Atmospheric Correction Software of Russian Spaceborne Devices data

Vladimir V. Belov, Yury V. Gridnev, Anna V. Zimovaya, Mikhail V. Tarasenkov, Marina V. Engel'

V.E. Zuev Institute of Atmospheric Optics SB RAS, Tomsk, Russia, angel@iao.ru

Abstract. The software has been developed for thematic processing of data of Russian satellite systems. It is based on the algorithm of atmospheric correction developed by IAO SB RAS. The software allows retrieval of the reflection coefficients of the Earth's surface with the RTM atmospheric correction algorithm in the visible and near-IR range on the assumption of a uniform surface. The software includes converters for reading and unpacking input formats of satellite data and related metadata, an atmospheric correction module, and an auxiliary module for formation of the atmospheric model. The atmospheric correction includes procedures for statistical simulation of the Earth's surface illumination and for calculation of the spherical albedo of the atmosphere, intensity of radiation noninteracting with the surface, and intensity of radiation reflected by the surface.

Keywords: satellite data; statistical simulation; atmospheric correction.

1 Introduction

In 2018, the works on development of the software and information support system for data of some devices for remote sensing of the Earth (RSE) installed on satellites of the Russian satellite group has been accomplished in IAO SB RAS. The software serves for retrieval of the reflection coefficients of the Earth's surface in the visible and near-IR ranges from the optical radiation received by the satellites.

One of the ways to solve the problem of atmospheric correction of satellite images of the Earth's surface is the solution of the Radiation Transfer Equation (RTE). In the case of the atmosphere as a multicomponent medium, it is necessary to take into account the mechanisms of radiation absorption and scattering by molecules and atmospheric particles (such as an aerosol, clouds, atmospheric gases, etc.).

The radiation intensity and fluxes forming the signal received by a satellite device are usually calculated with the use of two approaches based on numerical methods. One of them is the DISORT discrete ordinate method used in the well-known computer codes, such as MODTRAN, 6S, Streamer. The DISORT method is mostly used for spectral ranges with prevalent scattering [1, 2]. For ranges with strong atmospheric absorption, the more accurate k-correlation algorithm is applied [3].

Our software is based on the methods for atmospheric correction of satellite images of the Earth's surface developed in IAO SB RAS [4, 5]. The proposed algorithms are based on the Monte Carlo technique as the most versatile method for RTE solution, which imposes practically no restrictions on the geometry of the problem and optical parameters of the atmosphere.

However, for implementation of the methods based on RTE solution, the data on the optical and meteorological state of the atmosphere at the time of satellite measurements should be necessarily available. Other problems to be solved in development of the software for atmospheric correction of satellite images are to determine and obtain the optimal set of the data about the atmosphere, sufficient for calculation of the distorting characteristics of the atmosphere with an acceptable accuracy, and then to form the optical model of the atmosphere based on these data.

2 Algorithmic Basis

The algorithm for atmospheric correction of measurements in the visible and near-IR spectral ranges with the accurate consideration of the lateral illumination and additional illumination of the Earth's surface by the reflected radiation has been developed in IAO SB RAS. Within the scope of this algorithm, the problem of retrieval of the distribution of reflection coefficients over the Earth's surface is solved in the following formulation (Figure 1). The spherical 'atmosphere-surface' system is considered. The atmosphere is believed to consist of spherical homogeneous layers, whose optical parameters are set by the LOWTRAN-7 generator of optical models [6]. The Earth's surface is a Lambertian surface with the unknown distribution of the reflection coefficient over the surface. A passive satellite system is assumed to be at the height h_d from the surface. It is oriented in the direction $\boldsymbol{\omega_d}$ and observes some part of the surface. Let the spatial resolution of an optical receiver forming the image be constant within the observed zone. The parallel flux of solar radiation is incident on the atmospheric top in the direction $\boldsymbol{\omega_{sun}}$. The radiation received by the satellite system consists of the sun haze I_{sun} (solar radiation scattered in the atmosphere and noninteracting with the Earth's surface), nonscattered radiation reflected from the observed part of the Earth's surface I_0, and the surface haze I_{surf} (scattered radiation reflected from the Earth's surface).

With the known atmospheric parameters and intensities measured by the satellite system, the task is to retrieve the distribution of the reflection coefficient over the observed area of the Earth's surface.

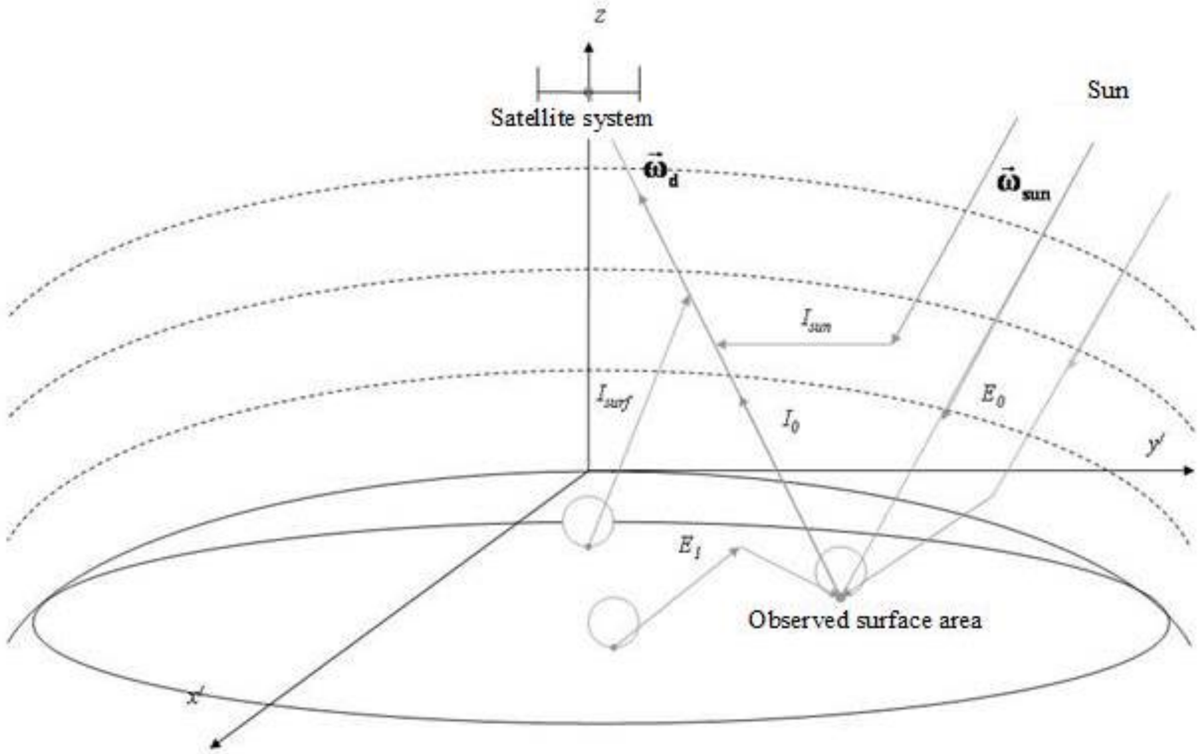

Figure 1. Geometry of problem formulation.

The problem is solved with the theory of linear systems as applied to optics of disperse media [7]. The algorithm is time-expensive, since the computations are performed for every pixel of a satellite image. For faster computations, the following approaches are proposed by the developers of the method:

1. The image is divided into isoplanar zones, within which the point spread function (PSF) can be assumed constant, which allows PSF to be calculated only once for every pixel of an isoplanar zone.
2. The lateral illumination radius is preset.
3. The radius of the zone of formation of additional illumination is preset.
4. The intensity of solar haze is calculated at nodal points in place of calculation for every sighting direction of the satellite system.

The algorithm for atmospheric correction of satellite images of the Earth's surface in the visible and near-IR wavelength ranges allows correct consideration of the following factors:

– Intensity of solar haze;
– Lateral illumination in the image isoplanar zones;
– Additional illumination of the surface by the radiation reflected from it;
– Sphericity of the Earth's surface.

However, in this version of the software, the problem of retrieval of the reflection coefficients is solved in the single approximation with the use of Eqs. (1) and (2)

$$r_{surf,i} = \frac{Q_i/E_0}{1+\gamma_1 Q_i/E_0}, \tag{1}$$

$$\bar{Q}_i = \frac{I_{sum,i} - I_{sun,i}}{\frac{1}{\pi}T_i + I_{dif,i}}, \tag{2}$$

where $r_{surf,i}$ is the Earth's surface reflection coefficient; E_0 is the Earth's surface illumination with the ignored contribution of reflected radiation; γ_1 is the spherical albedo of the atmosphere; $I_{sum,i}$ is the total intensity of received radiation; $I_{sun,i}$ is the intensity of the solar haze; T_i is the direct transmission coefficient from an observed pixel to the receiving system; $I_{dif,i}$ is the intensity of the surface haze at the unit luminosity of the Earth's surface.

3 Model of the Atmosphere

Model data, RSE data, prognostic data, radio balloon data, AERONET network data, and others can be used as information about the optical and meteorological state of the atmosphere at the time of satellite measurements. Among the mentioned types, only RSE data can be obtained in real time and provide the relatively high spatial resolution comparable with the spatial resolution of satellite radiometric channels.

As a result of the studies accomplished in IAO SB RAS, a technique for using the data on the state of the atmosphere from MODIS spectroradiometer measurements in the atmospheric correction of satellite IR images was proposed and justified [8,9]. The combined validation of MODIS data has confirmed the feasibility of their using for atmospheric correction [10-12].

Within the scope of the developed software, the data on optical properties of the atmosphere are saved in the optical model of the atmosphere, which is generated by the specially developed code. The model of the atmosphere is formed for data of every channel of the satellite device and includes the following parameters: solar constant, profiles of aerosol and molecular extinction and scattering coefficients, and scattering phase function for 32 atmospheric layers in the height range from 0 to 100 km. In addition, the model includes instrumental characteristics of the devices.

The MODIS spectroradiometer measurement data are used as a source of information about atmospheric parameters. Data of ground-based measurements can be invoked as an alternative. Basic characteristics for construction of the optical model are the central radiation wavelength λ, width $\Delta\lambda$ and the instrument function of a measurement instrumentation channel, aerosol optical thickness of the atmosphere at λ = 0.47, 0.55, and 0.66 μm, total ozone content, surface pressure, total water vapor column, and vertical temperature profile.

For formation of the models of optical properties of the atmosphere at the observation time (or close time), the software uses the data on solar constants, absorption spectra of O_2, O_3, and H_2O, LOWTRAN-7 aerosol models, total water vapor column, total ozone content, and data on molecular scattering coefficients of the air under normal conditions.

4 Architecture of the Software

The atmospheric correction software can perform the following functions:

1) decoding the data of satellite measurements and related metadata, preparing the data for calculations, saving the calculated results in the standard format;

2) forming the optical model of the atmosphere;

3) calculating radiation fluxes forming the radiation received by the satellite device;

4) performing the atmospheric correction.

The software functions are executed by different modules.

The module of data preparation includes a converter for reading and saving the initial data and calculated results in the GeoTIFF format [13], which is now used most often for storage of measurements of Russian satellite devices and metadata. This format provides for the feasibility of using standard programs for viewing and analyzing calculated results (for example, ENVI). The converter is developed in the GDAL environment [14] and has an interface for the use with Python, C, and Fortran modules. We plan to extend the module functions through addition of codes for conversion of data in other standard formats.

The module for calculation of atmospheric correction additions is a set of Fortran programs. Calculations are performed by the Monte Carlo technique with the algorithms taking into account the atmospheric sphericity [15,16]. In this version of the software, statistical simulation of the surface illumination is carried out, the spherical albedo of the atmosphere, intensity of radiation noninteracting with the surface, and intensity of radiation reflected by the surface are calculated. Atmospheric correction is performed with allowance for the calculated correction additions.

The order of data processing and call of converters and computation modules is set by the Python control module. Our software operates in the Linux operation system. It was developed and tested in the openSUSE leap 42.3 environment. The software operation is shown schematically in Figure 2.

Free software was used as development tools.

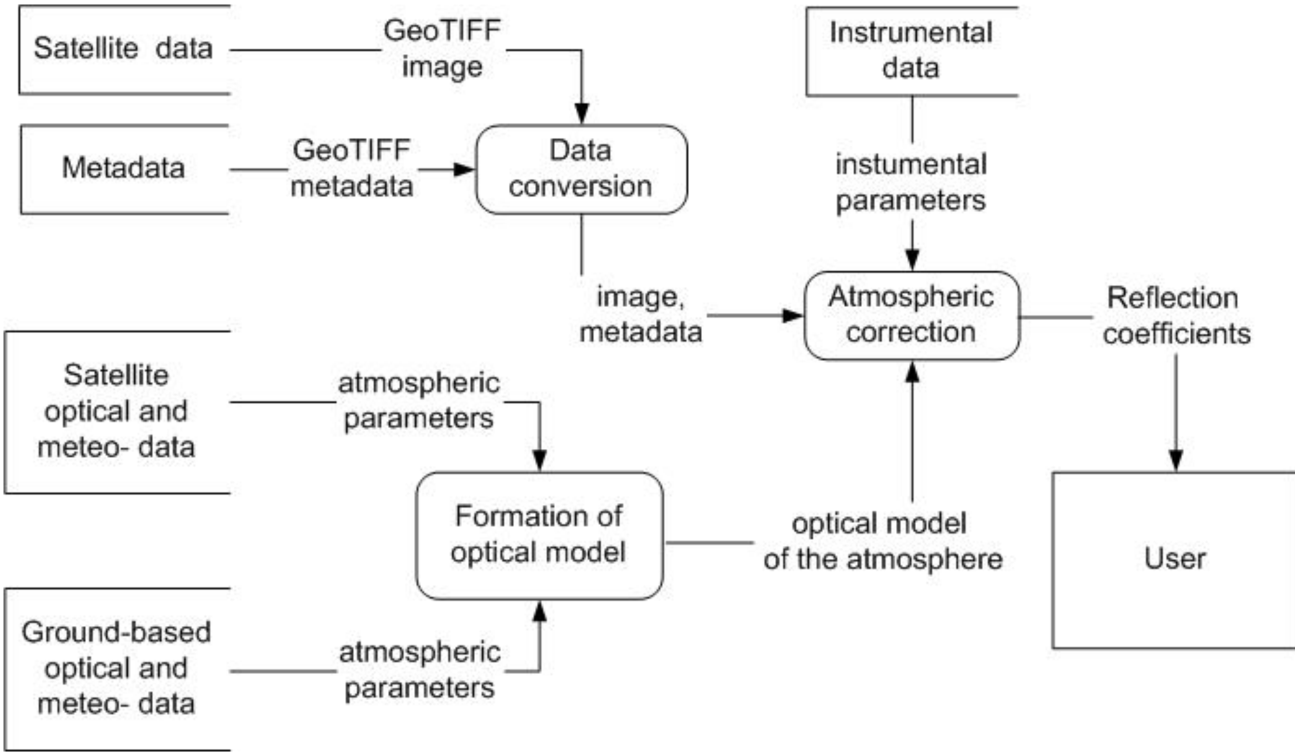

Figure 2. Scheme of the software

5 Conclusions

The software package under consideration serves for retrieval of the reflection coefficients (albedo) of the Earth's surface from satellite measurements of light fluxes by Russian Sangur and GSA devices of the Resurs-P satellite and KMSS of the Meteor-M satellite. In the first version of this software, a separate control module was developed for each device because of insufficient standardization of satellite data and metadata formats.

For the further development of the software for thematic processing of data of Russian satellite devices, we plan

1. To include additional calculation modules providing for calculation of atmospheric correction additions;
2. To increase the computation speed by using parallel programming technologies;
3. To include the generator of optical models of the atmosphere into the software. To use network sources of data necessary for formation of optical models of the atmosphere as a component of the software;
4. To develop the user interface. To complement it with imaging tools and tools for analysis of satellite images;
5. To extend the list of satellite devices, whose data can be processed with the proposed software.

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