

Analysis of UV-B irradiances measured simultaneously at two stations in the Czech Republic

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Abstract. The 10 min sums of erythemal UV-B irradiances measured during approximately 10 months at two locations with different altitudes were analyzed. The magnitude of the altitude effect averaged over the whole period varies between 4 and 8%/1000 m. The value of radiation amplification factor (RAF) derived from the relationship between UV-B irradiance and total ozone is about 1.1. The value of RAF is slightly higher if derived from the relationship between the ratio of UV-B to global solar irradiance and total ozone. A statistical model relating clear-sky UV-B irradiance with solar zenith angle, total ozone, and Julian day was developed. Unfortunately, knowledge of the daily average total column ozone does not adequately improve the forecast of UV-B irradiance.

1. Introduction

The results of measurements all over the world indicate that the atmospheric total ozone is decreasing [Bojkov *et al.*, 1995; Chandra *et al.*, 1996; Rusch *et al.*, 1994; Reinsel *et al.*, 1994; Vaniček *et al.*, 1992]. As the ozone filters the harmful UV-B radiation (280-315 nm), the reduction of total ozone causes an increase in the terrestrial UV-B dosages, which has contributed to the rise of human interest in UV-B radiation and ozone.

Solar UV-B radiation intensity measured at the ground level is governed mainly by four factors: (1) the length of the path of solar beams through the Earth's atmosphere, (2) cloudiness and atmospheric turbidity, (3) total ozone concentration, and (4) surface albedo [Burrows, 1997]. The length of the path is determined by the altitude of the measuring site and solar zenith angle. The influences on UV-B from clouds and solar zenith angle variations dominate over ozone effects [McKenzie *et al.*, 1991]. However, for given solar zenith angle, clear-sky and no-snow-cover conditions, the total ozone is the main factor.

As the harmfulness of UV-B radiation decreases with increasing wavelength, the dosage of the UV-B radiation can be expressed in terms of erythemally weighted solar irradiance, "erythemal irradiation" [McKinlay and Diffey, 1987]:

$$E = \int w_E(\lambda) I(\lambda) d\lambda \quad (1)$$

where $I(\lambda)$ is spectral irradiance and $w_E(\lambda)$ is an erythemal weighting function (equal to erythemal action spectrum).

The relationship between changes in clear-sky erythemal irradiance and total ozone Ω is commonly expressed with use of the radiation amplification factor (RAF):

$$\Delta(\ln E) = -\text{RAF} \Delta(\ln \Omega), \quad (2)$$

which implies

$$\frac{E}{E_0} = \left(\frac{\Omega}{\Omega_0} \right)^{-\text{RAF}}, \quad (3)$$

where Ω_0 and E_0 are the reference values of total ozone and erythemal UV-B radiation. The recent studies [McKenzie *et al.*, 1991; Németh *et al.*, 1996; Ambach *et al.*, 1997] indicate that the value of RAF is close to 1.0.

In 1996-1998, a joint project of the Institute of Atmospheric Physics and the Czech Hydrometeorological Institute (CHMI) was run. The aims of the project included (1) monitoring of UV-B radiation on a territory of the Czech Republic, (2) operational information service [Vaniček, 1996, 1998], and (3) short-range forecasting of UV-B radiation intensity [Vaniček, 1998]. The present study gives the analysis of the data obtained during the period August 1996 to June 1997. The paper consists of the following points: (1) comparison of the UV-B measurements made at the two locations, including quantification of the altitude effect (section 3); (2) determination of the radiation amplification factor and its dependence on a solar zenith angle (section 4.1); and (3) determination of the regression function relating UV-B irradiance with solar zenith angle and total ozone (section 4.2).

2. Data

UV-B radiation was measured simultaneously by Robertson-Berger broadband filter UV radiometer (RB-biometer) at two sites: Hradec Králové (HK) (50.17° N, 15.83° E; 278 m above sea level (asl), operated by the Solar and Ozone Observatory of CHMI [Vaniček, 1995, 1996]) and Milešovka (MIL) (50.55° N, 13.93° E; 827 m asl, operated by the Institute of Atmospheric Physics). The HK station is located on a southern periphery of the town (100,000 inhabitants) in a flat lowland area of the river Labe basin. The MIL station lies on top of an isolated hill located in the "České středohoří" mountain range in northwestern Bohemia.

The data used in the present study include (1) 10 min sums of UV-B irradiance measured by the two RB-biometers; (2) daily averages of total ozone concentration measured by

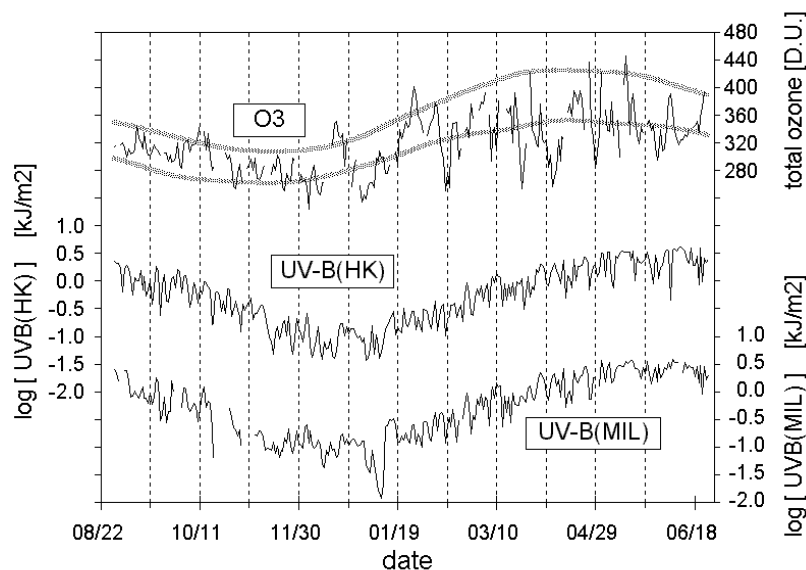


Figure 1. Time series (August 29, 1996; June 25, 1997) of daily averages of total ozone measured by Dobson spectrophotometer in Hradec Králové (top graph) and daily sums of UV-B irradiance measured in Hradec Králové (UV-B(HK), middle graph) and Milešovka (UV-B(MIL), bottom graph). The shaded lines in the top graph demarcate $\langle A-S, A+S \rangle$ interval, where A and S are the mean and standard deviation of total column ozone in HK based on the 1962-1990 period.

Dobson spectrophotometer in HK [Vaniček, 1991, 1992a]; the time series for the total ozone and daily sums of UV-B irradiance are displayed in Figure 1; (3) hourly totals of global solar radiation measured by a Kipp-Zonen CP-11 in HK; and (4) hourly fractions of sunshine duration measured at both stations. To process effectively the data, three databases were created: (1) database of 10 min data; each term is represented by a 10 min sum of UV-B irradiance, solar zenith angle related to the center of the 10 min interval, and total ozone (average value related to given day); (2) database of hourly data; each term is represented by hourly sums of UV-B and global solar irradiances, solar zenith angle related to the center of the 1 hour interval, hourly fraction of sunshine duration, and total ozone (average value related to a given day); (3) database of daily data; daily sums of UV-B and global solar irradiances, fraction of possible sunshine (the ratio of daily sunshine duration to the solar daylength), and daily average of total ozone. The databases consist of measurements made from August 1, 1996 to June 25, 1997. The 10 min database includes 4986 clear-sky observations made in HK and 3240 clear-sky observations made in MIL (the dropped MIL observations were caused by occasional interruptions of power supply and control computer defects); 2330 clear-sky observations were made in both stations simultaneously. The hourly database is composed of 3395 terms, 665 of them are with 100% sunshine in MIL, 689 with 100% sunshine in HK, and 423 terms are with 100% sunshine simultaneously in both locations.

3. Comparison of Two Stations

Prior to the experiment, a side-by-side calibration of the two RB-biometers was made to guarantee mutual concordance of the simultaneous measurements. The stability of this concordance during the whole period is demonstrated in Figure 2, which displays the time series of the concordance char-

acteristic defined as

$$\text{FIT}(\text{HK}, \text{MIL}) = 2(E_{\text{MIL}} - E_{\text{HK}}) / (E_{\text{MIL}} + E_{\text{HK}}), \quad (4)$$

where E_{MIL} and E_{HK} are daily sums of UV-B irradiance in the two locations. The zero value of $\text{FIT}(\text{HK}, \text{MIL})$ indicates perfect fit, values ± 1 indicate that the difference of the two UV-B irradiances is equal to the average of the two. The data displayed in the figure were categorized into three groups according to sunshine duration: (1) the days with sunshine exceeding 30% of possible sunshine duration in both stations (number of days = 100; average value of $\text{FIT}(\text{HK}, \text{MIL}) = -0.01$; standard deviation of $\text{FIT}(\text{HK}, \text{MIL}) = 0.15$), (2) the days with sunshine below 30% at least in one station but exceeding 10% in both stations ($n = 49$, $\text{ave}(\text{FIT}(\text{HK}, \text{MIL})) = -0.08$, $\text{s.d.}(\text{FIT}(\text{HK}, \text{MIL})) = 0.34$), and (3) the days with sunshine below 10% at least in one station ($n = 131$, $\text{ave}(\text{FIT}(\text{HK}, \text{MIL})) = -0.04$, $\text{s.d.}(\text{FIT}(\text{HK}, \text{MIL})) = 0.50$). As the increasing value of the standard deviation of $\text{FIT}(\text{HK}, \text{MIL})$ indicates decreasing concordance between the UV-B sums measured in the two stations, the figure demonstrates that the fit between the two stations improves with increasing sunshine duration. Importantly, the concordance characteristic exhibits no trend. The good fit of the two devices is also seen in Figure 3, which displays the daily cycle of UV-B irradiance on a day with 100% sunshine.

To assess the effect of the altitude on UV-B irradiance, the hourly UV-B sums measured parallel at the two locations during terms with 100% hourly sunshine duration (simultaneously at both locations) were compared. On applying the linear regression to all clear-sky observations, it was found that UV-B irradiances in MIL are 1.5% higher on average. However, if we want to extract the altitude effect from the data, we must account for the different latitudes of the two stations. The different latitudes make the solar zenith angles in MIL systematically 0.38° greater, and consequently, the vertical component of solar irradiance upon entering the atmosphere is consistently lower compared to HK. To

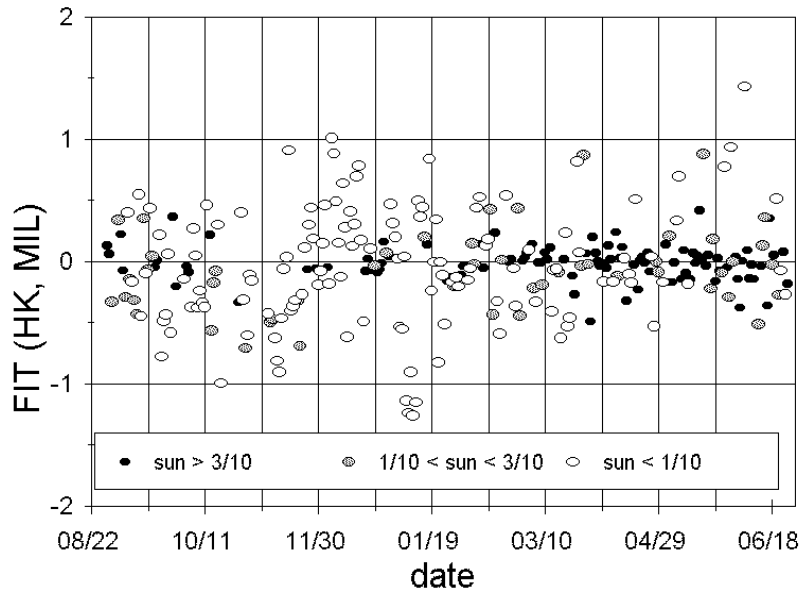


Figure 2. Mutual concordance of daily sums of UV-B irradiance measured in Hradec Králové and Milešovka. The concordance is measured by characteristic FIT(HK, MIL) defined by equation (4): solid, dashed, and open circles represent terms with daily sunshine duration exceeding 30% at both locations, daily sunshine duration is less than 30% at least at one location, and daily sunshine duration is less than 10% at least at one location, respectively.

eliminate this effect, the UV-B sums measured in MIL were multiplied by a coefficient

$$k(\theta) = \left| 0.38 \frac{\delta E^{\wedge}(\theta)}{\delta \theta} \right| / E^{\wedge}(\theta), \quad (5)$$

where θ is solar zenith angle and $E^{\wedge}(\theta)$ is a mean UV-B irradiance (derived in section 4) for given solar zenith angle. On applying the linear regression to the modified data, the mean UV-B irradiances in MIL were now found, on average, 3.4% higher than in HK. The dependence of the ratio of UV-B hourly sums measured at the two stations on a solar zenith angle and the magnitude of the “latitude effect” are displayed in Figure 4. Attributing the difference between the two stations to the altitude effect, we find that the UV-B irradiance increases by 4 to 8%/1000 m, which agrees with the value derived from a radiative transfer model and used by National Weather Service and EPA [Long *et al.*, 1996]. On the other hand, this increase of UV-B irradiance is lower than the values referred by Kudish *et al.* [1997] (10.2 to 17.3%/1000 m in Israel; the measurements were made close to the Dead Sea) and Blumthaler *et al.* [1993] (18±2%/1000 m in summer and 23±6% in winter in the Alps). It is assumed that the differences between the magnitudes of the altitude effect calculated in the present study and the two cited studies (it should be noted that the relations among the altitude effects derived in the individual studies are about the same whether the reduction of UV-B irradiance is related to given pressure interval or unit altitude) are due to local effects, such as air pollution, albedo, and viewing geometry [Long *et al.*, 1996]. Moreover, the discrepancy between this study and previous studies may be contributed by different type of data used in the analysis: Kudish *et al.* [1997] and Blumthaler *et al.* [1993] derived the altitude effect from the daily UV-B sums, while the hourly sums were used in this study.

4. Dependence of UV-B Irradiance on Total Ozone and Solar Zenith Angle

4.1. Dependence of UV-B Irradiance on Total Ozone

Ground level UV-B irradiance is mainly affected by solar zenith angle and cloudiness. The effect of cloudiness is apparent in Figure 5 which shows the series of hourly UV-B sums during three consecutive days. For clear-sky conditions and given solar zenith angle the UV-B irradiance is mainly affected by concentration of total ozone. The effect of total ozone on UV-B radiation is usually expressed in terms of equation (3). Values of RAF have been determined from

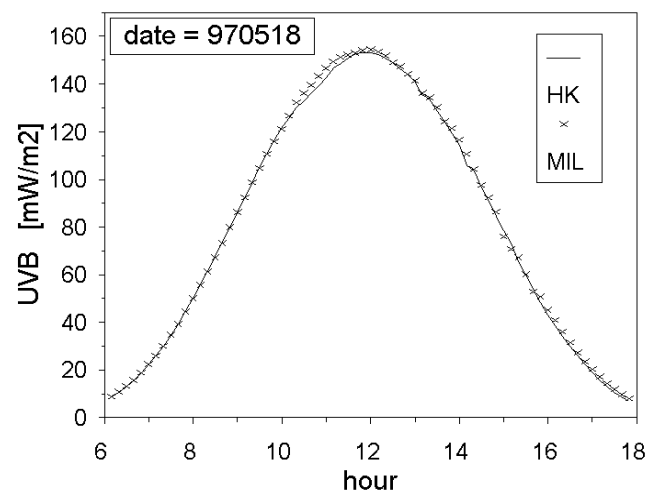


Figure 3. Daily cycle of 10 min sums of UV-B irradiance in Hradec Králové (HK) and Milešovka (MIL) during a sunny day.

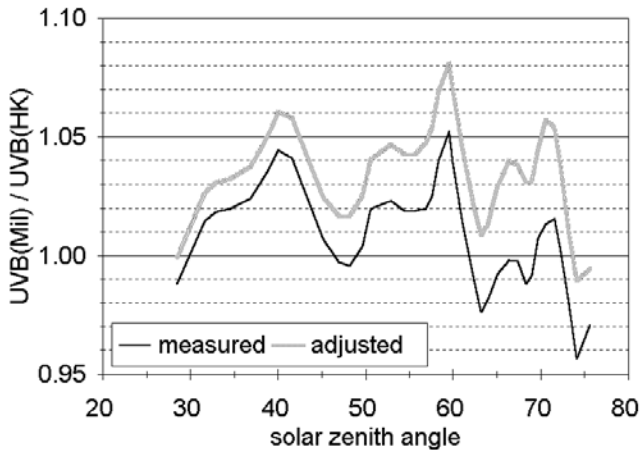


Figure 4. Comparison of clear-sky UV-B irradiance at the two sites; measured is the ratio of hourly sums of UV-B irradiances measured at given solar zenith angle at the two stations, adjusted is the same, but the UV-B irradiances in Milešovka were adjusted for different latitude (see text).

experimental data in many recent studies. *McKenzie et al.* [1991] determined RAF from clear-sky UV-B observations at given solar zenith angles. They found RAF values lie within the range 1.25 ± 0.15 and tend toward higher values at larger solar zenith angles. They suggested that the ozone dependence of RAF can be ignored (the sensitivity of RAF to total ozone was lower than the measurement uncertainties). *Németh et al.* [1996] studied the dependence of the ratio of daily sums of UV-B and global radiation on total ozone using observations from both cloudy and clear-sky days and obtained $RAF = 0.9$. Similarly, *Ambach et al.* [1997] analyzed data from Innsbruck and derived $RAF = 1.22 \pm 0.095$ from the relationship between the deviations of total ozone and the ratio of the erythemal effective irradiance to the total irradiance (daily sums) from their average seasonal cycles.

Two approaches were used in this paper to derive RAF from the measured data. In the first approach, RAF was determined using a bilinear regression analysis, namely, the solar zenith angle, θ , and the logarithm of the total ozone, $\ln \Omega$, were the independent variables and the logarithm of 10 min sums of the UV-B irradiance, $\ln E$, was the dependent variable. The parameters of the regression model were fitted separately for five subsamples in which solar zenith angle varied within $\theta \pm 5^\circ$ intervals, $\theta \in \{30^\circ, 40^\circ, 50^\circ, 60^\circ, 70^\circ\}$. The second approach differs from the first one by using logarithm of the ratio E/G (hourly sums of ultraviolet and global solar irradiances) as a dependent variable in the bilinear regression. The first method was applied to data from both HK and MIL. The second method was applied only to observations from HK, since global solar radiation was not measured in MIL Observatory. To eliminate the effect of varying Earth-Sun distance, the UV-B irradiances were divided by a correction coefficient [Burrows et al., 1994]:

$$C_d = 1.00011 + 0.034221 \cos(\gamma) + 0.00128 \sin(\gamma) + 0.000719 \cos(2\gamma) + 0.000077 \sin(2\gamma), \quad (6)$$

where $\gamma = 2\pi[(J-1)/365]$ and J is a Julian date. The resultant values of RAF (including error intervals) are displayed in Figures 6 and 7. The first figure displays values determined

from 10 min data in both stations; the second figure displays values for HK determined by both approaches. It is seen that the values of RAF vary mainly between 0.9 and 1.2. The weighted average (weight = $1/s$, where s is a standard error of RAF for a given solar zenith angle) of RAF is about 1.06 (HK) and 1.11 (MIL) if determined from 10 min UV-B sums, and 1.15 (HK) if determined from the ratios of hourly sums of UV-B and global irradiances. The figures suggest that the radiation amplification factor depends on the solar zenith angle, exhibiting a maximum within 40° - 60° . The higher values of RAF determined from E/G ratio may be due to some "hidden factor" which affects the UV-B irradiance and is correlated with total ozone but not included in UV-B versus total ozone regression. The hypothetical hidden factor may be related to the clearness of the atmosphere which is greater in cold air masses typically containing higher total ozone concentrations. As a result, the UV-B irradiances experienced in these ozone-rich cold air masses are systematically higher, and the values of RAF obtained from regressing UV-B irradiance on total ozone are therefore rather underestimated. This effect is partly eliminated if the E/G ratio is used as a dependent variable since both global (G) and UV-B (E) irradiances are similarly affected by clearness of the atmosphere. Anyway, the resultant values of RAF obtained in both approaches are not so different and are in good agreement with values obtained in the above cited studies.

4.2. Regression Model Relating Clear-Sky UV-B Irradiance With Total Ozone and Solar Zenith Angle

Having determined the dependence of UV-B irradiance on total ozone, we may use equation (3) to define E^* , the UV-B irradiance normalized for mean Earth-Sun distance and the mean total ozone, $\Omega_0 = 339$ Dobson units (DU) (the annual mean of total ozone in HK, based on Dobson measurements made during 1992-1990):

$$E^* = E \left(\frac{\Omega}{\Omega_0} \right)^{RAF} C_d^{-1}, \quad (7)$$

where RAF was set to 1.06. To develop the statistical model for estimating UV-B irradiance from the solar zenith angle

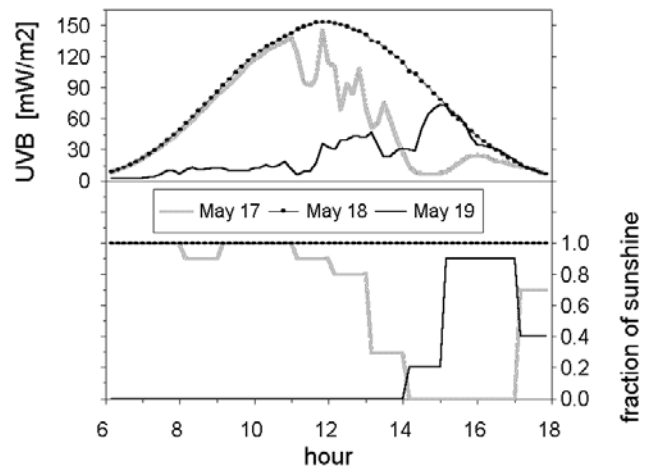


Figure 5. Daily cycle of 10 min sums of UV-B irradiance (top) and hourly sunshine fractions (bottom) measured in Hradec Králové during three consecutive days.

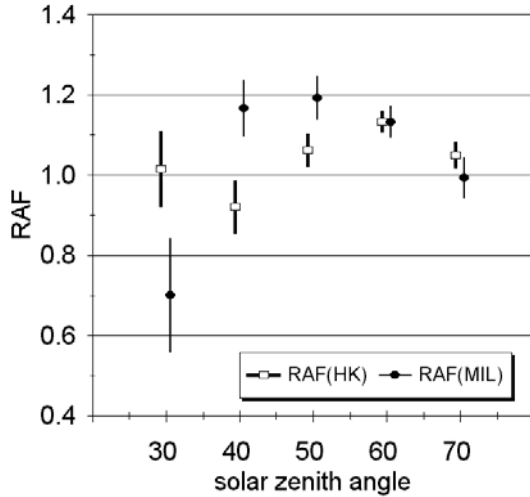


Figure 6. Dependence of the radiation amplification factor (RAF) on the solar zenith angle. The values of RAF were determined by bilinear regression with solar zenith angle (θ) and logarithm of total ozone being the independent variables and logarithm of UV-B irradiance being the dependent variable. The values of RAF relate to $\theta \pm 5^\circ$ intervals. The vertical lines demarcate standard error intervals.

and the total ozone, the relationship between E^* and solar zenith angle will be now parameterized. The regression function relating E^* (dependent variable) with solar zenith angle (independent variable) is expressed as

$$\ln E^* = a \ln(\cos\theta) + b + c\mu + d\mu^2, \quad (8)$$

where $\mu=1/\cos\theta$ is an air mass. The above formula, which is different from the one suggested by *Burrows et al.* [1994], is advantageous in that it vividly separates effects of total ozone and solar zenith angle on UV-B radiation. Similarly to the *Burrows et al.* [1994] formula, the derivative $\delta E/\delta\theta$ is zero for $\theta=0$ (although solar zenith angles below 26.5° do not occur in both Czech locations and the model, thus has no practical

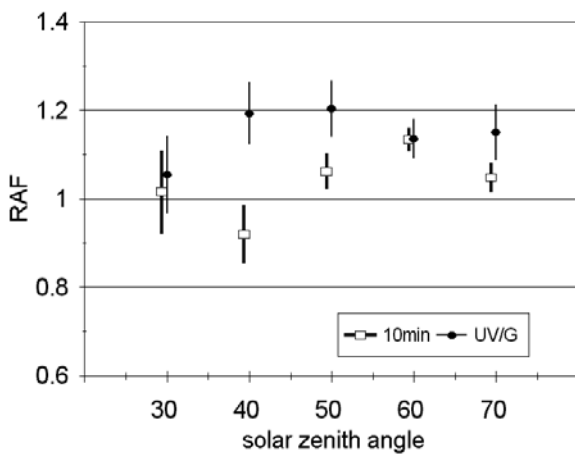


Figure 7. Radiation amplification factor determined from clear-sky measurements made in Hradec Králové; 10 min: the values of RAF based on 10 min sums of UV-B irradiance; UV/G: the values of RAF based on ratios of hourly sums of UV-B and global radiation. The vertical lines demarcate standard error intervals.

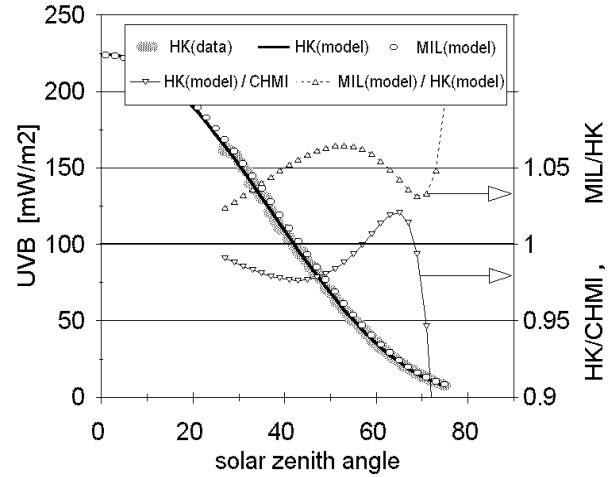


Figure 8. Dependence of clear-sky UV-B irradiance (normalized for the mean total column ozone, 339 DU, and the mean Earth-Sun distance) on solar zenith angle. HK(data), data measured in Hradec Králové (smoothed averages of 10 min sums); HK(model), statistical model for Hradec Králové; MIL(model), statistical model for Milešovka; HK(model)/CHMI, the ratio of HK(model) and current operational model used by CHMI; MIL(model)/HK(model), the ratio of models for Hradec Králové and Milešovka.

meaning in this region). The complete statistical model for estimating UV-B irradiance then has the form

$$E^{\wedge} = C_d (\cos\theta)^a \exp(b + c\mu + d\mu^2) \left(\frac{\Omega}{\Omega_0}\right)^{-RAF}. \quad (9)$$

The values of parameters a , b , c , and d were derived from the set of 10 min UV-B sums by minimizing the mean square error: $a = 2.696056$, $b = 5.474571$, $c = -0.09888$, and $d = 0.040392$ for HK; $a = 1.610082$, $b = 6.3914608$, $c = -1.134713$, and $d = 0.1547409$ for MIL. The regression models are displayed in Figure 8. The figure shows that the UV-B model for MIL gives slightly higher values than those corresponding to the altitude effect determined in section 3

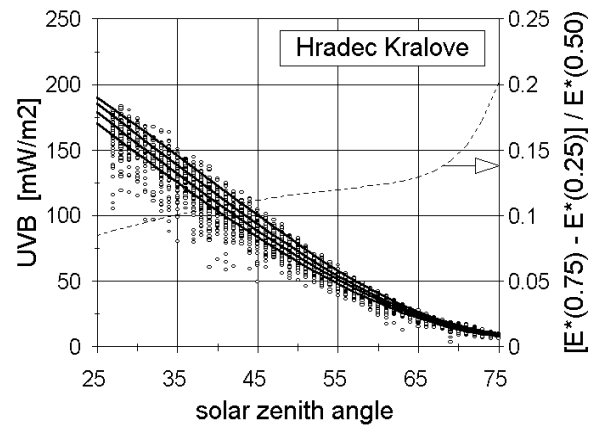


Figure 9. Variability of UV-B irradiances normalized for the mean total column ozone (339 DU) and mean Earth-Sun distance. Circles, measured data; solid lines, regression functions fitted to conditional quantiles E_{α}^* ($\alpha = 0.25, 0.50, 0.75$, and 0.95 from bottom to top) of normalized UV-B irradiance. Dashed line shows the variability of normalized UV-B irradiance in terms of $(E_{0.75}^* - E_{0.25}^*)/E_{0.50}^*$ ratio.

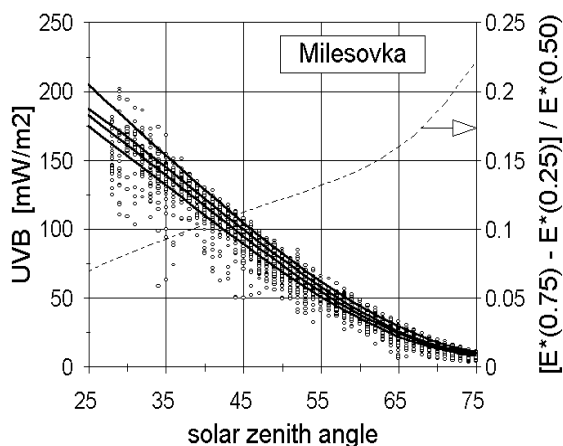


Figure 10. Same as in Figure 9 but for Milešovka.

from the pairs of concurrent measurements. Although the regression curves are drawn for zenith angles lying within 0° - 75° interval, it must be remembered that the regression functions were determined from measurements with $\theta \in (27,75)^{\circ}$, and therefore the accuracy of the regression function beyond this range is reduced. Figure 8 also indicates that the regression model determined for Hradec Králové differs only slightly from the current CHMI operational UV-B model which was based on the *Burrows et al.* [1994] formula [Vaniček, 1996, 1998]. The discrepancy may be partly due to the different type of the regression function and partly due to the fact that the present CHMI model was optimized with the use of Brewer data obtained from other and shorter period (M. Janouch, private communication, 1998).

To show the variability of clear-sky UV-B irradiance for a given solar zenith angle, the regression functions were also fitted for conditional quantiles of normalized UV-B irradiance, $E_{\alpha}^*(\theta)$, $\alpha = 0.25, 0.50, 0.75$ and 0.95 ($\text{Prob}\{E^* \leq E_{\alpha}^*(\theta) | \theta\} = \alpha$). The curves of the quantile characteristics are displayed in Figure 9 (HK) and Figure 10 (MIL) and show that the variability of normalized clear-sky UV-B irradiance expressed in terms of the $(E^*_{0.75} - E^*_{0.25})/E^*_{0.50}$ ratio (dashed lines in the figures) is about the same for both locations: 50% of E^* values deviates by less than 9% from its median for zenith angle being 30° . The mean relative deviation increases with increasing solar zenith angle to about 17% (20%) for $\theta = 70^{\circ}$ in HK (MIL). Accuracy of the regression models is shown in the bottom graph of Figure 11 (solid lines) in terms of the mean relative standard error, defined as $s[E - E^*(\theta, \Omega)]/[E^*(\theta)]$, where E is a measured value of UV-B irradiance, $E^*(\theta, \Omega)$ is value estimated from equation (9), $E^*(\theta)$ is value estimated only from solar zenith angle (E^* determined with the use of equation (8) is multiplied by the Earth-Sun correction coefficient, C_d), and $s[\cdot]$ denotes the standard deviation of the variable given in the brackets. To assess the contribution that a knowledge of total ozone has on accuracy of the model, the error for UV-B being estimated only from solar zenith angle is also displayed (dashed lines with open symbols in the bottom graph). The accuracy of the statistical model is good. The mean relative standard error varies from 8.5% (10.5%) for $\theta = 30^{\circ}$ to 13% (23.5%) for $\theta = 70^{\circ}$ in HK (MIL). Comparing these numbers with those related to UV-B forecasts based just on solar zenith angle, we see that the capability of total ozone to explain variability of UV-B irradiance increases with increasing solar zenith angle

(compare top graph in Figure 11). At its maximum ($\theta = 60^{\circ}$), the standard error is reduced by about 40-50%. Unfortunately, the predictive power of total ozone at the lowest solar zenith angles (the greatest emphasis is placed upon UV-B forecasts at these situations) is the lowest; namely, only about 15% of standard error is reduced due to a knowledge of total ozone.

5. Conclusion

The present paper analyzes the UV-B radiation measured by Robertson-Berger broadband filter UV radiometers at two locations in the Czech Republic. The analysis was focused on (1) mutual comparison of measurements at the two stations (including quantification of the altitude effect and comparison of the daily cycles during clear-sky days), (2) determination of the radiation amplification factor, (3) parameterization of the regression function relating clear-sky UV-B irradiance with total ozone and solar zenith angle.

The UV-B irradiances were found mutually comparable at the two locations (Figures 2 and 3). Slightly higher values in MIL (Figure 4) are assumed to be due to the altitude effect. The magnitude of the altitude effect (UV-B irradiance increases by 4 to 8%/1000 m) is in good agreement with the value derived from a radiative transfer model and used by National Weather Service and EPA [Long *et al.*, 1996], but it is lower than the altitude effects detected by other authors [Kudish *et al.*, 1997; Blumthaler *et al.*, 1993]. This discrepancy may be contributed partly by local climatological and environmental effects and partly by different format of data used in the individual studies.

Radiation amplification factor (RAF) was determined by two methods. On the basis of regression of UV-B irradiance on total ozone, the value of RAF was determined to be about 1.1, whereas slightly higher (by less than 10%) value of RAF was derived from the relationship between the ratio of UV-B to global solar irradiance and total ozone. This discrepancy may be due to some "hidden factor" which affects the UV-B

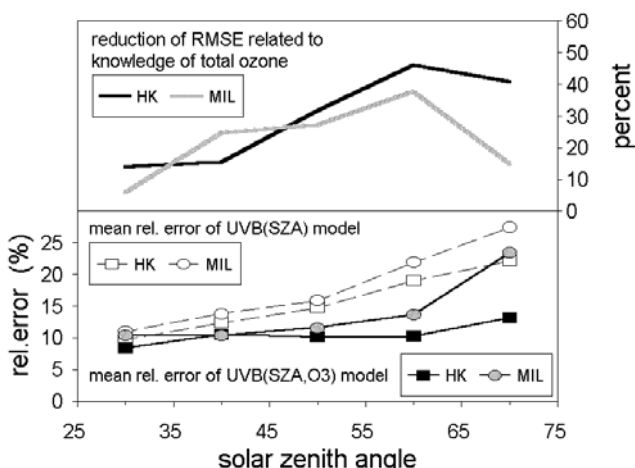


Figure 11. Accuracy of the regression model for UV-B irradiance. (bottom) Solid lines with solid symbols represent the mean relative error of UV-B irradiance estimated from the solar zenith angle and total ozone (using equation (9)); dashed lines with open symbols represent mean relative error of UV-B estimated only from the solar zenith angle. (top) Reduction of the error related to the knowledge of total column ozone.

irradiance and is correlated with total ozone but not included in UV-B versus total ozone regression. It is hypothesized that the hidden factor may be related to the clearness of the atmosphere which is greater in cold air masses typically containing higher total ozone concentrations. Anyway, the resultant values of RAF obtained in both approaches are not so different and are in good agreement with values found in the literature [McKenzie *et al.*, 1991; Németh *et al.*, 1996; Ambach *et al.*, 1997].

By applying regression analysis to clear-sky measurements, the statistical model for estimating UV-B irradiance from solar zenith angle, total ozone, and Julian day was developed. The root-mean-square error of the model varies from 8% for $\theta = 30^\circ$ to 14% for $\theta = 70^\circ$. For MIL Station, the error is slightly greater, especially for higher solar zenith angles. This may be partly due to meteorological factors not included in the analysis and partly to problems with precision of the computer clock in MIL which reduced the accuracy of attributing the solar zenith angle to individual 10 min intervals. Although the UV-B irradiance is significantly correlated with total ozone, a knowledge of total ozone does not adequately improve the forecast of UV-B at low solar zenith angles. To improve the quality of the statistical model, i.e., to explain a greater portion of the variance of UV-B irradiance, it is suggested to enlarge the set of explanatory variables (predictors) by additional meteorological information (e.g., turbidity and snow cover), to account for the vertical profile of ozone and to use more time-specific total ozone concentration instead of the daily average.

It was stated in section 1 that the UV-B irradiance is affected also by surface albedo which significantly increases if a snow cover occurs. Although the snow cover was not assumed in the present analysis, an additional assessment was made to estimate its effect. In HK, no UV-B measurements were made at nonzero snow cover conditions and solar zenith angle below 40° , and only few measurements were made in a presence of snow cover at higher solar zenith angles in winter. In Milešovka, which is the mountain-top station, more terms with nonzero snow cover occurred due to lower temperatures and higher precipitation. Nevertheless, the statistical UV-B models derived in both stations only from terms with no snow cover differ from the respective models derived from all data by less than 0.2% for $\theta < 60^\circ$. The effect of the snow cover on the statistical model becomes more pronounced only at higher values of θ . More frequent occurrence of snow cover may also contribute to the greater variability of UV-B irradiance at higher solar zenith angles in Milešovka. Detailed analysis of the effects of the snow cover and other meteorological factors on UV-B irradiance remains for further investigation.

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