Some problems of solar-terrestrial physics connected with formation and dynamics of atmospheric aerosol

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The interdisciplinary problems of solar-terrestrial physics connected with formation and dynamics of atmospheric aerosol are considered. In particular, the problems of astroclimate and optical weather are studied in the Geophysical Observatory of ISTP SB RAS (Tunkinskaya valley). Among other problems are: separation of a component in the upper atmospheric radiation, which is stipulated by the solar radiation scattering; the atmospheric aerosol effect on the UV-radiation variations; testing of the hypothesis on variation of the exoatmospheric spectral distribution of solar radiation; estimating the effect of heliogeophysical disturbances of different nature on optical characteristics of the atmosphere.

The project Aeronet organized by the American Space Agency NASA, represents the automated network of aerosol monitoring. It numbers more than 120 stations located at all continents of the world.[1] The observations are carried out by means of the solar multispectral photometer SE-318 operating in eight spectral channels and measuring both direct and scattered solar radiation.

The primary problems of the project are studying the aerosol effect on the planet climate, revealing the features of spatiotemporal aerosol variations, and the subsatellite control for space sensing of the Earth natural resources. The main parameters determined by the solar photometer are the aerosol optical thickness (AOT) and moisture content of the atmosphere. Owing to the application of modern methods of the inverse problem solution, except for AOT and moisture content of the atmosphere, the aerosol microstructure, refractive index, scattering phase function, asymmetry factor, and the aerosol single scattering albedo[2] can be restored.

The given study presents some problems of solar-terrestrial physics, which are not directly referred to the Aeronet project. However, the data on atmospheric aerosol can be involved for solving these problems.

One of them is the accounting for aerosol effect on the ground UV-radiation (UVR). The ground-based UVR observation methods allow obtaining the valid data on the ground UVR-flow in local observation points. The fragmentariness of the obtained data of the UVR-variation leads to necessity in using different methods of their interpolation, that essentially reduces their validity.

The restoration of UVR-flows at a level of the Earth surface from the satellite observation data is widely used nowadays with the help of the TOMS equipment (Total Ozone Mapping Spectrometer) that allows obtaining the data on spatial UVR-variations in different points of the globe. A considerable disadvantage of the TOMS satellite data is ignoring of tropospheric aerosol effect in the UVR restoration algorithm.

The description of test algorithm of the UVR-flows in the interval from 320 to 400 and from 290 to 320 nm under cloudless conditions, including the estimations of different error sources, which can be applied to the TOMS satellite data is presented in Ref. 3. It is found that aerosols can reduce the ground UVR-flows over some areas by more than 50%.

The satellite data validation by UVR due to the comparison with results of the ground-based observations[4,5] has revealed the systematic overestimation of satellite data in mid-latitudes of the northern hemisphere. It is shown in Ref. 6 that the accepted error in estimation of the UVR-daily dose restoration by the TOMS data (± 12%) should be considered too optimistic.

A high correlation between the results of ground-based and satellite (TOMS) UVR-measurements is registered at long-term intervals, i.e., month, year.[7] Nevertheless, there are time intervals, when the correlation of recorded values for erythemal radiation is disturbed in individual days. This can be connected both with methodical differences in determination of ground UVR-levels in ground-based and satellite measurements, and with disregard of the atmospheric aerosol effect on the level of ground UVR according to the satellite data.

The same work[7] shows an asymmetry of the UVR seasonal behavior relative to the summer solstice, which consists in excess of the UVR-values in the second half-year as compared to the first one at identical angles of altitude of the Sun. It was assumed in the study that the asymmetry is caused by the well-defined seasonal behavior of the total ozone content and by meteorological features of the given region. If to take into account the fact that the most clean atmosphere (by aerosol content) is in the autumn–winter period, that is typical for the majority of regions in temperate latitudes,[2] one can suppose that the asymmetry is caused by disregard of the aerosol component at the UVR restoration.

Investigations of spatiotemporal UVR variations in five towns (including Irkutsk and Tomsk)[8] revealed the “spring feature” of the UVR behavior, which consists in seasonal behavior deviation determined by the angle of altitude of the Sun. The similar “spring

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feature" is distinguished in Ref. 9 (figures) connected with investigation of UVR in Tibet.

Figure 1 presents the UVR variations (by the TOMS data), AOT, moisture content (by the "Aeronet" data), and total ozone content (TOC) for Tomsk in 2003. In the "spring feature" (April–May), the time scales of UVR, AOT, and TOC variations coincide. Some typical features on the curve of the UVR variation can be compared with TOC variation, others – with AOT variation. Probably, the "spring feature" of the UVR seasonal behavior is formed under the action of several factors and requires a special analysis.

In the Geophysical Observatory of ISTP SB RAS, one of the types of regular observation is connected with investigation of the natural glow in the upper atmosphere. For this purpose, it is necessary to know the spectral atmosphere transparency and other elements of astroclimate and optical weather. The studying of scattering and absorption of the upper atmosphere natural glow in the Earth troposphere is quite a difficult problem. Therefore, in Ref. 10, the problem of diffuse radiation transmission by the atmosphere from the spherical glowing layer is solved theoretically. In particular, the glow intensities of the upper layers obtained at different transparencies much differ from each other, and it is necessary to measure simultaneously the glow intensity and the atmosphere transparency.

The effect of atmosphere transparency conditions on the registered characteristics of atmospheric natural glow as a distributed object differs from the effect of point astronomical objects. For the astronomical instruments, the main parameter limiting the observation conditions is the power attenuation, which can be described by the Bouguer law. For the distributed objects, the total energy illumination on the Earth surface is formed due to the direct and scattered illumination.

In case of large optical thicknesses, the optical radiation attenuation should be determined from the radiation transfer equation or from the empirical relations. Therefore, Ref. 11 shows that registration of the mid-latitudes light in October 30, 2003, in the Geophysical Observatory of ISTP SB RAS was carried out under overcast conditions. This mid-latitude light was induced by one of the most powerful magnetic storms for the whole period of instrumental observations in the Geophysical Observatory (from 1988 to 2006), being therefore of particular interest.

Real accounting for atmospheric radiation attenuation by the cloud cover from the distributed source is of great difficulty and depends on many factors. Therefore, to estimate the attenuation by the cloud cover and to reduce the registered glow intensities of atmospheric emissions to the clear sky conditions with their subsequent comparison with other midlatitudes lights, we have estimated the typical attenuation by the cloud cover from the experimental observations with the use of the archive data. The nights were chosen, which corresponded to the same season with rapid change of meteorological situation (clear–cloudy). For these nights, the registered intensities in atmospheric emissions were compared for clear and cloud observation intervals and the cloud cover attenuation coefficients were determined. The obtained attenuation coefficients were used for the reduction of registered values under the cloud cover to the clear sky conditions.

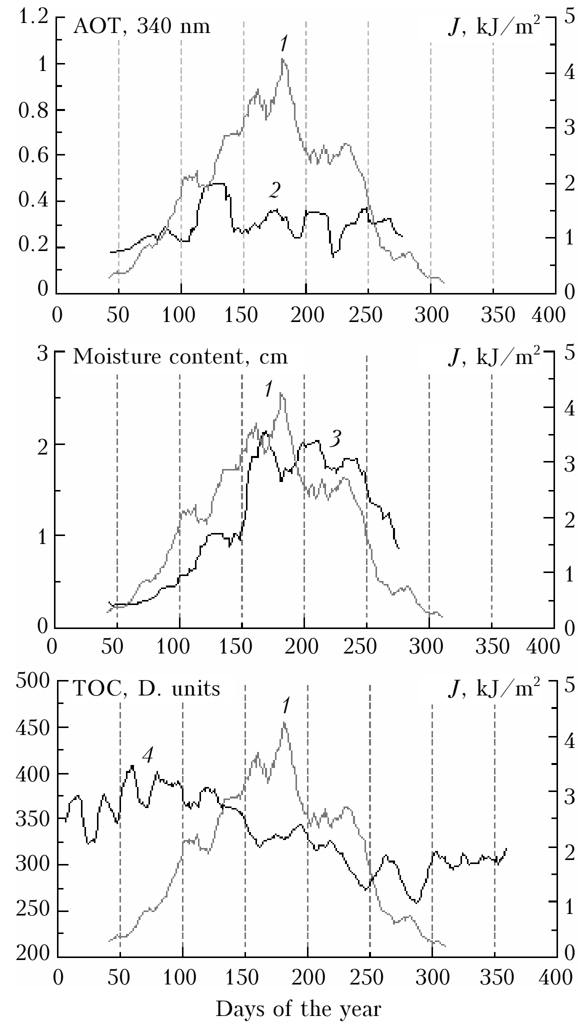

Fig. 1. Variations of UVR (*1*), AOT at $\lambda = 340$ nm (*2*), moisture content (*3*), and TOC (*4*) in Tomsk, 2003.

In connection with the described case, there is a problem of registration of the proper radiation of the upper atmosphere at any optical weather. To solve it, there is a necessity in a great amount of information about state, atmospheric composition, and radiation transmission of the upper atmosphere. In part, this problem can be solved when involving the data of solar photometer Aeronet.

Aerosol formations at different atmospheric altitudes can affect the spectral distribution of twilight and night glows of the atmosphere due to the continuous background component depending on the atmosphere state and being formed in view of sunlight multiple scattering.[12] In case of separation of the continuous spectrum of the upper atmosphere proper radiation, it is reasonable to take into the continuous background, together with the dynamics of aerosol formations and optical characteristics of the lower atmosphere. The multiple radiation scattering is manifested more essentially in blue and UV-spectral regions.

Besides, the direct radiation and scattered solar radiation [Na fluorescence, photodissociation of oxygen molecules $O_2 + h\nu \rightarrow O(^3P) + O^*(^1D)$] can contribute to excitation and variation of some emissions of the upper atmosphere in twilight periods. In this connection, interpretation of twilight variations of the upper atmosphere emissions is quite a difficult problem.

In a series of works, the connection of atmosphere transparency with solar and auroral activity has been marked and discussed (see, for example, Refs. 13 and 14). The physical mechanisms of such connections are still not clear and must be checked jointly with systematic data on the atmosphere transparency in different regions of the world. This is of great scientific interest owing to the search of possible reasons of climate and weather variations. Figure 2 presents the decrease of mean score of the atmospheric transparency after the increase of auroral activity [Ref. 14].

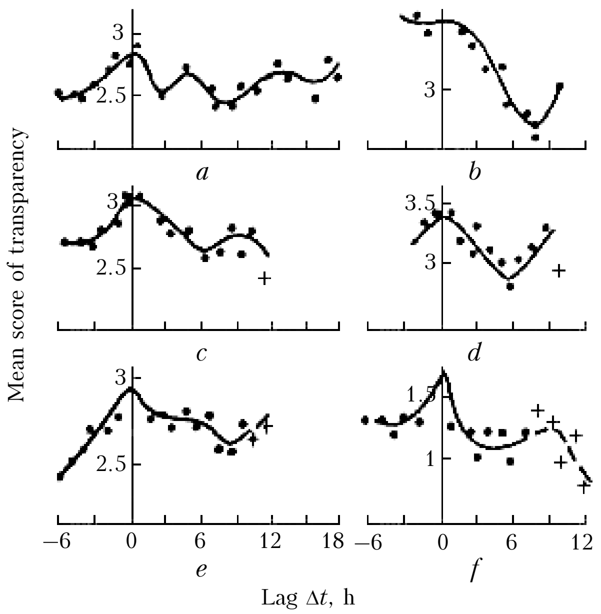

Fig. 2. Mean values of the atmosphere transparency in different observation points: the Golomyanny island (*a*); the Isachenko island (*b*); the Ust-Tareya (*c*); the Kresty (*d*); the Norilsk (*e*); the Igarka (*f*). The observation, where the light in brightness of 3 score and higher was registered, corresponds to the time Δt equal to 0. The crosses correspond to the minor statistics of measurements of the atmosphere transparency.

The atmosphere transparency was determined visually according to the limiting value of visible stars on the six-point scale (five denotes the perfect transparency; zero denotes the invisible stars). The authors relate one of the offered mechanisms to the variation of the troposphere temperature condition, to the condensation of water vapors and, as a consequence, to the atmosphere transparency reduction. The data of Aeronet solar photometer carrying out the simultaneous measurements of transparency and moisture content of the atmosphere, probably, can allow testing the mechanism of the atmosphere transparency variation in periods of geomagnetic activity strengthening using a great amount of statistical material.

One should also note the problem of testing the hypothesis of the exoatmospheric spectral distribution variation of solar radiation during the solar flares[15] based on observation of "abnormal" optical thickness values in some spectral ranges. Another explanation of the optical parameter disturbance of the atmosphere thickness during the solar events is given in Ref. 16. It is connected with atmospheric composition variation. In any case, the problem of "abnormal" optical thickness values and the atmosphere spectral transparency must be solved with Aeronet data.

Thus, the Aeronet observation data can be used to provide specific types of observation, to test mechanisms and hypotheses of the observed phenomena of solar-terrestrial physics.

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