ON ONE GENERALIZATION OF BOUGER – BEER LAW ON THE BASIS OF NEW INVARIANT PARAMETER OF SOLAR SPECTRAL IRRADIATION. APPLICATION FOR CALIBRATION OF GROUND SOLAR PHOTOMETERS

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In the given paper the possibility of introduction of invariant indexes of sun spectral radiation, obtained in the result of the summarizing of Bouger-Beer law for the case of three-wave atmosphere measurements has been considered. It is shown, that calibration of three-wave photometer on proposed invariant allows us to eliminate the influence of atmosphere parameter changeability on wave length.

The solar energy is the main source of energy for biosphere of the Earth. It directly controls the atmospheric and oceanic circulations and climate. The proper understanding of this energy is essential for true assessment of processes taken place in the system Earth – atmosphere. Historically, prior the satellite measurements the total solar energy calculated for average value of distance between the Sun and the Earth was considered as "Solar Constant". The systematic ground measurements of variations of solar constant are carried out during more than one hundred years, on Program of Solar Constant of Smithsonian Astrophysical Observatory [1]. At the basis of multi-number experimental researches, including satellite measurements of "Solar Constant", at present time existing prevailing scientific opinion states that only satellite measurements are really capable to detect the variations of solar constant, linked with magnetic activity of the Sun, for example, 11 years, 27 days and other cycles of variation [2].

At the same time methods and equipment for ground atmospheric measurements suffered great changes and modifications. The world-wide network AERONET was specially organized to carry out dynamic components of atmosphere [3]. The possibility of obtaining components extra-atmospheric data from satellites and synchronous data from ground networks allows us to carry out direct comparison of them to determine adequacy of ground measurements of solar constant. Results of one of such researches are described in [2] where comparison of synchronous measurements is carried out. These data were obtained from the instrument SOLSTICE installed in satellite UARS and AERONET network photometers beginning from January 1, 1998 till October 28, 1999.

As a result of held research it was revealed, that measured by instrument SOLSTICE the variation of solar-spectral radiation, determined as standard deviation divided to average value was equal to 0.12 % and 0.14 % in wavelength 340 nm and 380 nm.

But variations of ground measurements in aforementioned wavelengths were equal to 2,0 % and 1,8 %. These values of variation are more than one order in comparison with values of variation of solar irradiation measured by help of satellite instruments SOLSTICE. On the basis of aforesaid data it was concluded, that ground measurements cannot be used for research of variability of solar constant. Such a dubious conclusion is dangerous, because it rejects any possibility of calibration of ground photometer using solar irradiation. This conclusion is justified by such a wrong suggestion, that variability of atmosphere cannot be removed from results of ground measurements. The purpose of this article is demonstration of fallibility of such opinions on an example of recently proposed three-wave lengths technology of atmospheric measurements [4, 5].

As it was noted earlier, the accuracy of ground methods of determination of the solar constant is mainly depends on variability of atmosphere.

Further in this article we shall speak about UV band and mentioning the variability of atmosphere or optical depth of atmosphere we shall consider not temporal changes, but changes on wavelength of measurements. It is well-known, that one of major parameters of variability of random processes is autocorrelation function. For example, the changeability of function $\tau_A = f(\lambda, t)$, where τ_A - optical depth of atmosphere; λ - wavelength; t - time parameter of current measurements, can be characterized by following two – measured autocorrelation function:

$$R_\tau(\Delta\lambda, \Delta t) = \frac{1}{B(\tau)} \int_0^{\Delta\lambda_{max}} \int_0^{\Delta t_{max}} \tau(\lambda + \Delta\lambda; t + \Delta t) \cdot \tau(\lambda; t) d(\Delta\lambda) d(\Delta t). \qquad (1)$$

At present, there are many sources, where the data on correlation dependence of optical depth of atmosphere separately on time and wavelength of measurements are given. For example, the results of atmospheric variability research in UV band are given [6]. These results are obtained on the basis of 19,568 measurements of direct solar irradiation carried out in Riverside site and similar series of measurements, by number of 21,972 measurements carried out in Mt. Wilson site.

The computed valued of correlation indices for all pairs of wavelength are shown in Table 1[6]. It is shown, that Riverside site is characterized with strong correlation between results of measurements in all wavelengths. For the Mt. Wilson site, the correlation indices are slightly weak.

Table 1

Riverside	306 nm	312 nm	318 nm	326 nm	333 nm	368 nm
300 nm	0,99	0,97	0,93	0,94	0,92	0,92
306 nm		0,99	0,95	0,97	0,95	0,95
312 nm			0,97	0,99	0,97	0,97
318 nm				0,99	1,00	0,99
326 nm					1,00	0,99
333 nm						1,00
Mt. Wilson	306 nm	312 nm	318 nm	326 nm	333 nm	368 nm
300 nm	0,94	0,85	0,76	0,69	0,62	0,59
306 nm		0,92	0,85	0,82	0,77	0,74
312 nm			0,98	0,96	0,93	0,91
318 nm				0,98	0,96	0,95
326 nm					0,99	0,98
333 nm						1,00

Thus, the results of research described in [6] have shown, that autocorrelation function (1) of optical depth of atmosphere, calculated on wavelength,

$$R_\tau(\Delta\lambda)=\frac{1}{B(\tau)}\int_0^{\Delta\lambda_{max}}\tau(\lambda+\Delta\lambda;t)\cdot\tau(\lambda,t)d(\Delta\lambda) \quad (2)$$

has a positive and higher values. Physically, it may be explained by such a fact, that the optical depth of atmosphere in UV band is mainly formed with aerosol and ozone, the quantitative and qualitative parameters of which are not changing during the short period of measurements.

It should be noted, that this phenomenon is rightful also for atmospheric measurements on horizontal route. For example as it is shown in [7], the higher correlation values exist for results of measurements of optical depth of aerosol in UV and visible bands carried out in on-earth layer of atmosphere.

According to the method of Langly plots, each deviation of measured value of solar constant is directly determined with deviation of optical depth of atmosphere, if optical mass is constant. From well-known formula of Bouger-Beer one can obtain following equation, which is basis of Langly plot method:

$$\ln I_0 = m\tau_\Sigma + \ln I , \quad (3)$$

where I_0 - «Solar constant»; m - optical mass; τ_Σ - total optical depth of atmosphere; I - the measured value of solar spectral irradiation.

It is obvious, that upon condition of stability of solar constant, $m=const$, and stability of parameters of ground photometer, each differed from zero measured value of $\frac{d\ln I_0}{d\lambda}$ is caused by differed from zero value $\frac{d\tau_\Sigma}{d\lambda}$.

The presence of strong correlation in values of τ_Σ on λ leads to strong correlation of $\ln I_0$ on λ, i.e. there is the error of measurement of I_0, depending from λ, which is caused by variation of τ_Σ. Therefore, the error of ground measurements of I_0 in comparison with the satellite measurements has a systematic feature and depends on λ.

But if we by modification of method of ground measurements, can succeed to generalize the relevant form of equation of Bouger-Beer, writing it in following form

$$P(I)=P(I_0)\cdot e^{-mP(\tau_\Sigma)}, \quad (4)$$

where $P(I)$ - generalized parameter of solar-spectral irradiation, measured at the level of the Earth; $P(I_0)$ - the generalized parameter of solar-spectral irradiation at the external border of atmosphere; $P(\tau_\Sigma)$ - the generalized parameter of optical depth of atmosphere, meeting the following conditions

$$\frac{dP(\tau_\Sigma)}{d\lambda}=0 \quad (5a)$$

$$P(\tau_\Sigma)=0 , \quad (5b)$$

and consequently, following conditions

$$\frac{dP(I)}{d\lambda}=0 \quad (6a)$$

$$\frac{dP(I_0)}{d\lambda}=0 , \quad (6b)$$

while any variation of I_0 due to variation of magnetic activity of the Sun is lacking, we could, in principle, succeed to carry out ground measurements of parameter of solar-spectral radiation, where the obtained result would not depend on variation of λ.

It can be shown, that as a result of application of recently proposed 3 wavelength technology of atmospheric measurements, we can formulate the generalized parameters $P(\tau_\Sigma)$; $P(I)$ and $P(I)$, and in this case, the equation of Bouger-Beer may be generalized in the form of (4).

By the aim to form the generalized parameter of optical depth of atmosphere and generalized parameter of solar constant, we describe in brief the main provisions of method of three-wave lengths measurements. Let us assume, that there are wavelengths λ_1, λ_2 and λ_3, where $\lambda_1 < \lambda_2 < \lambda_3$ and we carry out following measurements

$$\left.\begin{aligned} I(\lambda_1) &= I_0(\lambda_1)\cdot e^{-m_1 \tau(\lambda_1)} \\ I(\lambda_2) &= I_0(\lambda_2)\cdot e^{-m_1 \tau(\lambda_2)} \\ I(\lambda_3) &= I_0(\lambda_3)\cdot e^{-m_1 \tau(\lambda_3)} \end{aligned}\right\}. \quad (7)$$

Now we should calculate generalized parameter $P(I)$ as follows:

$$P(I) = \frac{\sqrt[\chi]{I(\lambda_1)\cdot I(\lambda_3)}}{I(\lambda_2)}. \quad (8)$$

Taking into account (7) and (8) we have following generalized form of writing of Bouger-Beer law

$$P(I) = \frac{\sqrt[\chi]{I(\lambda_1)\cdot I(\lambda_3)}}{I(\lambda_2)}\cdot e^{-m\left[\frac{\tau(\lambda_1)+\tau(\lambda_3)}{\chi} - \tau(\lambda_2)\right]}. \quad (9)$$

Therefore, the generalized parameter of solar constant in (9) may be written as

$$P(I_0) = \frac{\sqrt[\chi]{I_0(\lambda_1)\cdot I_0(\lambda_3)}}{I_0(\lambda_2)}. \quad (10)$$

The generalized parameter of optical depth of atmosphere may be written as

$$P(\tau) = \frac{\tau(\lambda_1)+\tau(\lambda_3)}{\chi} - \tau(\lambda_2). \quad (11)$$

From the equation (11) it is obvious, that if by proper selection of $\lambda_1, \lambda_2, \lambda_3$ and χ we could ensure following conditions

$$P(\tau) = 0 \quad (12a)$$

and

$$\frac{dP(\tau)}{d\lambda} = 0 \quad (12b)$$

then the measured value of Z will be equal to generalized solar constant's parameter $\frac{\sqrt[\chi]{I_0(\lambda_1)\cdot I_0(\lambda_3)}}{I_0(\lambda_2)}$, which will not depend on wavelength.

Therefore, equations (12a) and (12b) are conditions for ensuring of accurate ground measurements of value of generalized solar constant (10).

From conditions (12a) and (12b) we have

$$\chi = \frac{\tau(\lambda_1)+\tau(\lambda_3)}{\tau(\lambda_2)}. \quad (13)$$

As it is shown in [5] 2 variants of realization of equation (13) are possible.

1) We should select $\chi = 2$; Wavelengths λ_1 and λ_3 are fixed; and wavelength λ_2 should be chosen using following formula

$$\tau(\lambda_2) = \frac{\tau(\lambda_1)+\tau(\lambda_3)}{2}. \quad (14)$$

2) The wavelengths $\lambda_1, \lambda_2, \lambda_3$ are fixed. The index χ should be chosen using equation (13).

In line with (12b) following condition should be met (if $\chi = 2$)

$$dP(\tau) = 0$$

or

$$\Delta P(\tau) = 0$$

or

$$\frac{\Delta\tau(\lambda_1)+\Delta\tau(\lambda_3)}{2} = \Delta\tau(\lambda_2). \quad (15)$$

For example, it easily can be shown that in small interval $\Delta\lambda = \lambda_1 \div \lambda_3$, upon linear approximation of dependence $\tau = \tau(\lambda) = k\lambda$, the conditions (14) and (15) easily may be met.

Therefore, we may conclude that the invariant of spectral solar radiation (10) exists and this invariant not depends on wavelength.

Wavelengths $\lambda_1, \lambda_2, \lambda_3$ may be chosen using conditions (12a) and (12b).

The practical value of the proposed invariant is linked with necessity initial calibration of ground measurement systems on extra-atmospheric sources.

As it is noted in [6], the satellite means of measurements are calibrated using stable UV irradiation of blue stellar. Calibration of ground meters on Sun irradiation using previous methods turned out impossible due to influence of variability of atmosphere. In this situation the suggested three-wavelengths invariant should be applied.

The single instrument to be chosen in this case should be the previously suggested [4, 5] three-wavelengths meters, the application of which will open the era in the theory and practice of ground atmospheric measurements.

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GÜNƏŞİN SPEKTRAL ŞÜALANMASININ YENİ İNVARİANT PARAMETRİ ƏSASINDA BUGER-BER QANUNUNUN BİR ÜMUMİLƏŞDİRİLMƏSİ BARƏDƏ. YERÜSTÜ GÜNƏŞ FOTOMETRLƏRİNİN KALİBRASİYASINDA TƏTBİQİ

Məqalədə göstərilmişdir ki, atmosfer dəyişiklikləri ilə əlaqədar olaraq yerüstü ölçmə vasitələri ilə Günəş şüalanmasında olan dəyişikliklərin müşahidə edilə bilməsinin qeyri-mümkünlüyü barədə qərarlaşmış elmi rəyə baxmayaraq, əvvəllər təklif edilmiş üç dalğa uzunluqlu ölçmə metodu və müvafiq qurğunun kalibrasiyası üçün Buger-Beer qanununun təklif edilmiş ümumiləşdirilməsindən alınan Günəş spektral şüalanmasının yeni invariantı tətbiq edildiyi halda bu cür müşahidələr mümkündür.

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О ВОЗМОЖНОСТИ КАЛИБРОВКИ НАЗЕМНЫХ СОЛНЕЧНЫХ ФОТОМЕТРОВ С ПОМОЩЬЮ ИНВАРИАНТНОГО ПОКАЗАТЕЛЯ СОЛНЕЧНОЙ СПЕКТРАЛЬНОЙ РАДИАЦИИ

В данной статье рассмотрена возможность введения инвариантного показателя солнечной спектральной радиации, полученной в результате обобщения закона Бугера-Бера для случая трехволновых атмосферных измерений. Показано, что калибровка трехволновых фотометров по предложенному инварианту позволяет устранить влияние изменчивости параметров атмосферы по длине волны.

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