SEASONAL VARIATION OF RATIOS OF MONTHLY TOTALS FOR THE COMPONENTS OF BROADBAND SOLAR RADIATION MEASURED IN KISHINEV, MOLDOVA

A. Aculinin and V. Smicov

Atmospheric Research Group (ARG), Institute of Applied Physics, Academy of Sciences of Moldova, Academiei str. 5, Chisinau, MD-2028 Republic of Moldova
e-mail: akulinin@phys.asm.md

(Received 24 October 2011)

Abstract

Data obtained during 2004–2010 at the ground-based solar radiation monitoring station in Kishinev (Chisinau) are used to study the seasonal variability of the multiyear averaged ratios of a set of monthly totals in four separate spectral sub-bands from UV through near IR relatively to the monthly totals of global radiation both in the UV spectral ranges (280–315 nm and 280–400 nm) and in the main spectral region (280-3000 nm). Spectral sub-bands consist of UV-B, UVe(erythemal), UV-A, Photosynthetically active (400–700 nm), and solar power (400–1100 nm) broadband radiation. Measurements of monthly totals are fulfilled for direct, global and diffuse broadband radiation. In each of cases for these ratios, respective range of values, annual means, minimum and maximum values are defined. It is shown the existence of the seasonal variation for the whole set of ratios.

1. Introduction

Solar radiation, as one of the key factors, determines the patterns of circulation of the atmosphere and climatic characteristics both in regional and in global scales on the Earth. Before reaching the ground, solar radiation is modified through absorption and scattering processes taking place in atmosphere and on the Earth's surface. The amount of solar radiation at the ground surface depends upon the physical properties of atmosphere and its components, such as aerosols, gases, and cloud structures. These components undergo temporal (hourly, diurnal, monthly, seasonally and yearly) and spatial (on height, on latitude and longitude) variations with specific influence upon the radiation exchange processes in "Earth-atmosphere" system. Ground-based stations and satellite platforms are now widely used for monitoring physical-chemical properties of the system, in particular, the solar radiation. Monitoring of solar radiation is fulfilled both at a lot of individual ground-based stations and at the stations incorporated into the specific networks. These stations are unevenly distributed around the world, but mainly they are concentrated on the land. At the same time, satellite platforms with the set of spectral radiometers on-board give the unique opportunity to carry out solar radiation observations continuously with high time and spatial resolution over the large areas of the Earth. On this account, solar radiation data acquired at numerous ground stations are used to validate satellite platform observations.

The objective of this paper is to study seasonal variability of the ratios between monthly totals of broadband solar radiation in four spectral sub-bands within the spectral region from UV to near IR to monthly totals of global radiation both in the UV spectral range and in the main spectral region (280–3000 nm). Measurements were fulfilled at the ground-based station in

Kishinev (Chisinau), Republic of Moldova in the course of period from 2004 to 2010.

2. Equipment and results of measurements

Continuous measurements of broadband solar radiation at the ground monitoring station at the Institute of Applied Physics started in October 2003. The ground-based station consists of three principal units operating in an automatic mode: radiometric complex, automatic weather station AWS MiniMet, and a sunphotometer Cimel-318. Radiometric complex includes the set of nine radiometric sensors from Kipp&Zonen directly connected to the datalogger CR10X SM 4M. Measurements of solar radiation within the wavelength range from UV to IR were carried out using radiometric sensors such as CM-11 pyranometers, CH-1 pyrheliometer, and PAR, UV-B and UV-A sensors. Measurements of global solar radiation were fulfilled using six sensors mounted on the stationary platform. Direct and diffuse solar radiation was measured using three sensors installed on the rotating platform known as an active sun-tracker 2AP BD [1, 2]. Ground-based solar irradiances recorded at a rate of 1 s with 1 min averaging for each sensor were used to derive hourly, daily, and monthly totals. A Cimel-318 sunphotometer was used to fulfill collocated and synchronous measurements of spectral aerosol optical depths (AOD) at seven wavelengths from 340 to 1020 nm alongside with the solar radiation measurements. Spectral measurements of AOD were carried out within the framework of the Aerosol Robotics Network (AERONET) project managed by the NASA/GSFC [3].

Global and diffuse broadband solar radiation was measured in four spectral sub-bands within the main spectral region ranged from 280 to 3000 nm: UV-B (280-315 nm), UV-A (315–400 nm), Photosynthetically active radiation or PAR (400-700 nm), and solar power or SP (400–1100 nm). Diffuse and global solar radiation was measured using radiometric sensors CM-11 and direct solar radiation was measured using sensor CH-1. PAR Lite and SP Lite sensors were used to measure Photosynthetically active and global solar power radiation. Diffuse and global UV-B and UV-A radiation was measured using two sensors: UV-S-B-C and UV-S-A-C. Diffuse and direct solar radiation, and diffuse UV-B(UVe erythemal) radiation was measured using respective sensors mounted on the rotating platform such as an active sun-tracker 2AP BD equipped with the shading ball arms.

Erythemal radiation in UV-B spectral range is derived from 1-minute averages of irradiances by using lookup tables of computed and corrected (during calibration procedure) values of the adjustment factor $\rho(X,\theta)$, where X is the total column of ozone content in the atmosphere and θ is a solar zenith angle at the time of observation. Erythemal radiation was obtained from convolution between the spectrum of solar radiation and CIE(1987) Reference Action spectrum [4] for erythema in human skin within the wavelength range of 280 to 400 nm. Standard erythema action spectrum provides an internationally accepted representation of the erythema-inducing effectiveness of wavelengths in the UV part of the spectrum.

Measurements of direct, diffuse, and global solar radiation within the main spectral region were also used in analysis. Monthly totals $Q_{i,m}$ of broadband solar radiation both in four spectral sub-bands and in the main spectral region are defined by simple integration of respective 1-minute averages of the above mentioned parameters and marked with additional subscripts ‘m’ and ’ i’. Index i=’dif’ and ’gl’ corresponds to diffuse and global components, respectively. The following relations were calculated on the basis of the measured data. They define the ratios between respective elements of the set of monthly totals as follows:

- ratios of monthly totals $Q_{dir,m}$ and $Q_{dif,m}$ of direct and diffuse solar radiation to monthly totals $Q_{gl,m}$ of global solar radiation derived in the main spectral region (280-3000 nm);

- ratios of monthly totals $QUVB_{i,m}$, $QUVA_{i,m}$, $QUVe_{i,m}$, $QPAR_{i,m}$ and $QSP_{i,m}$ of radiation derived in four separate spectral sub-bands to monthly totals $Q_{gl,m}$ of global solar radiation in the main spectral region, where index i='dif' and 'gl' corresponds to diffuse and global components, respectively;
- ratios of monthly totals $QUVB_{i,m}$ and $QUVe_{i,m}$(erythemal) of radiation derived in UV-B spectral region to monthly totals $QUVB_{gl,m}$ of global UV-B radiation in wavelength range of 280 to 315 nm (correspondence of index 'i' is defined as above) ;
- ratios of monthly totals $QUVB_{gl,m}$ and $QUVB_{dif,m}$ of radiation derived in UV-B spectral region to monthly totals $QUVBA_{gl,m}$ of global UV radiation in combined spectral region UVBA (UV-B + UV-A) of 280 to 400 nm.

Ratios R_m report the relative contribution of respective values of monthly totals derived in four spectral sub-bands into the values of monthly totals $Q_{gl,m}$ of global solar radiation, $QUVB_{gl,m}$ of global UV-B radiation and $QUVBA_{gl,m}$ of global UVBA radiation. Values of totals $Q_{gl,m}$, $QUVB_{gl,m}$ and $QUVBA_{gl,m}$ are considered as basic ones and all ratios R_m will be computed with respect to them. Multi-year (MY) mean values of ratios $<R_m>_{MY}$ are obtained from averaging of ratios R_m derived between respective elements of the set of monthly totals in the course of period from 2004 to 2010. Final results of the analysis of seasonal changes of the MY averaged ratios $<R_m>_{MY}$ are presented in Figs. 1-8. Summary of MY averaged ratios $<R>_{MY}$ of monthly totals $QUV_{i,m}$ derived in four spectral sub-bands in main spectral region over monthly totals $Q_{gl,m}$ derived for global broadband solar radiation is presented in Table 1.

Table 1. Summary of multi-year (MY) averaged ratios $<R_m>_{MY}$ of monthly totals $Q_{i,m}$ derived in four spectral sub-bands in the main spectral region (280-3000 nm) over monthly totals $Q_{gl,m}$ of global broadband solar radiation. Minimum and maximum values of $<R_m>_{MY}$ are presented below. Four spectral sub-bands include UV-B(+ erythemal UVe), UV-A, PAR, and solar power (SP) radiation. Monthly totals $Q_{dif,m}$ and $Q_{dir,m}$ of diffuse and direct of solar radiation are derived in the main spectral region. Indices i='dif','dir' or 'gl' correspond to diffuse, direct, and global components, respectively. Period of observations: 2004 to 2010

Ratio of monthly totals, R_m	Annual mean value ±1σ, in %	min{ $<R_m>_{MY}$ }, in %	max {$<R_m>_{MY}$}, in %
$Q_{dif,m}/Q_{gl,m}$	48.6±12.0	35.4	70.1
$Q_{dir,m}/Q_{gl,m}$	51.3±11.9	29.7	64.5
$QPAR_{gl,m}/Q_{gl,m}$	45.7±0.5	45.0	46.4
$QSP_{gl,m}/Q_{gl,m}$	94.8±0.2	94.4	95.1
$QUVB_{gl,m}/Q_{gl,m}$	0.13±0.04	0.07	0.18
$QUVB_{dif,m}/Q_{gl,m}$	0.10±0.03	0.06	0.13
$QUVe_{gl,m}/Q_{gl,m}$	0.018±0.004	0.012	0.023
$QUVe_{dif,m}/Q_{gl,m}$	0.013±0.002	0.010	0.016
$QUVA_{gl,m}/Q_{gl,m}$	8.54±1.10	7.19	10.23

Four spectral sub-bands include UV-B(+ erythemal radiation, UVe), UV-A, PAR and solar power (SP) radiation. Summary of MY averaged ratios $<R>_{MY}$ of monthly totals $QUV_{i,m}$ over monthly totals $QUVB_{gl,m}$ and $QUVBA_{gl,m}$ derived in ultraviolet (UV) spectral regions are presented in Table 2.

Seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $Q_{dir,m}$ and $Q_{dif,m}$ of direct and diffuse solar radiation to monthly totals $Q_{gl,m}$ of global solar radiation, such

as $<Q_{dir,m}/ Q_{gl,m}>_{MY}$ and $<Q_{dif,m}/ Q_{gl,m}>_{MY}$, respectively, is shown in Fig. 1. All monthly totals $Q_{i,m}$ were measured in the main spectral wavelength range. The seasonal variation of ratios $<R_m>_{MY}$ are clearly seen: a significant decrease in ratio $<Q_{dir,m}/Q_{gl,m}>_{MY}$ for direct solar radiation and an increase in ratio $<Q_{dif,m}/Q_{gl,m}>_{MY}$ for diffuse solar radiation are observed in late autumn and winter months. Respective averaged values of ratios $<R_m>_{MY}$ are $<Q_{dir,m}/Q_{gl,m}>_{MY}$ ~29.7% and $<Q_{dif,m}/Q_{gl,m}>_{MY}$ ~ 70.1% (see Table 1). It was due to increasing contribution of scattered radiation from cloudiness into the diffuse component $Q_{dif,m}$ during these months. At the same time, in the course of summer months, which are characterized by less influence of cloudiness, maximum of $<Q_{dir,m}/Q_{gl,m}>_{MY}$ and minimum of $<Q_{dif,m}/Q_{gl,m}>_{MY}$ with respective values of ~64.5% and ~35.4% can be observed. For both ratios $<Q_{dir,m}/Q_{gl,m}>_{MY}$ and $<Q_{dif,m}/Q_{gl,m}>_{MY}$ range of values is Δ ~ 34.8%. The range of values is defined as the following difference: $\Delta=\max\{<R_m>_{MY}\}- \min\{<R_m>_{MY}\}$.

Table 2. Summary of multi-year (MY) averaged ratios $<R>_{MY}$ of monthly totals $QUV_{i,m}$ over monthly totals $QUVB_{gl,m}$ and $QUVBA_{gl,m}$ derived in ultraviolet (UV) spectral regions. The recording such as UVBA means combined spectral range UVA+UVB (280-400 nm). Indices i='dif' and 'gl' correspond to diffuse and global components, respectively. Period of observations: 2004 to 2010

Ratio of monthly totals, R_m	Annual mean value ±1σ, in %	min{ $<R_m>_{MY}$ }, in %	max {$<R_m>_{MY}$}, in %
$QUVB_{dif,m}/QUVB_{gl,m}$	76.8±4.4	70.9	82.8
$QUVe_{gl,m}/QUVB_{gl,m}$	13.8±1.8	12.5	17.3
$QUVe_{dif,m}/QUVB_{gl,m}$	10.7±1.9	8.9	14.0
$QUVB_{dif,m}/QUVBA_{gl,m}$	1.19±0.43	0.56	1.73
$QUVB_{gl,m}/QUVBA_{gl,m}$	1.58±0.64	0.69	2.39

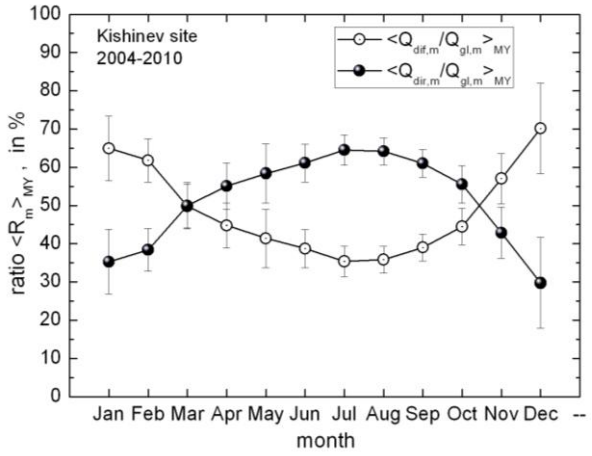

Fig. 1. Seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $Q_{dir,m}$ and $Q_{dif,m}$ of direct and diffuse solar radiation to monthly totals $Q_{gl,m}$ of global solar radiation. Monthly totals were derived in the main spectral wavelength range (280–3000 nm) in the course of period from 2004 to 2010.

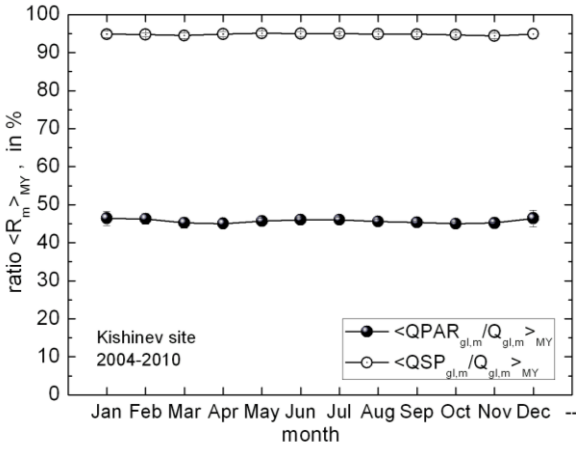

Fig. 2. Seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QPAR_{gl,m}$ and $QSP_{gl,m}$ of global Photosynthetically Active radiation (400–700 nm) and global solar power radiation (400–1100 nm) to monthly totals $Q_{gl,m}$ of global solar radiation measured in the main spectral wavelength range (280–3000 nm) .

Multi-year averaged ratios $<R_m>_{MY}$ of monthly totals $QPAR_{gl,m}$ of global Photosynthetically active radiation (400–700 nm) and global solar power radiation $QSP_{gl,m}$ to monthly totals $Q_{gl,m}$ of global solar radiation measured in the main spectral wavelength range show no seasonal variation (see Fig. 2). The respective annual mean values of ratios $<R_m>_{MY}$ are $<QPAR_{gl,m}/Q_{gl,m}>_{MY}$ ~ 45.7% and $<QSP_{gl,m}/Q_{gl,m}>_{MY}$ ~ 94.8% (see Table 1). In addition, minimum and maximum values of the MY averaged ratios $<R_m>_{MY}$ during the year are presented in this table. For ratios of monthly totals of PAR and SP broadband radiation to monthly totals of global solar radiation, the range of values is $\mathbf{\Delta}$ ~ 1.4% and $\mathbf{\Delta}$ ~ 0.6%, respectively.

Seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVB_{gl,m}$ and $QUVB_{dif,m}$ of global and diffuse UV-B radiation (280–315 nm) to monthly totals $Q_{gl,m}$ of global solar radiation is shown in Fig. 3. Respective annual mean values of ratios $<R_m>_{MY}$ are $<QUVB_{gl,m}/Q_{gl,m}>_{MY}$ ~ 0.13% and $<QUVB_{dif,m}/Q_{gl,m}>_{MY}$ ~ 0.10%. Minimum values of the MY averaged ratios $<R_m>_{MY}$ derived in the course of the year are observed in winter months with $<QUVB_{gl,m}/Q_{gl,m}>_{MY}$ ~ 0.07-0.08% and with $<QUVB_{dif,m}/Q_{gl,m}>_{MY}$ ~ 0.06%. Maximum values of the averaged ratios are observed in summer months with $<R_m>_{MY}$ ~ 0.18% for global UV-B radiation and with $<R_m>_{MY}$ ~ 0.13% for diffuse UV-B radiation (see Table 1). The range of values is $\mathbf{\Delta}$ ~ 0.11% and $\mathbf{\Delta}$ ~ 0.07%, for ratios of monthly totals $QUVB_{gl,m}$ and $QUVB_{dif,m}$ of global and diffuse UV radiation to monthly totals $Q_{gl,m}$ of global solar radiation, respectively.

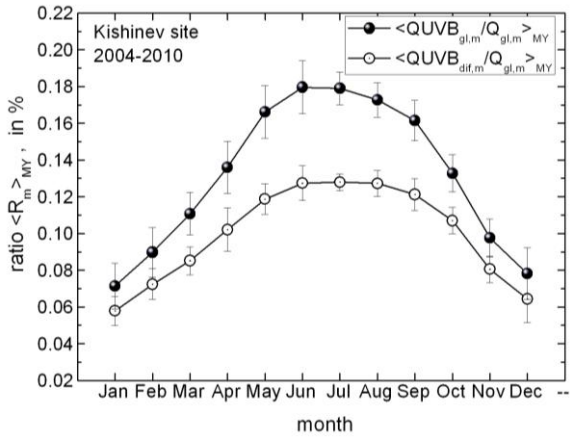

Fig. 3. Seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVB_{gl,m}$ and $QUVB_{dif,m}$ of global and diffuse UV-B radiation to monthly totals $Q_{gl,m}$ of global solar radiation measured in main spectral wavelength range (280–3000 nm).

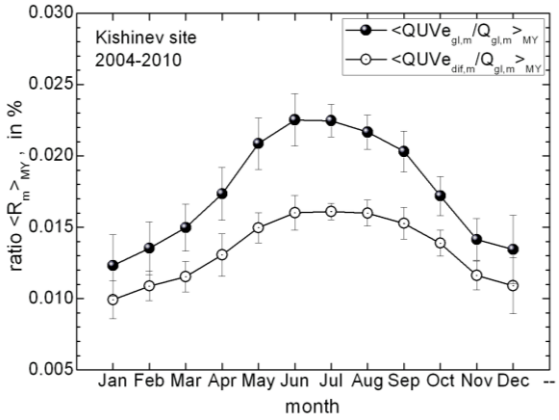

Fig. 4. Seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVe_{gl,m}$ and $QUVe_{dif,m}$ of global and diffuse UVe erythemal radiation to monthly totals $Q_{gl,m}$ of global solar radiation measured in main spectral wavelength range (280–3000 nm).

Figure 4 shows seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVe_{gl,m}$ and $QUVe_{dif,m}$ of global and diffuse UVe erythemal radiation to monthly totals $Q_{gl,m}$ of global solar radiation in the main spectral range.

Ratio $<R_m>_{MY}$ reaches its minimum in winter months (Dec.,Jan.) and maximum values in summer months (Jun.,Jul.) in the same manner as $<R_m>_{MY}$ concerning the ratios of monthly totals $QUVB_{gl,m}$ of global and $QUVB_{dif,m}$ of diffuse UVB radiation to monthly totals $Q_{gl,m}$ of global solar radiation. The minimum values of ratios $<R_m>_{MY}$ are $<QUVe_{gl,m}/Q_{gl,m}>_{MY}$ ~ 0.012% and

$<QUVe_{dif,m}/Q_{gl,m}>_{MY}$ ~ 0.010%. The maximum values of the averaged ratios $<R_m>_{MY}$ are ~0.023% for global UVe radiation and ~0.016% for diffuse UVe radiation. The annual mean values of ratios are $<QUVe_{gl,m}/Q_{gl,m}>_{MY}$ ~ 0.018% and $<QUVe_{dif,m}/Q_{gl,m}>_{MY}$ ~ 0.013% (see Table 1). For ratios of monthly totals of global and diffuse UVe erythemal radiation to monthly totals of solar global radiation, the range of values is **Δ** ~ 0.01% and **Δ** ~ 0.006%, respectively. Curves describing variation of MY averaged ratios $<R_m>_{MY}$ are similar to each other by the pattern of change, but differ in magnitude only (see Figs. 3, 4). It should be pointed out that variation of $<R_m>_{MY}$ shown in Figs. 3 and 4 bears resemblance to the variability of the year course of maximum of the sun height position above the horizon computed at the middle date of each month.

Figure 5 shows seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVA_{gl,m}$ of global UVA radiation (315–400 nm) to monthly totals $Q_{gl,m}$ of global solar radiation. In this case, $<R_m>_{MY}$ reaches minimum in summer months (Jul.,Aug.) with value $<R_m>_{MY}$ ~ 7.2%-7.3% and maximum in winter months (Dec.,Jan.) with the value $<R_m>_{MY}$ of ~10.2%. The range of values for ratio $<QUVA_{gl,m}/Q_{gl,m}>_{MY}$ is **Δ ~** 3.04%.

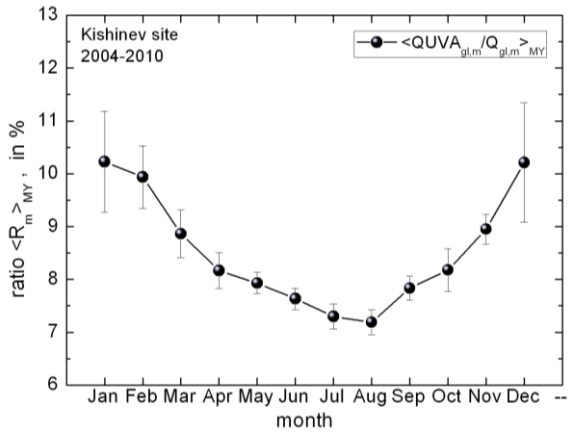

Fig. 5. Seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVA_{gl,m}$ of global UV-A radiation to monthly totals $Q_{gl,m}$ of global solar radiation measured in the main spectral wavelength range (280–3000 nm).

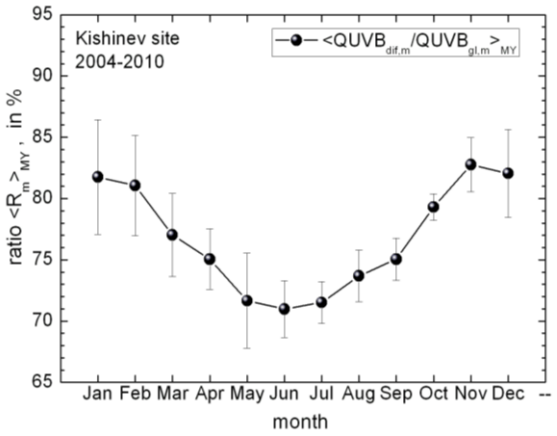

Fig.6. Seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVB_{dif,m}$ of diffuse UV-B radiation to monthly totals $QUVB_{gl,m}$ of global UV-B radiation. All functions were measured in the main wavelength range (280–315 nm).

Figures 6-8 show seasonal variation of the relative contribution of monthly totals $QUVB_{i,m}$ and $QUVe_{i,m}$ both into the monthly totals $QUVB_{gl,m}$ and $QUVBA_{gl,m}$. All ratios between these monthly magnitudes were averaged in the course of period from 2004 to 2010. Figures 6 shows seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVB_{dif,m}$ of diffuse radiation to monthly totals $QUVB_{gl,m}$ of global radiation. Both magnitudes were obtained in UV-B (280–315 nm) spectral sub-band of solar radiation. Maximum of ratio $<R_m>_{MY}$ is observed in late autumn (Nov.) and in winter months (Dec.,Jan.) with a value of ~82.7%, but minimum of ratio $<R_m>_{MY}$ is observed in summer months (Jun., Jul.) with a value of ~70.9%. The annual mean value of ratio is ~76.8% (see Table 2). The range of values for ratio $<QUVB_{dif,m}/ QUVB_{gl,m}>_{MY}$ is **Δ ~** 11.8%.

The existence of peaks in the winter months is probably due to large magnitude of cloudiness in comparison to the summer months. Summer months are characterized by lower

amount of cloudiness and by smaller number of cloudy days.

To determine the percentage of the magnitude $QUVe_{i,m}$ of erythemal radiation relative to $QUVB_{gl,m}$ global UV-B radiation, we introduced the following ratios $<R_m>_{MY}$ of monthly totals of erythemal UVe components of radiation to global UV-B radiation in the following form: $QUVe_{gl,m}/QUVB_{gl,m}$ for global and $QUVe_{dif,m}/QUVB_{gl,m}$ for diffuse UVe radiation. Seasonal variation of MY averaged ratios $<R_m>_{MY}$ is shown in Fig. 7 and summary of multiyear averages is presented in Table 2. Curves describing seasonal variability of ratios $<R_m>_{MY}$ show its maximum in winter (Jan.,Dec.) with values $<QUVe_{gl,m}/QUVB_{gl,m}>_{MY}$ ~ 17.3% and $<QUVe_{dif,m}/QUVB_{gl,m}>_{MY}$ ~14.0%. In summer months ratios $<R_m>_{MY}$ show their minimum with $<QUVe_{gl,m}/QUVB_{gl,m}>_{MY}$ ~ 12.5% (a fairly distinct plateau can be seen) from May to September and with $<QUVe_{dif,m}/QUVB_{gl,m}>_{MY}$ ~ 8.9% from May to July. For ratios of monthly totals of global and diffuse UVe erythemal radiation to monthly totals of global UV-B radiation, the range of values is $\mathbf{\Delta}$ ~ 4.7% and $\mathbf{\Delta}$ ~ 5.1%, respectively.

Figure 8 shows seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVB_{dif,m}$ and $QUVB_{gl,m}$ of UV-B radiation to monthly totals $QUVBA_{gl,m}$ of global UV radiation measured in combined spectral region UVBA (UV-B + UV-A) of 280 to 400 nm. Minimum values of the MY averaged ratios $<R_m>_{MY}$ derived in the course of the year are observed in winter months (Dec., Jan.) with $<QUVB_{gl,m}/QUVBA_{gl,m}>_{MY}$ ~ 0.69% and $<QUVB_{dif,m}/QUVBA_{gl,m}>_{MY}$ ~ 0.56%. Maximum values of the averaged ratios are observed in summer months with $<R_m>_{MY}$ ~ 2.39% (in July) for global UV-B radiation and with $<R_m>_{MY}$ ~ 1.73% (in August) for diffuse UV-B radiation (see Table 2). For ratios $<QUVB_{gl,m}/QUVBA_{gl,m}>_{MY}$ and $<QUVB_{dif,m}/QUVBA_{gl,m}>_{MY}$, the range of values is $\mathbf{\Delta}$ ~ 1.7% and $\mathbf{\Delta}$ ~ 1.2%, respectively.

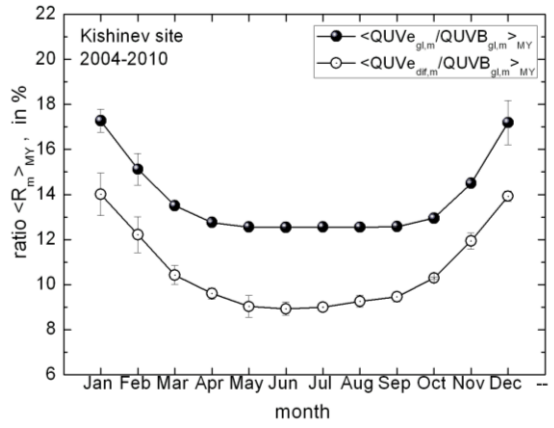

Fig. 7. Seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVe_{gl,m}$ and $QUVe_{dif,m}$ of global and diffuse UVe erythemal radiation to monthly totals $QUVB_{gl,m}$ of global UV-B radiation. Monthly totals were measured in main wavelength range (280–315 nm).

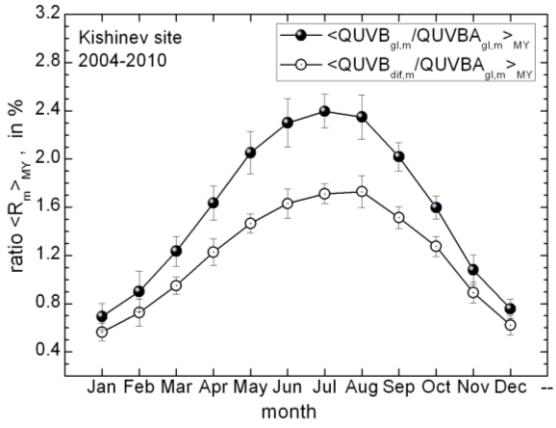

Fig. 8. Seasonal variation of MY averaged ratios $<R_m>_{MY}$ of monthly totals $QUVB_{gl,m}$ and $QUVB_{dif,m}$ of global and diffuse UVB radiation to monthly totals $QUVBA_{gl,m}$ of global UVBA radiation measured in combined spectral wavelength range UV-B+UV-A (280–400 nm).

3. Summary and conclusions

The objective of the work was to study seasonal variation of the multiyear averaged ratios of monthly totals measured in four separate spectral sub-bands from UV through near IR to monthly totals of global radiation both in the UV spectral range and in the main spectral region (280–3000 nm). In the capacity of spectral sub-bands were chosen the following wavelength ranges: UV-B(+erythemal radiation, UVe), UV-A, PAR, and solar power (400–1100 nm). Ratios were computed relative to the basic values such as monthly totals of UV-B, UVBA (in combined spectral range UV-B+UV-A; 280–400 nm), and solar radiation in the main spectral region. Time-series of data includes broadband solar radiation in spectral sub-bands measured with 1-minute averaging. Measurements of solar radiation were carried out at the ground-based station from 2004 through 2010.

All ratios between the respective pairs of monthly totals show seasonal variation, except for the ratios of monthly totals $QPAR_{gl,m}$ of global Photosynthetically active radiation (400–700 nm) and monthly totals $QSP_{gl,m}$ of global solar power radiation (400–1100 nm) to monthly totals $Q_{gl,m}$ of global solar radiation in the main spectral region. These last two ratios show no seasonal variations and their annually means are $<QPAR_{gl,m}/Q_{gl,m}>_{MY}$ ~ 45.7% and $<QSP_{gl,m}/Q_{gl,m}>_{MY}$ ~ 94.8%, respectively. Ratios of monthly totals of PAR and SP broadband radiation to monthly totals of global solar radiation show ranges of values which are $\mathbf{\Delta}$ ~ 1.4% and $\mathbf{\Delta}$ ~ 0.6%, respectively. Ratios of monthly totals $Q_{dir,m}$ and $Q_{dif,m}$ of direct and diffuse solar radiation to monthly totals $Q_{gl,m}$ of global solar radiation show the following seasonal variability: for $<Q_{dir,m}/Q_{gl,m}>_{MY}$ from 29.7% in winter to 64.5% in summer, and for $<Q_{dif,m}/Q_{gl,m}>_{MY}$ from 35.4% in summer to 70.1% in winter. For both ratios $<Q_{dir,m}/Q_{gl,m}>_{MY}$ and $<Q_{dif,m}/Q_{gl,m}>_{MY}$, the range of values is Δ ~ 34.8%**.** Minimum value of ratio $<Q_{dir,m}/Q_{gl,m}>_{MY}$ and maximum value of ratio $<Q_{dif,m}/Q_{gl,m}>_{MY}$ are observed in winter. These extreme values of ratios in winter are due to high values of cloudiness. In summer the cloudiness is less than in winter and the sequence of observed extremes is inverse. For global and diffuse UVB radiation with ratios $<QUVB_{gl,m}/Q_{gl,m}>_{MY}$ and $<QUVB_{dif,m}/Q_{gl,m}>_{MY}$, the range of values is $\mathbf{\Delta}$ ~ 0.11% and $\mathbf{\Delta}$ ~ 0.07%, respectively. The range of values for ratios $<QUVe_{gl,m}/Q_{gl,m}>_{MY}$ and $<QUVe_{dif,m}/Q_{gl,m}>_{MY}$ for global and diffuse UVe radiation is $\mathbf{\Delta}$ ~ 0.01% and $\mathbf{\Delta}$ ~ 0.006%, respectively. The range of values for ratio $<QUVA_{gl,m}/Q_{gl,m}>_{MY}$ is $\mathbf{\Delta}$ ~ 3.04%. Ratios of monthly totals $QUVe_{gl,m}$ and $QUVe_{dif,m}$ of global and diffuse UVe radiation to monthly totals of global UVB radiation $QUVB_{gl,m}$ show ranges of values which are $\mathbf{\Delta}$ ~ 4.7% and $\mathbf{\Delta}$ ~ 5.1%, respectively. In the case of ratios of monthly totals $QUVB_{gl,m}$ and $QUVB_{dif,m}$ of global and diffuse UV-B radiation to monthly totals $QUVBA_{gl,m}$ of global UVBA (UV-B+UV-A spectrum) radiation, the ranges of values are $\mathbf{\Delta}$ ~ 1.7% and $\mathbf{\Delta}$ ~ 1.2%, respectively.

References

[1] A. Aculinin, A. Smirnov, V. Smicov, T. Eck, and A. Policarpov, Mold. J. Phys. Sci. 3, 2, 204, (2004).
[2] Atmospheric Research Group site, Institute of Applied Physics, http://arg.phys.asm.md
[3] B.N. Holben, D. Tanre, A. Smirnov, T.F. Eck, et al., J. Geophys. Res. 106, 12 067, (2001).
[4] A.F. McKinlay and B.L. Diffey, # CIE Research Note, 6(1), 17, (1987).