Solar erythemal UV radiation climatology over Slovakia

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Abstract: Maps of the solar erythemal ultraviolet (UV) radiation daily doses were created for every month with horizontal resolution of 500 m at geographical domain 47.15N – 49.86N x 16.94E – 22.81E covering the territory of Slovakia. Cloud modification factor for the UV radiation (cmf_{UV}) was modelled utilizing a relation between the *cmf* of the total and UV radiation. Measurements of total ozone performed by the Brewer spectrophotometer at Poprad - Gánovce (inside the investigated domain) were considered representative for selected geographical area. Information on snow cover presence was the only meteorological parameter used in the model. Verification of the model was performed at 5 observatories equipped with broadband solar UV radiometers.

The maps of the *cmf* factor of the UV radiation were created utilizing measurements of total radiation performed at 9 observatories during 1995 – 2004 period and the model of *cmf* dependence on altitude. Maps of clear-sky UV radiation daily dose and UV radiation daily dose affected by average cloudiness were constructed for mean monthly total ozone, their upper and lower monthly limits, for two probability levels of snow cover occurrence as a criterion for the snow effect incorporation in the model and for 1 day representing typical values of every month. The maps of the erythemal UV radiation daily doses were created for average and limit conditions of factors affecting the erythemal UV radiation. The map-set can be considered as an atlas of the solar erythemal UV radiation over Slovakia.

Key words: solar erythemal ultraviolet radiation, total radiation, cloud modification factor, snow line, altitude, map visualization

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1. Introduction

Solar UV radiation manifests strong biological effects on life ecosystems. Overexposure to solar UV radiation can exhibit instantly (as e.g., skin erythema), but the disturbance of some physiological processes of life organisms can manifest as a consequence of large cumulative doses of the UV radiation (development of skin cancers, change of photosynthetic activity of plants) *(WMO, 2003)*. From the latter point of view, the knowledge on typical UV climate is important.

Determination of the UV climatology using directly its ground or satellite measurements is usually impossible due to restricted length of the UV radiation time-series or due to low density of sites with the UV radiation ground measurements. Modelling of the UV radiation and spatial interpolation methods are tools usually applied to the UV climatology estimation.

Several studies have been performed to determine the UV climatology at different space scales – from local studies of UV radiation long-term variability *(Lindfors and Vuilleumier, 2005)*, to regional analyses *(Luccini et al., 2006; Meloni et al., 2000)* or global UV radiation pattern determination *(Herman et al., 1999)*. Utilizing the UV irradiance modelling is a possibility for obtaining information on the solar UV radiation at places where measurements are not performed, which is important for map representation of the UV radiation geographical distribution. The UV radiation simulation can also improve the knowledge on its long-term variability in time periods in the past, when no reliable measurements were organized.

The total ozone, cloudiness, surface albedo, information on atmospheric turbidity, sunshine duration and total solar radiation are the proxies usually used as an input into the models. The models used to obtain UV radiation climatology can be separated into 3 groups, with respect to proxy data: (1) models utilizing total solar radiation as an radiative input parameter *(Kaurola et al., 2000; Den Outer et al., 2005)*, (2) models using sunshine duration as an radiative proxy parameter *(Lindfors et al., 2003; Lindfors and Villeumier, 2005)*, (3) models based on meteorological data only *(Engelsen et al., 2004)*. The UV-index and daily doses of erythemal UV radiation are the parameters most frequently employed for determination of the UV radiation climatology *(Luccini et al., 2006)*, but there was also an effort to model spectral UV irradiances *(Meloni et al., 2000; Gantner* *et al., 2000; Bodeker and McKenzie, 1996).* Comparison of UV radiation models utilizing different input parameters and different approaches to UV radiation modelling at four European places showed, that models involving total radiation as proxy parameter provided the best results *(Koepke et al., 2006).*

The reliability of the UV climatologies expressed in map form depends on UV radiation model quality, on availability of model input parameters and its space distribution *(Schmalwieser and Schauberger, 2001)* and also on interpolation method utilized for map visualization *(Tatalovich et al., 2006).*

The aim of this publication is to create maps of the erythemal UV radiation daily doses typical for the territory of Slovakia for every month, employing available radiative measurements and meteorological data. UV radiation climatology expressed in map form can be useful for the future local studies on UV radiation impact on the biosphere and human beings.

2. Material and methods

2.1. Data

Meteorological and radiative measurements performed at observatories of the Geophysical Institute of the Slovak Academy of Sciences and of the Slovak Hydrometeorological Institute were processed in this study. The UV radiation climatology was estimated utilizing ancillary data from the 1995 – 2004 decade, except of observatories Banská Bystrica and Lomnický štít, where total solar radiation data were only available from other time periods (Table 1).

The solar UV radiation has been measured at 5 observatories equipped with the broadband UV-B radiometers in Slovakia (Table 1). Stability of all instruments has been checked by their comparison with the national standard device periodically. The calibration of the broadband UV-B meters has been performed since 2002. Relative spectral response and relative angular response was certified by one operational UV-B radiometer located at Skalnaté Pleso under umbrella of international COST-726 campaign at Davos in 2006. The relative spectral responses of the instruments (known

Table 1. Stations utilized for determination of erythemal UV radiation climatology in Slovakia, their abbreviations, geographical coordinates and time periods with available total solar radiation (G) measurements, UV radiation measurements (UV-B) and information on snow cover are showed for every station

Station	latitude [° N]	longitude [° E]	altitude [m]	G	UV-B	snow
Hurbanovo (HU)	47.87	18.20	135	1995-2004	no	1995-2004
Bratislava (BA)	48.17	17.12	292	1995-2004	2002-2004	1995-2004
Košice (KE)	48.70	21.27	230	1995-2004	2002-2004	1995-2004
Banská Bystrica (BB)	48.73	19.12	427	1986-1993	no	no
Poprad-Gánovce (GA)	49.03	20.32	703	1995-2004	2002-2004	1995-2004
Stará Lesná (SL)	49.10	20.28	810	1995-2004	2002-2006	1995-2004
Štrbské Pleso (StP)	49.12	20.07	1387	1995-2004	no	1995-2004
Skalnaté Pleso (SP)	49.18	20.23	1778	1995-2004	2002-2006	1995-2004
Lomnický Štít (LS)	49.20	20.22	2635	1984-1992	no	no

from manufacturer) are close to spectral weight function used for separation of the radiation with erythemal effect on human skin *(McKinlay and Diffey, 1987)*. Differences between relative spectral responses of the instruments and erythemal action spectrum manifests significantly at the large solar zenith angles ($SZA > 60°$) and also depends on the total ozone and aerosol amount *(Bais et al., 1999)*. Relative angular responses of the instruments were not known.

The measurements of total solar radiation performed at 9 stations (Table 1) were utilized by this study. The CM-11 pyranometers have been operated at all investigated stations except of Stará Lesná and Skalnaté Pleso equipped with the Sontag pyranometers. Stability of all instruments is controlled regularly against the national standard device.

The distribution of the total solar radiation measurements over the territory of Slovakia is irregular. Five of 9 instruments are located in a small area of the High Tatras mountains in the northern part of Slovakia (Fig. 1). But on the other hand, the altitudes of observatories performing the total solar radiation measurements cover nearly the whole altitude range of the investigated geographical area. That is the reason, why dependences on altitude of both UV radiation modification by clouds and snow occurrence were parameterized to depict their spatial distribution.

Mean daily values of the total ozone and monthly climatology were obtained from measurements performed by the Brewer spectrophotometer MKIV at Poprad - Gánovce. It was considered, that total ozone measured at Poprad - Gánovce is representative for the whole investigated area.

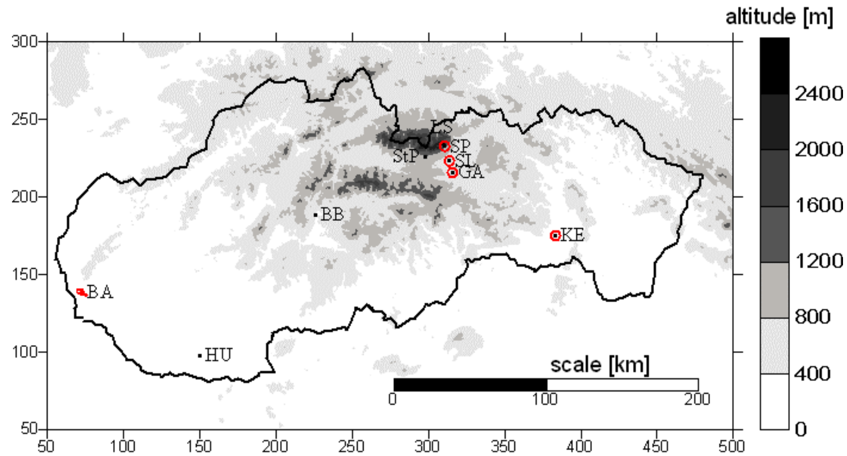

Fig. 1. Investigated territory with surface altitude and border of Slovakia depicted in the S-JTSK geographic projection. The places with measurements of total solar radiation are designed by black dots, places with UV radiation measurements are labelled by rings. The abbreviations of observatories relate to Table 1.

Information on daily snow cover (snow cover thickness) was available for all stations providing global radiation measurements except for Banská Bystrica and Lomnický štít.

Digital terrain model DMR500-SK in S-JTSK cartographic projection and resolution of 500 m available at the internet (`http://www.geomodel.sk/sk/download/download.htm`) was utilized for the erythemal UV radiation map visualization. The relief altitude at investigated territory varied in range from 50 m a.s.l. to 2650 m a.s.l. Maps of erythemal UV radiation daily doses were created for every month at geographical domain 47.15N – 49.86N × 16.94E – 22.81E covering the territory of Slovakia. The digital terrain model provided information on altitude at 1056 × 698 grid points of the selected domain.

2.2. Parameterization of erythemal UV radiation cloud attenuation

Neither length, nor spatial density of the UV radiation measurements was sufficient for the direct UV radiation climatology determination and presentation in map form.

The time series of the total solar radiation are longer and the number of the observatories is higher in comparison with the UV radiation measurements in Slovakia. The total solar radiation measurements were used as proxy data for the UV radiation cloud attenuation modelling.

The attenuation of radiation by clouds was expressed by cloud modification factor *cmf*. The *cmf* was defined as a ratio between the radiation measured by any cloudiness condition and the radiation corresponding to clear-sky condition. The attenuation of the UV radiation by clouds cmf_{UV} was modelled as a function of the total solar radiation cloud attenuation cmf_G for 6 categories of the SZA:

$$cmf_{UV} = f(cmf_G, SZA) \quad (1)$$

The model of daily values of cmf_{UV} is statistical. Dependence of the cmf_{UV} on the cmf_G was separately expressed by the 2nd degree polynomial function for every of the 6 SZA intervals. The value of the SZA related to the time of solar culmination. Regression parameters were determined using data obtained at 4 locations in Europe (Thessaloniki, Davos, Potsdam, Bergen) under the European action COST-726 *(Koepke et al., 2006)*.

It was necessary to get the total and UV radiation daily doses representing clear-sky condition for modelling of the cmf_{UV} and for validation of modelled erythemal UV radiation daily doses.

Daily sums of the clear-sky erythemal UV radiation were calculated from irradiances modelled by the TUV (total ultraviolet-visible) radiative transfer (RT) model *(Madronich, 1993)* assuming standard atmospheric conditions, fixed aerosol content (aerosol optical depth of radiation with wavelength λ = 340 nm - AOD_{340} was set to be 0.4) and its optical characteristics typical for continental aerosol, fixed no-snow surface albedo and for measured total ozone. The weight function for human erythema *(McKinlay and Diffey, 1987)* was applied to the modelled spectral irradiances. The integration step of 0.5 h was used in summation of modelled irradiances to obtain UV radiation daily doses. Modelled daily doses of clear-sky erythemal UV radiation were corrected if snow was present at any station. Fixed increase of erythemal UV radiation caused by snow of 15% was assumed *(Pribullová and Chmelík, 2005)*.

Clear-sky total irradiances were modelled by the libRadtran radiative transfer model *(Mayer and Kylling, 2005)* for standard atmosphere, no-snow conditions, fixed atmospheric aerosol content expressed by horizontal visibility of 25 km (corresponding to $AOD_{340} = 0.4$ used in the TUV RT model) and the SZA range of $90° - 20°$. Daily doses of the clear-sky total radiation were calculated from modelled irradiances for every place with measured total irradiance. The integration time step of 0.5 h was used for calculation of total solar radiation daily doses. If the snow was at any station, correction of the clear-sky total irradiance (SZA dependent increase of total radiation in comparison with no-snow condition was assumed) was performed in accordance with *Pribullová and Chmelík (2005)* local study conclusions (the most significant increase of the total radiation of 30% was assumed for the $SZA = 70°$).

Monthly averages of the cmf_{UV} factor were calculated for determination of the UV radiation cloud attenuation climatology. The modelled daily cmf_{UV} values for the investigated decade 1995 - 2004 were used for this purpose.

As places with available cmf_{UV} values were distributed irregularly over the investigated territory, the dependence of the cmf_{UV} on altitude was fitted.

2.3. Parameterization of snow reflectivity effect on erythemal UV radiation

To incorporate the snow effect in the UV radiation climatology map visualization, information on the typical space distribution of the snow cover over Slovakia was required. As the stations recording the snow cover were irregularly distributed, the dependence of the snow occurrence on altitude was modelled. Monthly probability of snow occurrence was first determined from all available data at every station. The altitude of defined probability of snow occurrence was calculated using the linear interpolation between the altitudes of stations with the snow occurrence probabilities below and above the defined limit. Two probability limits of 50% and 70% were chosen for the determination of altitudes above which the snow effect on the UV radiation was incorporated into the model.

2.4. Map visualization of erythemal UV radiation

Typical monthly erythemal UV radiation conditions were obtained by simulation of one day conditions characterized by an appropriate monthly total ozone, cloud attenuation conditions and snow cover distribution.

The erythemal UV radiation map construction was performed in the following steps:

1. The clear-sky daily doses of erythemal UV radiation were calculated by the radiative transfer model TUV for one day of every month. The calculations were performed for fixed continental aerosol content ($AOD_{340} = 0.4$) and 3 categories of the total ozone. The clear-sky daily doses were determined for fixed altitude and geographical coordinates of grid points regularly covering the investigated area (3 x 4 points).
2. The linear kriging interpolation method *(Isaaks and Srivastava, 1989)* was applied to recalculate the clear-sky UV radiation to all grid points of the digital terrain model.
3. The clear-sky UV irradiance recalculated for every grid point was then corrected for altitude. Linear increase of the clear-sky erythemal UV radiation of 15%/1000 m *(Pribullová and Chmelík, 2005)* was assumed.
4. The correction of the clear-sky UV irradiances with respect to snow cover was performed at all grid points with altitudes exceeding the limit where snow incidence is observed with both 50% and 70% probabilities.
5. The maps of monthly attenuation of erythemal UV radiation by clouds expressed by the cmf_{UV} were constructed assuming the derived dependence of the monthly cmf_{UV} on altitude.
6. The modeled clear-sky erythemal UV radiation daily doses were multiplied by the cmf_{UV} factor modelled for appropriate altitude and month at every grid point and maps of erythemal UV radiation daily doses reflecting the mean cloudiness effect were created.

Finally 12 x 3 x 2 maps were created for clear-sky and cloudy conditions. All maps together can be considered as the atlas of the erythemal UV radiation geographical distribution over the territory of Slovakia.

3. Results and discussion

3.1. Model of erythemal UV radiation daily dose

The model of the erythemal UV radiation daily doses created using the data provided by the COST-726 activity was applied to model the attenuation of the UV radiation by clouds in the conditions of Slovakia. The model validation on the independent COST-726 data *(Koepke et al., 2006)* shows, that the root mean square error (RMS) varied from 83 J.m^{-2} (12%) for Bergen, to 229 J.m^{-2} (9%) for Thessaloniki. The bias between modelled and measured data (expressed as a slope of fitted linear relation between modelled data and measured ones) was for all stations less than 5% and correlation coefficient between measured and modelled data exceeds 0.99 for the four European stations.

The model provides worse results at the 5 Slovak stations equipped with the UV radiometers, especially with respect to the relative RMS error (Table 2).

Table 2. Validation of the model of the erythemal UV radiation daily dose at the Slovak stations. The model absolute and relative RMS errors, correlation coefficient between modelled and measured data and bias of the model expressed as a slope of linear function fitting the modelled data as a function of measured ones

Station	RMS [J.m^{-2}]	RMS [%]	r	bias [%]
BA	149	17	0.995	5.3
KE	162	20	0.983	7.7
GA	186	14	0.994	-3.2
SL	173	27	0.994	1.2
SP	190	16	0.989	3.5

The correlation coefficient between modelled and measured data was in the range of 0.983 in Košice to 0.995 in Bratislava. The bias between measured and modelled data varied between 1.2% in Bratislava and 7.7% in Košice. The absolute and relative RMS errors of the model are summarized in Table 2. The absolute RMS error range (149 J.m^{-2} – 190 J.m^{-2}) was comparable with values obtained by validation of the European data, but the relative RMS error is significantly higher (14% in Bratislava – 27% at Stará Lesná).

The reason for the increase of the relative RMS error can be the worse quality of both the UV and the total solar radiation measurements especially at stations, where the automatic measurements have been performed (Bratislava, Košice, Poprad - Gánovce) and the daily doses of radiative data can be automatically summed from incomplete daily measurements. At Stará Lesná and Skalnaté Pleso, the daily doses of the total and UV radiation were calculated from hourly data and the days with incomplete hourly measurements were excluded from the validation. But the relative RMS error is high also at the Stará Lesná observatory. The relative differences between measured and modelled data increased at all stations during winter, when the SZA was low. Fig. 2 documents the increase of relative differences between the measured and modelled data at Stará Lesná in comparison with Bratislava in winter, what can relate to instrumental characteristics of the UV radiometer.

The model of the erythemal UV radiation daily dose was used for incorporation of the cloud effect in the erythemal UV radiation modelling over Slovakia.

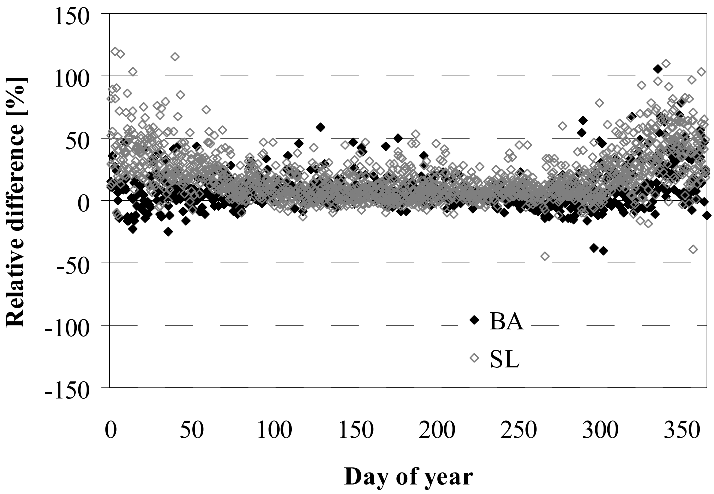

Fig. 2. Relative differences between modelled and measured erythemal UV radiation daily dose at Bratislava (BA) and Stará Lesná (SL).

3.2. Attenuation of erythemal UV radiation by clouds

The climatology of the erythemal UV radiation cloud attenuation was determined for every station with available measurements of the total solar radiation. The average monthly values of the cmf_{UV} are depicted in Fig. 3.

The difference between the annual course of the cmf_{UV} determined at the mountain stations and at the valley and low-land stations can be clearly seen

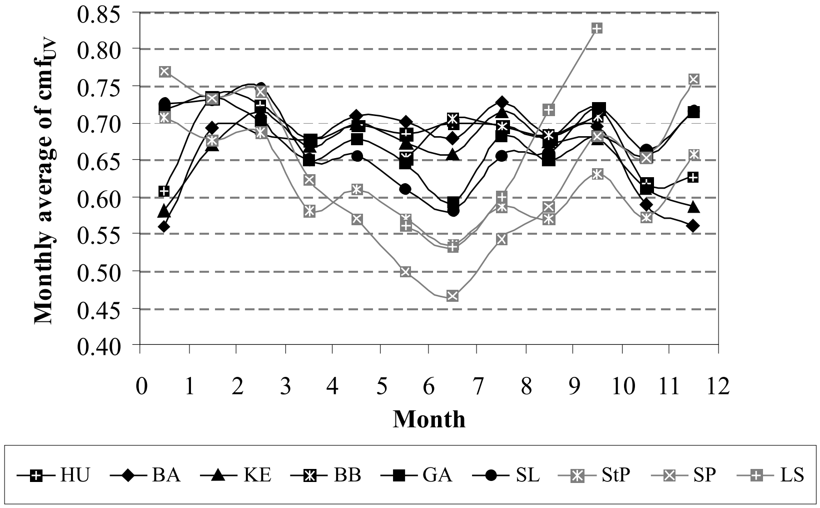

Fig. 3. Monthly mean of the cmf_{UV} calculated for all investigated stations (the abbreviations of stations are summarized in Table 1). The cmf_{UV} values determined for the mountain stations are depicted by gray symbols. The cmf_{UV} values for Banská Bystrica and Lomnický štít are depicted from June to October due to missing information on snow at these places.

from Fig. 3. The decrease of the cmf_{UV} to values ranging between 0.45–0.55 was detected at the Lomnický štít, Skalnaté Pleso and Štrbské Pleso during the summer months, especially in June. The lower cmf_{UV} values observed at Skalnaté Pleso in summer in comparison with Štrbské Pleso and Lomnický štít can partly relate to the complexity of the terrain surrounding the observatory. The horizon around the Skalnaté Pleso observatory is not ideal and the effect of shadowing manifests itself there. The cmf_{UV} decrease to value of 0.60 is also observed at Stará Lesná and Poprad - Gánovce observatories (located close to the High Tatras mountains) during the summer. Convective cloud formation can explain large attenuation of the erythemal UV radiation by clouds in the mountains during the summer.

The highest average values of the cmf_{UV} are observed at the mountain stations during winter (December, January). The decrease of the cloud attenuation effect with altitude in winter probably relates to low inverse cloudiness, more frequently formed at valleys and low-lands than at high mountains. Generally, the highest annual amplitude of the cmf_{UV} detected at the mountain stations results from the typical mountain cloudiness regime – intensive convective activity in summer and more frequent clear days in winter.

The valley and low-land stations Hurbanovo, Bratislava, Košice and Banská Bystrica exhibited less significant annual variability: cmf_{UV} values ranged between 0.65–0.70, except November – January, when the cmf_{UV} dropped to 0.55–0.65.

The largest mean annual UV radiation cloud attenuation of 0.61 was found at Štrbské Pleso, where convective clouds attenuate UV radiation in summer and low inverse cloudiness in winter. The leeward side position of this observatory to prevailing west winds in the High Tatras mountains also contributes to high occurrence of cloudiness at this place.

The mean annual cmf_{UV} values ranged from 0.61 at Štrbské Pleso to 0.68 at Hurbanovo.

An increase of the monthly cmf_{UV} with altitude was determined in period October – January. A decrease of the cmf_{UV} with altitude was found from May to August (Fig. 3). The dependence of the cmf_{UV} on altitude is less significant during September, November, February and especially in March, when the range of the cmf_{UV} values is small (0.68–0.75) and UV radiation cloud attenuation is nearly uniform over the whole investigated area.

The dependence of the cmf_{UV} on altitude was established to determine a geographical pattern of the cmf_{UV}. The 2nd degree polynomial function was used to express the dependence of the cmf_{UV} on altitude. The stations Banská Bystrica and Lomnický štít were excluded from the fitted vertical profile from October to June due to missing information on snow. The quality of modelled dependence is summarized in Table 3.

The lowest correlation coefficient between the modelled and measured data was determined for February, March, October and November, when

Table 3. Correlation coefficient r between the measured and modelled values of the cmf_{UV} and the absolute and relative RMS error of the modelled cmf_{UV} dependence on the altitude

Month	1	2	3	4	5	6	7	8	9	10	11	12
r	0.921	0.208	0.204	0.886	0.989	0.949	0.943	0.943	0.864	0.549	0.358	0.798
RMS	0.03	0.03	0.05	0.02	0.01	0.02	0.03	0.02	0.03	0.03	0.04	0.05
RMS [%]	5.4	4.6	7.8	2.9	1.2	4.1	5.0	3.7	4.0	4.1	6.0	7.9

the cmf_{UV} did not depend on altitude significantly. The relative RMS error is also large for January and July, in spite of relatively high correlation coefficients. The reason for this can be the deterioration of the cmf_{UV} vertical profile by the values from Štrbské Pleso in cold half-year. The cmf_{UV} was there close to or lower than the values observed at foot-hill and valley observatories Stará Lesná and Poprad - Gánovce from November to April. On the other hand, the cmf_{UV} values at Skalnaté Pleso, lower than those observed at Lomnický štít, were determined from June to August, what contributed to deterioration of fitted vertical increase of the cmf_{UV} with altitude in summer. The outstandingly low values of the cmf_{UV} in summer could partly relate to non-ideal horizon at Skalnaté Pleso.

An example of map visualization of the cmf_{UV} is shown in Fig. 4. The decrease and increase of the cmf_{UV} with altitude is clearly visible for July and January, respectively.

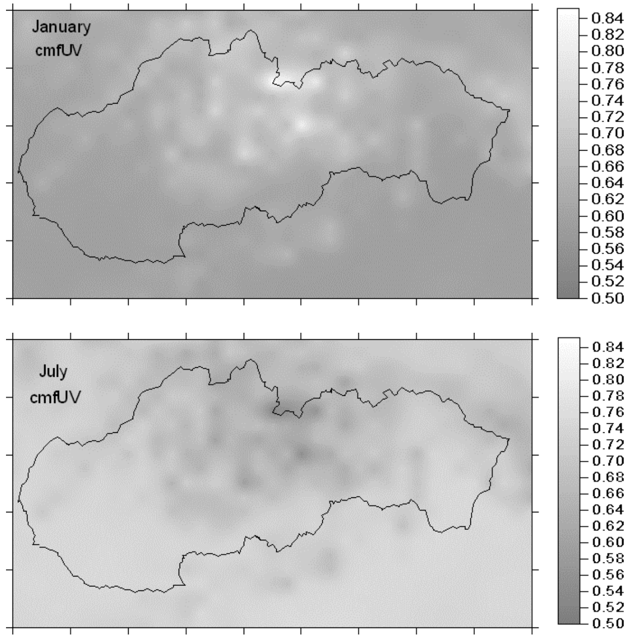

Fig. 4. Maps of the cmf_{UV} distribution over Slovakia in January and in July.

3.3. Climatology of the snow-cover

To estimate the altitude from which snow cover occurrence is typical for every month, the probability of the snow presence was calculated at every station with available information on snow (Fig. 5). The snow occurrence probability for every month was calculated as a ratio between the number of days with snow and number of all days. Due to missing snow information from the Lomnický štít, the whole vertical profile of the investigated area was not covered and it was assumed, that Skalnaté Pleso conditions are representative for all altitudes above this station. Two limit cases of the snow incidence probability of 50% and 70% were depicted.

The probability of the snow incidence below 50% and 70% was detected at all stations from June to October and from May to October, respectively. The snow incidence exceeding the probability of 50% was found for the station Hurbanovo (representing the lowest parts of the Danubian low-land) only in January. In May, the snow probability above 50% was still detected at Skalnaté Pleso. The altitudes of the defined snow incidence probability represented the limits for incorporation of the snow effect on the erythemal UV radiation (Table 4). The snow incidence was assumed for the whole

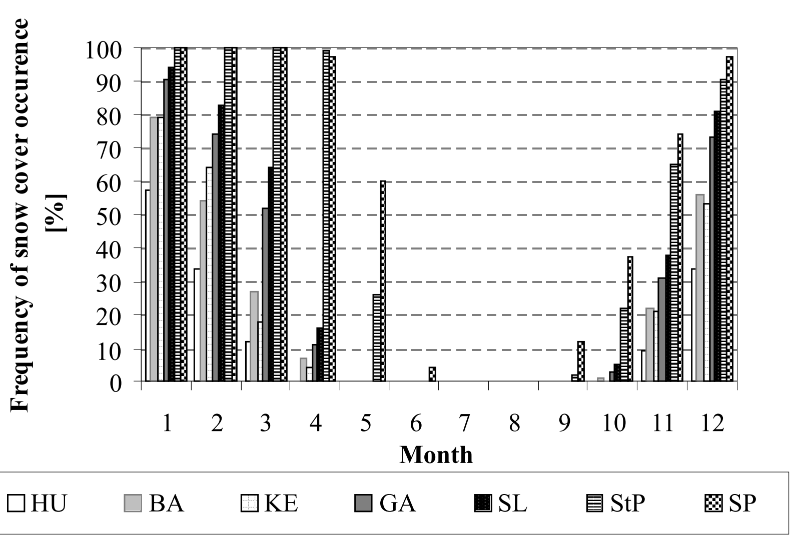

Fig. 5. Frequency of snow cover incidence at investigated stations (the abbreviations of the stations are summarized in Table 1) determined from the period 1995–2004.

investigated territory only in January.

The erythemal UV radiation values are enhanced by the snow reflectivity at inhabited areas with altitude around 1000 m a.s.l. in April. The snow cover is above populated areas in May, but the people present at the peak ski-resorts in the Tatras mountains can be affected by the enhanced erythemal UV radiation values due to snow.

Table 4. Altitudes (in meters) with probability of snow presence of 50% and 70% determined using linear interpolation of the snow incidence probability vertical profile

Altitude with snow probability P [m]		
Month	P = 50%	P = 70%
1	50	191
2	185	620
3	670	906
4	1046	1185
5	1677	>1778
11	1066	1615
12	215	630

3.4. Maps of erythemal UV radiation

The maps of erythemal UV radiation daily dose created as the result of the modelling and spatial visualization methods provide information on its range and spatial distribution over the investigated territory of Slovakia.

The decrease of the erythemal UV radiation with increasing geographical latitude could be expected for the area with homogeneous surface at the uniform altitude. Maps of clear-sky erythemal UV radiation daily dose did not follow the expected pattern. As high elevated places are concentrated in the north and central parts of Slovakia, the highest monthly values of the erythemal UV radiation were detected at these mountain peaks for clear-sky conditions, especially for the lower limits of the total ozone and snow cover presence simulated at high altitudes. The daily doses of the erythemal UV radiation close to 6 $kJ.m^{-2}$ were detected at the peaks of the Tatra mountains from June to August by the cloudless sky. Well expressed increase of the erythemal UV radiation with altitude is documented in Fig. 6 for the clear-sky condition in May and July.

The range of the erythemal UV radiation values over Slovakia decreased after incorporating the cloud effect on the modelled UV radiation (Fig. 7).

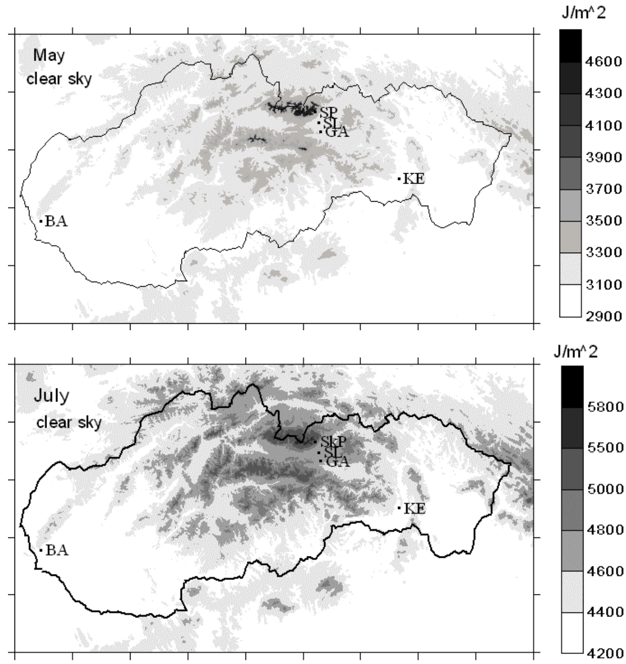

Fig. 6. Modelled clear-sky erythemal UV radiation daily doses for July and for May. The clear-sky UV radiation daily doses were calculated for the first day of month and corresponding monthly average values of the total ozone and appropriate snow conditions (the surface covered by snow was assumed from altitudes with snow incidence probability of 50%).

The vertical increase of the erythemal UV radiation influenced by mean cloudiness was still detected from November to May, when an increase of the cmf_{UV} factor with altitude was detected. But the geographical distribution of the UV radiation did not copy the relief as by the clear-sky conditions (Fig. 7 for May).

The spatial distribution of the erythemal UV radiation attenuated by average cloudiness did not follow the relief model from June to August. As can be seen from Fig. 7 for July, the highest erythemal UV radiation daily doses (of 3 kJ.m^{-2}) were detected at the southern parts of the Danube and the East-Slovak low-lands and at the peaks of the Tatra mountains. The erythemal UV radiation daily doses of 2 kJ.m^{-2} were found in the northern part of Slovakia with no significant differences between valleys and lower

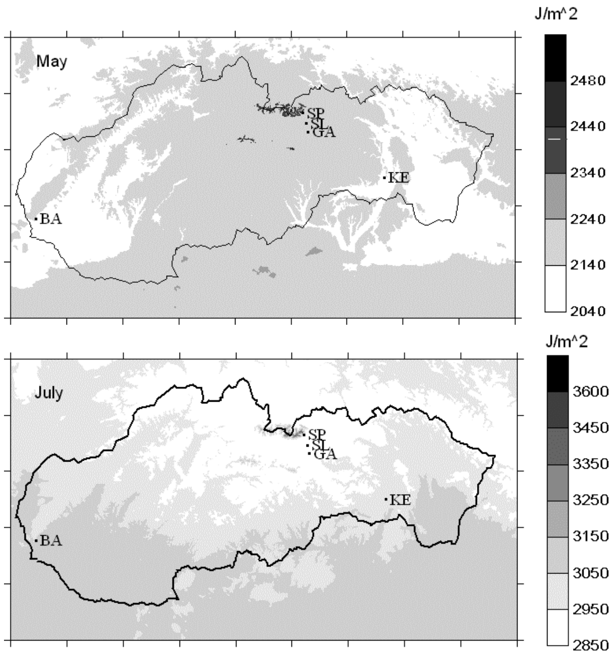

Fig. 7. Modelled erythemal UV radiation daily doses for July and for May assuming mean attenuation by clouds. The UV radiation daily doses were calculated for the first day of month and corresponded monthly average values of the total ozone, the cmf_{UV} and appropriate snow conditions (the surface covered by snow was assumed from altitudes with snow incidence probability of 50%).

mountain positions.

The overview of the range and annual course of the erythemal UV radiation daily dose can be seen in Fig. 8 for all observatories equipped with the UV radiometers. The erythemal UV radiation modelled by clear sky and under average cloudiness is presented for these stations. The modelled values were obtained by interpolation from maps for coordinates of every station. The mapped values were compared with monthly means of the measured UV radiation calculated from the period 2002–2004. A good agreement between the monthly mean of measured erythemal UV radiation and the modelled values (assuming monthly mean of both the total ozone and the cmf_{UV} and the surface covered by snow from altitudes with snow incidence probability of 50%) is documented in Fig. 8.

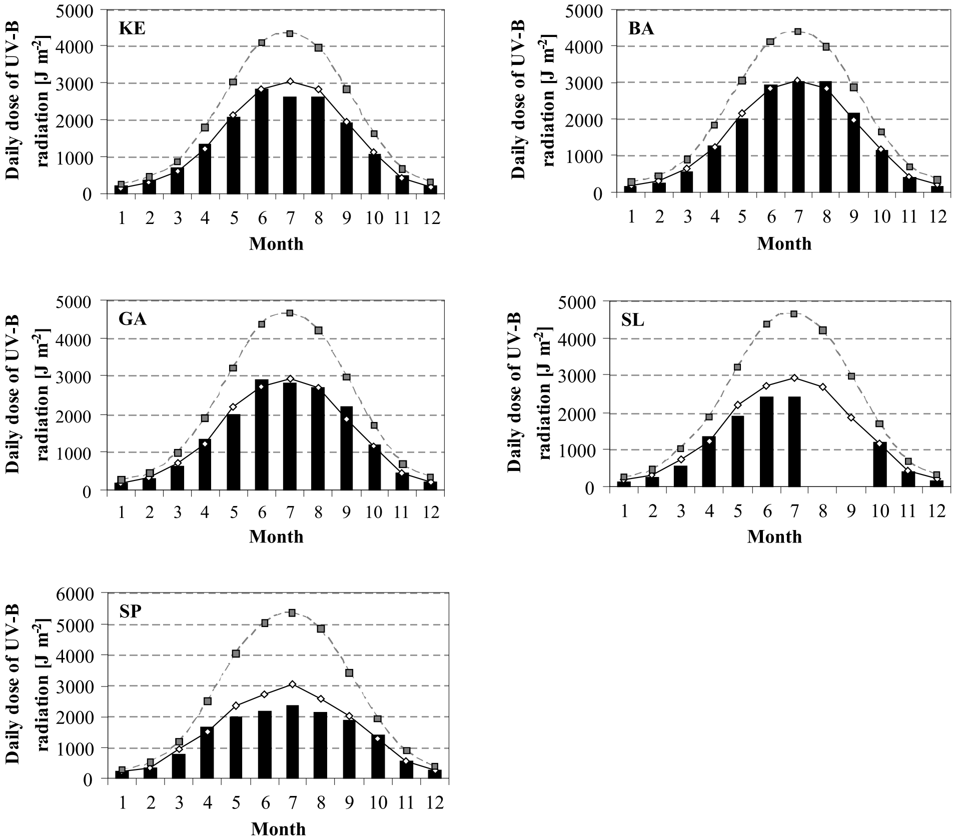

Fig. 8. Monthly mean values of the erythemal UV radiation calculated from measured data at stations equipped by the UV radiometers for the 2002–2004 period (black columns), the modelled clear-sky erythemal UV radiation (grey squares) and the erythemal UV radiation attenuated by mean cloudiness (white diamonds). The erythemal UV radiation was modelled for average total ozone and typical snow conditions (the surface covered by snow was assumed from altitudes with snow incidence probability of 50%).

The largest differences between modelled and measured erythemal UV radiation daily doses of about 20% were detected at all stations in February and March, when the cmf_{UV} factor did not manifest significant dependence on altitude. The best agreement between measured and modelled values of UV radiation daily doses was determined in Bratislava and at Poprad

- Gánovce, where the relative difference between modelled and measured values did not exceed 10% for the whole year, except for the period January – March. The summer values of the erythemal UV radiation were overestimated by the model at stations Stará Lesná and Skalnaté Pleso. These stations are strongly affected by convective clouds in summer. Differences between the total ozone, cloudiness, and snow presence during the periods 2002–2004 and 1995–2004, model error and interpolation error can contribute to discrepancies between modelled and measured mean values of erythemal UV radiation.

4. Conclusions

The high resolution maps of erythemal UV radiation daily dose were created for one day of every month characterized by typical (monthly average of the cloud modification effect, average total ozone) and the limit phenomena (clear-sky condition, upper and lower limits of the total ozone, lower and upper limits of snow incidence probability) affecting the erythemal UV radiation. The erythemal UV radiation was modelled over the small Slovak territory characterized by very diverse relief.

The cloud effect on the erythemal UV radiation was simulated by statistical modelling of the erythemal UV radiation cloud attenuation dependence on the total radiation and on the solar zenith angle. Results of the local studies on the snow and altitude influence on the total and erythemal UV radiation under clear-sky conditions performed in the High Tatras mountains *(Pribullová and Chmelík, 2005)* were used for the implementation of the vertical gradient of the UV radiation, and also for the incorporation of the snow reflectance effect on the UV and total radiation. The total ozone measured at Poprad - Gánovce was assumed to be representative for the whole investigated territory. The modelling was performed with the assumption of fixed aerosol content. The 10-years climatology of the total ozone, total solar radiation and snow cover was used for the determination of the typical pattern of the erythemal UV radiation distribution over the investigated territory. The dependence of both the UV radiation cloud modification and the snow probability occurrence on altitude was modelled for visualization of the erythemal UV radiation in maps.

The cloud attenuation of the erythemal UV radiation varied from 50% in the summer to 20% - 25% in December – January in the High Tatras mountains. The smallest erythemal UV radiation cloud attenuation of about 17% was detected at the peak observatory Lomnický Štít in October. The low variability of the UV radiation cloud modification was detected at the low-lands. The erythemal UV radiation cloud attenuation ranged between 30% and 35% for the whole year at low-lands, except of December and January when reduction of the UV radiation increased to 40%–45%.

The 10-years climatology of the snow cover showed that except of winter months, when the SZA is large, the probability of snow presence of 70% was detected at inhabited altitudes of about 1000 m a.s.l. in April. The increase of the erythemal UV radiation caused by high snow reflectivity is also probable at altitudes above 1600 m a.s.l., where some ski-resorts provide their activities in May.

The maps of the erythemal UV radiation distribution show that the highest daily doses of 6 kJ.m^{-2} can occur at the peaks of the High Tatra mountains under clear-sky conditions in summer. The erythemal UV radiation is reduced by clouds to values of 3 kJ.m^{-2} at low-lands and at the highest Tatra's mountain peaks. The daily doses of 2 kJ.m^{-2} were detected at the rest of the Slovak territory in summer. The maps show that the clear-sky erythemal UV radiation daily doses observed in March at mountain peaks are comparable with the July values observed under typical cloud condition at low-lands.

The resulting map-set of the erythemal UV radiation modelled for average and limit conditions can be considered as the atlas of the erythemal UV radiation over Slovakia. The maps will be available on the internet site of the Geophysical Institute (`http://www.ta3.sk/gfu/interes.htm`) in tabular and graphical form.

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