ATMOSPHERIC CORRECTION OF SATELLITE IMAGES OF THE EARTH'S SURFACE WITH ALLOWANCE FOR RADIATION POLARIZATION

A.V. Zimovaia, M.V. Tarasenkov, V.V. Belov

V.E. ZUEV INSTITUTE OF ATMOSPHERIC OPTICS
RUSSIAN ACADEMY OF SCIENCES, SIBERIAN BRANCH

1, Academician Zuev square
Tomsk 634055
Russia

1. PROBLEM FORMULATION

The problem is formulated as follows (Fig.1). A parallel flux of solar radiation is incident at the upper boundary of the atmosphere in the direction $\boldsymbol{\omega}_{sun}$. At a certain altitude h_d from the Earth surface, a satellite scanning optical-electronic system is located, which forms the image of the Earth surface area at the wavelength λ in the direction $\boldsymbol{\omega}_d$. The intensity of radiation received by the satellite system is considered to be known. The atmosphere is subdivided into spherical layers; each layer has its own aerosol and molecular scattering and attenuation coefficients $\sigma_{s,a}$, $\sigma_{s,m}$, $\sigma_{t,a}$, and $\sigma_{t,m}$ and aerosol and molecular scattering matrices $R_{ij,a}$ and $R_{ij,m}$. The Earth surface is inhomogeneous and reflects radiation by the Lambert law. It is required, knowing the received radiation intensity and the optical parameters of the atmosphere, to reconstruct the Earth surface reflection coefficients at the wavelength λ.

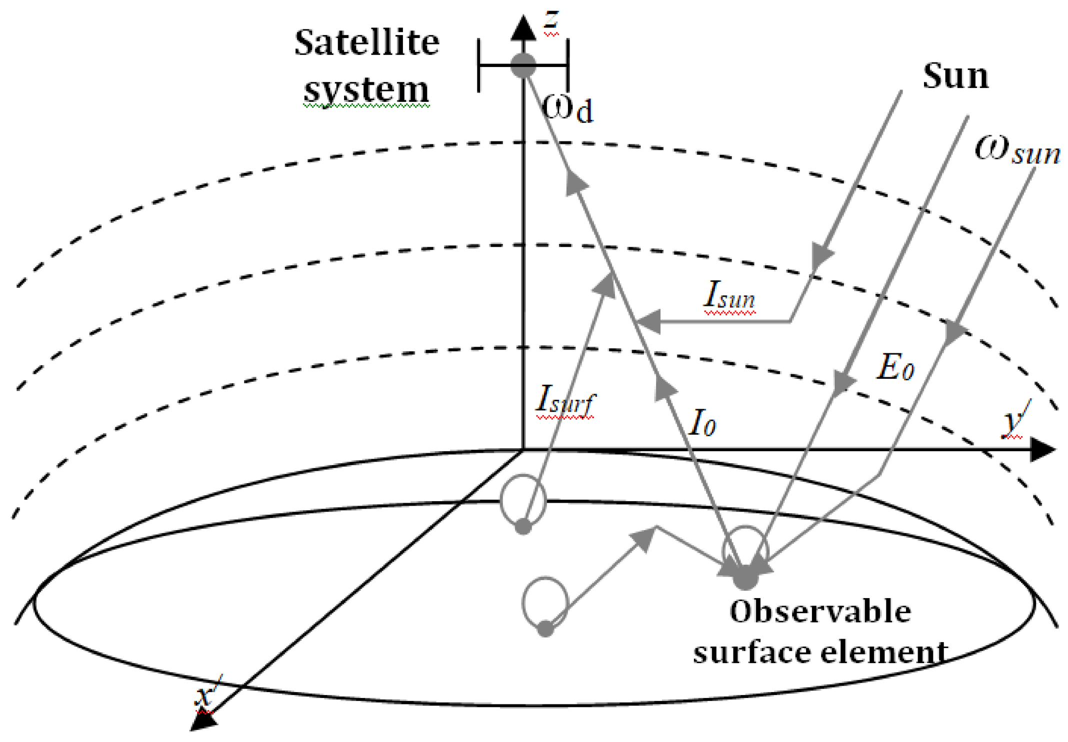

Fig.1 – Geometry of problem formulation

2. ALGORITHM OF SOLUTION

The step-by-step procedure of atmospheric correction is reduced to the following (Fig.2).

1. The transmission coefficient T is determined.
2. The Monte Carlo method is used to calculate the sun haze intensity I_{sun} taking into account the radiation polarization for calculation directions (35 directions).
3. The Monte-Carlo method is used to calculate the integral point spread function (PSF) at the points of the calculation grid for the receiver zenith angles of 0, 15, …, 60°; the approximation constants A, N are calculated by the LSM.
4. The side illumination radius $R_{surf,\,i}$ is calculated from formulas presented in [1]. For each of the i isoplanar zones, its own PSF $h_i(r_w, \varphi_w)$ of the channel of forming side illumination is calculated for $R_{surf,\,i}$ (here (r_w, φ_w) are the polar surface coordinates).
5. The coefficients of the system of linear algebraic equations (SLAE) from [1] are calculated to determine the luminosity Q of the Earth surface.
6. The Monte Carlo method is used to calculate the Earth surface illumination E_0 without re-reflections
7. The radius R_1 of the zone of forming additional illumination by reflected radiation is calculated from formulas presented in [1]. The Monte Carlo method is used to calculate the PSF $h_1(r_w)$ of the channel of forming additional illumination due to re-reflections within the radius R_1.
8. The coefficients of the nonlinear system of equations are calculated [1]. The solution of this system is the distribution of the reflection coefficient r_{surf} over the observation area.

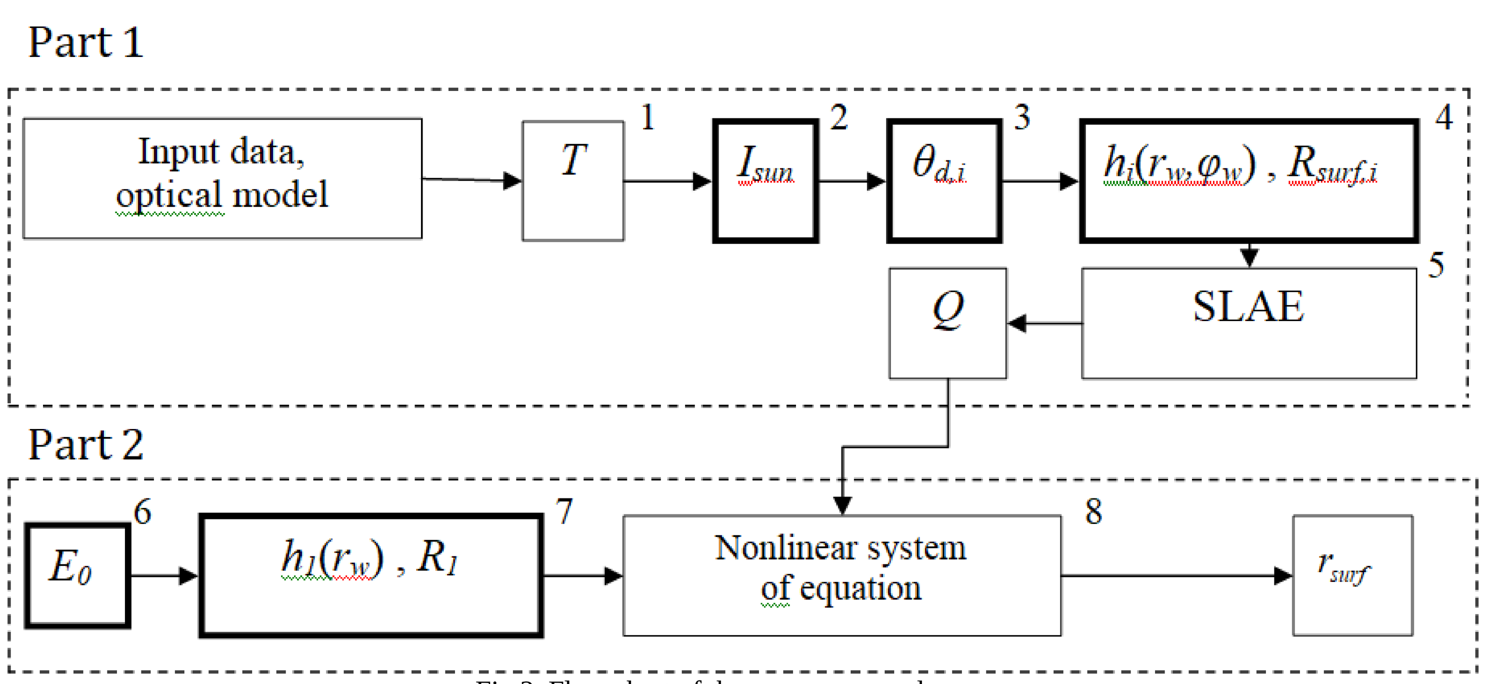

Fig 2. Flow chart of the program complex

3. SOME PREVIOUS FINDINGS

1. According to the results obtained [2], for weakly reflecting surfaces (r_{surf} = 0.1), the error Δr_{surf} caused by the neglect of polarization for a transparent atmosphere with the meteorological range of visibility S_M = 50 km was in the limits $-0.03 \le \Delta r_{surf} \le 0.02$, and for S_M = 10 km it was in the limits $-0.14 \le \Delta r_{surf} \le 0.07$.

2. The complex behavior of the error in determining Δr_{surf} as a function of the mutual position of the Sun and the receiving system is observed. Our analysis [3] of the reasons for this behavior has demonstrated that the error and its functional behavior are largely determined by the factor I_{sun}.

4. RESULTS OF NUMERICAL CALCULATIONS

To approbate the refined algorithm, two areas were considered, in the south of the Tomsk Region and in Moscow Region.

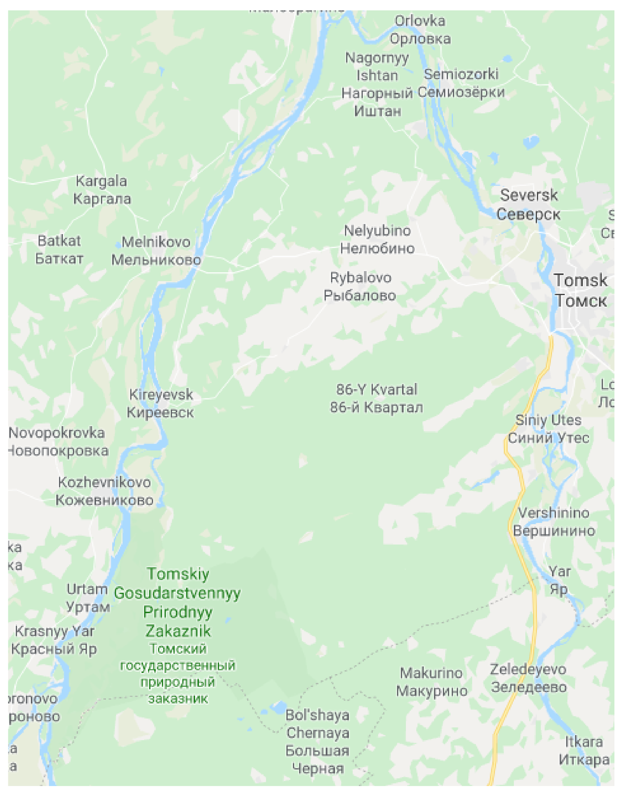

Fig. 3. Examined area in the south of the Tomsk Region

The first test area was located in the south of the Tomsk Region and had coordinates 55.95°–56.85°N and 84.05° –84.95°E (Figure 3). 7 series of images of the MODIS device registered since 17/06/2012 till 23/06/2012 in five channels Nos. 1 (0.645 μm), 2 (0.860 μm), 3 (0.469 μm), 4 (0.555 μm), and 8 (0.412 μm) with spatial resolution of 1000 m were processed. The AOD was determined from the data of the AERONET Tomsk-22 Station (56.417°N, 84.074°E) [4]. The model of the atmosphere was determined using the algorithm described above.

In the test area, the point was chosen located in the territory of the Tomskiy Gosudarstvennyy Prirodnyy Zakaznik. The reflection coefficients for this point, obtained by the suggested algorithms with and without allowance for the radiation polarization, the algorithm without correction and the MOD09 algorithm were compared with the results of ground-based measurements from [5] for young needles of a mature pine in summer taken as reference ones. For each channel and 7 days under study, the average deviations from the reference values were determined. The results are shown in Figure 4.

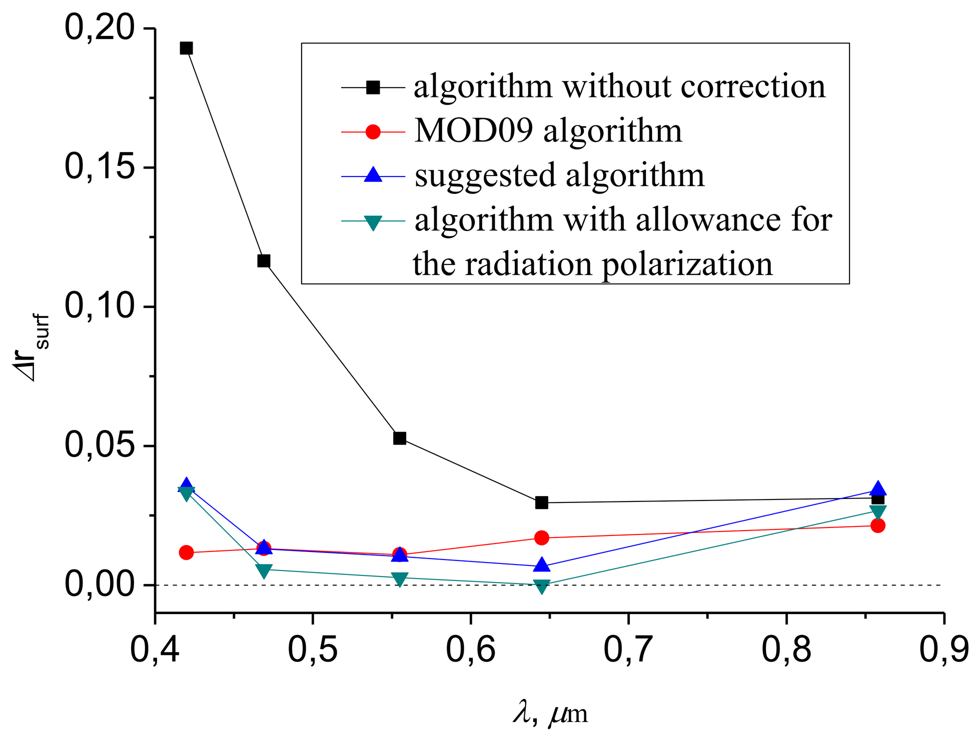

Fig. 4. Comparison of deviations of the results of reconstruction of the reflection coefficients from their reference values averaged over 7 images

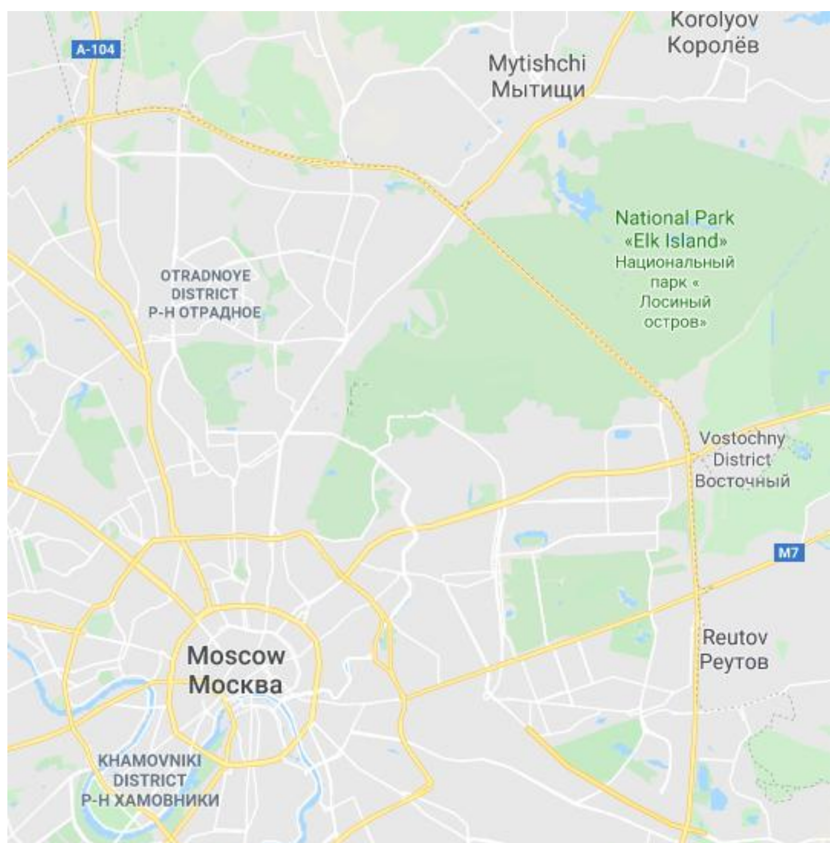

Fig. 5. Test area near Moscow

The second test area was located in the Northeast region of Moscow with coordinates 55.72°–55.95°N and 37.56°–38.10° E (Figure 5). Images recorded since 06/05/2017 till 07/05/2017 were processed.

The atmospheric correction was performed for the same five channels of the MODIS device as for the Tomsk Region. The molecular and aerosol absorption and scattering coefficients were chosen by the algorithm described above. The AERONET Moscow Station has the coordinates 55.707°N, 37.522°E.

In the test area, we have chosen the point situated in the Lociny Ostrov National Park with coordinates 58.85°N, 37.83°E. A comparison of deviations of the results of reconstruction of the reflection coefficients from its reference values at this point averaged over 4 images is shown in Figure 6. The analysis of the result obtained demonstrated that almost complete coincidence of the curves is caused by the low atmospheric turbidity.

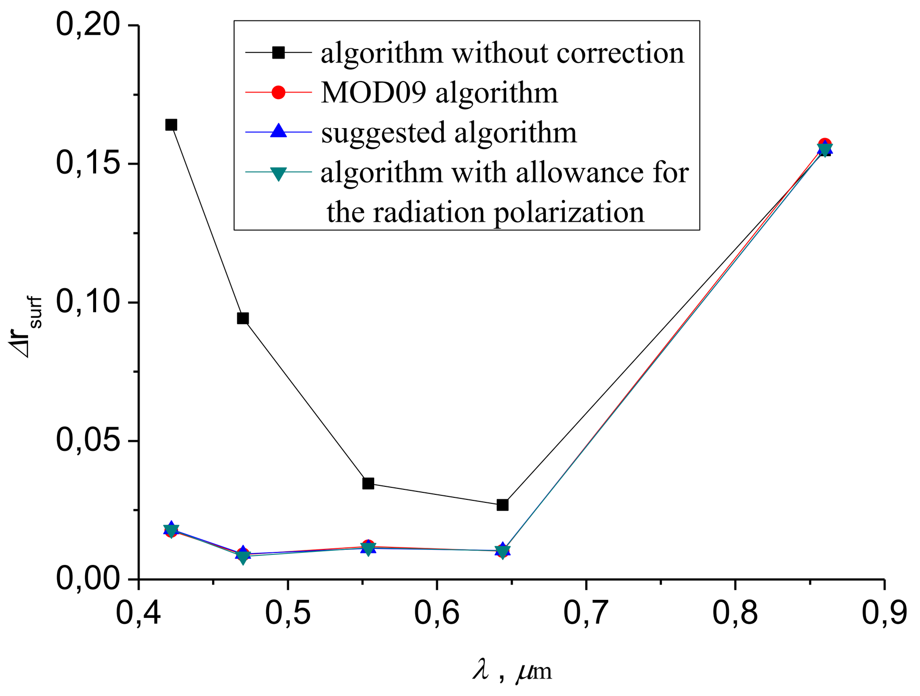

Fig.6

5. SUMMARY

Thus, the approbation of the refined algorithm of atmospheric correction has demonstrated that the allowance for the radiation polarization in the calculation of the sun haze intensity has allowed the error of the reconstruction of the Earth surface reflection coefficient to be reduced considerably

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