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Interrelations of UV-global/global/diffuse solar irradiance components and UV-global attenuation on air pollution episode days in Athens, Greece

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Abstract

An investigation of global ultraviolet (G_{UV}), global (G) and diffuse (G_d) solar intensities, continuously recorded over a period of five years at a station in Athens, Greece, and stored on the basis of hourly time intervals since 1996, has revealed the following: (a) UV-global irradiation, associated with the 290–395 nm wavelength region, constitutes 4.1% of global solar. (b) UV-global irradiance ranges from an average minimum of 2.4 W m^{-2} and 3.1% of global solar in January to an average maximum of 45 W m^{-2} and 7.8%, respectively, in June, both considered at 13:00, solar time. (c) There exists a good correlation among the two dimensionless irradiance ratios G_{UV}/G_d and G_d/G in the form of an exponential relationship. (d) UV-global monthly irradiation data show evidence of temporal variability in Athens, from 1996 to 2000. (e) Anthropogenic and photochemical atmospheric pollutant agents (O_3, CO, SO_2, NO_x, smoke) causing air pollution episodes seem to affect differently solar irradiance components. The main results of analysis (measurements within ± 2 h from solar noon) indicate that a buildup of O_3 and NO_x inside the urban Athens plume during cloudless and windless warm days could cause: (i) UV-global irradiance depletion between 5.4% and 14.4%. (ii) Diffuse solar irradiance enhancement up to 38.1%. (iii) Global solar irradiance attenuation ranging up to 6.3%.

Keywords: UV-global irradiance; Depletion; Global and diffuse solar irradiance; Air pollution; Correlation

1. Introduction

The contradicting evidences for either increase or decrease of terrestrial UV radiation has raised great concern since solar UV plays a very important role on human health, plant growth, animal welfare and material degradation. The significant solar irradiance values reaching ground level in urban Athens area, particularly around midday during warm period, render necessary an assessment of the temporal variation of UV-global, the ultraviolet solar (UV-A plus UV-B) component. In addition, long-term monitoring of the UV irradiance reaching ground in an urban environment leads to establishing the action and bilateral influence of UV in the generation of tropospheric ozone and other photochemical pollutants.

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Ultraviolet is radiation in the wavelength region of the electromagnetic spectrum between X-rays at 10 nm all the way through the inner edge of visible light approximately at 400 nm. Solar UV radiation, which comprises 8.73% (ASTM, 1981) of the exoatmospheric solar spectrum, consists of three wavelength band-regions, the UV-A (315–400 nm), the UV-B (280–315 nm) and the UV-C (<290 nm), accounting for 5.9%, 1.33% (Iqbal, 1983) and 1.5%, respectively. Earth's atmosphere significantly modifies the incoming solar rays due to the absorption and scattering action of oxygen, water vapor, carbon dioxide, ozone, water droplets, dust particles and other biospheric constituents of human and volcanic activities, on different regions of the solar spectrum. In particular, it is the stratospheric ozone's absorption that forms a lower boundary of the solar spectrum reaching the surface, at approximately 290 nm in the UV region. Ozone absorption is significant up to wavelength of 310 nm, decreasing fast afterwards, being zero practically at 345 nm.

Since the UV-C band-region falls beyond the portion of solar spectrum reaching Earth's surface, only UV-A and UV-B band-regions are relevant to ecosystems and the various activities of our life (Parrish et al., 1978; Giese, 1982; Scotto et al., 1988; Tevini, 1993; Parisi and Wong, 1997). As it comes out, UV-A band accounts for 90% or more of the UV-global irradiance shorter than 400 nm, while the remainder is in the UV-B region, at wavelengths shorter than 320 nm. Nevertheless, although UV-B radiation is 3–4 orders of magnitude more energetic than UV-A (McKinlay and Diffey, 1987), the harmful actinic effect of UV-A (Lavker et al., 1995) is not to be under-estimated because of the high UV irradiance level impinging Athens and all the Aegean area. Sutherland et al. (1991) found that UV-A exposure could cause DNA damage and skin-cell mutation to humans and other living organisms. In fact, UV-A is responsible for tanning (DIN 5031, 1979; Wong and Parisi, 1996) and premature skin aging as well as other biological effects due to its absorption by proteins and DNA. Based on laboratory experiments, Antonelli et al. (1997) found that bean plants exposed to UV-A treatment showed a stimulant response regarding their growth.

UV-B, besides being notably destructive to polymers and other plastics (Andrady and Horst, 1986), is easily absorbed by nucleic and aromatic acids thus having positive as well as deleterious effects on plants, marine ecosystems and humans (Berger and Urbach, 1982), depending upon the action spectra and the threshold dose received. Chronic exposure of humans to UV-B irradiance poses great risks for the development of erythema (DIN 5031, 1979; McKinlay and Diffey, 1987), accelerated aging of skin, malignant skin tumors, keratitis (DIN 5031, 1979), eye-lens cataract (Zigman, 1977), retinal degradation, DNA damage, immune deficiencies. On the other hand, exposure of humans to UV-B irradiance is needed for the production of vitamin D, the enhancement of one's physical well-being, and the cure of skin diseases such as psoriasis (Feister et al., 1992). Also, UV-B due to its bactericide effects at sufficient doses is used for the sterilization of surgical instruments and the killing of germs, bacteria and viruses in drinking water and food products.

Analysis of solar irradiance measurements taken at low altitude stations all over the world has revealed that monthly mean UV-global radiation constitutes a fraction that, in most cases, represents a value <5.5% of global solar. Results of monthly mean UV fractions of the global total are found in the literature, for different places. When a range is indicated, then the higher value is usually referred to rainy or cloudy conditions, and the lower is attributed to days with heavy scattering and UV absorption by dust or other atmospheric pollutants. So, Picha (1981) indicates percentages ranging from 4.5% for cloudless days to 5.2% for all days together. A value of 5.0% for the summer months to 5.7% for the winter ones is indicated by Nagaraja et al. (1984). Percentage-wise values ranging from 4.2% in December to 5.2% in August are reported for Kuwait (Al-Aruri et al., 1988; Al-Aruri, 1990). Elhadidy et al. (1990) reports percentages ranging from 2.1% for a dusty day to 4.5% for a rainy one, in Dhahran. Using an Eppley radiometer, Feister and Grasnick (1992) report UV percentage values ranging from 3.0–4.0% up to 6% for overcast skies. For the city of Makkah (Saudi Arabia), Khogali and Al-Bar (1992) have found percentage values ranging from a low 2.8% in July to a maximum 4.3% in February.

UV irradiance reaching Earth's surface is affected, in addition to the solar zenith angle, by altitude, the albedo of the surroundings, as well as atmospheric and other environmental forcing factors such as cloud cover, stratospheric and tropospheric ozone, SO_2 and aerosols. Surface ozone concentrations have been going up, since the second half of the 19th century (Bojkov, 1986). Nevertheless, it is after the 1950s when studies started to appear showing the significant influence imposed upon UV radiation by ozone and the other atmospheric pollutants present in the plume of an urban environment. As was suggested by Brül and Crutzen (1989) regarding tropospheric ozone, in general, and by Cartalis et al. (1992) for Athens, in particular, ozone, photochemical and other atmospheric pollutants exhibit a strong absorption preference towards UV (UV-B in particular) radiation. The filtering action of these agents has been found and reported by others (Liu et al., 1991; Mantis et al., 1992; Frederick et al., 1993; Ambach and Blumthaler, 1993; Varotsos et al., 1995). Thus, the EER (erythemal effective radiation, a notation adopted by Forster, 1995) dose during summers, at the pollution-free environment of the Aegean island of Kos, is measured 15% greater than in urban Athens (Bais et al., 1996). On the average, the EER irradiance measured in urban Athens is found at least 20% lower than the value estimated for clear sky conditions (Mantis et al., 1997). UV-B radiation reduction is shown to be close to 39% for urban Athens, during a day with high atmospheric pollution basically characterized by high smoke concentrations (Repapis et al., 1998). The polluted atmosphere in downtown Mexico City, at an altitude of 2500 m a.s.l., shows a 20% UV-B annual average (years 1994–1995) attenuation compared to a suburban site in the same Metropolitan area, but differences are found to be $>40\%$ on polluted days (Acosta and Evans, 2000).

The National Observatory of Athens, the oldest meteorological establishment of Greece, operates a meteorological station recording a number of atmospheric parameters including UV-B (since 1999), global and diffuse solar irradiance. Solar UV measurements have intensified in the 1990s in this part of the world, with new monitoring stations being added. A number of units operate, either in the National UV-B Observational Network of Greece (Zerefos et al., 1995; Bais et al., 1996; Ziomas, 1998), or otherwise, as in this current case. A number of studies have been reported based on solar irradiance data from these stations. Their scope was to provide scientific information on the very important issue of UV radiation based on site measurements. Reports can be found on UV radiation at ground level, regarding some Eastern Mediterranean sites. A number of these provide evaluation on the erythemal active UV (Zerefos et al., 1995; Mantis et al., 1997; Repapis et al., 1998; Ziomas, 1998; Mantis et al., 2000). Others show results indicative of the tropospheric surface ozone and aerosols action on UV-B depletion during air pollution episodes (Repapis et al., 1998; Papayannis et al., 1998; Mantis et al., 2000).

In this contribution, we study the temporal variability of UV-global radiation in urban Athens during normal days, as well as on days characterized by air pollution episodes. Results are presented based on measurements of UV-global, global, and diffuse solar irradiance components that were continuously monitored and logged at a ground station in urban Athens, for a 5-year period (March 1996 through December 2000). To improve modeling quality on availability and temporal variability of the UV-global, we shall show results of investigations on possible correlation events between the different solar components, including a number of empirical functional relations including absolute and normalized quantities.

2. Instrumentation description and measurements

Starting in 1991 (1996 for UV), solar irradiance measurements are taken using an automatic station located on the rooftop of a building at the TEI of Piraeus campus (37.97°N Latitude, 23.67°E Longitude). The TEI campus, part of the *Ancient Olive Orchard* of Athens, is situated in the midst of the greater Athens Metropolitan area.

The station is continuously monitoring the following solar irradiance components:

- Global solar using a PSP Eppley pyranometer.
- Diffuse solar using a PSP Eppley pyranometer with a shadow ring.
- Total solar on a vertical plane facing south, west, north and east using four Kipp & Zonen pyranometers, type CM 11. The CM 11 pyranometer is well suited for the measurement of incoming global solar radiation and fully compliant with all ISO 9060 Secondary Standard Instrument performance criteria.
- Global ultraviolet using a CUV3 Kipp & Zonen broadband radiometer. The CUV 3 is responsive across the natural UV spectrum, covering both the UV-B and UV-A spectral ranges, responding at 290–390 nm. The CUV3 radiometer has a response time <1.0 s, a good cosine response and non-linearity $<1\%$ over the full-scale range.

All pyranometers are serviced regularly and checked every 2 years against a PSP Eppley standard pyranometer. The CUV3 radiometer calibrated and used for the first time in 1996, it has been functioning continuously ever since, with regular services in between.

The Data Acquisition System (DAS) is programmed to scan the output of each one of these seven instruments every 60 s, average it over an hour period and store the result in the data logger's memory next to the channel number, solar hour, and corresponding (Julian) day of the year. At midnight, on a daily basis, all data stored in the data logger is dumped into a PC via a RS232, for future processing.

3. Data analysis and discussion of results

In this work, the measured monthly values of UV-global irradiation in urban Athens area are presented in Fig. 1 as a time series variation from March 1996 to December 2000. Looking at the literature, a considerable number of contradicting reports regarding UV variability at different places throughout the world can be found. Further focusing to the eastern Mediterranean region, investigations of the influence of photochemical air pollution on UV reaching the ground in urban Athens area presented by many (Varotsos et al., 1995; Bais et al., 1996; Papayannis et al., 1998) point to the same conclusion. They support the hypothesis of the filtering action air pollution has on UV (UV-B).

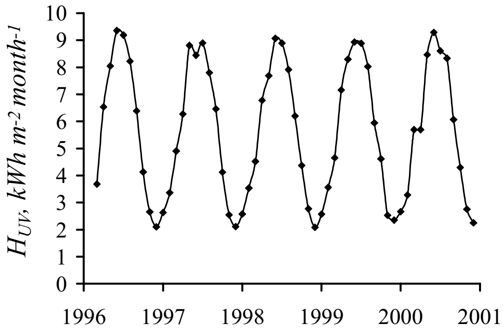

Fig. 1. Yearly time series of the monthly UV-global irradiation in urban Athens for the period 1996–2000, in urban Athens area.

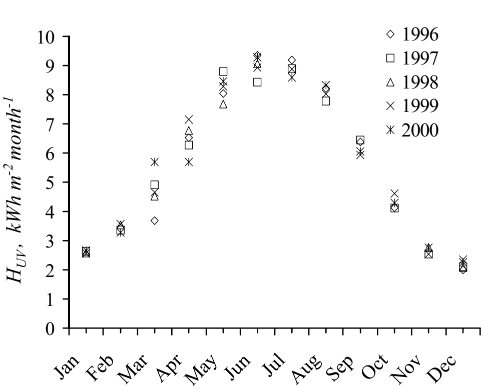

Fig. 2. Annual course of monthly UV-global irradiation time series, in urban Athens area, for the period 1996–2000.

Furthermore, Mantis et al. (2000), in Fig. 1, provide a scatter diagram of time series for 1993–1997 daily observations of erythemal irradiance in urban Athens area that shows a rather decreasing trend over the years

The variable weather conditions, often occurring during spring and appearing less frequently in summer and autumn, in Athens, may be the reason for the observed scattering of the monthly UV-global irradiation values shown in Fig. 2. Thus in March, monthly UV irradiation values may differ by as much as 61%. The absolute monthly UV-global varying from a minimum of 1.99 kWh m^{-2} month^{-1} in December 1996 to a maximum 9.36 kWh m^{-2} month^{-1} for the month of June, same year. Fig. 2 illustrates the yearly course of H_{UVM}, the monthly UV-global irradiation in urban Athens area (in kWh m^{-2} month^{-1}), for the period 1996–2000.

Fig 3 presents the plot of UV-global (H_{UVD}) against global solar (H_{D}), both expressed as monthly mean daily irradiation data obtained over the 5-year period, as well as the best line of fit given by Eq. (1), following a linear least-square regression analysis. The good linear correlation between H_{UVD} and H_{D}, observed mainly at below average H_{D} values, is an indication of the weaker filtering action of Athens plume on UV-global reaching the ground at moderate to low sun conditions. This could be attributed to the fact that surface ozone modulation on UV-global becomes important at higher solar irradiance levels which, in conjunction with warm weather and wind absence, might constitute the appropriate conditions for the production of O_3 and other pollutants. Thus O_3, a strong absorbing agent of UV up to wavelength 310 nm, would only affect UV-B and UV-C which both constitute, approximately, 25% of the UV-global.

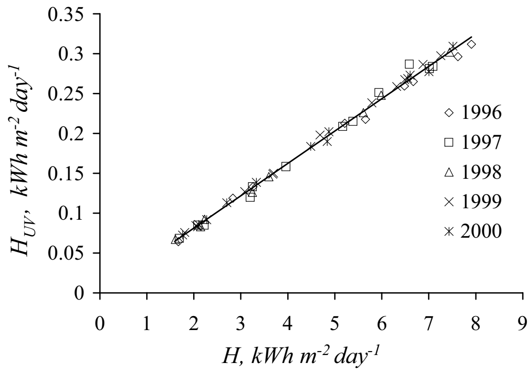

Fig. 3. Scatter diagram of the monthly daily mean irradiation values of UV-global (H_{UVD}) against Global solar (H_{D}), over the 5-year period. Solid line is the best-fit line expressed by the equation $H_{\mathrm{UVD}} = 0.0406H_{\mathrm{D}} - 0.0001$, where H_{UVD} and H_{D} are in kWh m^{-2} day^{-1}.

$$H_{\mathrm{UVD}} = 0.0406H_{\mathrm{D}} - 0.001, \tag{1}$$

where, $R^2 = 0.9955$, H_{UVD} and H_{D} are expressed in kWh m^{-2} day^{-1}.

It has been indicated that Rayleigh and particle scattering agents greatly diffuse global solar radiation, thus increasing its total path before it strikes Earth's surface and therefore enhancing its absorption (Bruehl and Crutzen, 1989). This action is particularly affecting the shorter wavelength regions of solar spectrum. So, in an urban environment, one should expect the relatively large diffuse component of the UV solar radiation to be depleted, being absorbed by ozone, aerosols and the rest absorbing agents, while traveling through the considerable thickness of boundary layer, before reaching the ground. This holds true for the greater Athens Metropolitan area where measurements (Papayannis et al., 1998) have indicated an aerosol extinction profile value twice as big over the city (at an altitude of 1500–1700 m) as it is outside the polluted urban zone. Under these circumstances, ground measurements of solar irradiance should simultaneously show depletion of UV, enhancement of diffuse solar, and attenuation of global solar by an amount equal to the part that has turned to diffuse due to scattering effect.

In order to reduce the effects of solar zenith angle, turbidity and albedo, hourly UV-global and diffuse solar were expressed in ratios relative to solar diffuse (G_{UV}/G_d), and solar global (G_d/G), respectively. An attempt to form ratios of hourly UV-global relative to solar global resulted in extended point scattering, when plotted accordingly. Figs. 4a and b are the scatter diagrams showing the variation of G_{UV}/G_d with G_d/G, at 13:00 and 09:00 solar time, respectively, for each hour of the 5-year period 1996–2000. The white line curve passing through the 13:00 solar time data points in Fig. 4a is the best fit exponential-type line having an expression given by Eq. (2). This line form is associated with 97.89% of the variance ($R^2 = 0.9789$) of G_{UV}/G_d ratio and ariations of G_d/G. Similarly, in Fig. 4b, the 09:00 solar time data is best fitted by a similar exponential line expressed by Eq. (3) and 89.95% variance ($R^2 = 0.8995$).

$$G_{UV}/G_d = 0.0463(G_d/G)^{-0.9283}, \tag{2}$$

where $R^2 = 0.9789$ and

$$G_{UV}/G_d = 0.0426(G_d/G)^{-0.9348}, \tag{3}$$

where $R^2 = 0.8995$.

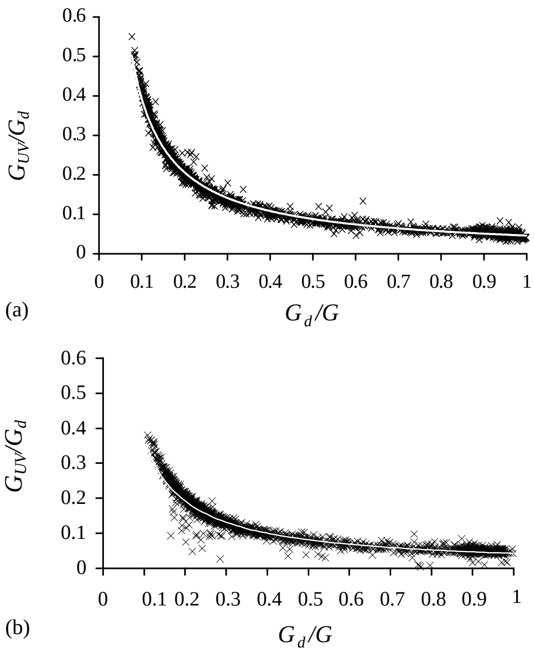

Fig. 4. Scatter diagrams of the hourly mean irradiances expressed in dimensionless ratios G_{UV}/G_d and G_d/G, for the 5-year period 1996–2000. Plotted values refer to solar irradiances at 13:00 solar time for (a), and 09:00 for (b), respectively.

In order to investigate the effect of a polluted urban atmosphere upon UV-global when the problem is more acute, three summer cloudless pollution episode days were found, the exact dates are 4 July 1996, 8 July 1996, and 18 June 1997. These three days were picked up from the list of days with atmospheric pollution episodes given for each year in the Yearly Report Tables on Atmospheric Pollution of Athens, edited and published by the Greek Ministry of Environment, Land-Use and Public Works, Air Pollution network of Athens (PERPA). The measured solar irradiance components on these 3 days are compared to the corresponding irradiances measured during three other, but of same calendar, normal cloudless days. Specifically, conditions of episode day 8 July 1996 are compared to the respective conditions of the 8 July 1999, a normal and cloud-free day. Similarly, episode day 18 June 1997 is matched to the 18 June 1998. Finally, conditions of episode day 4 July 1996 are matched to the conditions of a fictitious day formed and expressed by the average of the irradiances measured on the 24 June 1996 and 12 July 1996, two normal and cloud-free days.

Next, the time series of UV-global (G_{UV}), diffuse solar (G_d) and global (G), the diurnal variation of the hourly mean solar irradiances in urban Athens during the three pollution episode days are compared to the specified matched normal-day solar irradiances. Fig. 5 includes three pairs of diagrams, each pair referring to a different episode day. So, diagrams (a) and (b) illustrate irradiance variations on the 4 July 1996, (c) and (d) on 18 June 1997, and (e) and (f) on 8 July 1996. As it could be seen, it is right after 10:00 (during a clear and windless day) when global solar increases most rapidly. The effect of this increase, combined with the high concentrations of pollutants emitted by cars during rush hour and still present in the atmosphere, seems to be the proper recipe for the photochemical production of ozone and NO_2. Concentrations (in $\mu g\,m^{-3}$) of NO_2 and O_3 the two major atmospheric pollutants (SO_2 presents no problem during the warm months) for these three highly polluted episode days are as follows:

On the 4 July 1996	NO_2	472	O_3	323
On the 18 June 1997	NO_2	294	O_3	383
On the 8 July 1996	NO_2	243	O_3	309

Fig. 5 confirms attenuation of UV-global and global solar, as well as enhancement of diffuse solar on each episode day. It is interesting to note that the greater drop or rise of irradiance occurred in between 10:00 and 14:00, solar time, except on the 4th July 1996, an episode day marked with the highest NO_2 concentration ($472\,\mu g\,m^{-3}$). On the same day, the greater irradiance differences were observed between 12:00 and 14:00, showing a shifting towards the early afternoon hours. Specifically, the sign (− for depletion, + for increase)

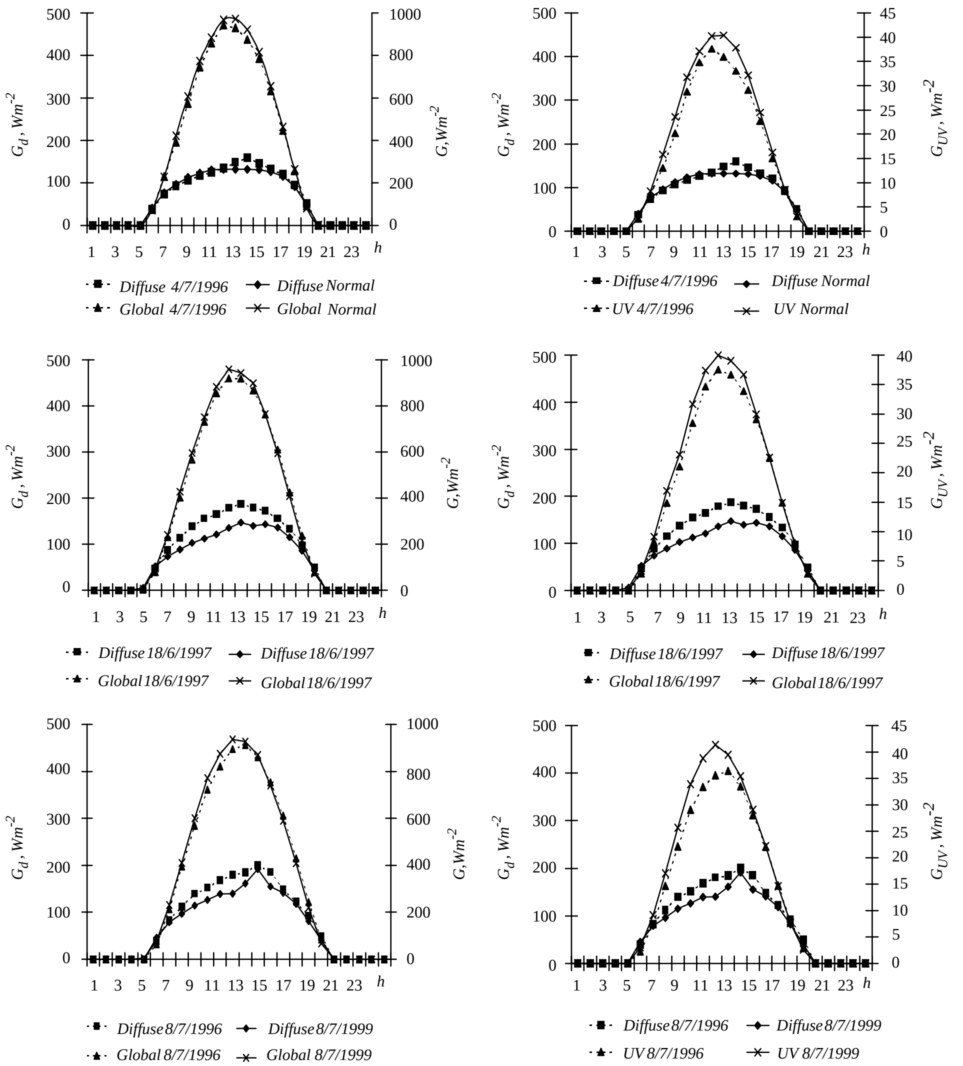

Fig. 5. Diurnal variation of diffuse solar (G_d), global solar (G) and UV-global (G_{UV}) irradiances, all expressed in $W\,m^{-2}$, for the episode cloudless day and its matching normal day, also cloudless. (a) Time series of G_d and G during pollution episode day 4 July 1996 and the corresponding averages of G_d and G between the two clear days 24 June 1996 and 12 July 1996. (b) Time series of G_d and G_{UV} during pollution episode day 4 July 1996, and the corresponding averages of G_d and G_{UV} between the two clear days 24 June 1996and 12 July 1996. (c) The same as in (a) but pollution episode day is 18 June 1997 and normal day is 18 June 1998. (d) The same as in (b) but pollution episode day is 18 June 1997 and normal day is 18 June 1998. (e) The same as in (a) but pollution episode day is 8 July 1996 and normal day is 8 July 1999. (f) The same as in (b) but pollution episode day is 8 July 1996 and normal day is 8 July 1999.

and the maximum observed percentage fractional deviations of UV-global, global solar and diffuse solar intensities recorded on an episode day and on a clear normal day are as follows:

Episode day 4 July 1996	Time of occurrence: 14:00
−12.6%	UV-global
−5.0%	Global solar
+20.7%	Diffuse solar

Episode day 18 June 1997	Time of occurrence: 10:00–12:00
−10.2%	UV-global
−4.1%	Global solar
+38.1%	Diffuse solar

Episode day 8 July 1996	Time of occurrence: 10:00–12:00
−14.4%	UV-global
−6.3%	Global solar
+28.2%	Diffuse solar

A systematic increase of the daily solar diffuse irradiation was logged on each consecutive episode day, during the 5-day period associated with photochemical air pollution, in July 1996, from 4 July through 8 July, that is not explained by normal day solar irradiance fluctuations. Shown below is the daily solar diffuse irradiation recorded on each consecutive day:

Date	4 July	5 July	6 July	7 July	8 July
Diffuse irradiation ($\mathrm{kWh\,m^{-2}\,day^{-1}}$)	1.72	1.71	1.83	1.85	1.87

Whereas, the corresponding daily solar diffuse measured one day before and two days after the 5-day string, namely on 3, 9 and 10 July, is only 1.39, 1.52 and 1.31, respectively, all values in $\mathrm{kWh\,m^{-2}\,day^{-1}}$.

Papayannis et al. (1998), comparing UV-B irradiance levels between clear and high aerosol day (episode day is 14 September 1994, solar zenith angle = 50°) in urban Athens area, report 10% disagreement between modeled (clear day) and measured UV irradiances in the 305–340 nm spectral region. This difference increases to about 20% for UV with wavelengths lower than 300 nm. A depletion of more than 35% in EER dose is reported for the same September day by Mantis et al. (2000). Acosta and Evans (2000), from measurements in the polluted downtown and a suburban site in the high altitude Mexico City, report UV-B differences observed between 11:00 and 16:00 >40% on polluted days.

Our results illustrate that comparing cloudless warm days of low and high air pollution levels in urban Athens, a reduction of 10–14.5% in the UV-global is detected within ± 2 h from solar noon. The lower UV depletion values obtained in this work are probably due to the fact that monitored UV-global constitutes mostly UV-A, a radiation much less affected by atmospheric pollutants compared to UV-B.

The principal boundaries of the UV-global diurnal variation could be specified in terms of the average–maximum, average–average and average–minimum daily distribution curves. These curves shown for the months of January and June form the lower and upper limit of the minimum and maximum UV-global daily intensity variations recorded at a ground station in Athens, over the annual course. Fig. 6 gives an example of these diurnal solar irradiance variation profiles. As it can be seen, solar noon UV-global intensity in Athens takes a minimum value 2.4 $\mathrm{W\,m^{-2}}$ in January, and a maximum one 45 $\mathrm{W\,m^{-2}}$ in June.

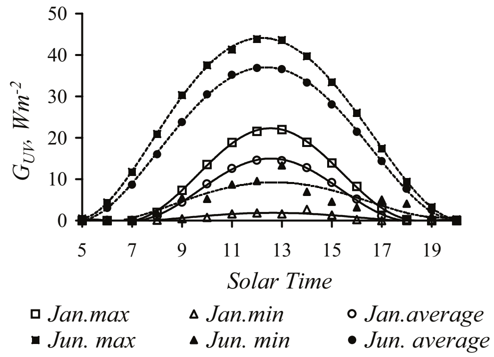

Fig. 6. Average–maximum, average–average and average–minimum diurnal UV-global irradiance variation curves, in $\mathrm{W\,m^{-2}}$, for the months of January and June, based on measurements recorded at a ground station in urban Athens area, over the 5-year period 1996–2000.

4. Concluding remarks

Measurements of UV-global irradiance along with solar diffuse and global irradiance data measured at the same site in urban Athens area, during the years 1996–2000, processed accordingly, lead to the following conclusions:

(a) Because of the limited length of the analyzed time period (5 years), UV-global change in Athens, (Fig. 1), does not constitute a statistical significant trend but represents the change observed during these years of measurements, thus, it should not be considered as an indicator of UV-global long-term change.

(b) Comparison of the monthly UV-global radiation values (Fig. 2) indicates large departures from the mean tending to occur from March through October, dropping to minimum during the cold period months of November through February.

(c) The plot of H_{UV} versus H (Fig. 3) and the derived linear regression, Eq. (1), indicate a clear linear correlation between UV-global and solar global, particularly in the region of moderate to low H values. Greater point scattering is observed towards higher solar radiation values, where UV-global may be influenced at a greater extend by the presence, or not, of suspended lower tropospheric aerosols, O_3 and other absorbing gases.

(d) The preference of plotting solar irradiances in dimensionless form, where UV-global forms a ratio with the corresponding diffuse solar and diffuse solar with solar global, produced results shown in Figs. 4a and b (13:00 and 09:00, respectively). These results clearly indicate: (i) To first order, the removal of influence of solar zenith angle, turbidity, albedo of the surroundings. (ii) A good agreement of the distribution of dimensionless data with an exponential fit, based on the model equation $G_{\mathrm{UV}}/G_{\mathrm{d}} = a(G_{\mathrm{d}}/G)^{-b}$, where a and b are constants. It should be noted that normalization of UV-global by solar global leads to extended point scattering and a poor correlation scheme. The resulting high values of correlation coefficients indicate that, in the absence of measured data, Eqs. (2) and (3) could be invoked to predict an estimate of G_{UV}, given G_d and G, at low and high solar zenith angles, respectively.

(e) The observed UV-global depletion during days with increased air pollution levels points to the conclusion that atmospheric pollutants are capable of reducing UV-global in urban Athens by as much as 14.4%, during warm cloudless and windless days, between 10:00 and 14:00. Another interesting observation is the continuous solar diffuse built-up noted on consecutive clear days with extreme air-pollution anomalies, a phenomenon that could be attributed to the thickening of urban plume formed by the presence of a residual aerosol layer and a gradual upward lifting of polluted air masses.

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