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CASE STUDY OF UV-B MODIFICATION DURING EPISODES OF URBAN AIR POLLUTION

C. C. REPAPIS,*,† H. T. MANTIS,† A. G. PALIATSOS,‡ C. M. PHILANDRAS,†
A. F. BAIS§ and C. MELETI§

†Research Centre of Atmospheric Physics and Climatology, Academy of Athens, 3rd September Street, 131 Athens 11 251 Greece; ‡Gen. Department of Mathematics, Techn. Inst. Piraeus, Thivon Street, 250, Athens 12 244 Greece; and §Laboratory of Atmospheric Physics, University of Thessaloniki, Thessaloniki 54006, Greece

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Abstract—Examination of the record of solar ultraviolet measurements made during the MEDCAPHOT study of air pollution in the Athens basin revealed a substantial reduction of UV-B on days with high levels of pollution. The magnitude of this relation is illustrated by a comparison of the UV on two days of a pollution episode with that on two days of low pollution. © 1998 Elsevier Science Ltd. All right reserved

Key word index: UV-B radiation absorption, Athens.

1. INTRODUCTION

The biologically active solar UV-B radiation has been monitored continuously in Athens since April 1993 employing the Yankee Environmental Systems (YES) pyranometer, model UVB-1, operated as a unit in the National UV-B Observational Network of Greece (Zerefos *et al.*, 1995). Summer UV-B levels in Athens average more than 15% below those at the rural site on the island of Kos (Bais *et al.*, 1996). Bruhl and Crutzen (1989) found that tropospheric ozone, an urban pollutant, plays a disproportionate role in UV depletion. Liu *et al.* (1991), Ambach and Blumthaler (1994), and Varotsos *et al.* (1995) all report a reduction in UV irradiance by anthropogenic pollutants. The MEDCAPHOT interval of intensive study of pollution levels offers a unique opportunity for a quantitative determination of the source of this UV depletion in the Athens basin. In this preliminary study, the UV records for two days of low pollution 1–2 September 1994 (days 244 and 245) are compared with two days of a severe pollution episode 14–15 September 1994 (days 257 and 258).

2. DATA

The YES instrument is mounted on the roof of the Academy of Athens Research Centre (alt. 95 m, lat. 38° 00′ N, long. 23° 44′ E). UV observations are recorded as 10 min average values of the pyranometer output in volts. Because the relative spectral distribution of UV at the surface varies with solar elevation, the instrument signal is not linearly proportional to UV irradiance. Conversion to units of irradiance of erythemal effective radiation (EER), the spectral irradiance convoluted with the CIE action spectrum (McKinlay and Diffey, 1987), or to the irradiance in the UV-B band (280–320 nm) are obtained as solutions to the radiative transfer computation employing a model developed by Green *et al.* (1974).

Supplementary meteorological observations of total solar radiation and cloud cover are taken from the Climatological Bulletin of the National Observatory of Athens. The Observatory is located 3 km southwest of the site of the UV measurements. Daily observations of the total ozone column using the Dobson instrument are made at the Laboratory of Meteorology of the University of Athens located less than 2 km to the south. These ozone data are reported in the WMO publication, Ozone Data for the World.

The MEDCAPHOT interval 20 August–20 September is a period in which there is an annual decline both in solar elevation and in total ozone. The late summer season is also the period of decline of the strength of the Etesians, the northerly winds of the Eastern Mediterranean monsoon circulation which ventilate the Athens basin.

3. COMPARISON OF UV ON DAYS OF LOW AND HIGH POLLUTION

The annual course of UV in Athens for 1994 is shown in Fig. 1 in a time series of EER dose

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*Author to whom correspondence should be addressed.

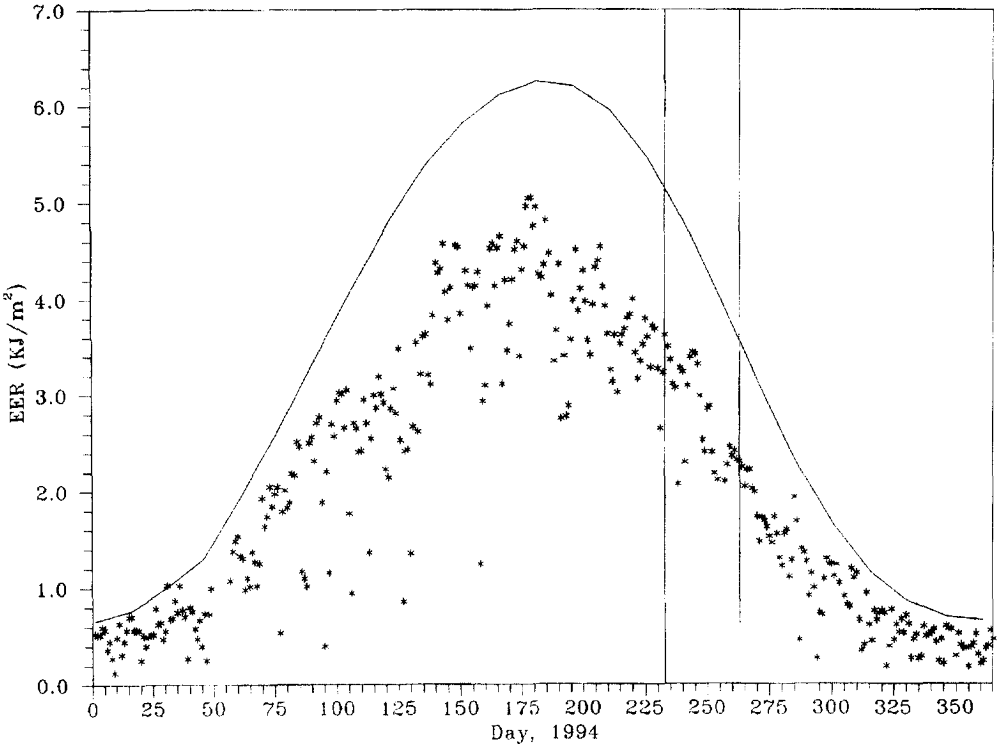

Fig. 1. Time series of EER dose at Athens, 1994. Vertical lines mark the MEDCAPHOT interval. The solid line represents a radiative transfer model solution assuming clear skies, average aerosols and a smoothed annual variation of total ozone for 1994.

($J\,m^{-2}d^{-1}$) with vertical lines marking the MEDCAPHOT interval. The solid curve gives the radiative transfer calculation of EER dose for a clear sky, average aerosol and a smoothed annual variation of the ozone column. The EER time series for the MEDCAPHOT period is shown at expanded time scale for comparison with observations of total solar radiation and cloud cover (Fig. 2, upper panel) and with ozone column (Fig. 2, lower panel). The low pollution days (244 and 245) and the high pollution days (257 and 258) are accented. The major fluctuations of the EER dose as well as the seasonal trend are well correlated with daily total solar radiation at the surface ($r = 0.94$). There is also a significant anticorrelation of both EER and total solar radiation with cloud cover; e.g. the lowest values of EER and total solar radiation occur on day 238 when the cloud cover is a maximum. Figure 2 also illustrates that day to day fluctuations in EER dose due to fluctuations in the ozone column are almost obscured by variations in cloud cover and UV depletion by other atmospheric components.

Pollution levels in Athens generally increase over the second-half of the MEDCAPHOT period and reach a maximum on the days of the pollution episode 257 and 258. Maximum values of pollutants observed in the Ministry of the Environment station network on these days are given in Table 1. Days 244 and 245 were chosen as examples of low pollution with little cloud cover and approximately the same total ozone column as the high pollution days (see Fig. 2).

Time series of UV irradiance for the low pollution days and the pollution episode are compared in Fig. 3. The irradiance is given in values of effective erythemal radiation (EER; left panel) and also as UV-B irradiance (right panel) to facilitate comparison with values reported in the literature. The smooth solid curve in the graphs in the panels on the left of Fig. 3 represent the EER irradiance calculated by a radiative transfer model (Madronich, 1987) assuming the observed ozone column and an aerosol optical depth of 0.38. Observed and modeled EER dose for the low and high pollution days are given in Table 2. The difference in UV levels under conditions of low and high pollution is expressed quantitatively by the comparison of plots of UV-B irradiance vs air mass for days 244 and 257 (Fig. 4). On the low pollution day 244, the UV-B curves are almost identical during solar ascent and descent. UV-B irradiance at air mass of 1.2 (solar zenith angle 34°) is 2.57 $W\,m^{-2}$ which is within a few per cent of the clear sky example for similar total ozone given by Estupinan in his Fig. 5 (1996).

In early morning on the high pollution day 257 (air mass 3.0; solar zenith angle ~70°) the UV-B irradiance is only a few per cent below that for the low

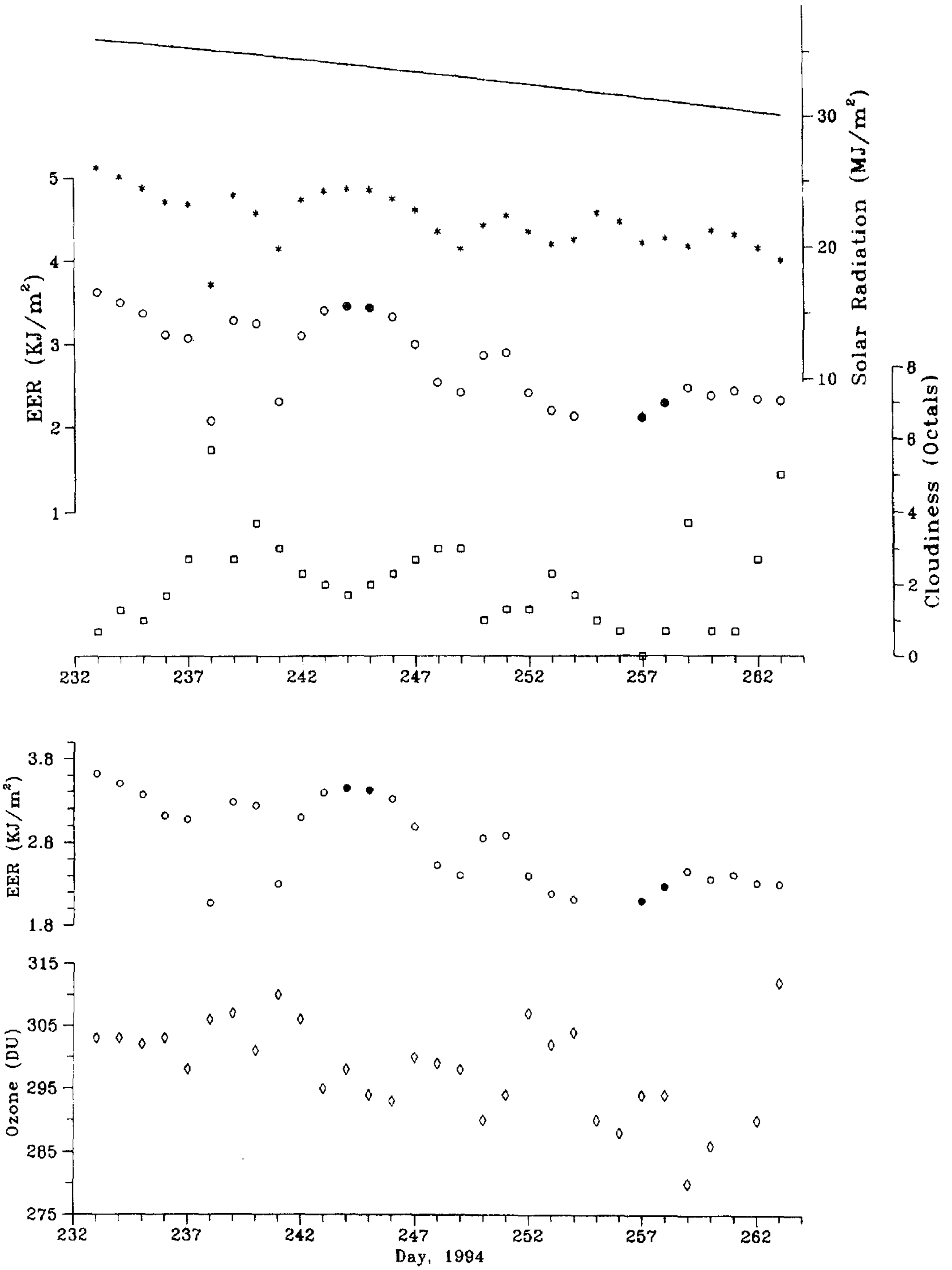

Fig. 2. Time series of EER dose (circles) for the MEDCAPHOT period compared, in the upper panel, with total solar radiation at the top of the atmosphere (solid line) and at the surface (asterisks) and with average cloud cover (squares); and, in the lower panel, with total ozone column (diamonds).

pollution day. By 10:00 LCT (air mass 1.4; solar zenith angle ~45°) the departure is greater than 35%. It is then followed by a slight recovery to a departure of only 25% in the early afternoon but the departure increases again to more than 30% by 15:00 LCT (air mass 1.6). A double diurnal maximum is also typical for pollutant emissions associated with the morning and afternoon periods of heavy traffic. Zerefos *et al.* (1995) showed the importance of the SO_2 as a UV-B absorber.

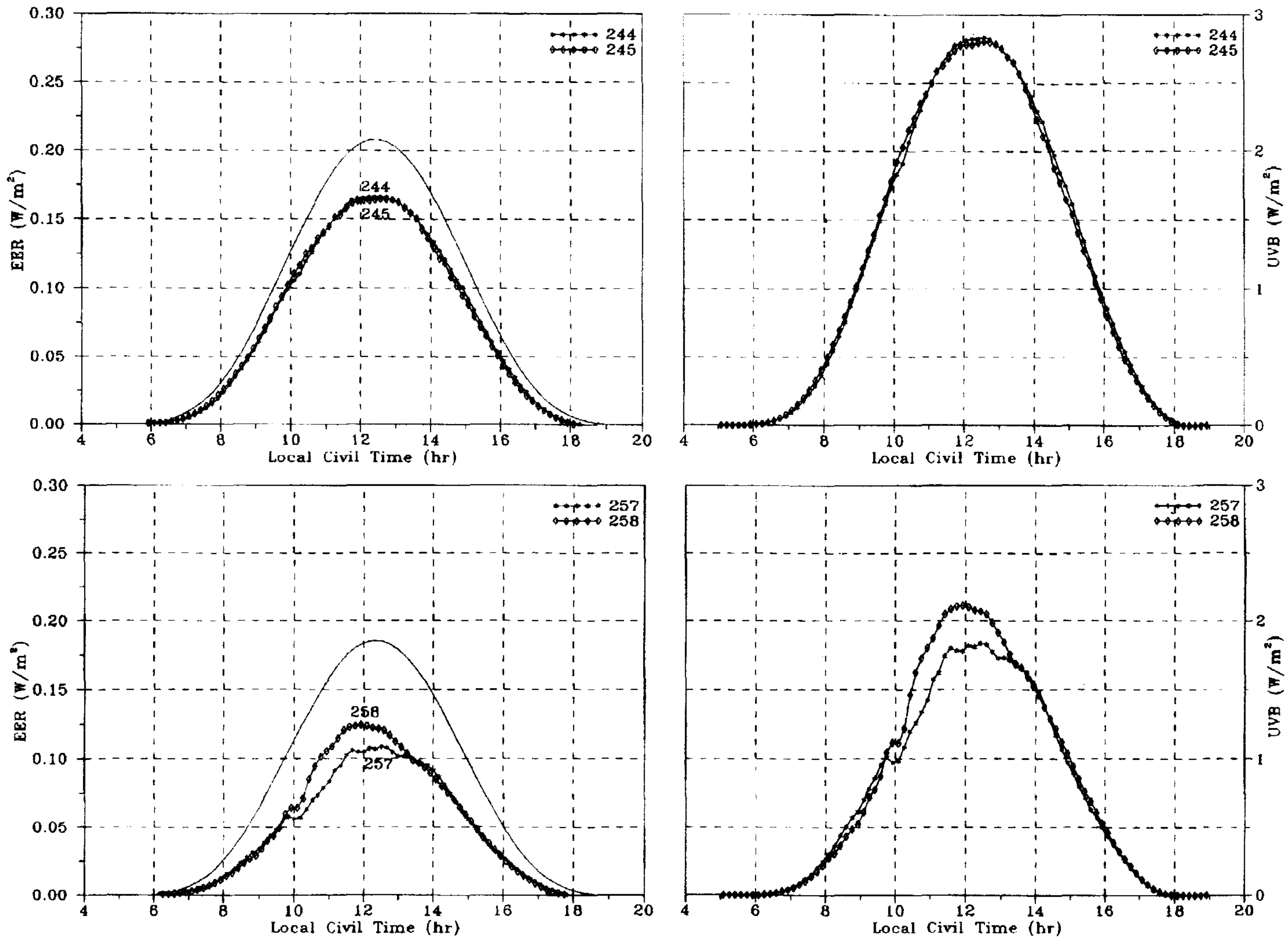

Fig. 3. Time series of UV irradiance for low pollution days 244 and 245 (upper panels) and for the pollution episode days 257 and 258 (lower panels). The irradiance is given as values of EER (left panels) and as UV-B (right panels) in W m^{-2}. The smooth curves in the EER graphs represent the model clear sky solutions (see text).

Table 1. Maximum values of the major pollutants observed at any station in the Athens network (ppbv)[a]

	1 h Avg			8 h Avg	24 h Avg	
Day	NO	NO_2	O_3	CO	SO_2	Smoke
14 Sep. (257)	516	161	156	9.0	33.6	265
15 Sep. (258)	552	198	146	8.1	49.4	265

[a] Values are given in ppbv with the exception of smoke which is in $\mu g\, m^{-3}$.

Table 2. Comparison of observed UV dose with clear sky model

Day	Ozone DU	UV-B ($kJ\, m^{-2}$)	EER ($kJ\, m^{-2}$)	EER model[a] ($kJ\, m^{-2}$)
1 Sep. (244)	298	59.9	3.45	4.36
2 Sep. (245)	294	59.5	3.43	
14 Sep. (257)	294	36.5	2.11	3.77
15 Sep. (258)	294	39.4	2.28	

[a] Madronich model assuming observed ozone and aerosol optical depth = 0.38.

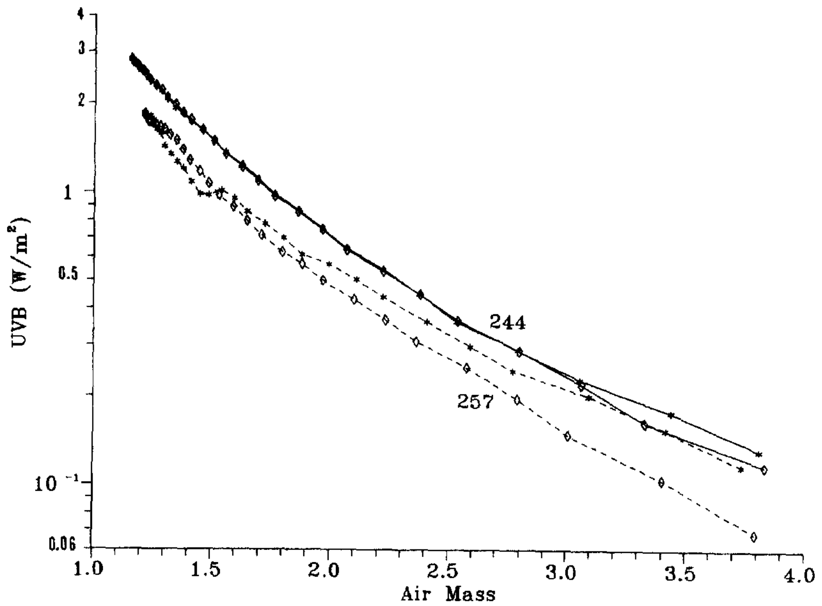

Fig. 4. UV-B irradiance vs air mass for low pollution day 244 and high pollution day 257; asterisks, observations during solar ascent; diamonds, during solar descent.

4. CONCLUSIONS

Values of EER dose during the MEDCAPHOT study were generally below that predicted by radiative transfer models assuming depletion by total ozone column and average stratospheric aerosol. The high correlation of EER with total solar radiation implies that cloud cover and aerosol load are major factors in UV depletion. Since the pollution episode day 257 was the lowest average daily cloud cover in the summer of 1994, it is assumed that the excess UV depletion on this date must be attributed to pollution. This hypothesis is also supported by the correspondence in the diurnal growth of pollutants and UV depletion. It will require a more detailed examination of the pollution records with their radiative properties to establish the source of the UV depletion quantitatively. Since the ozone column measurements are usually made near noon when the excess UV depletion is very large it would appear that diurnal variation of components of the pollution other than ozone must be important in producing the depletion.

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