Hrvatski meteorološki časopis, 35/36, 37–44, 2000/01.

UDK: 551.521.17
Prethodno priopćenje

ERYTHEMALLY EFFECTIVE UV RADIATION IN ZAGREB DURING MAY 1999

Eritemalno učinkovito UV zračenje u Zagrebu tijekom svibnja 1999.

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Primljeno 7. ožujka 2001, u konačnom obliku 30. ožujka 2001.

Abstract: This paper is a presentation of erythemally effective irradiance measurements carried out in Zagreb, Croatia. The amounts of UV irradiance are expressed as erythemally effective dosages in $MEDh^{-1}$, where one MED equals 250 Jm^{-2}. The paper presents the results obtained in May 1999. The maximal and minimal noontime means of erythemally effective irradiance were 3.149 $MEDh^{-1}$ and 0.508 $MEDh^{-1}$, respectively. The daily course in clear sky conditions has a bell-shape distribution. For cloudy sky, the daily course curve is asymmetrical with reduced amounts of erythemally effective dosages.

Simultaneous measurements of global irradiation and relative humidity were used to examine their connection with erythemally effective dosages. The simple linear regression method has shown that the relationship between erythemally effective dosages (predictand) and global radiation (predictor) gives better results than the same method with relative humidity as a predictand. On the other hand, the highest value of the correlation coefficient was obtained by multiple linear regression including both predictors. However, the improvement was not significant compared to the results obtained by simple linear regression with global radiation as the only predictand.

Key words: erythemally effective irradiance, global irradiation, relative humidity.

Sažetak: U radu su dani rezultati mjerenja eritemalno učinkovitog zračenja u Zagrebu, Hrvatska. Iznos UV zračenja prikazan je kao eritemalno efektivna doza izražena u $MEDh^{-1}$, pri čemu 1 $MEDh^{-1}$ odgovara 250 Jm^{-2}. U radu su prikazani rezultati dobiveni za svibanj 1999. godine. Najveća i najmanja srednja podnevna vrijednost eritemalno učinkovitog zračenja bila je 3.149 $MEDh^{-1}$, odnosno 0.508 $MEDh^{-1}$. Krivulja dnevnog hoda u uvjetima vedrog neba ima zvonolik oblik. Za oblačne dane ona je nepravilnog oblika i manjih iznosa eritemalno efektivnih doza.

Istovremena mjerenja globalnog zračenja i relativne vlažnosti korištena su za procjenu njihove povezanosti s eritemalno efektivnim dozama. Jednostavna linearna regresija pokazala je da veza između eritemalno efektivnih doza (zavisna varijabla) i globalnog zračenja (nezavisna varijabla) daje bolje rezultate nego ista metoda koja kao nezavisnu varijablu koristi relativnu vlažnost. S druge strane, najveće vrijednosti koeficijenta korelacije postižu se korištenjem višestruke linearne regresije koja uključuje obje nezavisne varijable. Međutim, poboljšanje nije znatno u usporedbi s rezultatima linearne regresije s globalnim zračenjem kao nezavisnom varijablom.

Ključne riječi: eritemalno učinkovito zračenje, globalno zračenje, relativna vlažnost.

1. INTRODUCTION

Stratospheric ozone depletion increases the amount of ultraviolet radiation reaching the ground. Since UV radiation has an important impact on the biosphere, its increase has caused concern about the sensitivity of UV irradiation to atmospheric conditions. Various numerical models have been developed in order to estimate the contribution of different atmospheric constituents and processes to UV transfer through the atmosphere (Burrows, 1997; Dvorkin and Steinberger, 1999; Forster, 1995; Zeng *et al.*, 1994). A reduction in the number of model predictors decreases the accuracy of the modelled values. However, according to Burrows' recent study (1997), models with more than one predictor can give satisfying results.

Besides scientific purposes, UV forecasting can be used to inform the public about expected UV dosages and potential dangerous health affects. Thus, being given expert advice on protective behaviour, people can avoid overexposure and minimize health risks. The erythemal effectiveness of UV radiation is wavelength dependent. For a better perception of the influence of UV radiation on the human skin, erythemally effective irradiation (EER) is commonly used. It has been internationally recommended to use the McKinley and Diffey action spectrum to obtain EER. It is a standard erythemal action spectrum adopted by the Commission Internationale de l'Eclairage (CIE). The action spectrum gives the spectral response of human skin to UV radiation. EER is the product of the actual UV-spectral irradiance and the erythemal action spectrum. If EER is integrated over the 290–400 nm wavelength range, it gives the skin harmful dose of UV radiation. Furthermore, instantaneous doses can be integrated over a period of time (usually an hour) to get a dosage of EER energy. The smallest EER dosage, which induces reddening of the skin or erythema, is called the minimal erythemal dose (MED). Since every person has his/her own individual skin characteristics, the MED sufficient to produce erythema also depends on the skin type of the person. However, the skin can be classified into one of six general types (Webb, 1995), so the EER dosage can be calculated for every skin type separately.

In order to inform the public about the intensity of UV radiation and about its possible effects on human health, it is useful to express it as an ultraviolet index (UVI) or in sunburn time. The UVI is a unitless value obtained as a ratio of the erythemally weighted dose rate and the WMO standard UV index unit (25 mWm^{-2}) (Long *et al.*, 1996). The 25 mWm^{-2} is the representative EER dosage required to produce reddening of white, fair skin (which can be described as skin that never tans and always burns). Sunburn time is a way to inform the public about how long the human skin can be exposed to the sun before erythema (reddening or sunburn) occurs. It is usually expressed in minutes and also depends on the skin type. It can be calculated by dividing 60 minutes by the amount of MED in one hour. It is commonly calculated for solar noon (when EER is the most intensive in clear sky conditions) and for the most sensitive skin type. It is very important to note that both, the UVI and the sunburn time are only relevant as general information, while the real damage caused by UV irradiation depends on the individual characteristics of each person. It should be emphasised that there are other definitions of MED and UVI. For instance, Josefsson (1997) defined 1 MED as equal to 210 Jm^{-2}. Thus, the numerical values given by different authors have to be considered carefully before making any comparison.

Forster *et al.* (1995) have modelled UV radiation at the earth's surface and shown that UVB irradiance is strongly affected by the vertical profile of the ozone and by the temperature of the ozone layer. The influence of aerosol depends on its type and size, and on the vertical position of the aerosol layer. It also depends on the solar zenith angle (which determines the path of the solar beam through the atmosphere and thus influences scattering and absorption).

Various models have been used to estimate cloud effects. Cloud influence on UV radiation is important as well as the influence of ozone (Bais *et al.*, 1997). According to Long *et al.* (1996), the forecasted values for cloudy sky conditions overestimate the measured UVI. For clear sky conditions, the model underestimates the measured UV values. Furthermore, Forster *et al.* (1995) have found that the difference between modelled and measured UVB irradiance is larger for cloudy than for clear sky conditions.

This paper presents the results of measurements of erythemally effective UV irradiance during May 1999. Cloud influence on the daily courses is evident. Changeable cloudiness can be easily recognised by the specific jagged shape of the daily curve. As global irradiance and relative humidity were measured at the same place, an attempt was made to find their connection with EER. For this purpose, both simple and multiple linear regression was applied.

2. INSTRUMENTS AND DATA

Measurements of erythemally effective UV radiation have begun recently at the Andrija Mohorovičić Geophysical Institute, Zagreb, Croatia. Measurements are performed by a Scintec UV-S-E-T sensor. This sensor has a spectral response that is adapted to the erythema (sunburn) action spectrum of the human skin (CIE 1987 weighting). The sensor has an internal termostatting at 25°C. The output is expressed in MED per hour, where 1 MED equals to 250 Jm^{-2} after weighting with the CIE 1987 erythema action spectrum. Hourly mean values expressed in $MEDh^{-1}$ are used in this paper. The sensor has a cosine error of ±4% at the zenith angle from 0° to 70°.

Hourly measurements of global irradiation on a horizontal surface are made by a Moll-Gorczynski pyranometer (type Kipp&Zonnen, CM6), which is part of the META 801 automatic meteorological station. The pyranometer works in the 300 nm – 2.5 nm wavelength range. The hourly values of global irradiation used in this study are expressed in Jcm^{-2}. The UV sensor and the pyranometer are located on the roof of the Institute approximately 10 m above the ground. The horizon is fully open without any objects which could shadow the instruments. Relative humidity, which is also used in this work, is measured by a hair hygrometer (A. Thies type 1000), also part of the META 801 station. The measurement range is from 10% to 100%, the hourly mean values being expressed as percentage. The instruments are constantly supervised by the experts of the Jozef Stefan Institute (Ljubljana, Slovenia), and the necessary calibrations are regularly performed.

3. RESULTS AND DISCUSSION

3.1. Diurnal courses for cloudy and clear sky conditions

The hourly means of the EER dosages for two days in May 1999 (clear and cloudy conditions) are presented in figure 1. On the cloudy day, cloudiness was 10, 9 and 7 tenths at 7, 14 and 21 CET time, respectively.

The EER dosages exhibit a bell-shaped diurnal distribution with the maximum at noon, which is characteristic for clear sky conditions. The beginning and the end of the curve coincide with sunrise and sunset, while the

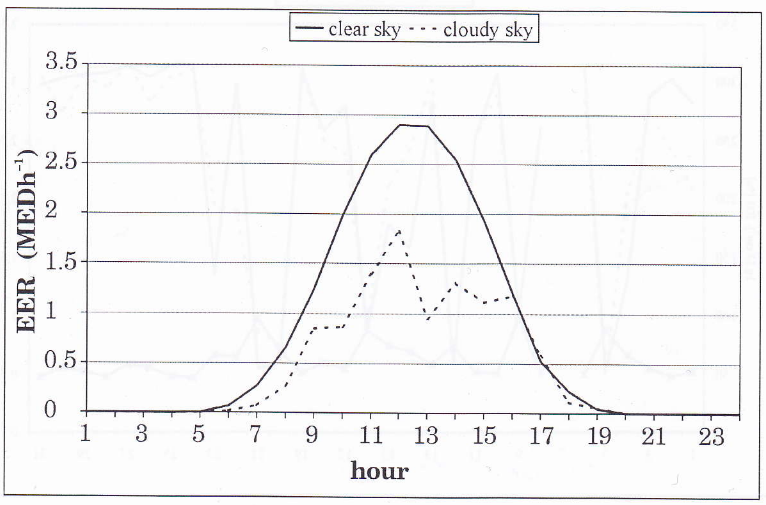

Figure 1: Hourly means of erythemally effective radiation dosages for clear sky conditions (10 May, bold line) and for cloudy sky conditions (16 May, dashed line).

Slika 1: Satni srednjaci eritemalno učinkovitog zračenja u uvjetima vedrog neba (10. svibnja, puna linija) i uvjetima oblačnog neba (16. svibnja, crtkana linija).

maximum is at noon (2.899 $MEDh^{-1}$). The corresponding sunburn time is approximately 21 minutes.

The influence of cloudiness can be easily noted on the diurnal course of EER for cloudy conditions. The curve does not have a regular bell shape in this case. Changeable cloudiness resulted in an asymmetrical diurnal course with marked peaks. The noontime mean value of EER was about two-thirds of the noontime value on the clear sky day. The instantaneous EER dosage at 7 a.m. on 10 May (with one-tenth cloudiness) was 0.405 $MEDh^{-1}$, while the EER dosage at the same hour on 16 May (with 10-tenths cloudiness) was 0.100 $MEDh^{-1}$. Thus, the EER dosage is about 4 times grater on a clear sky than on a cloudy sky day. Consequently, the sunburn time is 4 times longer on a cloudy day. The instantaneous EER dosage at 2 p.m. on 10 May (with one-tenth cloudiness) was 2.311 $MEDh^{-1}$. The EER dosage at the same time of day on 16 May (with nine-tenth cloudiness) was 0.913 $MEDh^{-1}$, which is 2.5 times smaller than on 10 May. Obviously, EER dosage is markedly influenced by clouds. However, the variability of the diurnal course and the smaller amounts of EER dosage in days with cloudy sky conditions can not be attributed only to the amount of cloud covering the sky. A more detailed analysis of EER changes should include all the other elements that influence UV radiation transfer through the atmosphere – cloud optical depth, ozone, aerosols, etc.

3.2. Monthly course

The noontime means of EER dosages, noon values of global irradiation (Ig) and noontime means of relative humidity (RH) during May 1999 are presented in figure 2. The data for 7 May are omitted because UV data for this day were not available. The minimal amounts of the noontime EER, Ig and RH were 0.508 $MEDh^{-1}$, 52 Jcm^{-2} and 47%, respectively. The corresponding maximal noon values were 3.149 $MEDh^{-1}$, 316 Jcm^{-2} and 98 %. The maximal sunburn time was 118 minutes, while the minimal was 19 minutes. The average monthly values of noontime EER, Ig and RH were 2.27 $MEDh^{-1}$, 230.87 Jcm^{-2} and 62.07%, respectively. The monthly course of EER corresponds to the monthly course of Ig. The negative correlation between EER and RH and as well as between Ig and RH is obvious. It is well known that absorption by water vapour has a significant influence on the transfer of solar radiation through the atmosphere. Water vapour absorption essentially covers the entire infrared region of the solar spectrum. An increase in RH indicates an increase in water vapour content and the-

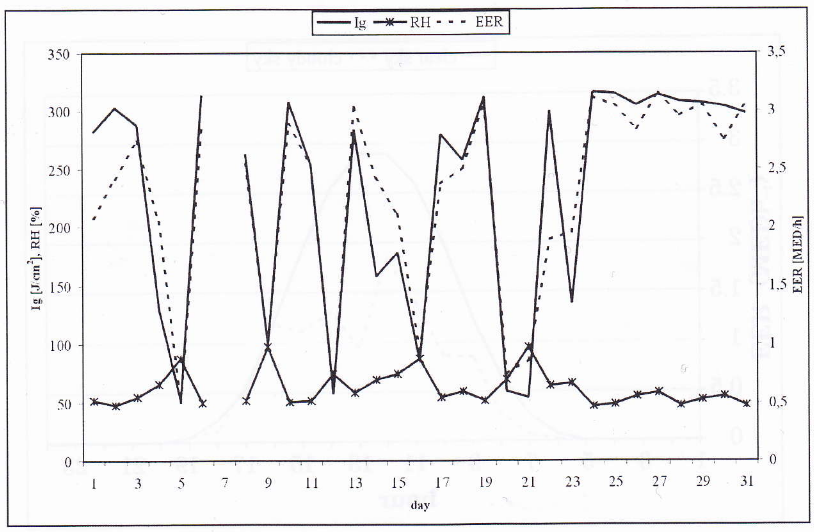

Figure 2: Noontime means of erythemally effective radiation dosages (dashed line), relative humidity (bold line with stars) and noontime global irradiation (bold line).

Slika 2: Podnevni srednjaci doza eritemalno učinkovitog zračenja (crtkana linija), relativne vlažnosti (puna linija sa zvjezdicama) i podnevnog globalnog zračenja (puna linija).

refore greater absorption. Consequently, global irradiation decreases. Water vapour does not have an impact on the absorption of UV radiation, which is mainly affected by stratospheric ozone. However, RH can influence aerosol scattering and consequently radiation quantities (e.g. visibility). Also, Rayleigh's scattering is very important for UV radiation transfer due to the well-known reciprocal dependence on the fourth power of wavelength. Relative humidity influences Rayleigh's scattering cross sections slightly and hence the refractive index of the air. Thus, RH is negatively correlated to EER. It is worth to mention that water vapour has also an indirect effect on UV radiation through formation of aerosols and cloud droplets.

3.3. Interdependence of EER, Ig and relative humidity

As EER, Ig and RH are measured simultaneously at the same location, their possible dependence was examined. The simplest is linear dependence. Based on the data for May 1999, EER–Ig, EER–RH and Ig–RH linear regressions have been made for every hour. The absolute values of correlation coefficients (r) for EER–Ig, EER–RH and Ig–RH regressions are plotted in figure 3.

Student's t-test has shown that all the coefficients are significant at a 99% level. The calculated values of correlation coefficients vary during the day. Generally, the r-values are smaller in the morning and early evening. The largest values are in the middle of the day. Astronomical factors, as the annual variation of the Sun–Earth distance and the diurnal variation of the incidence angle of solar radiation, have a significant impact on the amounts of UV and global radiation reaching the ground. The Sun–Earth distance does not change significantly through the day, but the incidence angle does. So, the diurnal changes in UV, Ig and RH interdependence is partly due to the Sun's movement across the celestial sphere. The Sun travels along the celestial sphere from approximately east to west each day. The position of the Sun determines the incidence angle of solar radiation on the top of the atmosphere and hence the amounts of direct and diffuse irradiation. The Sun's position on the celestial sphere is usually specified by the angle of solar altitude. Solar altitude is the highest at solar noon, and so the corresponding incidence angle is the biggest. As the Sun moves along a circle on the celestial sphere, the direct and diffuse irradiation received at some place on the Earth change during the day. Direct irradiation reaches its greatest amount at solar noon, while the por-

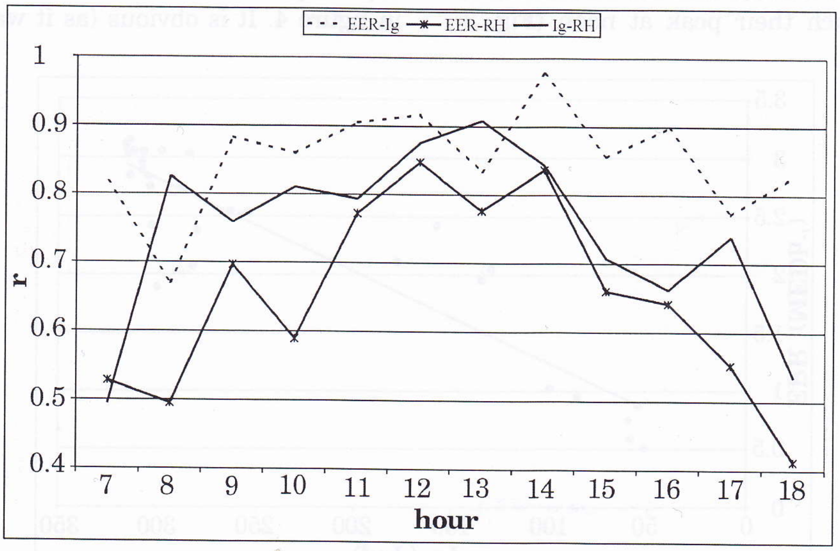

Figure 3: The absolute values of the correlation coefficients of the EER–Ig (dashed line), EER–RH (bold line with stars) and Ig–RH (bold line) linear regressions.

Slika 3. Apsolutne vrijednosti koeficijenata korelacije linearnih regresija: EER–Ig (crtkana linija), EER–RH (puna linija sa zvjezdicama) i Ig–RH (puna linija).

tion of the direct radiation in global radiation is reduced at the beginning and at the end of the day. UV radiation is also more scattered at the beginning and at the end of the day, but different atmospheric constituents act in the scattering processes than in global radiation. In the middle of the day, the path of the solar beam is the shortest, so UV and global radiation is effected by scattering and absorption processes to a lesser extent. Thus, there is a close connection between EER and Ig. After sunrise and before sunset, the incidence angles are smaller and the portion of diffuse radiation is increased as scattering increases. Due to the fact that there are differences in the scattering processes of UV and global radiation, a decrease in the solar altitude angle causes weakening of the EER–Ig interdependence.

3.4. Linear regression

As shown in previous sections, there is a significant correlation between EER, Ig and RH. The noon value of EER is commonly used because, in clear sky conditions, UV irradiance reaches its peak–amount at noon. Thus, the EER dosage is most harmful in this part of the day. Consequently, sunburn time is minimal and therefore exposure to the sun should be the shortest. In accordance with the aforesaid and with the fact that the correlation coefficients reach their peak at noon (Fig. 3), the noontime values during May 1999 are considered in this chapter.

Linear regression is a simple statistical model based on the least–squares regression procedure. It is useful in statistical forecasting and for the interpolation of missing data. Due to many factors, some of the measured values can be insufficient. Therefore, it is worth to find a possible connection between elements measured at the same place, which may be used for bridging data gaps. The available measured data determine which predictors will be used. Naturally, there has to be a physical connection between the predictors and the predictand. The linear regression is presented by the regression parameter, b_1 (the slope), and the regression constant, b_0, which determine the equation of the particular straight line, $y = b_1x + b_0$. The real, measured values differ from the values obtained by the regression equation, so the goodness of fit can be demonstrated by the sum of squared errors (SSE) or by the correlation coefficient (r).

A linear regression between *EER* (dependent variable, i.e. predictand) and *Ig* and *RH* (independent variables, i.e. predictors) has been made. The linear regression of the form:

$$EER = 0.008Ig + 0.449 \quad (1)$$

superimposed on the measured data is shown in figure 4. It is obvious (as it was expected)

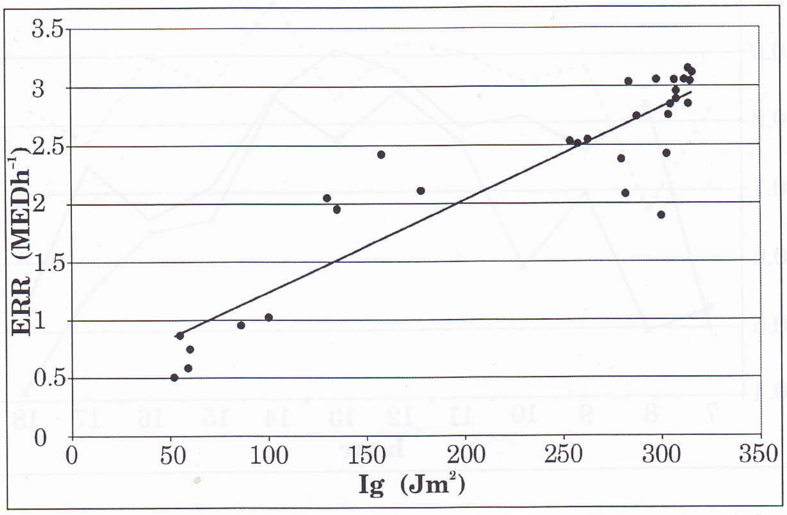

Figure 4: The linear regression between EER and Ig (bold line) based on measured data in May 1999 (points).

Slika 4: Linerna regresija za EER i Ig (puna linija) na temelju podataka za svibanj 1999. godine (točke).

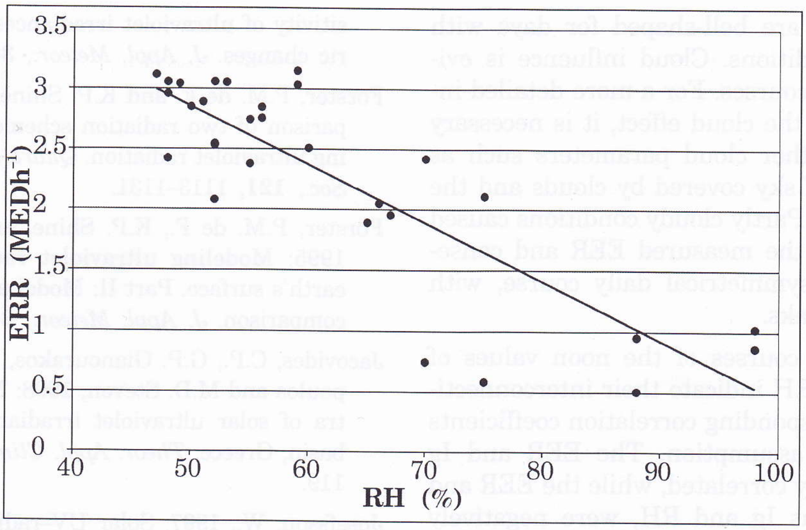

Figure 5: The linear regression between EER and RH (bold line) based on measured data in May 1999 (points).

Slika 5: Linearna regresija za EER i RH (puna linija) na temelju podataka za svibanj 1999. godine (točke).

that the regression line shows a positive EER–Ig correlation. The correlation coefficient is 0.917 and the SSE is equal to 3.276. So, a high correlation coefficient indicates significant correlation between the EER and Ig noon values in May 1999.

Figure 5 presents the linear regression line of the form:

$$EER = -0.048RH + 5.261 \quad (2)$$

together with the measured data. The associated absolute correlation coefficient is r = 0.847, which is smaller than in the earlier case, but it is still significant at a 99% level. The SSE is 5.811 (greater than the previous). This shows the regression is stronger when Ig is used as the predictor.

In accordance with the above results, the EER dosages are in correlation with both Ig and RH with significant correlation coefficients. Therefore, an attempt was made to present the EER dosages by using both predictors through a more general model of multiple linear regression. This is commonly used when a predictand is presented with more then one predictor. The prediction equation in the case of two predictors takes the form $y = b_1x_1 + b_2x_2 + b_0$. Again, the regression parameters can be found by minimising the sum of squared residuals. Based on the noon data of EER, Ig and RH for May 1999, the multiple regression resulted in the equation:

$$EER = 0.007Ig - 0.011RH + 1.451 \quad (3)$$

The corresponding correlation coefficient is 0.92 (the SSE is 3.10). Evidently, this method gives the highest correlation coefficient. However, an examination of the Ig–RH dependence also indicated their connection. They were negatively correlated with the absolute correlation coefficient $r = 0.876$ (greater than for EER–RH dependence). Thus, the predictors are strongly correlated and the use of both of them is not appropriate. It can be presumed that EER dependence on Ig already, in a certain amount, contains a mechanism of RH influence on EER. Furthermore, it is well known that the more predictors are used, the more unreliable regression is. The multiple regression in relation to the EER–Ig simple linear regression has given a correlation coefficient that increased only by 0.3%, while the sum of squared errors decreased by 5.4%. Consequently, the use of a more complicated linear regression is not reasonable.

4. CONCLUSIONS

This paper presents the first results of erythemally effective ultraviolet radiation measurements performed in Zagreb, Croatia. The daily courses are bell-shaped for days with clear sky conditions. Cloud influence is evident on daily courses. For a more detailed investigation of the cloud effect, it is necessary to examine other cloud parameters such as the portion of sky covered by clouds and the optical depth. Partly cloudy conditions caused variability in the measured EER and consequently an asymmetrical daily course, with prominent peaks.

The monthly courses of the noon values of EER, Ig and RH indicate their interconnection. The corresponding correlation coefficients confirm this assumption. The EER and Ig were positively correlated, while the EER and RH as well as Ig and RH, were negatively correlated. The correlation coefficients also differed during the day. Generally, the highest r-values appeared in the middle of the day.

The dependence between EER, Ig and RH was investigated by simple and the multiple linear regression models. Based on the corresponding correlation coefficients and on the sum of squared errors, multiple regression has given the best presentation of measured data. However, the improvement obtained by multiple regression in relation to the EER–Ig simple linear regression, is not considerable.

Acknowledgement: *The author is thankful to Dr. Sc. Zujezdana Bencetić Klaić for reading the manuscript and advising.*

REFERENCES

Bais, A.F., M. Blumthaler, A.R. Webb, J. Groebner, P.J. Kirsch, B.G. Gardiner, C.S. Zerefos, T. Svenoe and T.J. Martin, 1997: Spectral UV measurements over Europe within the Second European Stratospheric Arctic and Midlatitude Experiment activities. *J. Geophys. Res.*, **102(D7)**, 8731–8736.

Burrows, W.R., 1997: CART regression models for predicting UV radiation at the ground and in the presence of cloud and other environmental factors. *J. Appl. Meteor.*, **36**, 531–544.

Dvorkin, A.Y. and E.H. Steinberger, 1999: Modeling the altitude effect on solar UV radiation. *Solar Energy*, **65**, 181–187.

Forster, P.M. de F., 1995: Modeling ultraviolet radiation at the earth's surface. Part I: The sensitivity of ultraviolet irradiances to atmospheric changes. *J. Appl. Meteor.*, **34**, 2426–2439.

Forster, P.M. de F. and K.P. Shine, 1995: A comparison of two radiation schemes for calculating ultraviolet radiation. *Quart. J. Roy. Meteor. Soc.*, **121**, 1113–1131.

Forster, P.M. de F., K.P. Shine, and A.R. Webb, 1995: Modeling ultraviolet radiation at the earth's surface. Part II: Model and instrument comparison. *J. Appl. Meteor.*, **34**, 2426–2439.

Jacovides, C.P., G.P. Gianourakos, D.N. Asimakopoulos and M.D. Steven, 1998: Measured spectra of solar ultraviolet irradiances at Athens basin, Greece. *Theor. Appl. Climatol.*, **59**, 107–119.

Josefsson, W., 1997: Solar UV–radiation monitoring 1996. *SMHI Reports Meteorology and Climatology*, RMK No. **74**, 1–7.

Long, C.S., A.J. Miller, L. Hai-Tien, J.D. Wild, R.C. Przywarty and D. Hufford, 1996: Ultraviolet index forecasts issued by the National Weather Service. *Bull. Amer. Meteor. Soc.*, **77**, 729–748.

Lubin, D., E.H. Jensen and H.P. Gies, 1998: Global surface ultraviolet radiation climatology from TOMS and ERBE data. *J. Geophys. Res.*, **103(D20)**, 26061–26091.

O'Hirok, W. and C. Gautier, 1998: A three-dimensional radiative transfer model to investigate the solar radiation within a cloudy atmosphere. Part II: Spectral effects. *J. Atmos. Sci.*, **55**, 3065–3076.

Scotto, J., G. Cotton, F. Urbach, D. Berger and T. Fears, 1988: Biologically effective ultraviolet radiation: Surface measurements in the United States, 1974 to 1985. *Science*, **239**, 762–764.

Seckmeyer, G., R. Erb, and A. Albold, 1996: Transmittance of a cloud is wavelength-dependent in the UV-range. *Geophys. Res. Lett.*, **23**, 2753–2755.

Seckmeyer, G., B. Mayer, G. Bernhard, R. Erb, A. Albold, H. Jäger and W.R. Stockwell, 1997: New maximum UV irradiance levels observed in central Europe. *Atmos. Environ.*, **31**, 2971–2976.

Webb. A.R., 1995: To burn or not to burn. *Weather*, **50**, 150–154.

Wilks, D.S., 1995: Statistical methods in the atmospheric sciences. Academic Press, San Diego, 467 str.

Zeng, J., R. McKenzie, K. Stamnes, M. Wineland and J. Rosen, 1994: Measured UV spectra compared with discrete ordinate method simulations. *J. Geophys. Res.*, **99**, 23019–23030.