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The recent UVB variability over southeastern Europe

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Abstract

The UVB erythemal irradiance measurements obtained at Thessaloniki, Greece (40°N) are analysed. The variability of the erythemal irradiance is compared with that of the total columns of ozone and SO_2. It is shown that these two factors explain about 50% and 26% respectively of the total variability of the erythemal irradiance. The influence of the reduced total ozone levels observed during the last 4 years on the increase in the solar UV irradiance at 305 nm is also presented. Finally, a comparison between stations with different air pollution levels under clear skies shows that air pollution can significantly reduce the UVB dose levels received at the ground.

Keywords: UVB variability; UVB erythemal irradiance; Ozone; SO_2; Southeastern Europe

1. Introduction

The depletion of ozone and the expected UVB enhancement, with its many biological, ecological and chemical consequences, have been extensively documented in the past decade [1,2]. Of particular significance are the results published by several scientists on extreme ozone deficiencies associated with UVB enhancements on various time scales [3–7]. The geographical and seasonal variability of erythemal irradiance is now better understood in terms of astronomical factors, amounts of ozone, clouds, aerosols and a variety of local factors, such as albedo and air pollution. This paper focuses on the results obtained from measurements of the national UVB network of Greece, which is operated by the Laboratory of Atmospheric Physics (LAP) at the Aristotle University of Thessaloniki (AUTH), Greece

2. Short description of the network and data

The UVB monitoring network of LAP started operating and has been developed since 1991 and presently comprises five stations in Greece and one in Reykjavik, Iceland. The primary objective of this network was to establish a reliable and detailed database of UV measurements obtained in different environments, which could be supplemented by other ancillary data related to UV transfer measurements. It also aims to facilitate basic research on solar UV radiation and its transfer through the atmosphere. The heart of the network is a core station located at LAP, AUTH at 40.5°N, 23°E. The peripheral stations cover a wide range of atmospheric and exposure conditions, from heavy urban to clear tropospheric environments. At all stations, the solar UV biological dose is monitored continuously using YANKEE broad-band radiometers, together with total solar radiation, at a time resolution of 1 min. In addition, two Brewer UV spectrophotometers (one single and one double monochromator) operate at the core station continuously recording (spectral resolution, 0.5 nm) the UV solar spectrum.

All measurements of the network are gathered in the core station, where firm quality control ensures their reliability. Most of the peripheral stations are connected through modems to the core station to facilitate frequent control of their operation and data transmission. A system for the absolute calibration of all the solar radiation instruments of the network is established in the core station to ensure the precise calibration and regular maintenance of the whole network. Additional control of the instruments' stability is achieved by cross checking, at regular intervals, their measurements with those obtained by the two spectrophotometers. The data presented in this work are obtained from the stations of Thessaloniki (40.5°N), Athens (38.0°N), Kos (36.8°N) and Aktion (38.9°N). These stations provide UVB dose rate measurements weighted by the Commission Internationale d'Eclairage (CIE) erythemal action spectrum [8]. All erythemal irradiance data have been adjusted to the mean sun–earth distance before entering the calculations presented here.

A variety of ancillary measurements are also performed at this station, including the UVB erythemal irradiance, the UVA and visible global radiation, the direct-sun UVB erythemal irradiance, the UVB surface albedo and meteorological observations. In addition, a programme for monitoring

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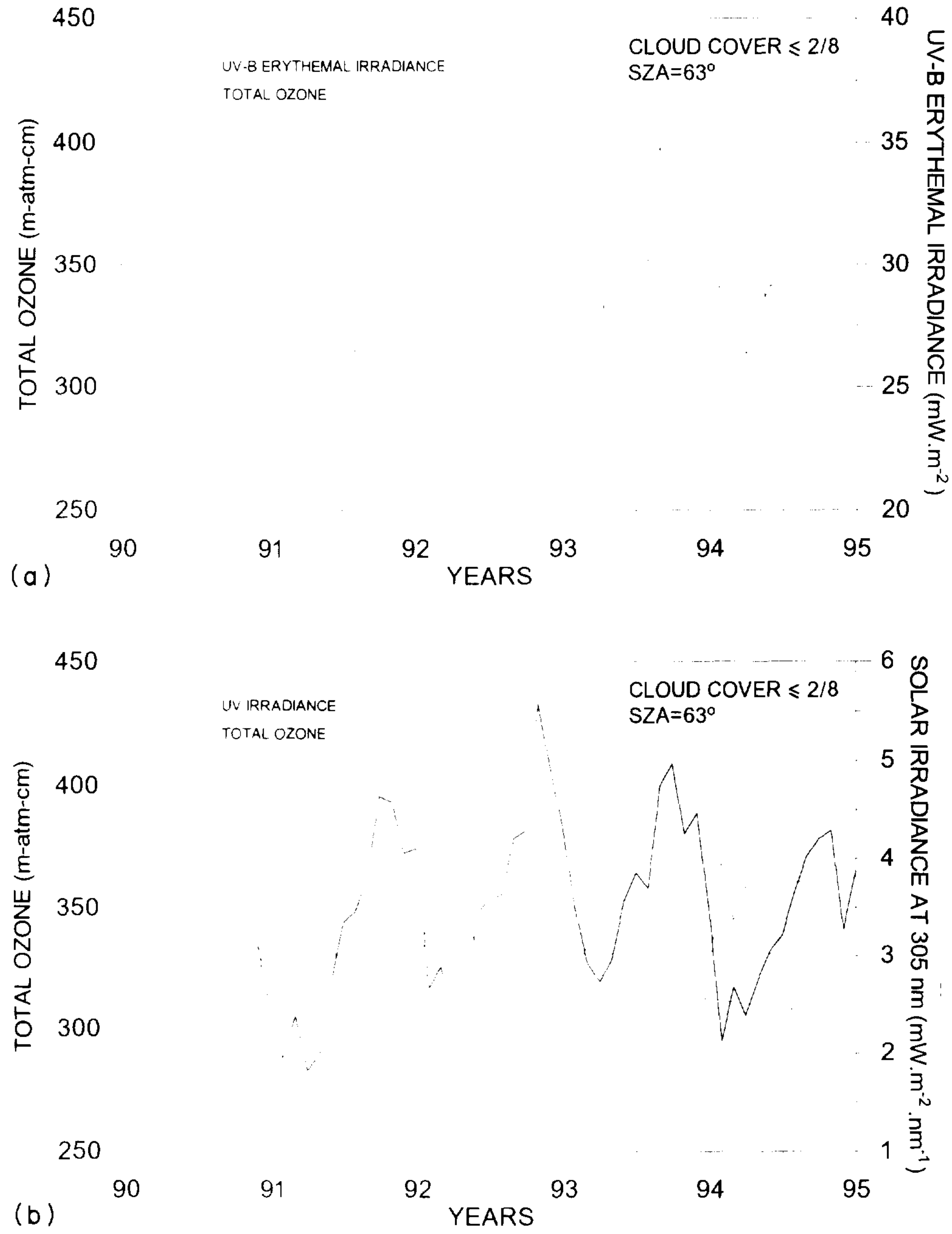

Fig. 1. (a) Monthly mean values of solar UVB erythemal irradiance (full curve) measured at 63° SZA under clear skies (cloudiness 2/8 or less) and total ozone (broken curve) at Thessaloniki during the period from August 1991 to October 1994. (b) Monthly mean values of solar UV irradiance at 305 nm (full curve) measured at 63° SZA under clear skies (cloudiness 2/8 or less) and total ozone (broken curve) at Thessaloniki during the period from November 1990 to October 1994. Straight dotted lines represent linear regression lines on the monthly mean data.

the O_3 and SO_2 total columns has been in operation since 1982 and was recently supplemented by measurements of the ozone vertical distribution (ozone soundings). Cloud cover data are taken hourly from both the nearby aerological station and visual observations at LAP.

3. Results and discussion

Fig. 1(a) shows time series measurements of total ozone (m-atm-cm) (broken line) and the erythemal irradiance (mW.m^{-2}.nm^{-1}) (full line) during the period from July 1991 to October 1994. The data shown are for practically cloudless skies (cloudiness less than 3/8) and for a constant solar zenith angle (SZA) of 63°. The opposition of the two environmental variables, i.e. O_3 and erythemal irradiance, is highly significant ($r = -0.67$, for 880 pairs) at the 99% confidence level. This anti-correlation describes the effect of ozone on the erythemal irradiance reaching the ground, being free from cloud and other seasonal effects (constant solar elevation), but it includes the influence of other factors such as air pollution and scattering processes. The latter explain

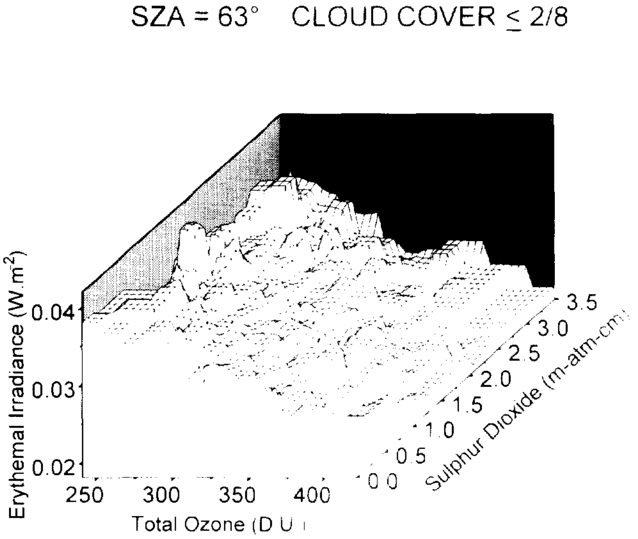

Fig. 2. A three-dimensional presentation of solar UVB erythemal irradiance measured at 63° SZA vs. total ozone and columnar SO_2 at Thessaloniki during the period from August 1991 to October 1994

more than half of the total variance of the UVB erythemal irradiance. The results in Fig. 1(a) are confirmed by independent UVB spectral measurements obtained by the Brewer spectrophotometer. For comparison, the global solar irradiance at 305 nm is presented in Fig. 1(b), together with the total ozone, for the period from November 1990 to October 1994. In addition to the overall significant anti-correlation, the time series in Fig. 1(b) shows that the gradual ozone decline in this period (1.9% per year) was accompanied by an increase of about 4% per year in the solar UV irradiance at 305 nm.

Since the effects of clouds have been discussed elsewhere [9], we show here only the dependence of the erythemal irradiance at Thessaloniki on total ozone and total columnar SO_2 amounts in Fig. 2. This figure shows that, in addition to the absorption of UVB by ozone, SO_2, which is an effective UVB absorber [10], is a significant factor determining the erythemal irradiance reaching the ground. Fig. 2 shows data for an SZA of 63° and for cloudiness less than 3/8. Both total ozone and SO_2 are in units of m-atm-cm STP (so-called Dobson units) and the erythemal irradiance is in $W.m^{-2}$. From Fig. 2, we can see that the anti-correlation between the erythemal irradiance and SO_2 is enhanced for ozone values higher than about 300 m-atm-cm STP.

Before calculating the correlation coefficient between the erythemal irradiance and SO_2, and in order to avoid the interfering ozone effect, the time series of erythemal irradiance was first de-ozonized. "De-ozonization" was performed as follows. First, we calculated an exponential regression equation relating the erythemal irradiance with total ozone. At 63° SZA, for cloudiness of 2/8 or less and for Thessaloniki, this relationship is given by the equation

$$\text{UVB erythemal irradiance} = a\,e^{-bX} \qquad (1)$$

where a and b are constants ($a = 3.24 \times 10^{-3}$ and $b = 8.14 \times 10^{-2}$) and X is the total ozone amount.

Eq. (1) is then used to "de-ozonize" the erythemal irradiance, i.e. to subtract from each value of the measured irradiance the irradiance calculated from Eq. (1) determined solely by total ozone. What remains after this de-ozonization process is the variability of the erythemal irradiance reaching the ground that cannot be determined by ozone absorption. This de-ozonized erythemal irradiance is then correlated with the columnar SO_2 amounts and the anti-correlation is statistically significant at the 99% confidence level ($r = -0.50$, for 850 pairs), explaining about 26% of the variance of the erythemal irradiance. If we restrict the calculation to those days with total ozone higher than 310 m atm cm, the correlation coefficient is enhanced to $r = -0.61$ (450 pairs) and the variance of the erythemal irradiance explained by the columnar SO_2 becomes 37%.

Fig. 3 shows the monthly mean values of the erythemal irradiance received at an SZA of 63° at four representative stations of the national network of Greece (LAPNET), together with the monthly mean total ozone values measured at Thessaloniki. Although the monthly mean erythemal irradiances at 63° SZA include all days regardless of cloudiness, the opposition of the erythemal irradiance vs. ozone is still highly significant at all stations of LAPNET and the corresponding correlation coefficients exceed the 95% significance level.

As appears from the discussion above, a considerable percentage of the variability in the erythemal irradiance can be attributed to the effect of air pollution and atmospheric aerosols. An example of such an effect can be seen in Fig. 4, which shows the average of the five largest observed daily erythemal irradiances at the three easternmost stations of LAPNET during the period from October 1993 to November 1994. Although we do not intend to quantify the overall effect of air pollution on the erythemal irradiance in this study, it is evident from this figure that the UVB erythemal irradiance levels at Kos (an Aegean island, free of air pollution) are significantly higher than those measured either in Athens or at Thessaloniki. It should be mentioned here that a fraction of the observed differences in the irradiance levels can be explained by the latitude differences between the stations. Model calculations showed that this fraction is less than half of the observed differences, which supports the hypothesis that tropospheric pollution and aerosols are capable of reducing considerably the UVB dose levels at the ground. The model used to compare the erythemal irradiance at various latitudes is the well-known Green's model [11]. In the model, we used the measured total ozone at Thessaloniki and assumed clear sky conditions and the same aerosol load for all cases. Similarly, the erythemal irradiance levels measured at Thessaloniki are much higher than those at Athens, a city with considerably higher pollution levels. This effect becomes more significant if we consider that Athens is located about 2.5° to the south of Thessaloniki.

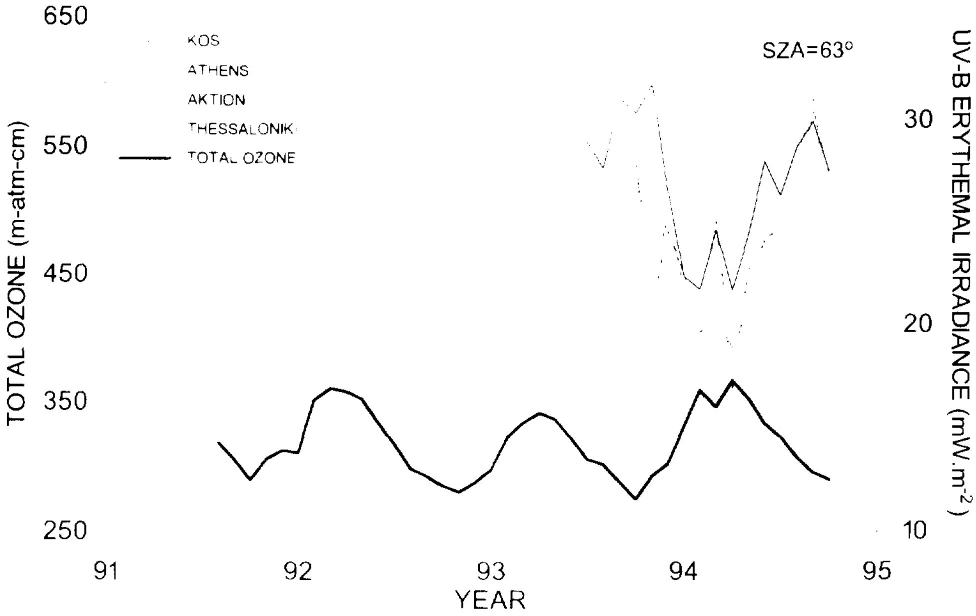

Fig. 3. Monthly mean values of UVB erythemal irradiance at 63° SZA at four representative stations of the Greek UVB network (LAPNET). The thick full line represents the monthly mean total ozone values measured at Thessaloniki

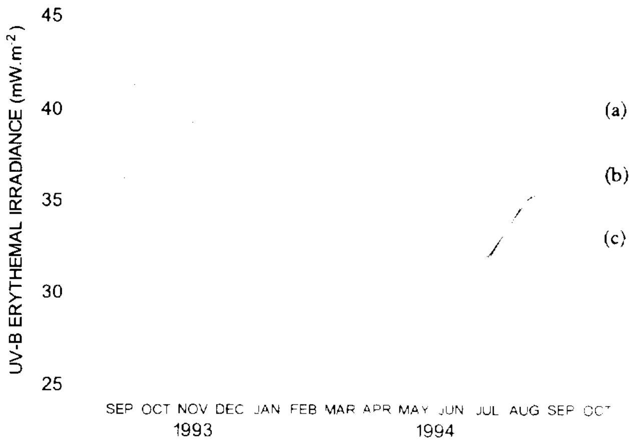

Fig. 4. Average of the five largest observed UVB erythemal irradiances in each month for the three eastern stations of LAPNET during the period October 1993 to November 1994. (a) Kos; (b) Thessaloniki; (c) Athens

4. Conclusions

From these results, the following conclusions can be made.

(1) The anti-correlation between the erythemal irradiance reaching ground level in Greece at 63° SZA in cloudless skies and ozone is highly significant ($r = -0.67$, for 850 pairs). Indeed, for all stations of LAPNET, regardless of the station location and environmental exposure, the main control over the erythemal irradiance reaching the ground is the total ozone, which explains more than 40% of the total variance of the erythemal irradiance.

(2) Similarly, a highly significant anti-correlation exists between de-ozonized measurements of the erythemal irradiance and the SO_2 column amounts ($r = -0.51$, for 850 pairs), since SO_2 is a strong UVB absorber.

(3) If we consider the overall variance of the erythemal irradiance explained by the variance of both the total ozone and columnar SO_2 amounts, this exceeds 70%, leaving about 30% of the total variance unexplained. This stresses the importance of other factors (such as haze, aerosols, albedo and other pollutants) in determining the variability of the UVB erythemal irradiance reaching ground level.

(4) Even stronger anti-correlation exists between ozone and the solar irradiance at 305 nm. The 1.9% per year decline of ozone in the last 4 years has resulted in about a 4% per year increase in the levels of solar irradiance at 305 nm.

(5) From a preliminary, qualitative comparison between the erythemal irradiances measured at three stations, it appears that air pollution can be responsible for reducing the levels of UVB erythemal irradiance reaching the surface.

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