VARIABILITY OF SURFACE SOLAR IRRADIANCE AND AEROSOL OPTICAL DEPTH DURING PARTIAL SOLAR ECLIPSE OF JANUARY 4, 2011 IN KISHINEV, MOLDOVA

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Abstract

Variation of surface solar irradiance and aerosol optical depth (AOD) during the partial solar eclipse on January 4, 2011 is analyzed on the basis of the ground observations at the Kishinev (Chisinau) site. Maximum of magnitude of the eclipse obscuration was 0.701. Evaluations of reduction of solar irradiance or "dimming" effect are derived. "Dimming" effect at the maximum magnitude of the solar eclipse was defined as the ratio of measured values of solar irradiance to the values estimated in the absence of the eclipse and it was 77.9% for global UV-B radiation and 73.6% for global solar radiation (280-3000 nm), respectively. The reduction in solar irradiance due to the solar eclipse event ranged from 36.5% to 41.7% for partial sums during the period of eclipse and from 17.2% to 19.6 % for daily totals. The existence of non-uniform variability of the derivative of the function of solar irradiance on time in the course of the solar eclipse was shown.

1. Introduction

The phenomenon of visual coverage of the solar disk by the moon is called as a solar eclipse and can be identified as complete, annular, or partial eclipse. The extent of obscuration of the solar disk by the moon and duration of the eclipse depends on time and position of the point of observation on the Earth's surface. Eclipse events are rather frequent and they can be observed from 2 to 5 times all around the world in the course of a year. For example, 37 events of visible solar eclipses were observed in Moldova in the course of recent 100 years. All these eclipses were characterized as partial. Solar eclipses become a powerful instrument for investigation of the atmosphere, since during the solar eclipse, it is possible to measure the optical properties of the atmosphere and changing of its chemical composition, such as ozone content [1-4]. Solar radiation, spectral transmittance, and polarization properties remain the main measurable parameters subjected to influence of the solar eclipse [4-7].

The subject of this paper is to study diurnal changes of broadband solar radiation at the Earth's surface during the partial solar eclipse, which was observed at the ground-based station in Kishinev (Chisinau), Moldova on January 4, 2011.

2. Equipment and results of measurements

Continuous measurements of broadband solar radiation at the ground-based solar radiation monitoring station at the Institute of Applied Physics started in October 2003. The station consists of three principal units operating in automatic mode: radiometric complex, automatic weather station, and a sunphotometer Cimel-318. Radiometric complex consists of a set of nine radiometric sensors from Kipp&Zonen connected to a CR10X SM 4M datalogger. Solar radiation was measured within the wavelength range from UV to IR by using of the radiometric sensors such as CM-11 pyranometers, CH-1 pyrheliometer, and PAR, UV-B, and UV-A sensors. Six sensors were mounted at a stationary platform to measure global solar radiation. Direct and diffuse solar radiation was measured by using of three sensors placed at a rotating platform known as an active sun-tracker 2AP BD [8, 9]. We used data from measurements that were averaged over period of 1 min for each sensor. Collocated and synchronous measurements of spectral aerosol optical depths (AOD) at seven wavelengths from 340 nm through 1020 nm were fulfilled with a Cimel-318 sunphotometer. Measurements of AOD were carried out within the framework of the Aerosol Robotics Network (AERONET) project managed by the NASA/GSFC [10]. Regular measurements of total ozone content (TOC) at the site were made by using of a hand-held Microtops II ozonometer.

A regular solar eclipse took place in the world on January 4, 2011. In Kishinev this solar eclipse was observed as a partial eclipse with eclipse magnitude rated as 0.775 regarding the solar diameter coverage fraction and eclipse obscuration as 0.701 regarding the shadowed fraction of the solar disk. The solar eclipse was lasting from 07:15:09 UTC to 11:15:33 UTC. The maximum occultation was observed at 09:43:04 UTC.

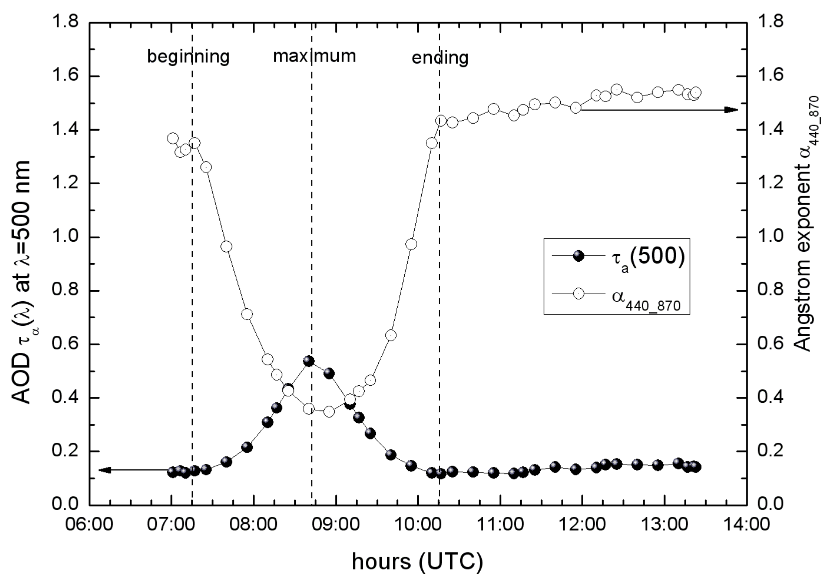

Fig. 1. Diurnal variation of AOD $\tau_a(\lambda)$ at λ = 500 nm and retrieved Angstrom exponent α_{440_870}. Measurements were made with a Cimel-318 sunphotometer at the Kishinev site during the solar eclipse event on January 4, 2011.

In the course of this day, the overall meteorological conditions were the following: cloudless sky with light haze. Diurnal variation of aerosol optical depth $\tau_a(500)$ measured with a sun photometer during the partial solar eclipse is shown in Fig. 1. The vertical dashed lines show the beginning, culmination (maximum magnitude), and ending of the solar eclipse. AOD $\tau_a(500)$ was practically constant and showed no significant variation both in the morning and afternoon hours. Respective mean values of AOD were $<\tau_a>\sim0.13$ (in the morning hours) and $<\tau_a> \sim0.14$ (in the afternoon hours). This fact confirms the stability of the optical properties of the atmosphere during the eclipse observation. For comparison, for the month of January respective climatological mean value of AOD $<\tau_a(\lambda)>$@ λ=500 nm obtained at the Kishinev site in the course of observation from 1999 to 2010 is 0.13. Diurnal variation of the Angstrom exponent α_{440_870} is also shown in Fig. 1. Parameter α_{440_870} was retrieved from analysis of spectral dependence of measured AOD τ_a (λ). The appearance of distinctive maximum in $\tau_a(500)$ and minimum in α_{440_870} is clearly observed from Figure 1. It should be noted that these extrema are fictitious. Their appearance is due to the blocking of direct viewing of the Sun by the moon during the solar eclipse and they cannot be connected with the decreasing of the transparency of atmosphere. The daily mean value of TOC was ~347 DU.

The 1-minute interval of averaging of solar irradiance data from direct observations at the radiometric complex is well suited to observe all consecutive stages of the solar eclipse in detail and to determine its impact upon the levels of solar radiation at the Earth's surface. Diurnal variation of global, direct, and diffuse solar radiation measured at the Kishinev site during the solar eclipse event occurred on January 4, 2011 is shown in Fig. 2.

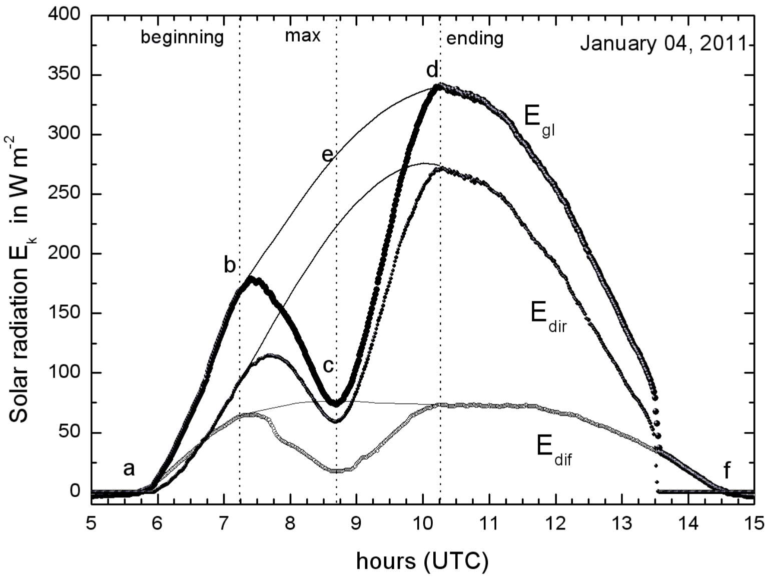

Figure 2. Diurnal variation of global, direct, and diffuse solar radiation (280-3000 nm) measured at the Kishinev site during the solar eclipse event occurred on January 4, 2011. Vertical dotted lines correspond to the beginning, culmination (max), and ending of the solar eclipse. Thin curves show the expected variation of solar radiation in the case of absence of the solar eclipse.

It is clearly seen that the obscuration of the solar disk resulted in temporal "dimming" or reduction of solar radiation fluxes measured at the Earth's surface. The appearance of the minimum on the curves, describing diurnal variation of solar radiation (280-3000 nm) corresponds to the maximum of solar disk obscuration. An analogous variation is typical for UV-B, UV-A, and PAR irradiances. Temporal variations of expected solar irradiance, as if the measurements were performed in the absence of the solar eclipse, are marked by thin curves in Fig. 2. To obtain corresponding estimates of the expected values, we used an interpolation of diurnal solar radiation variation by a polynomial of degree n = 7. Ascending and descending branches for each of the curves describing daily variation of measured solar irradiance before and after the solar eclipse were used in the interpolation procedure. These expected values are used to evaluate the influence of temporal "dimming" effect caused by the solar eclipse. To obtain evaluations of impact of the solar eclipse on levels of solar radiation, the following values of "dimming" effect $\Delta_k=(1-R_k)\cdot 100\%$, are computed. Functions R_k represent the ratio of solar irradiance measured in the course of the solar eclipse to values of the expected levels of solar irradiation in the absence of the eclipse and derived from the interpolation procedure. Ratios R_k are calculated as follows:

- for k=1, $R_1=Q_c/Q_e$, which corresponds with the ratio of expected levels of solar irradiance to levels of solar irradiance measured at the culmination of the solar eclipse;
- for k=2, $R_2=Q_{bcd}/Q_{bed}$, which corresponds with the ratio of expected totals of solar radiation to the measured ones during the period of the solar eclipse;
- for k=3, $R_3=Q_{abcdf}/Q_{abedf}$, which corresponds with the ratio of values of expected daily totals of solar radiation to the measured ones.

The subscripts at values Q represent a set of points which are used to compute totals by using integration procedure and instantaneous values. Integration is fulfilled along the path designated by chains of points for curves describing both measured and expected variation of solar irradiance. These points are marked on curves in Fig. 2. Measurable quantities such as 1-minute averages of solar irradiance at solar eclipse culmination, intermediate sums in the course of the period of solar eclipse, and daily totals of solar radiation will be utilized for evaluations of functions *Q* and respective "dimming" effects. Values of "dimming" effect Δ_k of solar radiation computed for the set of observable parameters, such as UV-B, UV-A, solar (280-3000 nm), solar (400-1100 nm) and PAR radiation, are presented in Table 1. "Dimming" data, such as at the culmination of the solar eclipse Δ_1 and the sums collected in the course of period of the solar eclipse Δ_2, ranged from 73.5 to 78.3% and from 36.5 to 41.7%, respectively. Evaluations of "dimming" effect for daily totals of solar radiation Δ_3 varied from 17.2 to 19.9% due to partial solar eclipse. In particular, for global solar radiation "dimming" data $\Delta_{1,2,3}$ were 73.6, 37.4, and 17.7%, respectively.

Table 1. Variability of "dimming" effect Δ_k due to the partial solar eclipse for the group of spectral broadband components of solar radiation (from UV-B to near IR) falling onto the horizontal plane. For each of observable parameters, values of Δ_k are computed through the ratios of solar radiation measured in the course of solar eclipse to the estimated values of solar radiation in the absence of the eclipse. Solar eclipse event is dated January 4, 2011

Observable parameters of broadband solar radiation	dimming, Δ_1 (at the culmination of solar eclipse), %	dimming, Δ_2 (for sums during the solar eclipse), %	dimming, Δ_3 (for daily totals), %
UV-B(global), 280-315 nm	77.9	38.5	19.6
UV-B(diffuse), 280-315 nm	78.3	39.5	19.9
UV-A(global), 315-400 nm	75.9	37.4	17.8
PAR(global) , 400-700 nm	73.7	36.5	17.2
solar(global), 400-1100 nm	74.2	39.2	18.7
solar(global), 300-2800 nm	73.6	37.4	17.7
solar(diffuse), 300-2800 nm	76.7	41.7	18.9
solar(direct), 300-4000 nm	73.5	38.0	18.8

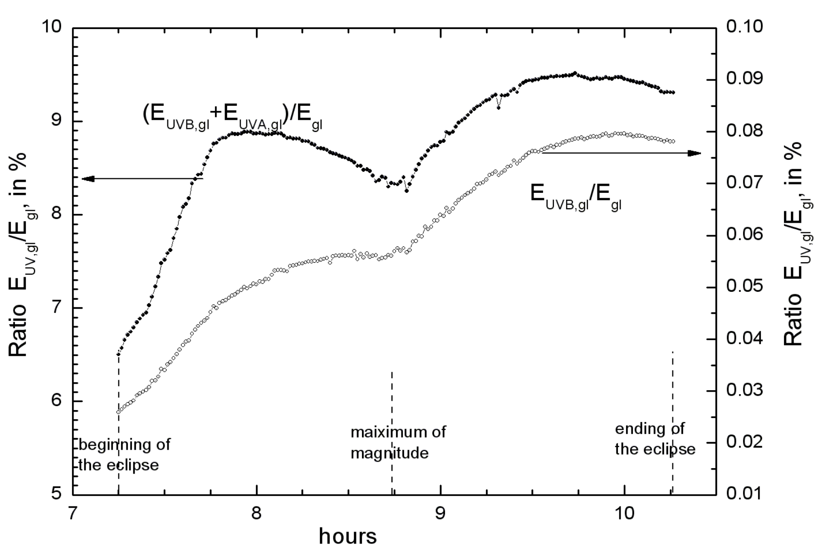

Fig. 3. Variability of ratios $E_{UV,gl}$ /E_{gl} of components of global UV-A+B and UV-B radiation $E_{UV,gl}$ to the global solar radiation E_{gl} (280-3000 nm). Vertical dashed lines correspond to the beginning, culmination (maximum), and ending of the solar eclipse.

Contributions of global UV radiation $E_{UV,gl}$ with individual components UV-A+B and UV-B relatively to global solar radiation E_{gl} are defined as ratios of respective values, $E_{UV,gl}/E_{gl}$. Variability of these ratios in the course of the partial solar eclipse is presented in Fig. 3. On an average, values of these ratios are $\langle E_{UV\text{-}A+B,gl}/E_{gl}\rangle \sim 8.8\%$ and $\langle E_{UV\text{-}B,gl}/E_{gl}\rangle \sim 0.06\%$. Analysis of diurnal variability of ratios $E_{UV\text{-}A+B,gl}/ E_{gl}$ and $E_{UV\text{-}B,gl}/E_{gl}$ for clear day conditions showed that curves describing these ratios are similar to curves of UV and solar radiation variation with maximum in midday. At the same time, we can clearly see from Fig. 3 that, in the course of the solar eclipse, these ratios have a minimum corresponding to the point of eclipse culmination.

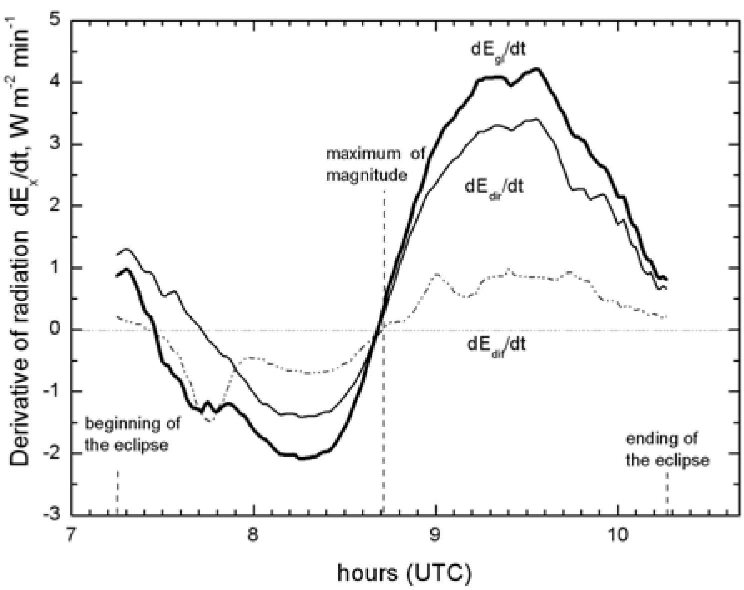

Fig. 4. Variability of derivative dE_x/dt ($W\cdot m^{-2}\cdot min^{-1}$) for global, direct, and diffuse solar irradiances. The vertical dashed lines correspond to the beginning, culmination, and ending of the solar eclipse. Measurements were made at the Kishinev site during the solar eclipse event occurred on January 4, 2011.

The rate of change or derivative of global, direct, and diffuse solar radiation on time, dE_x/dt ($W\cdot m^{-2}\cdot min^{-1}$) in the course of the solar eclipse is presented in Fig. 4. These curves were smoothed using the adjacent averaging pocedure with the sequence of 11 points. The non-uniform variability of dE_x/dt is clearly seen from Fig. 4. Two features should be noted: (1) the existence of two extrema for derivative dE_x/dt, which were located before and after culmination of the solar eclipse; (2) condition of $dE_x/dt=0$ corresponded to the point in time t_o=08:40:23 UTC that occurred earlier than the time of culmination (maximum of magnitude) of the solar eclipse at t_c= 08:43:04 UTC. For example, extreme values for the derivative of global solar radiation on time dE_{gl}/dt were ~ -2.1 $W\cdot m^{-2}\cdot min^{-1}$ and ~4.2 $W\cdot m^{-2}\cdot min^{-1}$, respectively, before and after culmination of the solar eclipse.

3. Summary and conclusions

The influence of the partial solar eclipse on January 4, 2011 upon the levels of solar radiation on the Earth's surface was analyzed. The measurements of solar radiation were carried out using a ground-based radiometric complex equipped with a set of broadband solar radiation sensors in the wavelength range from UV to near IR. The data used in this study were 1-minute averaged values of global, direct and diffuse solar radiation. This time resolution was sufficient to study the consequent phases of the solar eclipse. The stability of the optical characteristics of the atmosphere at the Kishinev site was controlled using concurrent sun photometric measurements throughout the day of observation. Evaluations of the "dimming" effect due to the solar eclipse were based on the ratios of the solar radiation data from direct observations to the expected values derived from polynomial interpolation as if in the case of absence of the solar eclipse. Ratios were computed at the culmination of the eclipse, in the course of the eclipse, and for daily totals. In particular, ratios of measured values of global solar radiation to expected ones were the following: ~73.6, 37.4, and 17.7%, respectively. Contributions from UV global radiation measured in two broadband wavelength ranges of UV-A+B and UV-B relatively to global solar radiation during the solar eclipse, on an average, were ~8.8% and ~0.06%. The existence of non-uniform variability of the derivative of solar irradiance on time, dE_x/dt, for global, direct, and diffuse solar radiation during the solar eclipse was shown. Extreme values for derivative of global solar radiance on time, dE_{gl}/dt, were about -2.1 $W \cdot m^{-2} \cdot min^{-1}$ and ~4.2 $W \cdot m^{-2} \cdot min^{-1}$, respectively, before and after the culmination of the solar eclipse observed on January 4, 2011.

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