented in Fig. S1. The selected images document the evolution of the smoke plume from the afternoon of 23 July, shortly after the wildfire ignition, through the evening development of the event and into the morning of 24 July, when the highest aerosol loadings were recorded at LIM. Although no meteorological cloud obstructed the solar disk during the analysed measurement, 985 extensive smoke and haze are visible in the sky images. Together with the coincident increase in AOD, these observations support the interpretation that the pronounced reduction in surface UV radiation was predominantly associated with enhanced aerosol loading rather than cloud attenuation. The event therefore demonstrates that substantial UV attenuation can occur under nominally clear-sky conditions when aerosol loading becomes exceptionally high.

4 Conclusions

990 This study provides an integrated assessment of surface ultraviolet radiation variability and operational UV Index forecasting over Cyprus using a combination of high-quality ground-based UV measurements, aerosol observations, satellite-derived ozone products, atmospheric model outputs, and independent cloud information. Spectral UV measurements from the Bentham spectroradiometer at the LIM reference station were combined with broadband SUV-E observations from five monitoring stations distributed across the island, providing a unique observational basis for characterizing regional UVI variability and 995 evaluating the CERYFOS and CAMS forecasting systems under contrasting atmospheric conditions.

The observations demonstrate strong spatial coherence in surface UVI across Cyprus, with all stations exhibiting a common seasonal evolution primarily controlled by solar geometry and large-scale atmospheric conditions. Nevertheless, substantial local variability occurs, particularly at the mountainous Kyperounda station. Its elevated location is associated with generally enhanced UVI and substantially greater day-to-day variability than at the lower-elevation stations. Kyperounda exhibited a mean absolute day-to-day UVI change of 1.08 UVI and a standard deviation of 1.64 UVI, compared with mean absolute changes of approximately 0.43–0.61 UVI at the other stations. Individual changes at Kyperounda reached –6.51 to +5.69 UVI. These results demonstrate that similar seasonal behaviour across a relatively small geographical region does not imply equivalent short-term variability and may translate into different forecasting challenges across sites, particularly over mountainous terrain.

1005 The forecast evaluation demonstrates that both CERYFOS and CAMS reproduce the observed UVI variability well under typical conditions, but their performance depends strongly on cloud occurrence. For the complete all-sky dataset, CERYFOS



exhibits a mean bias of -0.07 UVI, an RMSE of 0.72 UVI, and an R^2 of 0.94 , while CAMS yields corresponding values of -0.01 UVI, 0.60 UVI, and 0.96 . Performance improves substantially when the solar disk is unobstructed by clouds: the RMSE decreases to 0.47 UVI for CERYFOS and 0.40 UVI for CAMS, with R^2 values of 0.97 and 0.98 , respectively. Under cloudy conditions, however, the RMSE increases to 1.65 UVI for CERYFOS and 1.12 UVI for CAMS, accompanied by mean biases of -0.77 and -0.40 UVI, respectively. Both systems therefore tend to underestimate surface UVI during cloud-affected conditions, with the stronger negative bias in CERYFOS suggesting excessive cloud attenuation for a subset of cases. CAMS provides better overall statistical performance, particularly under cloudy conditions, whereas the differences between the two systems are relatively small when direct cloud obstruction is absent.

The seasonal behaviour of the CMF is broadly consistent between the two forecasting systems, with stronger cloud attenuation during DJF and values approaching unity during JJA. However, the deterioration in forecast performance for individual cloudy observations demonstrates that reproducing the seasonal cloud climatology does not necessarily imply accurate representation of individual cloud events. Uncertainties in the representation of cloud occurrence and properties therefore remain a major limitation for short-term operational UVI forecasting. The greater variability observed at large SZA in percentage terms does not correspond to a comparable increase in forecast differences and is largely associated with the lower UVI values occurring at high SZA.

The independent assessment of atmospheric composition inputs further clarifies the sources of clear-sky forecast uncertainty. Both TEMIS and CAMS TOC products reproduce the main ozone variability observed by OMI, and the relationship between ozone differences and UVI forecast errors is physically consistent. Nevertheless, differences in the ozone fields relative to OMI are generally associated with relatively small UVI forecast deviations, suggesting a limited influence on the larger forecast errors observed during the study period. In contrast, substantially larger UVI forecast departures occur in association with large AOD differences. CAMS AOD₃₈₀ generally agrees well with AERONET observations at LIM, with 62.4% and 87.0% of collocations falling within ± 0.05 and ± 0.10 AOD, respectively. Occasional larger CAMS–AERONET discrepancies are nevertheless observed, indicating limitations in the representation of some aerosol episodes. Because the same CAMS aerosol fields are used by both CERYFOS and CAMS, errors in the representation of aerosol loading constitute a common source of UVI forecast error in the two systems.

The wildfire of 23–24 July 2025 provides a particularly clear demonstration of this limitation. During the event, exceptionally high aerosol loading associated with the wildfire coincided with a strong reduction in surface UV radiation despite the absence of direct cloud obstruction of the solar disk. CAMS substantially underestimated the aerosol loading measured by AERONET, with CAMS – AERONET AOD₃₈₀ differences reaching approximately -1.4 on 24 July. Both forecasting systems consequently underestimated the aerosol attenuation and overestimated surface UVI by more than 4 UVI units during the most intense phase of the event. The temporal correspondence between increasing observed aerosol loading and increasing UVI forecast error, together with the much smaller response at Athalassa where the nearby NIC AERONET station recorded no aerosol enhancement, provides strong evidence that the large forecast errors were primarily associated with the underrepresentation of



1040 the exceptionally high aerosol loading during the event. This case demonstrates that even forecasts classified as nominally clear-sky can exhibit very large errors when exceptional aerosol events are not adequately represented.

The results show that CERYFOS and CAMS provide reliable operational UVI forecasts over Cyprus under typical atmospheric conditions, while identifying two distinct challenges. Cloud-affected conditions represent the principal challenge to forecast performance in the overall dataset, whereas inaccurate aerosol representation can become a major source of error during episodes of enhanced or rapidly evolving aerosol loading. Ozone-related differences were associated with comparatively smaller UVI forecast deviations during the investigated period. The results further demonstrate the importance of high-quality, spatially distributed ground-based observations for identifying forecast limitations that may not be apparent from climatological model evaluation alone. Continued integration of spectral and broadband UV measurements with all-sky imagery and aerosol observations, together with improvements in cloud forecasting and the representation of localized aerosol events such as wildfires and dust outbreaks, will be important for further improving operational UVI forecasts over Cyprus and the wider Eastern Mediterranean.

Code and data availability

Ground-based network measurements used for validation are available from the corresponding author upon request. AERONET data are available at <https://aeronet.gsfc.nasa.gov>, CAMS forecasts from the Copernicus Atmosphere Data Store (1055 <https://ads.atmosphere.copernicus.eu>), OMI total ozone from NASA GES DISC (<https://disc.gsfc.nasa.gov>) and TEMIS ozone forecasts from <https://www.temis.nl>. The operational regional UV index forecast fields generated by the CERYFOS platform are updated daily and are openly accessible to the public through the Eratosthenes Centre of Excellence UVI Nexus Hub platform at <https://uvinexushub.eratosthenes.org.cy/web/>.

Supplement link

1060 The link to the supplement will be included by Copernicus, if applicable.

Author contributions

Conceptualization: G.C., S.K., K.F.; Methodology: G.C.; Formal analysis: G.C., K.F., K.P., A.M., S.K.; Software: G.C., K.F., I.F., K.P., and S.K.; Validation: S.K., K.F., K.P., I.F.; Investigation: G.C., K.F., I.F.; Resources: K.P., S.K.; Data curation:



1065 G.C., K.F., A.N., D.H.; Visualization: G.C., K.P., S.K.; Writing (original draft preparation): G.C.; Supervision: S.K., K.F., K.P., H.D.; Writing (review and editing): all authors. All authors gave final approval for publication.

Competing interests

At least one of the (co-)authors is a guest member of the editorial board of Atmospheric Measurement Techniques for the special issue “Sun-photometric measurements of aerosols: harmonization, comparisons, synergies, effects, and applications”.

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