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UV variability in Moscow according to long-term UV measurements and reconstruction model

N. Y. Chubarova

Faculty of Geography, Moscow State University, Moscow, Russia

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Correspondence to: N. Y. Chubarova (chubarova@imp.kiae.ru)

Abstract

Long-term measurements of erythemally weighted UV irradiance (Q_{er}) have been analyzed for the 1999–2006 period as well as UV variability according to reconstruction model since 1968. The estimates of different atmospheric parameters effects, including NO_2 content, on Q_{er} have been obtained on seasonal and interannual scales. It has been shown that NO_2 content in conditions of large megalopolis provides average Q_{er} decrease of about 1.5–2%. The seasonal variations of the observed UV indices are discussed from the point of view of the impact on health. Using the reconstruction model we showed a distinct growth in Q_{er} since 1980 due to decrease in total ozone (+2.5% per decade), effective cloud amount transmission (+2.1% per decade) and aerosol loading (+1.1% per decade). However, there is no changes in Q_{er} over larger 1968–2006 period due to significant decrease in effective cloud amount transmission (−11% per decade) in 1968–1980.

1 Introduction

Ultraviolet (UV) irradiance has a strong influence on the biosphere (UNEP, 1994). During last decades significant efforts were made for organizing UV monitoring from space and at the ground by different devices in order to assess the temporal and spatial variability of UV irradiance over the world (WMO, 2007). In this paper we analyse the main features of erythemally-weighted (Q_{er}) irradiance in Moscow on the base of long-term ground measurements using broadband UV-B instrument and supplementary meteorological information including cloud and aerosol properties, surface albedo, and small gas species content. In order to understand the cause of Q_{er} variations we have analyzed the specific features of typical seasonal variation of main parameters and have made the estimates of their impact on Q_{er}. Moscow is a big city with high traffic and many power stations, which can provide high emissions of NO_x and, accordingly, high NO_2 content. Hence, special attention should be paid to estimating NO_2 effects on Q_{er}

during different seasons.

The level of UV indices in diurnal and seasonal cycles is characterized from the point of view of the impact on health. For this purpose two simple thresholds have been applied: one threshold – for protection from erythema according to (Vanicek et al., 2000) and the second threshold – for the vitamin D synthesis from (Holick and Jenkins, 2003). This approach makes it possible to characterize Moscow conditions from the point of view of people health and to obtain time periods with unfavourable UV conditions.

Because of large interannual variations of the atmospheric parameters Q_{er} can undergo significant changes in the past. And, as many biological and health related effects depend on UV dose accumulated during long period the assessment of possible UV irradiance changes in the previous decades is very important. To evaluate the UV-B irradiance in the past different sort of reconstruction models have been applied, which use various kinds of statistical or model approaches and different meteorological or radiative datasets (Kaurola et al., 2000; Fioletov et al., 2001; Krzyścin et al., 2004; den Outer et al., 2005; Chubarova et al., 2005; Lindfors and Vuilleumier, 2005; etc.). We have used the approach described in Chubarova et al. (2005) to reconstruct Q_{er} variability, to estimate the role of different atmospheric factors, and also to compare reconstructed interannual Q_{er} variations with the measured ones.

2 Method and data description

The UV-B monitoring in Moscow has been in operation by broadband UVB-1 YES pyranometers at the Meteorological Observatory of Moscow State University (MO MSU) since 1999. Initially all the instruments were tested at NREL laboratory of Colorado State University (courtesy of D. Bigelow and J. Slusser) in 1998 and directly at YES. Inc. company. Then they were cross-calibrated against the reference instrument, which in turn was calibrated in erythemally-weighted units against the ultraviolet spectroradiometer Bentham DTM-300 of the Medical University of Innsbruck in 1999 (Bais et al.,

1999) and directly in Innsbruck in 2005 (courtesy of M. Blumthaler). The corrections on total ozone and solar zenith angle have been applied to the initial data in order to minimize the errors for high solar zenith angles and large ozone content according to (Lantz et al., 1999; Chubarova, 2002).

The UV reconstruction model used in this study is based on the assumption that the year-to-year UV variability can be written as a sum of UV variations due to variations in total ozone, aerosol optical thickness, cloud optical thickness and cloud amount with account of surface albedo and solar angle (Chubarova et al., 2005). UV variations due to cloud amount were estimated using the effective cloud amount transmission (CQ_A). This characteristic is calculated as a combination of relative frequency of different cloud amounts weighted on their UV transmission with account for the surface albedo A in form of geometric progression. This reconstruction model has been successfully verified against 1968–1997 dataset of UV irradiance 300–380 nm (Chubarova and Nezval, 2000), satellite TOMS and METEOSAT retrievals (Chubarova et al., 2005) and some other data. In addition, the reconstruction model has been carefully tested against exact model calculations based on 8 stream DISORT method incorporated in the TUV model (Madronich and Flocke, 1998). For the large range of atmospheric parameters (total ozone of 250–450 DU, aerosol optical thickness at 380 nm (AOT380) of 0.05–0.6, cloud optical thickness of 0–60) this approach was shown to give uncertainty less than 2%. The uncertainty is larger in situations with high loading of absorbing aerosol with single scattering albedo (SSA) less than 0.85 which are rarely observed. The estimates of the Q_{er} loss due to different atmospheric factors (except effective cloud amount transmission) were also fulfilled using TUV model.

In order to characterise the atmospheric parameters, various datasets were applied. Two aerosol datasets are used in the study: the Moscow AERONET dataset at level 2, version 2 with additional cloud filtering according to (Ulyumdzhieva et al., 2005) which provides AOT340 and Angstrom parameter, and 1968–2006 AOT550 dataset. The AOT550 is calculated using direct shortwave irradiance and water vapour according to the method described in (Tarasova and Yarkho, 1991). The estimated AOT550 values were carefully tested against AERONET AOT measurements. The test has confirmed the absence of the bias for AOT550 less 0.5 if AOT550 is calculated with Angstrom parameter of $\alpha=1$ instead of the observed $\alpha=1.4$. Typical SSA in UV spectral region is about 0.92, which was calculated using Mi theory with the optical parameters taken from AERONET dataset in visible spectral region. The dataset of cloud optical thickness for 1968–2006 period was obtained according to the method developed by Tarasova and Chubarova (1994) with the use of global shortwave irradiance measurements in overcast conditions in Moscow.

The preliminary analysis of the influence of different small gas species on Q_{er} in Moscow conditions has revealed the most pronounced effects of NO_2 (Chubarova, 2006). To estimate total NO_2 content a combination of surface NO_2 measurements from TE42C-T gas analyzer and model vertical profile in the low 2 km has been applied following the methology described in Chubarova and Dubovik (2004).

3 Seasonal changes of main atmospheric parameters and their effects on UV irradiance.

In order to explain main features of UV seasonal variability it is necessary to analyze variations of main parameters affecting UV. Figure 1 presents mean seasonal changes for 1999–2006 period in total ozone content, aerosol and NO_2 optical thickness, effective cloud amount transmission with account for spatial snow albedo (CQ_A) and without it (CQ) as well as seasonal dependence of the sine of noon solar angles in Moscow. Solar angle is, of course, a dominating factor in UV irradiance change, however, we can see some interesting features in seasonal variations of other parameters. In ozone variations we observe typical for high latitudes seasonal cycle with maximum in spring (March) and minimum in the fall similar to the CQ_A variations which, in addition, have large values during summer time. The CQ_A values have the maximum in March due to less cloud amount and still presence of snow on the surface. According to our estimates snow can increase the CQ values on about 0.15–0.17 during winter months.

(A spatial snow surface albedo is considered to be 0.4 that is in accordance with the typical TOMS MLER values over Moscow.) AOT340 also has maximum in spring, in April, due to the absence of vegetation at ground and low precipitation, that lead to the increase of dust particles in the air. The second summer-fall maximum is explained by many factors: predominant air mass advection from the south, lack of precipitation and the effects of forest fires. The mean NO_2 content has also spring and summer maxima; the OT_{NO_2} at 340 nm is rather small (0.01–0.02) but still pronounced.

Figure 1b presents seasonal cycle of mean Q_{er} loss due to different atmospheric parameters. It is clearly seen that cloudiness is a dominating factor in summer and in the fall while during February–May period total ozone plays more important role in Q_{er} attenuation. The Q_{er} mean loss due to AOT varies from 4% in winter to 12–15% in April and July-September periods. The Q_{er} loss due to NO_2 is about 1.5–2% throughout the year, except May–June. The higher Q_{er} sensitivity to NO_2 in winter is explained by the bias of the Q_{er} effective wavelength at smaller solar elevation to longwave spectral region where there is higher NO_2 absorption.

It was interesting to make assessments of the Q_{er} response to the heterogeneity of aerosol loading within the city. For this purpose a special experiment has been organized with simultaneous measurements by AERONET CIMEL sun photometer at MO MSU and cross-calibrated GLOBE portable sun photometer in different parts of the Moscow area during summer of 2005 (case number is about 80). The frequency distribution of the obtained AOT500 differences lies in accordance with normal law and has zero bias. The difference reaches ±0.06 at 95% significant level that according to model calculations leads to ±3–4% additional variations in Q_{er}, due to heterogeneity of aerosol distribution over Moscow.

Figure 2a shows mean diurnal cycle of hourly UV indices (UVI) in different months over 1999–2006 period. Noon UVI values in summer can be 24 times larger than those observed in winter. Special attention has been paid to the determination of time periods with unfavourable UV conditions for people health. According to Vanicek et al. (2000) the UV protection is required when UVI are higher than 3. In Moscow for mean (typi-

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cal) conditions UVI are higher than 3 (but less than 4) only at 9:30–13:30 in June and July and at 11:30–12:30 in August. Slightly higher noon UV indices in August compare with the May UVI values are explained by seasonal ozone decrease from spring to fall, which influence is not compensated by aerosol loading increase and slightly lower solar angles (see Fig. 1). The maximal observed UV indices can conform middle (UVI=4–6) and even high (UVI=6–7) categories through April to September (see Fig. 2b). The maximum UVI value (UVI=7) observed in Moscow was recorded at noon time 27.06.2004, when total and low layer cloud amount were equal to 6 providing additional scattering from the cloud sides, sun disk was open, total ozone X of 303.3 DU and AOT340 of 0.25 were reduced against climatic values (See Fig. 1a).

According to the recommendations described in (Holick, Jenkins, 2003), the time, which is necessary for vitamin D synthesis is based on a threshold of 25% of Minimal Erythemal Dose. Using this second threshold we show the inability to get vitamin D for any skin type in typical meteorological conditions even at noon from October (except skin type 1) to February. Furthermore, even in conditions favourable for creating high UV level it is impossible to get vitamin D in December for any of skin types and in January (for any, except skin type 1). In November and February only at the highest UV levels it is possible to get vitamin D for skin types 1 and 2, which are most sensitive to UV impact.

4 The long-term UV variations

Figure 3a,b presents Q_{er} variations due to different atmospheric parameters for 1968–2006 period as well as reconstructed and observed long-term Q_{er} variability. There is quite satisfactory agreement between measured and model values that has confirmed the high quality of the reconstruction model. Due to variations in atmospheric factors the Q_{er} interannual changes are about ±16% during warm period. The influence of CQ_A on Q_{er} variability is dominated comprising ±10% while the ozone effects are slightly less (±8%). The predominant role of cloudiness is in accordance with our estimates shown in Fig. 1b for warm period. Interannual changes in aerosol loading also plays noticeable role, providing Q_{er} variation of ±2–3% while the role of cloud optical thickness is quite small (±1.5%) in Moscow.

In addition to high frequency and/or random Q_{er} variations, one can see pronounced low frequency variability in Q_{er} response to ozone, cloudiness and aerosol optical thickness changes and in Q_{er} itself (see Fig. 3). On the whole, since 1980 we can reveal linear statistically significant positive trends in Q_{er} due to ozone of about +2.5% and due to aerosol variations of about +1.1% per decade. The substantial growth of effective cloud amount transmission at the end of the century is getting down but still there is statistically significant increase in Q_{er} due to CQ_A of about +2.1% per decade since 1980. The changes in aerosol loading have global character: they are typical at least for the whole Russian territory (Makhotkina et al., 2005). Hence, all atmospheric factors "work" on the Q_{er} increase which comprises of about +6% per decade since 1980. At the same time during 1968–1980 period the significant drop in Q_{er} of −13.8% is explained by strong CQ_A decrease of −11% per decade. On the average, for the whole 1968–2006 period no statistically significant trend in Q_{er} has been revealed. These results are in agreement with the Q_{er} reconstructions over Central and Eastern Europe shown in (Krzy'scin et al., 2004), where a pronounced drop in Q_{er} in the late 1970s as well as Q_{er} increase in the 1990s has been obtained.

5 Conclusions

Measurements and reconstruction of erythemally weighted irradiance have revealed its significant seasonal and interannual variations due to different astronomical and atmospheric parameters. The role of effective cloud amount transmission and total ozone in Q_{er} perturbation was confirmed as most significant (15–45%) but their role was shown to change in seasonal cycle with maximum effects due to ozone in spring and due to cloudiness – in summer and in the fall. The change in aerosol loading can attenuate Q_{er} for 4–15% with minimum in winter and maximum in April and July–September. The mean effects of NO_2 on the Q_{er} attenuation are small but quite pronounced (1.5–2%).

The analysis of seasonal changes of UV indices has shown that mean noon UVI are 24 times higher in summer than in winter. Using the erythema threshold we have revealed that in typical conditions the UV radiation protection is necessary only at 9:30–13:30 in June and July and at 11:30–12:30 in August, however, maximal UV indices conform middle and high categories through April to September. Using the threshold for vitamin D synthesis from (Holick and Jenkins, 2003) we have shown the inability to get vitamin D for any of skin types in typical meteorological conditions even at noon from October (except skin type 1) to February. And in conditions favourable for the highest UV levels it is impossible to get vitamin D for any of skin types in December and January (except skin type 1). This provides quite unfavourable conditions for people health during long cold period in the Moscow area.

The reconstructed long-term changes in Q_{er} irradiance show a good agreement with the measured values during 1999–2006. The Q_{er} interannual changes comprises ±16% due to the variations in effective cloud amount transmission (±10%), total ozone (±8%) and aerosol loading (±2–3%). The Q_{er} growth of about 6% per decade since 1980 is explained by its increase due to ozone (+2.5% per decade), effective cloud amount transmission (2.1% per decade) and aerosol loading (+1.1% per decade). At the same time, the analysis of the Q_{er} over 1968–2006 period has revealed the absence of trend because of significant drop (−11% per decade) in effective cloud amount transmission which took place during 1968–1980. The Q_{er} variability over Moscow agrees well with the Q_{er} reconstructed data series over Central and Eastern Europe (Krzyścin et al., 2004) with a pronounced drop in the late 1970s and the increase in the 1990s. This confirms the global character of the observed Q_{er} variability.

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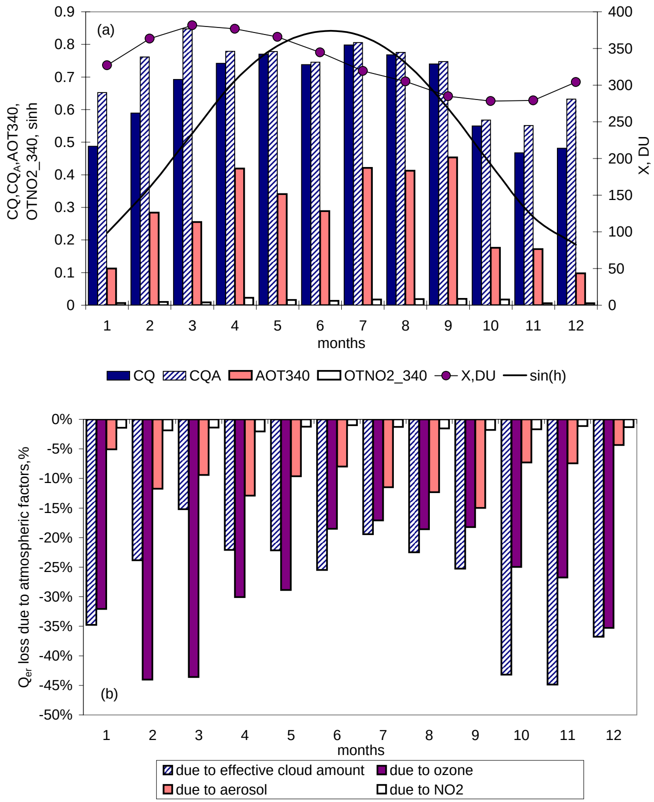

Fig. 1. (a) Average seasonal changes in total ozone (X), aerosol optical thickness at 340 nm (AOT340), NO_2 optical thickness at 340 nm ($OTNO_2$_340), cloud effective transmission (CQ_A and CQ) as well as the sine of noon solar angle (sinh). **(b)** Relevant seasonal Q_{er} loss due to monthly mean effective cloud amount transmission, aerosol, ozone, and NO_2 factors. 1999–2006. The loss is calculated as a relative difference in Q_{er} calculated with account and with no account for the analyzed factor. In case of ozone, the daily minima from 1979–2003 TOMS data series were taken as a proxy for theoretically lowest monthly ozone values over Moscow.

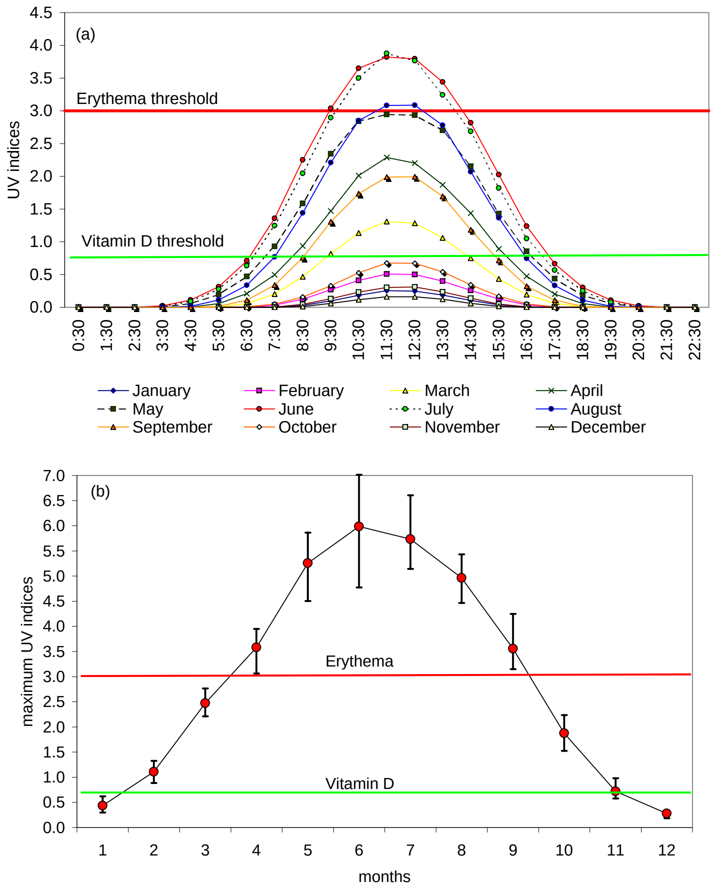

Fig. 2. **(a)** Diurnal cycle of mean UV indices in Moscow, 1999–2006 period. Solar time. **(b)** Mean UVI maxima for each month. Error bars show the range in UVI maxima observed during 1999–2006 period. Threshold for vitamin D synthesis is shown for skin type 2.

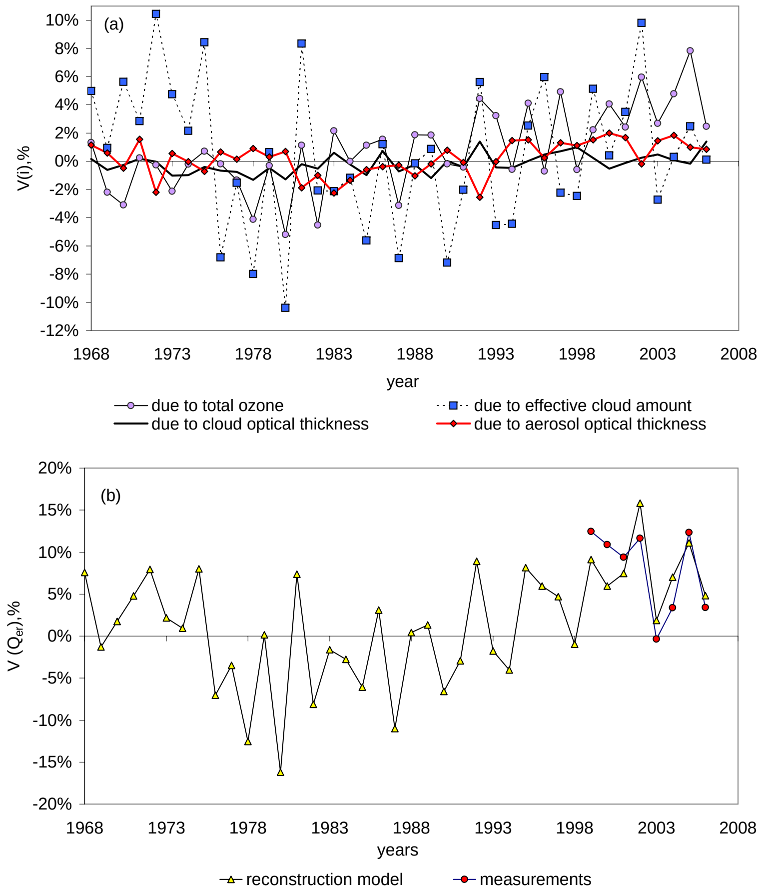

Fig. 3. (a) Changes in Q_{er} due to variations in total ozone, effective cloud amount, aerosol and cloud optical thickness according to the reconstruction model. **(b)** Observed and reconstructed interannual Q_{er} variability. The data are normalized on 1968–1997 period, May–September, Moscow.