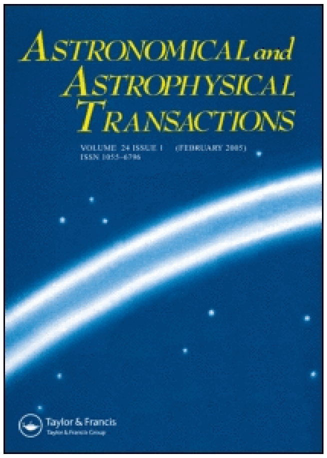

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Application of the iterative method *BVR* geostationary satellite observations accounting for atmospheric extinction

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The verification of and recommendations on the use of a method for *BVR* geostationary observations obtained at an observatory located in the desert are given.

Keywords: Atmospheric extinction; Electrophotometry; Geostationary satellites

Electrophotometric observations of geostationary satellites began at the Astrophysical Institute of the Kazakh National Academy of Sciences in 1979. At first, these studies were conducted with the AZT-8, and then with the 1 m telescope of the Assy-Tyrgen Observatory which was equipped with a special instrumentation and software [1, 2]. From 1998, regular observations with the quantum-optical system (QOS) (Priozersk) of the Sary-Shagan proving ground have been started. The QOS was set up on the 50 cm AZT-28 telescope which has coupled telescopic systems. One of the systems is used to receive coordinate information, and it consists of an electrophotometer working in a photon-counting mode with *BVR* filters. The second system consists of a photomultiplier (type 79) [3].

The advantage of the observational station at Priozersk is that there are many clear nights in that area (up to 280 in a year and approximately 100 of these are suitable for exact photometry). Also the completely open horizon allows us to observe at large zenith distances when necessary. However, there are some specific conditions that should be taken into account when processing photometric observations.

(i) The transparency can change considerably within any specific night. Therefore, of the methods that take into account extinction, it is possible to apply (but with great uncertainty) only those that are based on the Buger method with statistical average parameters of extinction.
(ii) The observational station is located in the desert near Balkhash lake. As a result, significant azimuthal effects occur, and the parameters of extinction appear to be variable both in

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time and in space. This causes variations in not only the optical thickness of an aerosol component but also the spectral absorption lines of water.

The technique for processing the electrophotometric observations [3] which we used allowed a 5% error in the conditions at Priozersk. When we carried out observations with large zenith distances, the errors could reach a magnitude of 0.05–0.08.

Incorrectly accounting for atmospheric extinction is the main source of these errors. Therefore we decided to modernize the software package used for processing the photometric observations by applying another technique to take extinction into account. The iterative method in [4] was taken as a basis for this. It allows us to take into account all the above-listed specific features of the observation station.

The basic idea of a method is the calculation of extinction corrections by the method of numerical integration:

$$m_i^0 = m_i - 2.5\lg\frac{\int F(\lambda)\phi_i(\lambda)P^{M_z}(\lambda)\mathrm{d}\lambda}{\int F(\lambda)\phi_i(\lambda)\mathrm{d}\lambda} + \text{constant}, \qquad (1)$$

where m_i^0 is the above-atmospheric magnitude in band i in the international system, m_i is the instrumental magnitude, $F(\lambda)$ is the distribution of energy in the spectrum of a star, $\phi_i(\lambda)$ represents the photometer curves of reactions, the constant is added to reduce the equation to that of the standard system, $P(\lambda)$ represents the curves of the light passing through the Earth's atmosphere and M_z is the air mass of the object according to Bemporad's formula.

It is assumed that most of the above-cited curves are known or (as a first approximation) can be obtained from any models. For example, the function of the light passing through the Earth's atmosphere can be represented as

$$P(\lambda) = P_0(\lambda)P_{\mathrm{a}}(\lambda), \qquad (2)$$

where $P_0(\lambda)$ represents the modelling curves of Rayleigh dispersion, curves of water pair absorption, oxygen, ozone, etc., and $P_{\mathrm{a}}(\lambda)$ represents the curves of light passing through atmospheric aerosols which, in turn, are represented as

$$-2.5\log[P_{\mathrm{a}}(\lambda)] = x^n + y, \qquad (3)$$

where x and y are parameters of extinctions caused by selective light passage and scattering and not by selective shielding components of atmospheric aerosols, the sizes of which are determined during the observations, and where n is a modelling parameter that can vary from 1.38 (theoretical) up to 4.0 (Rayleigh).

Thus, we divide the value of the extinction correction into two components: constant and variable. So the constant component will depend on the observatory location only and the variable component will change with weather conditions; it is desirable to estimate the values of these each night that observations are made.

The method of using a pair of stars which are aligned in approximately one direction but with air masses exceeding 0.3–1.0 to define the instant extinction parameters has been chosen. The technique of carrying out observations and processing them has been tested by compiling a catalogue [5] using estimations of parameters obtained at the high-mountain observatory of the Sternberg Astronomical Institute from the results in [6, 7]. Then we carried out additional observations of standard stars of various spectral classes in order to find out which elements of this technique could be neglected under the conditions at Priozersk. The effects which are recognized as essential have been taken into account in the new program for processing the observations.

The results obtained show that the x variations from observations of one night (as is necessary according to [5] for *BVR*) yield unsatisfactory results. It is much easier and more reliable to apply the average for a season (0.001–0.01). Thus the basic extinction variations are taken into account as not selective. The accuracy of these parameters is insufficient in the conditions in the flat region of Priozersk because of heterogeneity of the aerosol mass at large zenith distances ($Z \approx 70°$; $M_z > 2.0$). Therefore, it is necessary to use the average modelling parameters $x = 0.002$, $y = 0.05$ and $n = 3$ if it is not possible to obtain an instant value. For O to M stars, residual uncertainty can change the result by a magnitude of approximately 0.02–0.03. When we observe geostationary satellites, it is possible to minimize the values of errors by selection of standard stars from the A0 to K3 range.

By selecting a mathematical model of the atmosphere it is possible to apply either a minimal value of the constant part of $P(\lambda)$ (a dry and clean atmosphere), or mid-annual sizes of the parameters. Both opportunities are equally correct from a mathematical viewpoint, although there could be negative values of the parameters in the second case. We have chosen the first method because it is simple to control the instant estimations of a transparency.

Usually we obtain data about extinction change that depend on the time, azimuth and air mass when observing some standard stars (with δ from $-15°$ to $+20°$) during almost all the night. However, the same geostationary object can be observed with different standards. Therefore, in order to estimate its magnitude by the above-stated method (without any regular errors) it is necessary to know the magnitudes of the instrumental differences of these standards. For this purpose we use the method of network coordination of standard stars [8]. Because insufficient data have been observed to obtain the correctly coordinated network, we use the magnitudes in the *WBVR* catalogue. This catalogue is close to the photometric system and the same method of network coordination of standard stars was used to create it. Use of a homogeneous catalogue yields better results than a compilation such as [3]. However, it is desirable to use the magnitudes of the instrumental differences or to make corresponding corrections especially when estimating the extinction parameters by the method of a pair of stars.

About 60 stars from all range of spectral classes and luminosities have been measured for several nights at various azimuths and air masses to investigate the instrumental corrections and to obtain a network of instrumental magnitudes to a first approximation. The constancy of the above-atmospheric magnitudes of stars obtained from estimations both for one night and over several nights was the main requirement, and this was shown to be so by the results. Thus the accuracy of taking into account the extinction was also checked by the above-stated method.

The main conclusions and recommendations are as follows.

(i) The accuracy of determination of the magnitudes of the geostationary satellites was 0.01 (the root-mean-square error of one measurement). Nikonov's method gives an error that is twice this for processsing the same observations.

(ii) The instant variations in a transparency are the main sources of error. Therefore it is desirable to observe the standard near to the object both in time and in position. Thus the time factor appears to be even more significant than the azimuth.

(iii) To minimize the influence of all factors and the observation time for standard stars it is necessary to measure two to three stars of A0 to K3 type when recording an object. One of these should be near the object, and the others should have a magnitude $\Delta M_z \approx \pm 0.3$. It is not always possible to find stars that satisfy all these requirements. Therefore the problem of expansion of a network of standards for all ranges of geostationary orbits ($\delta < -20°$) and for weaker magnitudes ($m > 8$) remains.

(iv) It is necessary to continue methodical research on the expansion of a network also because of the spectral interval of stars used.

(v) The problem of accounting for the influence of absorption variations in the paired bands of water both in time and in azimuth has been insufficiently investigated. According to our observations the brightness of stars in the *R* filter increases during any specific night even if they are measured after a meridian. Attempts have been made to introduce a parameter to represent the moisture content, in a similar way to aerosols, in the system of least-squares equations. One variant of the required decision is the introduction of a negative value of the coefficient $y_R(t)$. To solve this problem, it would be more correct and desirable still to include in the system even one mean band value centred on the paired water bands.

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