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BIOLOGICALLY ACTIVE UV-RADIATION AND UV-RESOURCES IN MOSCOW (1999–2013)

ABSTRACT. The paper contains the analysis of long-term measurements of erythemally weighted UV-radiation (Q_{er}) at the Meteorological Observatory of Moscow State University over the 1999-2013 period. Main features of seasonal variability of Q_{er} as well as the Q_{er} dependence on different geophysical parameters are studied. We showed that the average annual Q_{er} attenuation due to cloudiness, total ozone content, and aerosols, is about 29, 30%, and 7%, respectively. The maximal loss of Q_{er} due to cloudiness is observed in November (48%), while ozone-dependent attenuation is maximal in February–March (44%). We used the original technique to assess the UV-radiation impact on human health in Moscow. Specifically, we have identified the UV potential for the erythema formation and synthesis of vitamin D in humans with different skin types. The UV-deficiency conditions are observed for all considered skin types (1–4) during all days from November to February. The probability of the UV-optimum conditions for different skin types was assessed. It was shown, for example, that for skin type 2, the UV-optimum conditions are dominant from March to April and from September to October (maximum in September – 60%). We have also identified the periods with UV-excess conditions. For skin type 2, these conditions may exist from April to August.

KEY WORDS: UV-radiation, erythemal dose, skin type, vitamin D, UV-resources, Moscow.

INTRODUCTION

UV-radiation at the Earth's surface has a significant impact on human health. On the one hand, the excess exposure to high doses of biologically-active UV-radiation causes human skin erythema[1]. It has been established that frequent exposure of humans to excessive doses of erythemally weighted UV-radiation is a risk factor for skin cancer. On the other hand, 90% of the required level of vitamin D in human body is formed under the influence of UV-radiation [Holick, Jenkins, 2003]. Vitamin D is necessary for the prevention of rickets; moreover, its optimal level decreases the risk of death from different kinds of skin cancer [Reichrath et al., 2008]. However, there are no places on the Earth with the optimal year-around UV-radiation conditions [McKenzie et al., 2009], i.e., the conditions that do not pose the risk of erythema formation in summer and deficiency of vitamin D production in human body induced by UV-radiation in winter. Therefore, it is important to study the UV-radiation regime in Moscow, in a major metropolis with 12 million inhabitants.

Monitoring of UV-radiation is conducted by means of ground- and satellite-based methods [Bais, Lubin, 2007]. The ground-based measurements have the least errors.

1 Erythema (from the Greek erythros [έρυθρός], meaning red) is redness of the skin or mucous membranes, caused by hyperemia of superficial capillaries due to inflammation.

However in Russia, the UV-radiation measurements, besides Moscow, are only organized at few stations: in Kislovodsk, Obninsk, Yakutsk, Tomsk and some other cities.

In photobiology, the term "action spectrum" is used to evaluate the effective dose [Vecchia et al., 2007]. The erythemal action spectrum adopted by the International Commission on Illumination [Mutzhas et al., 1993] defines the relative contribution of different wavelengths in the formation of erythema and has a maximum efficiency in the UV-B range. The erythemally weighted UV-radiation[2] (Q_{er}) is calculated by the expression:

$$Q_{er} = \int_{280}^{400} Q_\lambda E_\lambda d\lambda, \quad (1)$$

where Q_λ – is the spectral UV-radiation in W/m^{2}nm; E_λ – is the erythemal action spectrum.

An example of the Q_{er} spectral distribution under certain atmospheric conditions is presented in Figure 1. It clearly shows that the maximal Q_{er} efficiency is associated with the UV-B region of the spectrum, where absorption by ozone is significant.

Often, for convenience, the term "UV-index" (*UVI*) is used. The UV-index is dimensionless quantity and equal to the Q_{er} (in W/m^2 (eff)) divided by 0, 025 W/m^2 (eff). Usually, at mid-latitudes, *UVI* varies from 0 to 10.

Estimating the vitamin D weighted UV-radiation (Q_{vitD}), as well as the Q_{er} calculation, can be accomplished by assessing the spectrum of the previtamin D synthesis [Engelsen et al., 2005; Fioletov et al., 2010; Kazantzidis et al., 2009; Krzys'cin et al., 2011; Webb, Engelsen, 2006]. This action spectrum was adopted by the International Commission on Illumination and has the maximal effectiveness in the UV-B spectrum

[2] Erythemally weighted UV-radiation is measured in W/m^2 (eff), where the "eff" denotes the impact of weighting by the erythemal action spectrum.

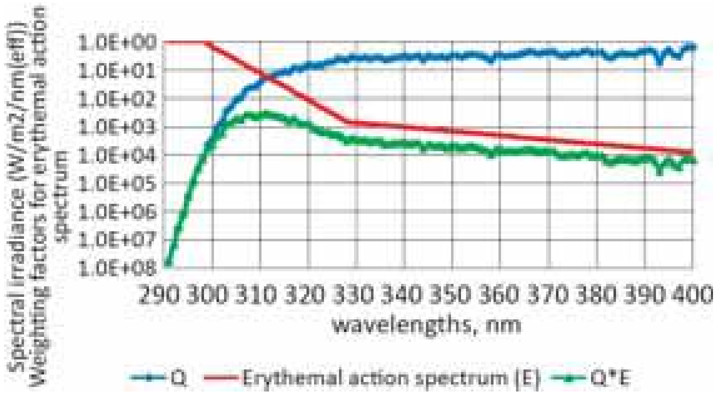

Fig. 1. Spectral distribution of UV radiation (Wm-2nm) (*Q*), erythemal action spectrum (*E*), and UV radiation weighted on erythemal action spectrum (Q_{er}) Wm-2nm$_{eff}$). Model calculation (solar zenith angle 60 degree, total ozone content = 300 DU), clear sky.

[Bouillon et al., 2006]. At the same time, according to [McKenzie et al., 2009], it has several drawbacks. In particular, it was obtained by the results of the experiment in 1982 with a monochromatic source of UV-radiation with a relatively coarse spectral resolution of 6–10 nm [Olds et al., 2010]. In the adopted action spectrum for vitamin D [Bouillon et al., 2006], an additional error is introduced by interpolation of the obtained experimental spectrum of wavelength 315 nm to 330 nm. At the same time, biologists and doctors in their experiments often use the erythemally weighted UV-radiation as a control during measurement of vitamin D [Holick, Jenkins, 2003], which complicates the assessment thresholds. Therefore, for further evaluation of the contribution of UV-radiation in the vitamin D production in human skin, we will use the quantitative ratio to the Q_{er} values as suggested in [Holick, Jenkins, 2003].

Until recently, analysis of patterns of change of erythemally weighted UV-radiation and vitamin D weighted UV-radiation was considered separately [Engelsen et al., 2005; Fioletov et al., 2004; Fioletov et al., 2010; Kazantzidis et al., 2009; Krzys'cin et al., 2011; Webb, Engelsen, 2006]. However, in order to characterize the complex action of UV-radiation on humans, it is important to have their simultaneous estimation. Earlier, in the evaluation of UV-radiation effects on human health, we suggested the use of the term “UV-resource”, that equals to the ratio of erythemally weighted UV-radiation and vitamin D weighted UV-radiation from the point of view of their effect on human health [Chubarova, Zhdanova, 2013; Chubarova, Zhdanova, 2012]. Thus, in these studies, the UV-resources in Russia [Chubarova, Zhdanova, 2012] and Northern Eurasia [Chubarova, Zhdanova, 2013] were evaluated using the Tropospheric Ultraviolet and Visible (TUV) Radiation Model and satellite data of the basic geophysical parameters as input. However, satellite measurements of cloudiness, albedo, and aerosols have significant uncertainties. Possible errors are linked with the separation of snow and cloud cover, problems with reliable aerosol retrievals in winter, etc. In addition, satellite measurements do not allow consideration of the daily variations of many important atmospheric characteristics. In this connection, we used ground-based measurements to evaluate the UV-resources in Moscow, which are the most accurate and reliable.

The main objectives of this work is the analysis of the erythemally weighted UV-radiation using the experimental data over 15 years of measurements during 1999–2013 at the Meteorological Observatory of Moscow State University (MO MSU), identification of the most important geophysical factors affecting its variations, as well as analysis of the UV-resources in Moscow.

MATERIALS AND METHODS

Continuous measurements of erythemally weighted UV-radiation by broadband devices with a spectral sensitivity close to the erythemal action spectrum have been conducted by MO MSU since February 1999 [Chubarova, 2002]. Registration and analysis of the measurements made with one-minute time increments was done with the help of the specially developed software SUN [Rosental et al., 1999]. Through 2012 inclusively, UVB-1 YES pyranometers were used. Since the beginning of 2013, the measurements were done by a KIPP & Zonen UV-SET pyranometer. The main sources of measurement errors with these devices are the differences between the spectral curve of the device and the erythemal response curve, as well as deviations from the cosine law for UVB-1 instruments. Therefore, according to the WMO (World Meteorological Organization) recommendations and methods developed at MO MSU [Chubarova, 2002], necessary corrections were made in the dataset. For quality control, comparison of the measurements recorded by the UVB-1 devices with the measurements by the control UVB-1 YES pyranometer are done annually; the UVB-1 YES itself is calibrated by the spectroradiometer referenced to the international etalons. In 2005, 2008, and 2011 the instrument calibration was performed against the European reference spectroradiometer Bentham DTM300 at the Medical University of Innsbruck (Austria). Also, the existence of residual temperature dependence of the UVB-1 recording devices of the old series was discovered. This factor led to an underestimation of the radiation measurements in the cold season, because temperature stabilization at 45°C was not provided at low air temperatures. In this regard, additional studies were accomplished, which allowed us to make the corresponding correction taking into account the dependence between the device temperature and ambient temperature [Chubarova et al., 2013]. Homogeneity of erythemally weighted UV radiation measurements in 2013 during the transition to the UV-SET KIPP & Zonen pyranometers was checked and guaranteed by multiple comparisons with the control UVB-1 YES pyranometer and reference to the measurements for the previous observation period.

MO MSU adopted the following scheme for the generation of the electronic archives of erythemally weighted UV-radiation. Hourly Q_{er}, obtained using a constant conversion factor at the solar angle of 30° and the total ozone content (TOC) of 300 DU formed initial the Version 1 UV database. The Version 2 UV database included the spectral-corrected data from the Version 1 database. For the UVB-1 devices, the cosine errors were also considered in the Version 2 UV database [Chubarova, 2002]. Finally, the Version 3 UV database includes in addition temperature-corrected data (only for the UVB-1 YES devices) [Chubarova et al., 2013]. In the present study, we used the Version 3 UV database. The measurement error of erythemally weighted UV-radiation is ± 5% [Chubarova, 2002].

To assess the impact of the main atmospheric parameters on Q_{er}, we used TOC data received by the satellite instruments TOMS and OMI and the aerosol optical thickness at a wavelength of 380 nm (AOT_{380}) using AERONET measurements by MO MSU [Chubarova et al., 2011]. According to the method presented in [Chubarova, 2008], we calculated the effective cloud Q_{er} transmittance (*CQ*), taking into account the frequency of cloud amount at different layers and additional impact of surface albedo on the *CQ* value. Surface albedo, in turn, was estimated according to [Chubarova, 2008] using the following equation:

$$A = w_a A_1 + (1 - w_a) A_2, \qquad (2)$$

where A_1 is snow albedo in the UV-spectrum, A_2 is grass albedo in the UV-spectrum, and w_a is the fraction of snow cover.

The average monthly Q_{er} loss due to AOT_{380} was obtained as the relative difference between Q_{er} calculated considering the average monthly AOT_{380} values and Q_{er} at $AOT_{380} = 0$. The TOC-dependent Q_{er} loss was calculated as the relative difference between the model Q_{er} values obtained at the average monthly TOC and the minimal monthly TOC for 1979 and 2003.

In order to evaluate the effect of UV-radiation on human health, it is necessary to know the threshold (minimal) dose of UV-radiation, which may lead to the synthesis of vitamin D and erythema.

Literature sources widely use the term "the minimal erythemal dose (*MED*)" that represents the minimal dose of erythemally weighted UV-radiation needed for appearance of human skin redness. According to the international Fitzpatrick classification [Fitzpatrick, 1988], several skin types are identified based on the *MED* values (Fig. 2). The Fitzpatrick scale represents the modernized Von Luschan skin types scale. The Von Luschan scale determines the geographical distribution of people with different skin color. Most common skin types on the territory of Russia are 1, 2, and 3 according to the Fitzpatrick scale. Therefore, in this study, we estimated the effect of UV-radiation on people with skin types 1, 2, and 3 on the Fitzpatrick scale. In addition, we also discussed skin type 4 that is typical of people living at more southern latitudes. Selected skin types correspond to the following *MED* values: type 1 – 200 J/m^2_{eff}, type 2 – 250 J/m^2_{eff}, type 3 – 300 J/m^2_{eff}, and type 4 – 450 J/m^2_{eff}.

For the assessment of vitamin D threshold, it is necessary to account the open human body fraction that depends on air temperature and, to some extent, wind speed. Therefore, for calculating the open human body fraction

Fig. 2. The Fitzpatrick skin scale (from http://www.skincancer.org/).

the values of effective air temperature were also applied [Chubarova, Zhdanova, 2012; Chubarova, Zhdanova, 2013].

Thus, the threshold for the vitamin D synthesis (*P*) for human skin type *I* is:

$$P_i = \frac{0.06MEDi}{S_{(teff)}}, \quad (3)$$

where *S* is the open human body fraction; *MED* is the minimal erythemal dose.

The transition coefficient 0.06 was obtained according to medical recommendations, which state that the necessary moderate level of vitamin D is 600 IU (International Unit) and that the irradiation by one *MED* of the whole body results in the synthesis of 10, 000 IU of vitamin D. A more detailed description of the methodology used to assess UV-resources can be found in [Chubarova, Zhdanova, 2012; Chubarova, Zhdanova, 2013].

This work used the classification of the UV-resources presented in [Chubarova, Zhdanova, 2013]. The classification consists of several classes: 100% UV-deficiency (vitamin D is not synthesized during 24 hours), midday UV-deficiency (vitamin D is not synthesized at midday), UV-optimum (at midday, a necessary per day amount of vitamin D is synthesized, but erythema is not formed), and several classes of UV-excess identified according to the International Classification of *UVI*. For example, for a person with skin type 2, according to the recommendations, the hazardous conditions from UV-radiation occur at *UVI* greater than 3. For each skin type, different UV-excess thresholds exist. To account for these changes, the hourly *UVI* thresholds for skin type 2 ($j = 2$), according World Health Organization, are recalculated into the hourly erythemal doses for different skin types using a conversion: $UVI\ K_j\ 3600/40$, where K_j accounts for skin type difference $K_j = MED_j / MED_{j=2}$ [Chubarova, Zhdanova, 2013].

For assessment of the UV-resources in Moscow, for each day in 1999–2013, the following parameters were selected: the maximal hourly erythemal doses (*ED*) that often correspond to the midday hours, and daily ***ED***. For the vitamin D weighted threshold calculations, the daily data of air temperature at the height of 2 m and wind speed at the height of 10 m at 12 o'clock (winter Moscow time) were used. Thus, we have identified the categories of UV-resources for each day over 1999–2013.

RESULTS AND DISCUSSION

Variability of erythemally weighted radiation in Moscow

Let us consider the main characteristics of the monthly mean *ED* variability in Moscow over the 15 years of the observations since 1999. Fig. 3 shows pronounced seasonal changes in average and extreme (minimal and maximal) *ED* values. The annual variation is characterized by the maximum in July,

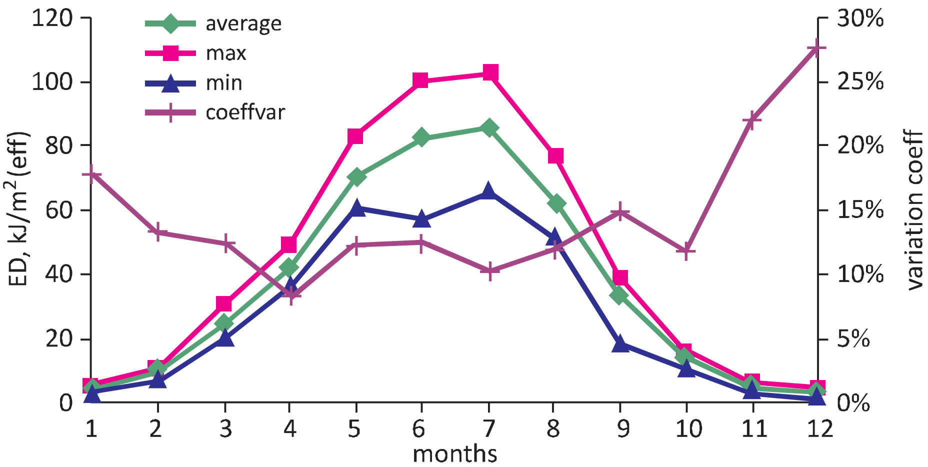

Fig. 3. Seasonal cycle of monthly mean, minimum, maximum ED values (kJ/m$^2_{eff}$), and variation coefficient (in %), Moscow (1999–2013).

Table 1. Statistical parameters of monthly mean ED values

Month	Mean, J/m2(eff)	Maximum, J/m2(eff)	Minimum, J/m2(eff)	Standard deviation, J/m2(eff)	Skewness	Kurtosis
1	113	321	19	55	0.91	0.58
2	293	956	37	155	1.09	1.46
3	791	2011	145	385	0.50	–0.51
4	1394	2846	194	579	0.06	–0.71
5	2278	4099	393	823	–0.17	–0.64
6	2770	4506	458	869	–0.44	–0.42
7	2783	4514	522	808	–0.47	–0.20
8	2003	3727	211	729	–0.20	–0.55
9	1130	2479	135	496	0.13	–0.46
10	422	1191	50	255	0.80	–0.09
11	136	513	25	85	1.23	1.37
12	70	176	15	34	0.85	0.20

while the minimum is observed in February. On average, the annual *ED* in Moscow is 433 kJ/m^2 eff. The bias of the ED maximum to July from June, when the highest solar angles are observed, is explained by slightly lower TOC and, hence, less *ED* absorption in July. It was possible to identify the cause of larger *ED* absorption in June than that in July by comparing the seasonal *ED* variability with the seasonal changes in long-wave UV-radiation (300–380 nm) that is practically not absorbed by ozone [Chubarova et al., 2014] and whose seasonal changes are characterized by maximum in June. The coefficient of variation of monthly *ED* (the ratio of the standard deviation to the mean) is the highest during the period from November to January (maximum – 28% in December) due

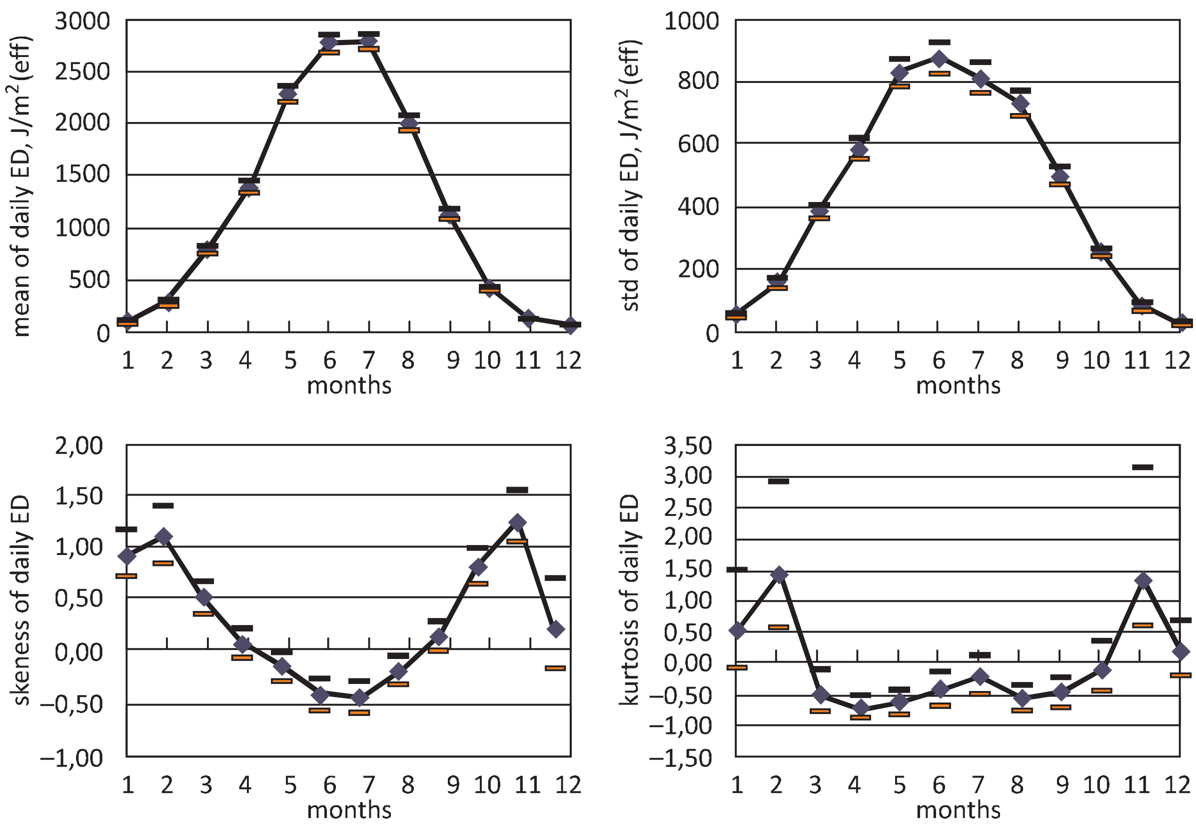

Fig. 4. Seasonal changes in *ED* daily mean, standard deviation, skewness, and kurtosis at a 95% significance level.

to the large variations in synoptic conditions. In the warm season (April to September), the coefficient of variation of monthly *ED* is 8–15% (minimum – 8% in April) due to the decrease of variations in cloudiness and TOC.

Let us discuss the main statistical parameters of the daily *ED* values. Table 1 presents the daily *ED* first four moments of the distribution for each month (average, standard deviation, excess, and skewness) as well as the minimal and maximal values. Fig. 4 shows their seasonal variation at a 95% significance level obtained by the bootstrap method [Efron, Tibshirani, 1993]. The method allows assessing significance levels independently from the type of distribution function. The kurtosis is statistically significant positive from November to February and negative from March to September. The skewness is characterized by significantly positive values from September to April and negative values from May to August. This character of variation is associated primarily with changes in cloud conditions throughout the year. Fig. 5 presents an example of the typical, of warm and cold periods, relative frequency of the average *ED* in January and July. In January, the distribution has right-positive skewness, while in July it is distinctly skewed to the left. This is largely due to the predominance of dense cloud cover in winter with occasional periods of clear sky weather conditions with relatively high *ED* values and predominance of cloudless conditions with high *ED* values during the warm season.

The hourly *ED* are presented in Fig. 6 that shows the isopleths of the mean (a) and standard deviation (b) as functions of solar time (hours) and months. The maximal average hourly *ED* corresponds to the noon time in July; the maximal standard deviation of the hourly *ED* correspond to June, which is associated with large variations of the TOC and cloudiness in June compared to July. Table 2 shows the absolute maximal hourly *ED* expressed in the units of *UVI*. The absolute maximum *UVI* (7.7) was recorded on June 27, 2004, which was associated with partial cloudiness that did not obstruct the solar disk and significantly increased the multiple scattering of UV-radiation, at TOC = 303 DU, and relatively low AOT_{340} = 0,25.

Fig. 7 shows the seasonal changes of various geophysical parameters that determine the level of Q_{er} at ground. Fig. 7b shows the Q_{er} losses due to these parameters. The main factor that determines the seasonal variation of Q_{er} is solar angle. At the same time, variations of other parameters are important for the analysis of the year-to-year changes in seasonal Q_{er} variability. The mean annual

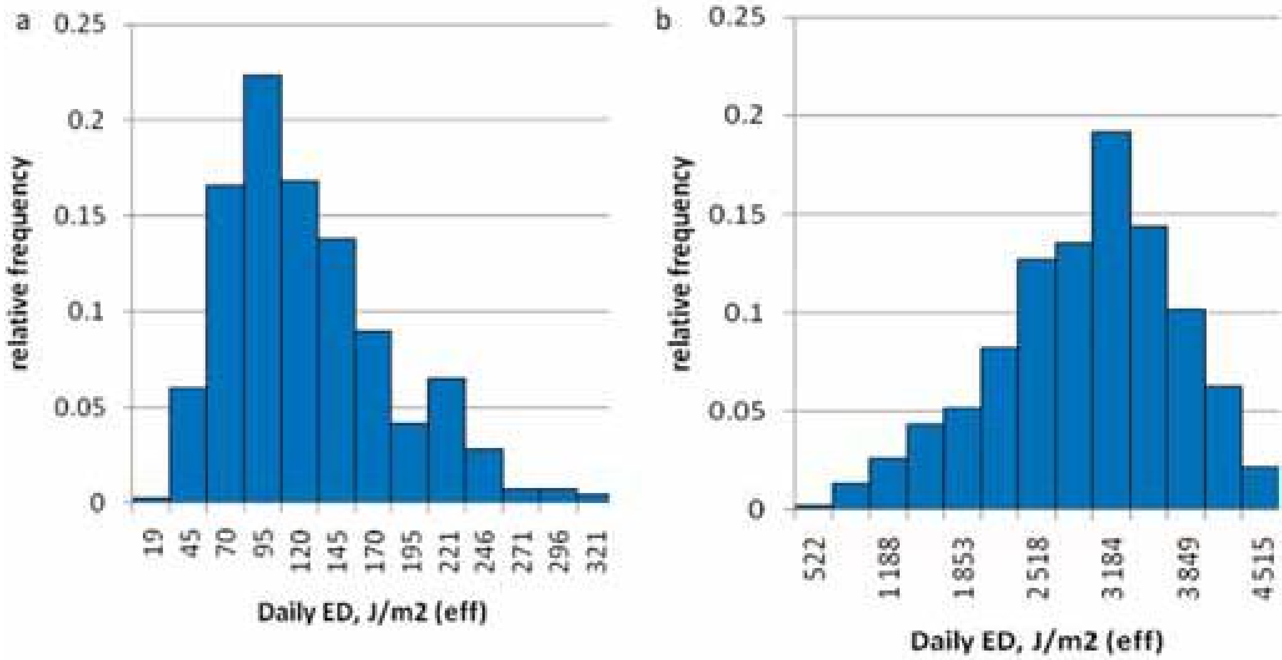

Fig. 5. Relative frequencies of daily mean ED values in January (a) and in July (b), 1999–2013.

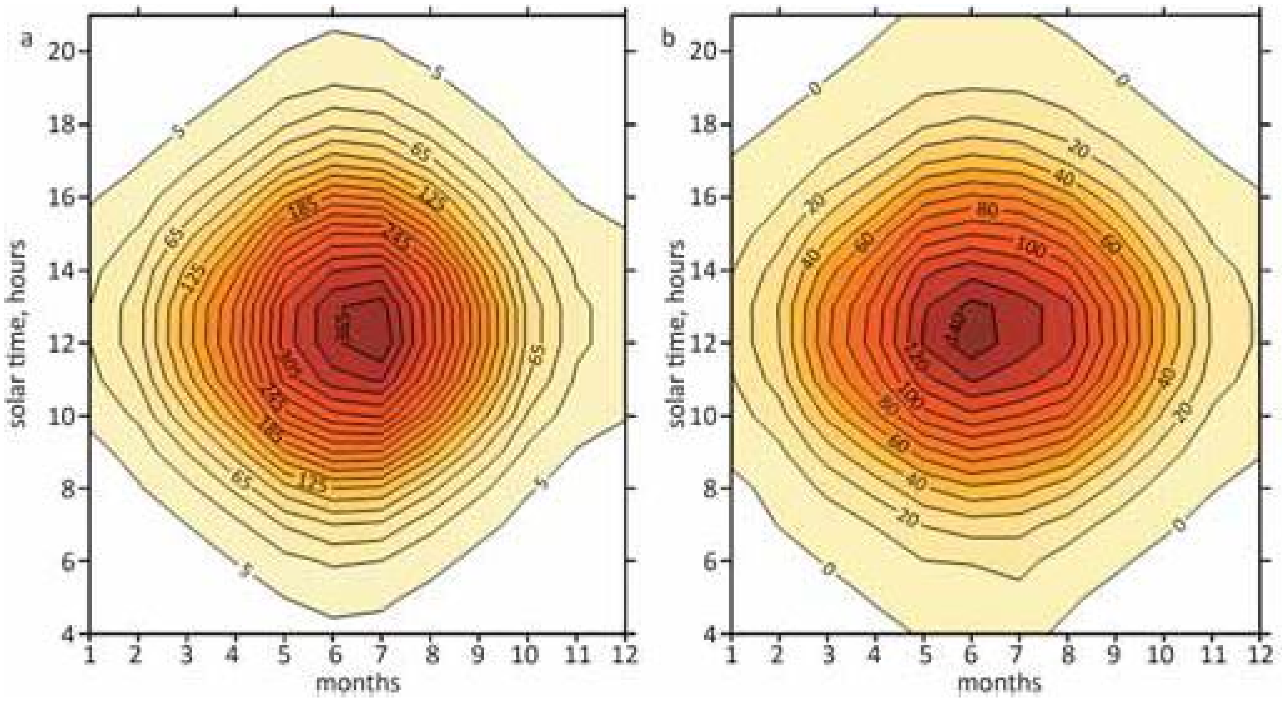

Fig. 6. a) hourly mean *ED* values (J/m^2_{eff}), b) std of hourly *ED* (J/m^2_{eff}) as a function of time and month.

attenuation of Q_{er} due to ozone absorption is 30%. The maximal ozone-dependent Q_{er} loss is observed in February and in March (44%), which agrees with the seasonal variation of the TOC (Fig. 7a). The mean attenuation of Q_{er} due to cloudiness is 29%, which is very close to ozone impact. They are the largest in November (48%) due to the increase in the cyclonic activity in the fall period and are the smallest in March and July (less than 20%). The Q_{er} *loss* due to the aerosol content compared with the loss associated with the molecular atmosphere is about 7% with the maximum (about 10%) in April, August and September (Fig. 7b) and depends on the character of seasonal changes of aerosol optical thickness [Chubarova et al., 2011] (Fig. 7a). Surface albedo may play an important role in the Q_{er} increase in conditions with snow cover. According to some assessments in [Zhdanova, Chubarova, 2011], the increase of Q_{er} in cloudless conditions due to reflection from the surface is 17% of the relative albedo that is equal to zero.

Table 2. Maximal UV indices (UVI)

Months	UVI
1	0.8
2	2.0
3	3.8
4	4.9
5	6.4
6	7.7
7	7.2
8	6.2
9	4.3
10	2.5
11	1.2
12	0.5

Seasonal losses of Q_{er} in Moscow due to the main factors over the considered period 1999–2013 and in 1999–2006, studied in [Chubarova, 2008], are qualitatively the same, but there are small quantitative differences. For example, the Q_{er} losses due to aerosol, over the shorter period of measurements, were larger (up to 12–15% in July–September) compared with that over the 1999–2013 observation period considered in this paper. This indicates a trend of purification of the atmosphere and a smaller aerosol effect in recent years. Due to changes in cloud cover in recent years, Q_{er} losses have increased in March, November, and December (3–6%) and decreased slightly in June (3%).

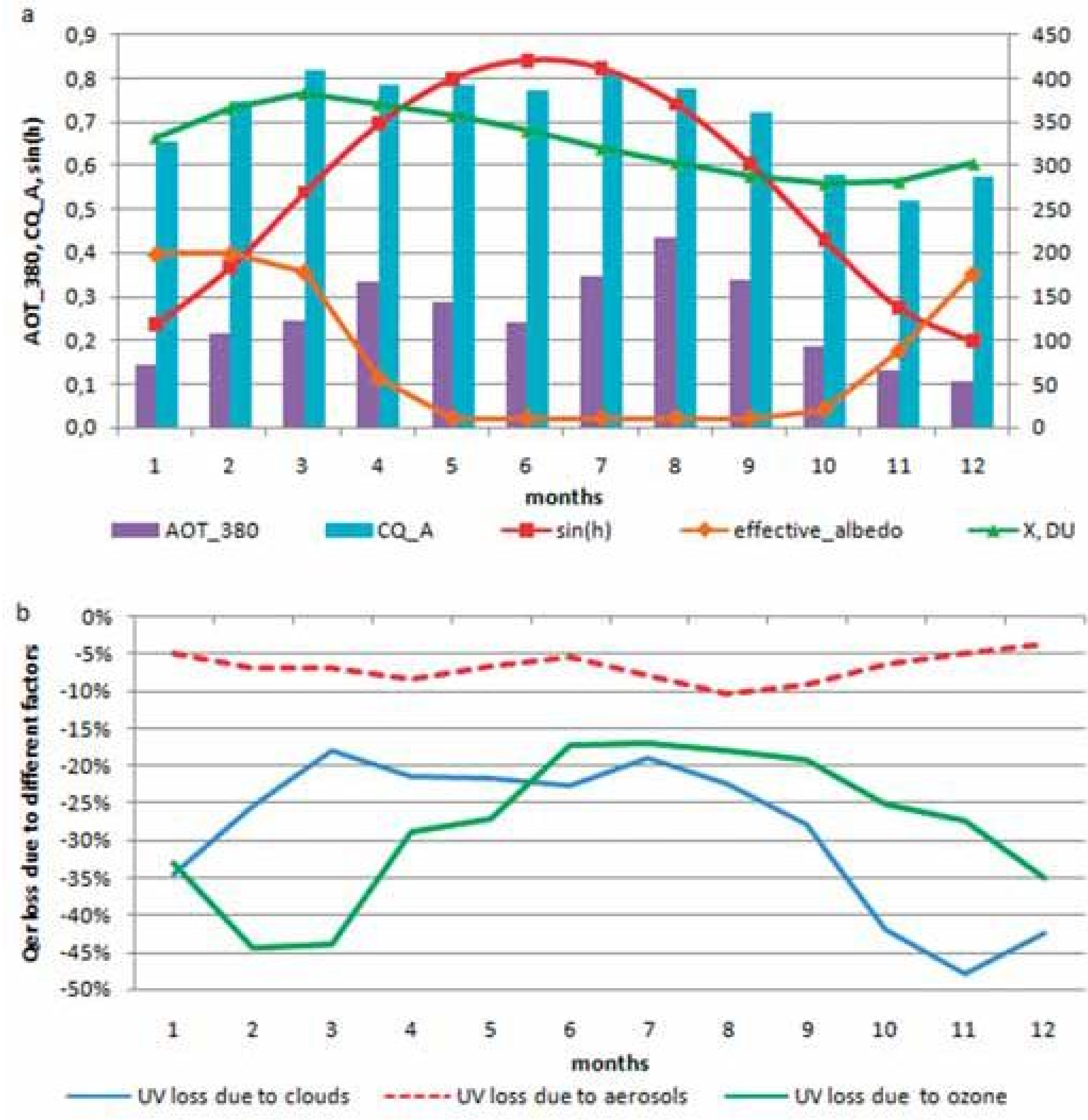

Fig. 7. a) Seasonal changes in total ozone (X), aerosol optical thickness at 380 nm (AOT_380), effective cloud transmission (CQ_A), sine of noon solar angle over 1999–2013 period. b) Relative seasonal changes in Q_{er} loss due to total ozone, effective cloud transmission and aerosol optical thickness.

The analysis of the UV resources in Moscow

Table 3 shows the categories of UV-resources for different skin types for each month, obtained for the monthly mean *ED* over 1999–2013 period.

The probability of occurrence of different categories of UV-resources for each month for the considered skin types was calculated using the following equation:

$$V_k = \frac{N_k}{N}, \qquad (4)$$

where N_k is the number of days corresponding to certain categories of UV-resources $N = 15n$, n is the number of days in a month, and 15 is the number of years of measurements.

Fig. 8 shows the probability of categories of UV-resources for all months. Since each type of skin corresponds to a certain MED, the observed probabilities of the categories UV- resources for different skin types differ significantly.

In winter, UV-deficiency conditions are observed almost for all skin types. Only in

Table 3. Seasonal changes in the average UV-resources for different skin types

	Skin type 1	Skin type 2	Skin type 3	Skin type 4
Jan	100-% UV-deficiency	100-% UV-deficiency	100-% UV-deficiency	100-% UV-deficiency
Feb	Noon UV-deficiency	Noon UV-deficiency	Noon UV-deficiency	100-% UV-deficiency
Mar	UV-optimum	UV-optimum	Noon UV-deficiency	Noon UV-deficiency
Apr	Moderate UV-excess	UV-optimum	UV- optimum	UV- optimum
May	Moderate UV-excess	Moderate UV-excess	Moderate UV- excess	UV- optimum
Jun	High UV-excess	Moderate UV-excess	Moderate UV- excess	UV- optimum
Jul	High UV-excess	Moderate UV-excess	Moderate UV- excess	UV- optimum
Aug	Moderate UV-excess	Moderate UV-excess	Moderate UV- excess	UV- optimum
Sep	Moderate UV-excess	UV-optimum	UV- optimum	UV- optimum
Oct	UV-optimum	Noon UV-deficiency	Noon UV-deficiency	Noon UV-deficiency
Nov	Noon UV-deficiency	Noon UV-deficiency	100-% UV-deficiency	100-% UV-deficiency
Dec	100-% UV-deficiency	100-% UV-deficiency	100-% UV-deficiency	100-% UV-deficiency

February, there is some probability of the UV-optimum conditions for skin type 1. December is characterized by the 100% probability of UV-deficiency for all skin types.

Spring is a transition period from UV-deficiency to UV-optimum and even to UV-excess. Early as March, there can be the UV-optimum conditions for all skin types; there may be even moderate UV-excess in the last decade for skin types 1 and 2, when the solar angle is higher than 35 degrees. In April, the probability of the UV-optimum and UV-excess conditions for all skin types increases. The moderate UV-excess conditions prevail (66%) for skin type 1; there is the equal probability of the UV-optimum and of moderate UV-excess conditions for skin type 2; the probability of the UV-optimum and UV-excess conditions is 63 and 25%, respectively, for skin type 3; the UV-optimum is prevailing (80%) for skin type 4. In May, the UV-excess conditions are of high probability (90%) for skin type 1; the moderate UV-excess conditions prevail (75% and 72%, respectively) for skin types 2 and 3; the UV-optimum conditions are dominant (76%) for skin type 4.

In summer, almost for all skin types, there is the absence of the UV-deficiency conditions while the probability of the UV-excess conditions increases. However, in August, the risk of erythema significantly decreases compared to other summer months, and the probability of the UV-optimum conditions reaches 84% for skin type 4.

In autumn, again, the UV-deficiency conditions are possible. However, in September, for skin types 1, 2 and 3, still even moderate UV-excess is possible. At the same time, the UV-optimum conditions prevail for skin types 2, 3, and 4. In October, the hazard of erythema does not exist for all skin types except the skin type 1. In November, the UV-deficiency conditions are observed for all skin types.

The methodology for the determination of the threshold values of UV-radiation doses necessary for the vitamin D synthesis presented in this paper is not the only methodology that exists; there are other methods for the identification of the threshold values. In [Engelsen et al., 2005], the scientists have selected the threshold considering the UV radiation at three wavelengths using the results of medical experiments in Boston, USA. The results showed that vitamin D is not synthesized in winter at latitudes higher than 50 degrees. Testing of our method also supported this conclusion [Chubarova, Zhdanova, 2013]. The threshold value obtained in the experiments in Boston [Engelsen et al., 2005], was also used to investigate the potential for the vitamin D synthesis in three cities: Thessaloniki, Greece (41°N), Bilthoven, The Netherlands (52°N), Jokioinen, Finland (61°N) [Kazantzidis et al., 2009]. In this study, the effective doses for vitamin D were derived directly from the vitamin D formation spectral curve. It was shown that using the threshold values presented in [Engelsen et al., 2005] in Bilthoven, there was no synthesis

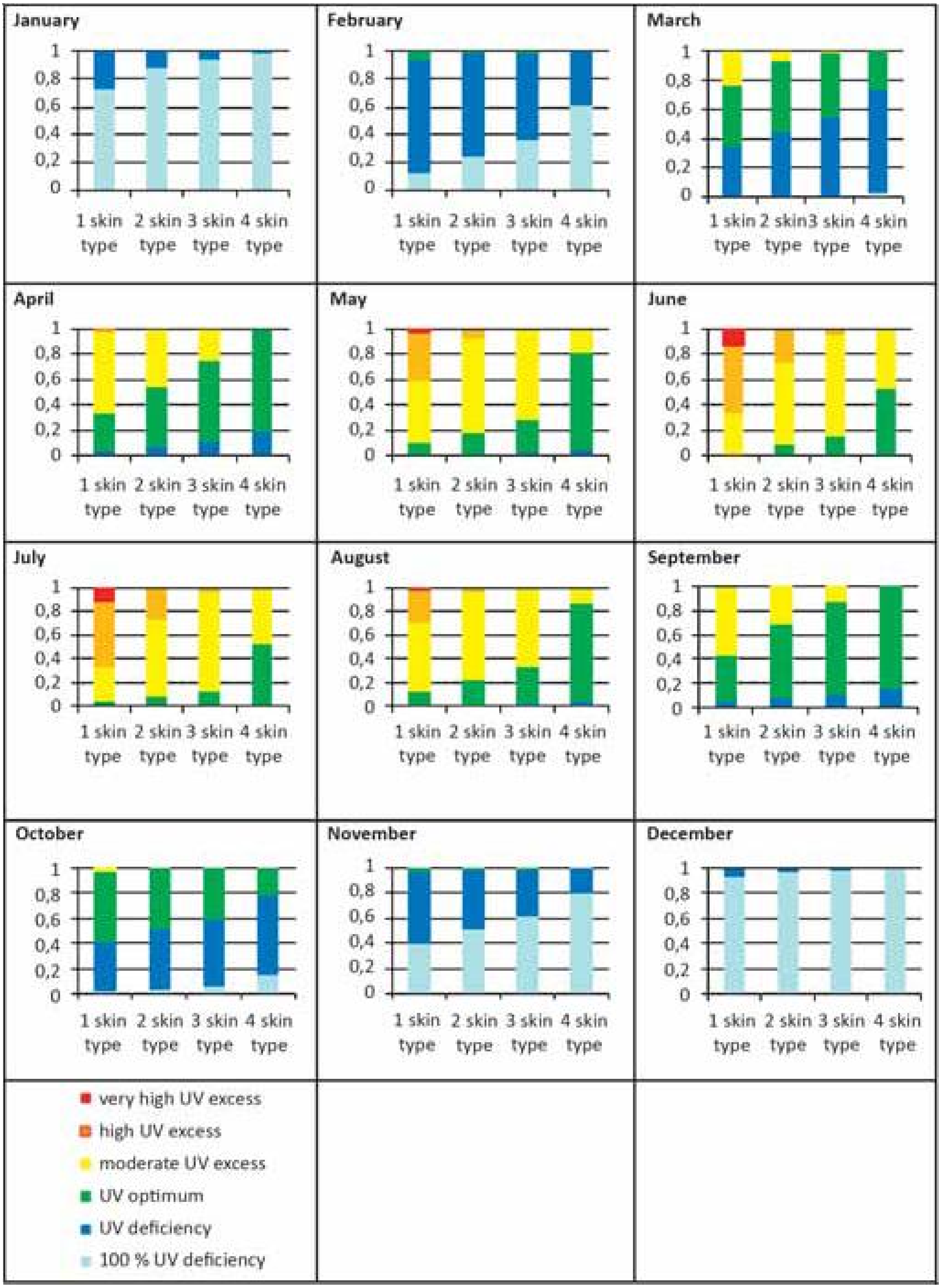

Fig. 8. Probability of different types of the UV-resources for the various skin types

of vitamin D in humans with skin types 1–3 from the middle of November, which agrees with the results obtained for Moscow. In [Krzys'cin et al., 2011], a mathematical model of UV-radiation induced vitamin D synthesis variation showed that in Belsk, Poland (52°N), sufficient vitamin D doses may not synthesize in humans even in summer. The study [Fioletov et al., 2010] showed that vitamin D was synthesized in people with skin type 2 at 54°N in North America during the whole year. Therefore, these two studies contradict each other.

It should be emphasized that the vitamin D synthesis in human skin and erythema formation depend on many factors associated with specific features of a person. These factors include, for example, age, habits, etc. These factors will be accounted for in the future, using parameterization methods.

It is necessary to add that the obtained monthly average values of UV-resources agree completely with the assessments obtained in our previous model estimates of UV resources for the closest to Moscow grid point in conditions of mean cloud cover [Chubarova, Zhdanova, 2013]. This demonstrates the reliability of the earlier assessments for the territory of Northern Eurasia.

CONCLUSION

The continuous long-term measurements of erythemally weighted UV-radiation at MO MSU in Moscow revealed its seasonal variation and the role of different geophysical parameters in its variability. Besides the astronomical factor that mainly controls the seasonal erythemally-weighted UV radiation variations, the main factors affecting Q_{er} in Moscow are TOC and clouds. During the year, the mean Q_{er} absorption by ozone varies from 18 to 44 % with the maximum in February-March. The attenuation due to cloud cover ranges from 17 to 48% with the maximum in October-December. The major role of clouds in the attenuation of UV-radiation was noted in [Belan et al., 2012]. However, in Moscow the effects of cloudiness and ozone on Q_{er} are comparable. The attenuation due to atmospheric aerosol ranges from 4 up to 10 % in April and August-September. The mean cloud effect on Q_{er} in Moscow conditions of about 29% is also in agreement with its 35% effect obtained in Austria at the Sonnblick Observatory [Simic et al., 2008].

Analysis of the statistical parameters of the daily and hourly erythemal doses allowed us to identify differences in the UV-radiation regime for various months. The highest daily and hourly *ED* values are observed in July, while the largest dispersion is observed in June. The distribution of the daily *ED* has statistically significant positive skewness from September to April and negative skewness from May to August.

Using the methodology developed earlier [Chubarova, Zhdanova, 2012; Chubarova, Zhdanova, 2013] and the measurements obtained at MO MSU, we have assessed the daily UV-resources in Moscow in 1999–2013 for people with different skin types. We have demonstrated that the UV-deficiency conditions exist for all considered skin types during all days from November to February.

The UV-optimum conditions are dominant in March and October (maximum in October – 56%) for skin type 1; in March, April, September, and October for skin type 2 (maximum in September – 60%); in April and September (maximum in September – 77%) for skin type 3; from April to September (maximum in August and September – 84%) for skin type 4.

The high probability of UV-excess is observed from April to September (maximum in June – 100%) for skin type 1; from April to August (maximum in July – 93%) for skin type 2; from May to August (maximum in July – 88%) for skin type 3; from June to July (maximum in July – 47%) for skin type 4.

The obtained average values of UV-resources agree completely with the model-based assessments of UV-resources based on satellite data for the closest to Moscow grid point in mean cloud cover conditions [Chubarova, Zhdanova, 2013].

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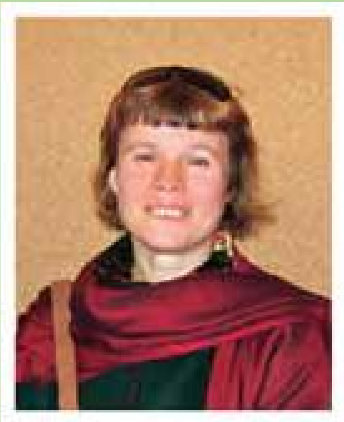

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