Seasonal variability of the diffuse radiation at Mlyňany

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A b s t r a c t : Hourly, monthly, and annual sums of the diffuse radiation at the Meteorological Observatory Mlyňany during the 1993–2005 period were used to study the daily and seasonal variability of the diffuse radiation and to estimate their temporal tendency.

The obtained results confirmed that the diffuse radiation trend at Mlyňany has a decreasing tendency. According to expectation the annual course of the diffuse radiation is characterized by a summer maximum and by winter minimum. The largest part of the diffuse radiation falls to one's share in the growing season (nearly 70% from the total annual sum), in spite of the fact that the vegetation period represents roughly a half of the year.

The share of the diffuse radiation in the global solar radiation was considered for all wavelengths of the solar spectrum. According to our calculations the relative portion of the diffuse radiation in the global solar radiation represents 41.1% at Mlyňany (in annual mean).

Key words: diffuse radiation, linear trend, regression analysis, annual and daily course, harmonic analysis, method of least squares

1. Introduction

The transfer of solar and infrared radiation represents the prime physical process that drives the circulation of the atmosphere and the ocean currents. It is apparent that an understanding of the climate and the mechanisms of climatic changes must begin with detailed understanding of radiative processes and the radiative balance of the earth and the atmosphere.

Most of the light that reaches our eyes comes not directly from its sources but indirectly by the process of scattering. We see diffusely scattered sunlight when we look at clouds or at the sky. The land and water surfaces,

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and the objects surrounding us are visible through the light that they scatter. An electric lamp does not send us light directly from the luminous filament but usually glows with the light that has been scattered by the glass bulb. Unless we look at a source, such as the sun, a flame, or an incandescent filament with a clear bulb, we see light that has been scattered. In the atmosphere, we see many colorful examples of scattering generated by molecules, aerosols, and clouds containing droplets and ice crystals. Blue sky, white clouds, and magnificent rainbows and halos, to name a few, are all optical phenomena due to scattering. Scattering is a fundamental physical process associated with the light and its interaction with matter. It occurs at all wavelengths covering the entire electromagnetic spectrum (*Kuo-Nan Liou, 1980*).

2. Material and methods

Sporadic observations and measurements of some meteorological elements have been carried out at Mlyňany in 1920 (*Bero et al., 1992; Steinhübel, 1957*). However, systematic observations of the atmosphere conditions have begun considerably later (in 1962), when the meteorological station was established in the arboretum park. The primary localization of the meteorological station did not quite satisfy the required conditions for the meteorological observations, and therefore the previous meteorological station was removed from the observational area of the Meteorological Observatory of the Institute of Meteorology and Climatology of the SAS (in 1969), now the Arboretum Mlyňany $\varphi = 48°19'$N, $\lambda = 18°20'$E, $h = 195$ m a.s.l.).

Measurements and registration of the diffuse radiation are systematically carried out at the meteorological observatory since 1993. To measure the diffuse radiation, the observational site was equipped with Sonntag's pyranometer (with electroplated thermopile) with the shadow-ring *(Sonntag, 1963)*. Synchronously, with the diffuse radiation (D) and global solar radiation (G), the measurements and observations of other meteorological elements are made. A 10-minute scanning interval of the local time is used for each sensor. Observations of fractional cloudiness values (N) are available at intervals of 1 hour.

The measured data are subject to studying temporal variability of the diffuse radiation in the lowland position (clear non-urban site) Mlyňany. To determine the temporal variations of the diffuse irradiance, the 13-year measurements (1993–2005) of diffuse radiation were used for periods with varying cloudiness. As a clear sky we considered all cases when the clouds amount was less than 2/10 and at the same time sunshine duration was equal to 10. On the other side, the cloudy sky was characterized by clouds amount in a range ($2/10 \leq \mathrm{N} \leq 8/10$), and the overcast sky - by clouds amount greater than 8/10 and sunshine duration equal to zero.

3. Results and discussion

By processing the 13-year measurements of diffuse radiation at Mlyňany many statistical characteristics were obtained. Some of them, namely the annual and monthly sums of diffuse radiation, have been published in the previous papers *(Ostrožlík, 2005a; Ostrožlík, 2005b)*. For instance, it was shown that the mean annual sum of diffuse radiation is 180.397 kJ cm^{-2}. In individual years annual sums varied between 157.086 kJ cm^{-2} (in 2003) and 201.637 kJ cm^{-2} (in 1994). It follows that the fluctuations of the annual sums of diffuse radiation are in a range of 44.551 kJ cm^{-2}. Further statistical characteristics are subject to our study.

In order to estimate the trend of the diffuse radiation (D) with the time (t) (variable t denotes the corresponding year in the time series) the method of regression analysis was applied (*Anděl, 1985; Kendall and Stuart, 1968; Nosek, 1972*). In the first approximation a simple linear model was assumed and by the method of the least squares the regression coefficients were calculated.

According to our calculations, the analytical expression of the temporal change of the annual values of the diffuse radiation [kJ cm^{-2}] at Mlyňany can be written in the form

$$D = 6631.198 - 3.227\,t.$$

Deviations of annual sums of the diffuse radiation from the long-term average and their trend component at Mlyňany are illustrated in Fig. 1. From the course of the curves it is apparent that the variability of the annual

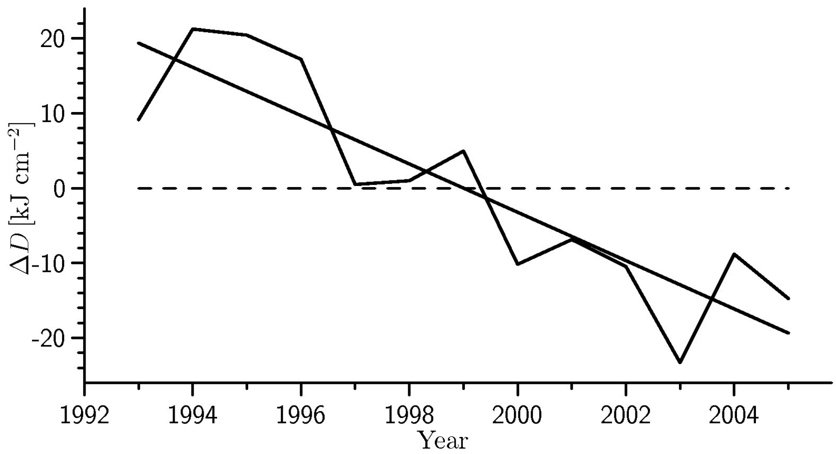

Fig. 1. Course of deviations of the diffuse radiation from the long-term average in kJ cm^{-2} and linear trend of these deviations at Mlyňany during the 1993-2005 period. Value of 0 kJ cm^{-2} refers to the long-term average.

sums is large, and the tendency of diffuse radiation has an expressive negative trend.

The analysis of the monthly sums showed that the mean monthly sum of the diffuse radiation is 15.033 kJ cm^{-2}, at the average cloud conditions. Mean monthly sums in the months of the warming part of the year (June, July) are about 4 times higher than in the months of the cold part of the year (November – January). In individual years the mean monthly sums vary between 13.091 kJ cm^{-2} and 16.803 kJ cm^{-2}. According to our evaluation of 13-year period, the highest monthly sum of diffuse radiation was measured in June 1995 (30.609 kJ cm^{-2}), whereas the lowest measured value occurred in November 2003 (3.595 kJ cm^{-2}).

Mean monthly sums of diffuse radiation - experimental and theoretical - at Mlyňany are graphically presented in Fig. 2. Harmonic analysis was used in these calculations (*Brooks and Carruthers, 1953; Conrad and Pollak, 1962*). The course of the curves indicates an expressive annual course of the diffuse radiation with one maximum (June) and one minimum (December), and with an amplitude about 19.472 kJ cm^{-2}.

An analytical expression of the theoretical curve can be written in the form

$$D = 15.0331 + 9.6913 \sin(x + 298°39'),$$

where x is a time angle. It is computed from $x = iz$, $z = 360°/P$, $i = 0, 1, 2.....n - 1$, if P denotes the length of the period investigated. For example, in our case $n = 12$, $P = 12$ months, and $z = 360°/12 = 30°$.

From the first comparison of the curves – experimental and calculated – we can see that in the case of annual course of the diffuse radiation the fitted curve gives a good agreement between the observed and calculated values.

The annual course of the standard deviations, as well as the annual course of the mean monthly sums of the diffuse radiation, is also characterized by a simple course with the maximum in the summer months (a certain exception represents only July) and minimum in the winter months (Fig. 2). It is apparently a result of more intensive variability of clouds amount during the summer.

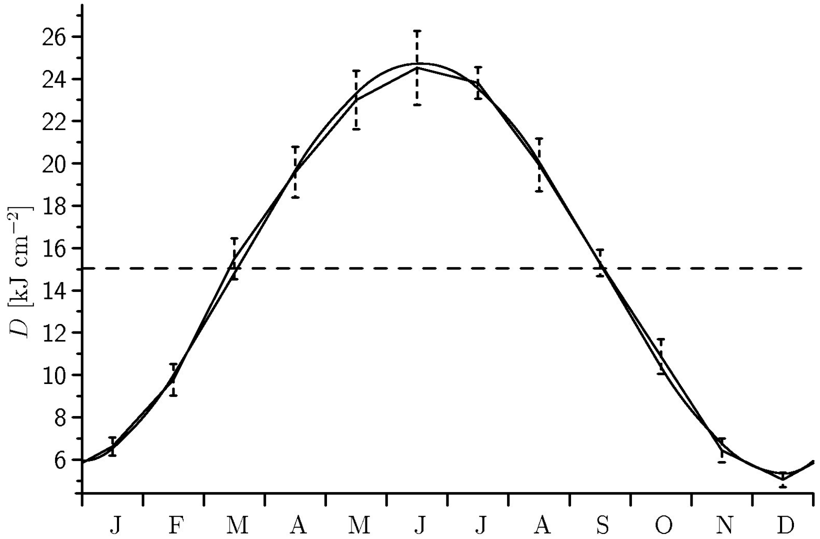

Fig. 2. Annual course of mean monthly sums of the diffuse radiation (D) and its first harmonic component in kJ cm^{-2} at Mlyňany during the 1993–2005 period. Error bars represent variance and indicate variability within the month.

As results from the previous interpretation, the greater part of the diffuse radiation falls to one's share in summer months, and on vegetation period from April to September, respectively. It also confirmed the calculated values. The average sum of the diffuse radiation during the growing season is 126.141 kJ cm^{-2}. It represents approximately 69.9% of the annual sum of the diffuse radiation, in spite of the fact that the total length of the vegetation period represents roughly one half of a year. The diffuse radiation portion to the total annual sum in % during the year is given in Table 1.

The annual course of the mean daily sums of the diffuse radiation at

Table 1. Share of the monthly sums of diffuse radiation in the total annual sum in % at Mlyňany during the 1993 – 2005 period

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Mlyňany	3.7	5.4	8.6	10.8	12.7	13.6	13.2	11.1	8.5	6.0	3.6	2.8	100

Mlyňany is illustrated in Fig. 3. It is characterized by a simple course. The mean daily sums of the diffuse radiation vary from 0.163 kJ cm^{-2} in December to 0.817 kJ cm^{-2} in June. It turns out to this, that the annual amplitude is high, about 0.654 kJ cm^{-2}. Calculations show that the mean daily sum of the diffuse radiation is 0.494 kJ cm^{-2}.

The share of the diffuse radiation in the total intensity of the global radiation depends first of all on the physical state of the atmosphere. As it has been already published *(Smolen, 1980)*, under clear skies when the scattering of direct solar radiation is affected only by air molecules and dust particles, the portion of the diffuse radiation on the all flux density of the global solar radiation is considerably smaller than under the cloud conditions. In like manner, *Berland* (1961) paid a great attention to this problem. In consequence of cloudiness the scattering of the direct solar radiation usually increases (*Lapin and Tomlain, 2001; Tomlain and Hrvoľ, 1991*). A comparison of 4 annual courses of diffuse radiation under the different cloud conditions is presented in Fig. 4. Actually, under the cloudy sky (curve 3), the mean hourly sums of the diffuse radiation are in every month of the year the highest. However, under the clear sky (2) and under the overcast sky (4) the corresponding monthly values are almost equal and their annual courses are very similar.

Processing the experimental material showed the mean hourly value of

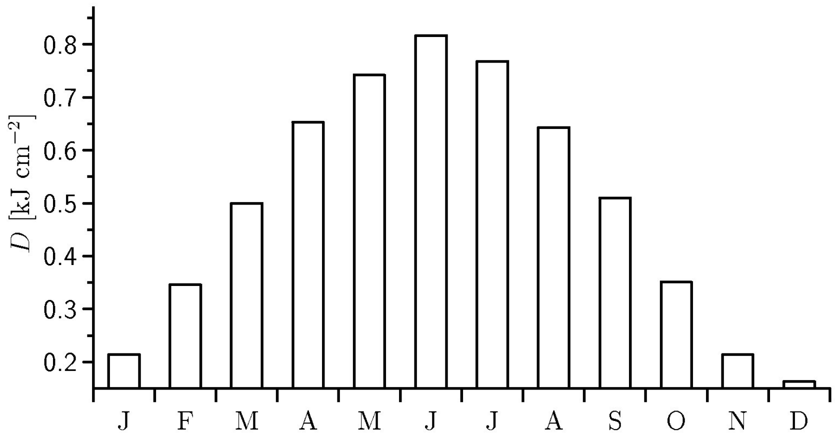

Fig. 3. Histogram illustrating the variability of mean daily sums of the diffuse radiation in kJ cm^{-2} at Mlyňany during the 1993–2005 period.

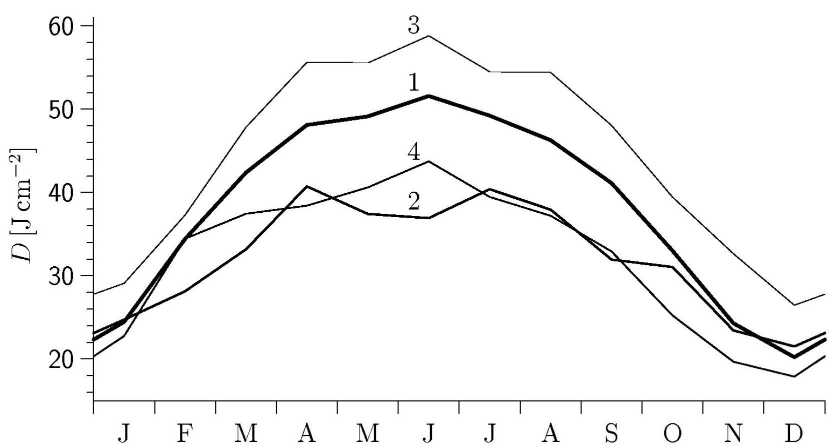

Fig. 4. Annual course of mean hourly sums of the diffuse radiation at Mlyňany under the different cloud conditions: 1 – average cloud conditions, 2 – clear sky, 3 – cloudy sky, and 4 – overcast sky. Average during the 1993-2005 period.

the diffuse radiation at Mlyňany to be 41.667 J cm^{-2}. The daily course of the mean hourly sums of the diffuse radiation is presented in Fig. 5. It can be seen that the diffuse radiation has an expressive daily course.

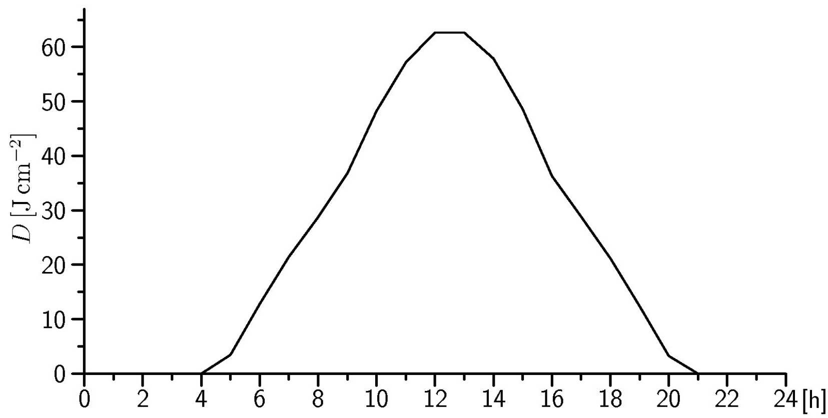

Fig. 5. Daily course of mean hourly sums of the diffuse radiation (D) in J cm^{-2} at Mlyňany during the 1993–2005 period.

During a day, with the sunrise and by the development of the convective clouds, the flux density of the diffuse radiation increases. We can see that the highest values of diffuse radiation flux density occur at noon (midday hours), and the mean values are 62.663 J cm^{-2} and 62.631 J cm^{-2} (12 and 13 h). According to the expectation, the minimal values of diffuse radiation occur in the evening and morning hours, and in the interval from 21 to 4 h the diffuse radiation is always equal to zero. Of course, in individual months of the year, not only the flux density, but also the length interval of diffuse radiation is changeable. In the summer months the corresponding hourly values are higher than in the remaining part of the year, and at the same time the length duration of diffuse radiation is also longer than in the winter season.

Generally, the periodic variation of the Sun elevation is first of all the main physical cause of the periodic annual and daily variations of the diffuse radiation.

As stated above, the diffuse radiation is one of the components which to a considerable measure influence the global solar radiation. The share of the diffuse radiation in the global radiation was determined for all the short-wave spectral range. According to our results the relative share of

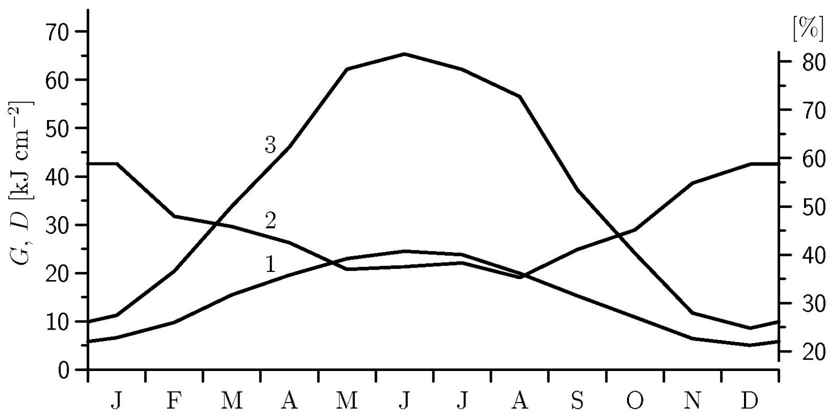

Fig. 6. Annual course of mean monthly sums of the diffuse radiation (1) and global solar radiation (3), and the portion of diffuse radiation in global solar radiation in % (2). Average during the 1993-2005 period.

the diffuse radiation in the global solar radiation is large, approximately 41.1% at Mlyňany (in annual mean). The annual course of the portion of the diffuse radiation to the global solar radiation is simple (Fig. 6, curve 2). What is interesting: it is characterized by a maximum in winter months (November – January) and by a minimum in the warm part of the year (May – August), although the annual courses of both – the global and the diffuse radiation are strictly reverse. The monthly values of this share vary in a range of 23.6%, from 35.3% (August) to 58.9% (January). Similar results can be found in works of *Tomlain (1983)* and *Tomlain and Hrvoľ (1991)*. They analyzed this problem from wider point of view for some selected localities on the territory of the Slovak Republic.

4. Conclusions

By processing the hourly, monthly, and annual sums of the diffuse radiation at the Meteorological Observatory Mlyňany during the 1993-2005 period, many characteristics were obtained.

Based on the evaluation of the obtained results we can state that at Mlyňany:

- the years 1994 and 2003 are characterized by extreme values of the diffuse radiation (maximum and minimum, respectively),
- the diffuse radiation trend has a decreasing tendency,
- the annual course of the diffuse radiation is characterized by a maximum in summer and a minimum in winter,
- the largest part of the diffuse radiation falls into the growing season,
- the relative share of the diffuse radiation in the global solar radiation is 41.1%,
- in the case of the annual course the fitted curve of the first harmonic component gives a good agreement between experimental and calculated values,
- the temporal changes of the diffuse radiation are typical in this climatic characteristic for the corresponding lowlands on the Slovak territory.

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