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Validation of OMI erythemal doses with multi-sensor ground-based measurements in Thessaloniki, Greece

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ABSTRACT

The aim of this study is to validate the Ozone Monitoring Instrument (OMI) erythemal dose rates using ground-based measurements in Thessaloniki, Greece. In the Laboratory of Atmospheric Physics of the Aristotle University of Thessaloniki, a Yankee Environmental System UVB-1 radiometer measures the erythemal dose rates every minute, and a Norsk Institutt for Luftforskning (NILU) multi-filter radiometer provides multi-filter based irradiances that were used to derive erythemal dose rates for the period 2005–2014. Both these datasets were independently validated against collocated UV irradiance spectra from a Brewer MkIII spectrophotometer. Cloud detection was performed based on measurements of the global horizontal radiation from a Kipp & Zonen pyranometer and from NILU measurements in the visible range. The satellite versus ground observation validation was performed taking into account the effect of temporal averaging, limitations related to OMI quality control criteria, cloud conditions, the solar zenith angle and atmospheric aerosol loading. Aerosol optical depth was also retrieved using a collocated CIMEL sunphotometer in order to assess its impact on the comparisons. The effect of total ozone columns satellite versus ground-based differences on the erythemal dose comparisons was also investigated. Since most of the public awareness alerts are based on UV Index (UVI) classifications, an analysis and assessment of OMI capability for retrieving UVIs was also performed.

An overestimation of the OMI erythemal product by 3–6% and 4–8% with respect to ground measurements is observed when examining overpass and noontime estimates respectively. The comparisons revealed a relatively small solar zenith angle dependence, with the OMI data showing a slight dependence on aerosol load, especially at high aerosol optical depth values. A mean underestimation of 2% in OMI total ozone columns under cloud-free conditions was found to lead to an overestimation in OMI erythemal doses of 1–5%.While OMI overestimated the erythemal dose rates over the range of cloudiness conditions examined, its UVIs were found to be reliable for the purpose of characterizing the ambient UV radiation impact.

1. Introduction

Changes in climate and atmospheric composition may lead to unprecedented changes in the Ultraviolet (UV) radiation that reaches the Earth's surface, raising the concern of indirect and direct effects to plants, ecosystems and humans (IPCC AR5, 2014; Tevini, 1993; WMO, 2007; WHO, 2008; Gao et al., 2009; among others). Since 1982, when the ozone depletion was firstly observed (e.g. Farman et al., 1985; Bhartia et al., 1985), ground-based UV monitoring sites have been deployed at several locations all over the globe as a response to the raising concern of potential enhanced surface UV levels (Ghetti et al., 2006). Most of these sites nowadays provide high frequency measurements for a variety of surface UV radiation products, such as the erythemal weighted dose rates, UV index, and so on. These data are used to validate model projections and satellite estimates, and to alert public awareness regarding the effects of the exposure to high solar UV radiation levels (Schmalwieser et al., 2002; Gies et al., 2004; Tanskanen et al., 2007a, b; Weihs et al., 2008; McKenzie et al., 2001; WHO, 2008;

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among others).

Up-to-date, space-borne UV product estimates originate from a variety of instruments onboard different platforms (Arola et al., 2002; Tanskanen et al., 2006). One of them is the Ozone Monitoring Instrument (OMI) on board the Aura platform that provides estimates of surface erythemal dose rates and daily doses at overpass and noontime along with UV index (UVI) values since its launch in July 2004. Studies on OMI UV products (irradiances, erythemal doses and UV index) have reported differences of up to 30% or even higher under certain conditions overestimation in OMI UV products when compared with corresponding ground-based measurements, while these discrepancies were mainly observed at urban areas with higher aerosol loads (Kazadzis et al., 2009a; Kazadzis et al., 2009b; Ialongo et al., 2008; Antón et al., 2010; Cachorro et al., 2010; A Jebar et al., 2017). In 2009, a study by Arola et al. (2009) introduced a correction on the OMI data for absorbing aerosols which led to smaller discrepancies between OMI and ground-based data, with OMI performance being improved due to the imposed aerosol correction (Mateos et al., 2013; Muyimbwa et al., 2015; Cadet et al., 2017; Bernhard et al., 2015).

In this study, OMI UV erythemal dose rates and UVI values at overpass and local noontimes were thoroughly evaluated in Thessaloniki, Greece (lat: 40.69° N, lon: 22.96° E, alt: 60 m) for the period 2005–2014, using a suite of ground-based instruments located at the Laboratory of Atmospheric Physics (LAP), at the Aristotle University of Thessaloniki, Greece together with retrieval models. The influence of solar zenith angle (SZA), total ozone column (TOC) and aerosol optical depth (AOD) on the satellite UV products was also analysed, while the impact of three basic types of cloudiness conditions defined as: unstable cloudy (partially covered sun disk), stable cloudy (fully covered sun disk), and unoccluded sun disk, were also investigated.

Consequently, this study provides an innovative, complete and in-depth evaluation of the erythemal products provided by OMI/Aura, where the synergy of a wide suite of ground-based measurements is proven invaluable in order to examine, quantify and eventually unfold the dynamics of all the parameters potentially affecting the satellite retrievals.

The backbone of the paper is as follows. In Section 2 the ground-based instrumentation with the corresponding measurements are provided, while the OMI measurements are presented in the second subsection. In the following section (Section 3), the methodology applied to retrieve erythemal dose rates from irradiance measurements originating from the NILU-UV multi-filter radiometer is analysed, and the results are validated against collocated erythemal dose rate measurements from the UVB-1 radiometer placed also in the site. Then, the evaluation of the OMI erythemal dose rates is presented in Section 4, where the influence of the SZA, ozone, aerosols and cloudiness type is examined. At the end of the same section, the UV index comparisons are presented in order to elaborate on the ability of OMI UV Index estimations to serve as a public alert source, especially during the summer when the impact of the exposure to excess UV doses is more detrimental. The study concludes with its 5th and final section by summarizing the main findings of the validation process.

2. Datasets and instrumentation

2.1. Ground-based measurements

At the Laboratory of Atmospheric Physics at Aristotle University of Thessaloniki, Greece (LAP/AUTh: http://lap.physics.auth.gr), three different types of solar radiation sensors provide estimates of erythemal dose rates continuously since 2005 as per the joint International Organization for Standardisation and Commission Internationale de l' Éclairage standard ISO 17166:1999(E)/CIE S 007–1998 (and which we will abbreviate as 'CIE' here). For each instrument, different methods were applied in order to derive the erythemal dose rates, based on the characteristics of the measurements and the technical aspects of each instrument.

A Brewer MkIII spectrophotometer with serial number #086 (B086) measures the UV solar spectrum (286.5–363 nm) with a wavelength step of 0.5 nm at LAP since 1993. It is equipped with a double monochromator which is eliminating influences of stray light (scattered photons/signal at one wavelength that is affected by radiation from other wavelengths) in the measurements, thus providing better accuracy especially in the shorter UV wavelengths (Zerefos and Bais, 1997; Karppinen et al., 2014). The uncertainty in the B086 spectra that are used in this study is 5% for wavelengths higher than 305 nm and solar zenith angles (SZA) smaller than 80° (Fountoulakis et al., 2016a), while low recorded signals at lower wavelengths and higher SZAs lead to higher uncertainties in the measurements (Fountoulakis et al., 2016b; Gröbner et al., 2006). In order to obtain solar spectra up to 400 nm, the SHICrivm algorithm (Slaper et al., 1995) has been applied to the original data, while the outcome was weighted with the erythemal dose action spectrum (McKinlay and Diffey, 1987) and integrated over the nominal wavelength range. Although B086 provides high accuracy erythemal dose rates, the frequency of the measurements is one every 20–40 min while a complete scan lasts ~7 min. Therefore, even though B086 scans cannot capture high frequency changes in the radiation field, these measurements provide a unique tool to monitor and assess the stability of other instruments that provide measurements with higher frequency (Zempila et al., 2016a).

A Yankee Environmental System (YES) UVB-1 radiometer has also been operating since 1991. The UVB-1 is a broadband instrument with a spectral response that simulates the erythemal action spectrum proposed by McKinlay and Diffey (1987) and thus provides erythemal dose measurements on a 1-min basis. Using libRadtran radiative transfer model simulations (Emde et al., 2015), look up tables are calculated with respect to SZA and the TOC which are used to convert the UVB-1 measurements into erythemal irradiance due to differences between the actual and the desired spectral response (Lantz and Disterhoft, 1998; Webb et al., 2006). The TOC values for these corrections are obtained from collocated measurements from a second Brewer spectrophotometer with serial number 005 (B005) (Meleti et al., 2012; Zerefos, 2002; Fragkos et al. 2014a, b, 2016). Under clear (cloudless) skies, the erythemal irradiances from B086 and UVB-1 (within 1 min from the mean time of the B086 scan) have shown a satisfactory agreement; within 4% (1σ) for SZAs less than 80° for the period 2004–2014, that is in compliance with the results presented in Hülsen et al. (2008). This agreement testifies that UVB-1 erythemal dose rates have similar uncertainty level with the ones derived from B086 UV spectra (Garane et al., 2006; Bais et al., 1996a,b; Bais et al., 1985). Periodic intercalibrations of UVB-1 and B086 ensure the long-term stability of the instrument.

A Norsk Institutt for Luftforskning (NILU)−UV multi-filter radiometer has been operational since 2005 and forms part of the Greek UV network of NILU-UV radiometers (Kazantzidis et al., 2006). The NILU-UV with serial number 04103 provides 1-min measurements in 5 UV channels with nominal central wavelength at 302, 312, 320, 340 and 380 nm and a full width at half maximum (FWHM) of 10 nm. The instrument is also equipped with an additional channel that measures the photosynthetically active radiation (PAR). In this study, measurements of the PAR channel were used to determine cloud-free cases based on the cloud detection algorithm proposed by Zempila et al. (2016b). By calibrating the NILU measurements with the B086 coincident irradiances, we estimate that the uncertainties of the NILU irradiance measurements used in this study are less than 5.5% (Zempila et al., 2016a). In Section 3 a description of the methodology used to derive erythemal dose rates from the NILU UV irradiances measurements is provided, while comparisons with UVB-1 measurements are presented in the second part of the section.

Additionally at LAP, a CM21 (Kipp&Zonen) pyranometer provides global horizontal irradiance (GHI) measurements at 1-min intervals along with the corresponding standard deviation. Although the

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