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A computing programme for coordinate transformations of vector magnetometer data

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Introduction

The *in situ* measurements of the magnetic field vector with three-component flux-gate magnetometer carried out in the ionospheric-magnetospheric region allow to obtain important information on the electric currents along the field lines of the magnetic field of the Earth, on the ionospheric current systems, and on the main magnetic field and its secular changes. These data are also useful for the solution of other problems — computation of the induced electric field $V\times B$ in reducing electric field measurements representing a portion of complex experiments, in determining the actual orientation, etc.

These problems are resolved with precise measuring magnetometric equipment [1]. Besides, the data processing should also be correct and should facilitate data application in scientific analysis and estimates of the technical state of the measurements during performance and especially during continuous experiments.

Significant advantage of the magnetometric data analysis is the availability of a model of the main Earth magnetic field, and of the field generated in the Earth's interior respectively as, for example, IGRF-1980, GSFC/12/83, etc. This is an important premise for the study of the outer magnetic field, generated by ionospheric-magnetospheric sources [2].

Another premise for this elaboration is the methodics suggested for the coordinate transformations of the magnetometric data provided by a near-earth orbiting satellite [3]. It is assumed that the magnetic disturbances by field-aligned currents in coordinate systems related with an excentric dipole are transformed into two-dimensional, which facilitates their analysis and interpretation.

We can mention, on the other hand, the necessity of connecting the methodics for the determination of the magnetic axes orientation of the sensor with a common software system [4].

The individual aspects of the methodics were specified and supplemented in the process of testing of the developed programmes. The following goals were pursued in obtaining the end software product: reduction of the input-output operations at the expense of increasing the processing rate; decrease of the magnetic tape number; simplification of the usage; analysis of the causes for computer processing interruption, detailed message output on the causes and options of processing continuation from the interruption site.

Description

The general flow chart is shown in Fig. 1. The SEANCE programme is a control module. It drives the modules implementing the individual steps of the technological process. Input data and operation control parameters are supplied to the SEANCE programme. The input data are: magnetic tape with navigational parameters — LGEOGR; magnetic tape with telemetric data — SINP; disc file with correcting co fficients — IYSYSO 5.

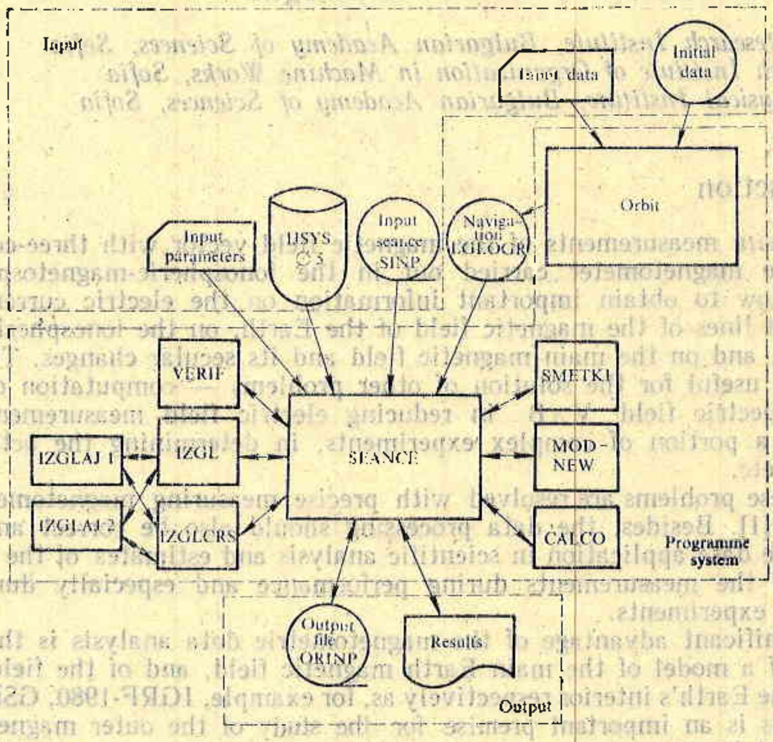

Fig. 1

The following data serve to contiol the software mode of operation with the aid of parametric cards: beginning/end of measurement to ensure processing of determined seance period. If these parameters are not provided, the complete seance is processed and the beginning/end times are taken from the header block of the telemetric information; format flags of the introduced steps (interval steps of the input seance, step of input band with geography and step of output band); module input parameters — MODNEW.

The software output is a tape file, containing the following information: interval number, time, geographic coordinates, measured components, theoretical components, differences between measured and modelled field in different geophysical coordinate systems, geophysical coordinates of observed points, orientation telemetric data (angular velocities and solar situation). Line printer information of step 8 s is printed simultaneously with the formation of the magnetic tape.

The SEANCE software executes the following steps: stores tables (calibration data) into the main memory; reads the header block of the telemetric information and prints it upon selection; reads the parametric cards and initiates its functions in agreement with the data contained in them; transmits control to MODNEW module, which executes the preparatory steps for the magnetic field model application; reads 190 intervals from the telemetric information. They are tested against uncertainties, i. e. against deviations from the smooth change of the compensation step numbers. This is done by VERIF module. If intervals are reliable we proceed to "smoothing" the telemetric information in order to eliminate deviations at the reswitching of steps. For the purpose, IZGL and IZGLCRS modules are used, which in turn function via the auxilliary modules IZGLAJ 1 and IZGLAJ 2. They reveal step change instances and determine reliable intervals before and after reswitching. Assuming both smoothly changing process and short intermediate process duration — up to 1 sec, the "smoothing" is made with the aid of a straight line across the already determined reliable intervals. The four modules are loaded in order to process cases, where the reswitching is made within the limits of the 190 intervals available in the main memory.

After completing the above mentioned steps, the control is transferred to SMETKI module, which converts the information into physical paremeters. The SEANCE module combines the 190 intervals read into the main memory with the navigation data. The records are compared after measurement time. A special subroutine maintains comparison time of the measurements. This is formed on the basis of the assumption that the time of each sequential interval is obtained form the time of measurement adding a constant step. If due to certain reason the time of the entering interval differs from the comparison time within the limits of half a step, a correction of time is introduced transposing comparison time into the record obtained. A warning message is issued. In this case it is assumed that the difference is the result of random disturbance during the determination of the time of measurement. In case we obtain a greater difference for a given interval, an error message is printed and SEANCE procedure ceases operation in emergency mode.

The so-called "reference points" are formed during the combination between navigation data and output records depending on the step given as input parameter. These are the output records containing navigation data.

The CALCO module for main earth magnetic field computations (IGRF-1980) is finally included. The field is represented in series by spherical harmonic coefficients. The differences between the measured model field by components and module are also computed. The 190 intervals, combined with navigation data and processed during the former steps, are read as input data. The model of the main magnetic field is computed for the respective geographic coordinates, located at the reference points. A step of 8 s is selected, containing precise number of intervals. The differences between measured and model field for the intermediate points are obtained with linear interpolation of the model values at the reference points. The CALCO module computes the coordinates of the excentric dipole in earth radii units, the coordinates of the north pole of the excentric dipole, the polar angle and the long. in grades. The same module transforms the geographic lat. and height into geocentric supplement to the lat. and a geocentric radius. The model field is computed into topocentric coordinates and is transformed into geodetic (geographic) coordinates. Coordinate transformations of the observation point are made, i. e. from Cartesian geodetic into Cartesian geomagnetic, spherical geomagnetic, Cartesian excentric geomagnetic, spherical excentric geomagnetic, excentric radius and modified excentric lat. As a result of temporal transformations, we obtain the geomagnetic local time and the excentric geomagnetic time. Afterwards, an interpolation between the reference points is made. For each observation point a transformation is made, i. e. the measured field is converted from orbiting into topocentric coordinate system and further into topocentric geomagnetic, topocentric geomagnetic with one axis along the magnetic field, excentric geomagnetic and excentric geomagnetic with one axis along the magnetic field.

Finally the SEANCE module forms the output records of the magnetic tape from the 190 processed intervals. The described cycle of performance is repeated until the input information for the determined period of processing time is exhausted.

The information on the output magnetic tape can be used for the general case of the geophysical analysis. In case no unifold interpretation is possible, an orientation correction is introduced. The determination of the orientation becomes possible with auxilliary software, exploring information form ORINP file. This far, only determination of the sensor axes deviations from nominal position is made using data from the magnetometer. The statistical examination of these results is also used to control the sensor location, that of the magnetic axes respectively, with regard to the physical axes of the object. Further options are foreseen to use the sensors for the angular velocities determination, as well as to provide solar sensor determination of the actual orientation. The orientation correction will be introduced solely for the cases when the processing data cannot be interpreted unifold. ORINP file can be used also for the determination of the orthogonality of the sensor axes. For the purpose, a Fourier series are used for the data of the differences between the theoretical and measured module of the field. This processing is also made after auxilliary software.

The software system is realized in operational medium DOS-ES, excluding the navigation programme, elaborated by Prohorenko into operational medium OS [5].

The requirements to the machine configuration are as follows: main memory 300 kb; disc drives — 2 pc 2314; magnetic tape drives — 3 pc; punched card input; line printer output.

The system exploration has shown it reliable and simple in performance.

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Программа ЭВМ о координатных трансформациях при замерах вектора магнитного поля

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(Резюме)

Исследование продольных токов в ионосферно-магнитосферной области осуществляется на основе трансформации данных, полученных от непосредственных замеров вектора магнитного поля в геофизической координатной системе. С помощью этой программы обрабатываются данные трехкомпонентного магнитометра с автоматическим растяжением диапазона. В качестве входных данных используются географические координаты точек наблюдения и телеметрические данные компонентов, которые задаются в орбитальной координатной системе. Основные операции программы следующие: отбрасывание ложных кадров, преобразование телеметрических данных в физические величины; трансформация измеренного вектора в геофизическую координатную систему, включающую координаты относительно эксцентрического диполя; вычисление разностей между наблюдаемым и модельным полями.

При написании программы осуществлена оптимизация операций вход — выход. Большинство программ, написанных на PL—1, структурировано. Данные читаются большими порциями, что делает программу более удобной для пользования.

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A complex satellite experiment of investigating aerosolic optical properties in the atmosphere

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Aerosols substantially affect the thermal regime of the Earth-atmosphere system by scattering and absorbing large portion of the sun irradiation in all spectral ranges. Therefore, the investigation of the optical properties of the aerosols in the earth atmosphere via satellite systems is of significant importance for the solution of many problems of climatology, meteorology, geospace research, environmental pollution, etc.

This paper considers the possibilities of a satellite radiational experiment providing for determination of the spectral and spatial dependence of the main optical characteristics of the aerosols: coefficient of 'scattering, indicatrix of scattering $\gamma_\lambda(h)$ and optical thickness $\tau_{a\lambda}(h)=\int_h^H \sigma_{a\lambda}(l)\,dl$.

Figure 1 illustrates the block-diagram for the measurements. Let us suppose that the observer is situated at a height H above the Earth surface. It

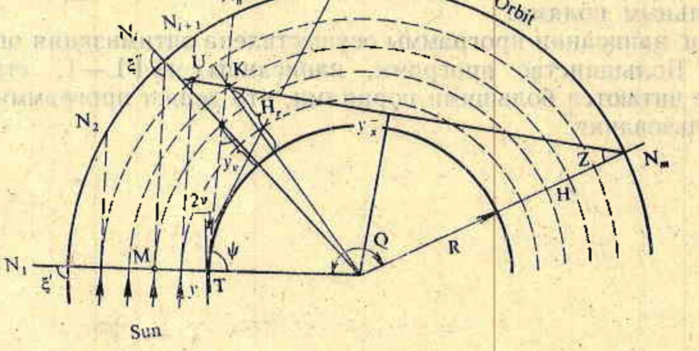

Fig. 1

is assumed that the atmosphere represents a sphere of radius $R_n > R$; (R — Earth radius) and is subdivided into n layers of radii $R_1, \ldots, R_n$ ($R_i = R + \Delta h_i$). We have incident parallel flux of solar irradiation at the outer atmospheric side. In the area of the terminator ($N_1 - N_n$) the experiment includes sequential measurements on the intensity of the scattered irradiation sunward and in nadir, and within the time interval $N_{n+1} = N_m$ when the space vehicle is in the earth shadow — scanning by horizon altitude was made. When the sun is spectrometered through the atmosphere, the intensity is determined by the unifold scattered and weakened by atmosphere irradiation $I_{1\lambda}$ and the intensity of the multifold scattered irradiation $I_{d\lambda}$:

$$(1) \qquad I_\lambda(s, y) = \frac{P_{u\lambda}}{M_y} \{ I_{1\lambda}(s, y) + I_{d\lambda}(s, y) \},$$

where $P_{u\lambda}$ is a hatch transmission function (in observations from an orbiting station). $M(y)$ defines the weakening of the irradiation in the result of refraction divergence [1] at perigee height on the line of sight y, $I_{s\lambda}$ is the intensity of the solar irradiation outside the atmosphere for the spectral range of registration $\Delta\lambda$. Based on the transmission theory,

$$I_{1\lambda} = I_{s\lambda}\, e^{-2m_\xi \int\limits_y^H \sigma_\lambda(l)\, dl} P_\lambda(y, s),$$

$$I_{d\lambda}(s, y) = \int\limits_y^H e^{-(\tau_\lambda - \tau_{1\lambda}) m_\xi} \cdot \sigma_\lambda \frac{(h)}{4\pi} \cdot \int\limits_{4\pi} p_\lambda(s, s'; h)\, I'_\lambda(s, s'; h) P_\lambda(s, h)\, d\omega\, m_\xi\, dh,$$

where $\tau_\gamma = \int\limits_y^H \sigma_\lambda(l)\, dl$, $\tau_{1\lambda} = \int\limits_h^H \sigma_\lambda(l)\, dl$, $p_\lambda(s, s'; h)$ is a scattering function, $s(\xi, A)$ determines the direction of sight, ξ and A are zenith and azimuthal solar angles, $I'_\lambda(s, s'; h)$ is the intensity of a light flux, propagating at height h for direction s, $P_\lambda(s, y)$ is an absorption function of atmospheric gases into the investigated spectral range, $\sigma_\lambda(h)$ is a scatter cross-section, $\sigma_\lambda(h) = \sigma_{a\lambda}(h) + \sigma_{R\lambda}(h)$, $\sigma_{a\lambda}(h)$, $\sigma_{R\lambda}(h)$, are coefficients of aerosolic and Rayleigh scatter, m_ξ is an air mass. In a random point M of the terminator area, the solar irradiation intensity is determined with the expression:

$$(2) \qquad I'_\lambda(s, h) = I_{s\lambda}\, e^{-m_{\xi_T} \int\limits_h^{-\infty} \sigma_\lambda(l)\, dl} P_\lambda(\xi_T, h).$$

In an elementary volume dV, including point M, there occurs irradiation scatter in all directions, as well as towards the observer. Along the path from the scattering point to the observer, the intensity of the light flux varies in the result of the scatter processes due to molecules and aerosolic particles and to absorption from atmospheric gases into the MN layer. For the intensity in point N_n within the terminator area we obtain:

$$(3) \qquad I_\lambda(H) = \int\limits_0^H I'_\lambda(h) e^{-\tau_\lambda(h)} P_\lambda(h) \sigma_\lambda(\xi_T, h)\, dh,$$

where $\sigma_\lambda(\xi_T, h)$ is a volumetric angular coefficient of scattering at height h.

At the moment N_i the intensity registered in nadir is determined by the intensity of the solar irradiation, weakened in the layer (y_v, H) as the lower atmospheric layers are not illuminated by the sun and do not contribute to the scattering of the direct solar irradiation. Similar to (3), we obtain for the intensity in point N_i:

$$I_\lambda(y_v) = \int_{y_v}^{H} I''_\lambda(h) e^{-\int_h^H \sigma_\lambda(l)\,dl} P_\lambda(h) \sigma_\lambda(\omega, h)\, dh, \tag{4}$$

where y_v is determined by the crossing point of the line of sight with a solar beam with perigee $y=0$ km, $y_v = \frac{R \sin\psi}{\sin\varepsilon} - R$, ω is the angle of scatter; $\psi = 90 - 2v$, v — angle of refraction.

$$I''_\lambda(\varepsilon, h) = \frac{I'_\lambda(h_1)}{M(h)} e^{-m_\varepsilon \tau_{5\lambda}(h)} P_\lambda(\varepsilon, h) + I_{d\lambda}(\varepsilon, y_v), \quad h_1 = h - y_v, \quad \tau_\lambda = \int_{h_1}^{y_v} \sigma_\lambda(l)\, dl. \tag{5}$$

The light scattered into the atmosphere becomes the main source of light after sunset, when the atmosphere is illuminated by the beams of the sunset. In addition, the lower atmospheric layers situated in the earth shadow are not illuminated by the sun and are not incorporated into the scatter from the direct solar irradiation. During the scanning at the horizon height (N_{n+1}, N_m), the observer is to be found into the planet shadow and the line of sight is located at the altitude y_x above the Earth surface and in point K at altitude H_r enters the sun-illuminated area. Based on the theory of transmission, following the propagation and scatter of irradiation along the beam path up to a random point U and into the direction of the line of sight KN, we obtain for the registred intensity at scanning by the horizon height:

$$I^{V}_\lambda(s, y_x) = P_{u\lambda} I^{IV}(s, y_x) e^{-m_z \tau_{6\lambda}} P_\lambda(s, h) + \int_{y_x}^{H} e^{-(\tau_{6\lambda} - \tau'_{6\lambda}) m_z} \frac{\sigma_\lambda(h')}{4\pi} \cdot \int_{4\pi} p(s, s'; h') I'^{IV}_\lambda(s, s'; h')\, d\omega \sec z\, dh', \tag{6}$$

where $\tau_{6\lambda} = \int_{y_x}^{H} \sigma_\lambda(l) dl$, $\tau'_{6\lambda} = \int_h^H \sigma_\lambda(l)\, dl$, $I_\lambda(s, h)$ is the intensity in the perigee of the line of sight y_x.

$$I^{IV}_\lambda(s, y_x) = I^{III}_\lambda(s, H_r) e^{-m_\gamma \tau_{5\lambda}} P_\lambda(s, y_x) + \int_{y_x}^{H_r} e^{-m_\gamma(\tau_{5\lambda} - \tau'_{5\lambda})} \frac{\sigma_\lambda(h)}{4\pi} \int_{4\pi} p(s, s', h) \cdot I'^{III}_\lambda(s, s', h)\, d\omega \sec\gamma\, dh, \tag{7}$$

$\tau_{5\lambda} = \int_{y_x}^{H_r} \sigma_\lambda(l)\, dl$, $\tau'_{5\lambda} = \int_h^{H_r} \sigma_\lambda(l)\, dl$, $I^{III}_\lambda(s, H_r)$ is the intensity in point K, determined as a sum of all the elements into direction KN.

$$(8)\qquad I_{\lambda}^{\mathrm{III}}(s, H_r)=\int_{H_r}^{\infty} I_{\lambda}^{\mathrm{VI}}(s, h)e^{-m_{\gamma}\tau_{3\lambda}}p_{\lambda}(\gamma, h)\,\sigma_{\lambda}(\eta, h)\,dh,$$

$\tau_{3\lambda}=\int_{H_r}^{h}\sigma(l)\,dt$, $I_{\lambda}^{\mathrm{VI}}(s, h)$ — irradiation intensity at random point U.

$$(9)\qquad I_{\lambda}^{\mathrm{VI}}(s, h)=\frac{I_{\lambda s}}{M(h)}e^{-m_{\xi''}\tau_{2\lambda}}P_{\lambda}(\xi'', y)+\int_{y}^{h}e^{-\sec\xi''(\tau_{2\lambda}-\tau'_{2\lambda})}\frac{\sigma_{\lambda}(h')}{M(h')\,4\pi}\int_{4\pi}p(s, s'; h')$$

$$.\,I'_{\lambda}(s, s', h')\,d\omega\sec\xi''\,dh',$$

$\tau_{2\lambda}=\int_{y}^{h}\sigma_{\lambda}(l)\,dl$, $\tau'_{2\lambda}=\int_{y}^{h'}\sigma_{\lambda}(l)\,dl$, η — angle of scatter, $\cos\eta=\cos\varepsilon\,.\cos\gamma+\sin\varepsilon$ $.\sin\gamma\cos A$.

Equations (1), (3), (4), (6) are basic equations of transmission into the complex radiational experiment including spectrometry of direct solar irradiation, nadire measurements into the terminator area and scanning of the horizon. They represent sophisticated functional dependences of the measured intensities of the scattered solar irradiation due to the atmosphere optical properties, namely to layers where it propagates. Initially, the spectral, vertical and spatial dependence of $\sigma_{a\lambda}(h)$ is determined in unifold scatter approximation. It is assumed that in each sublayer of the atmosphere the aerosolic scatter coefficient is presented by exponential approximation $\sigma_{a\lambda}(y_i)=\sigma_{a\lambda}(y_{i-1})\,e^{-\beta h}$, which is effective at high resolution of the experiment by altitude. We obtain for the optical thickness in the i th sublayer:

$$(10)\qquad \Delta\tau_{a\lambda}(y_i)=\frac{\sigma_a(y_{i-1})\,(e^{-\beta_i y_{i-1}}-e^{-\beta_i y_i})}{\beta_i}.$$

But for the case of single scattering with regard to the registred direct solar irradiation in two subsequent moments N_i and N_{i-1}, we obtain for $\Delta\tau_a(y_i)$:

$$(11)\qquad \Delta\tau_{ai}=\frac{1}{2m_{\xi}}\ln\frac{I_{\lambda}(s_i, y_i)M(y_i)\,P_{\lambda}(y_{i-1})}{I_{\lambda}(s_i, y_{i-1})M(y_{i-1})P_{\lambda}(y_i)}-\int_{y_{i-1}}^{y_i}\sigma_{R\lambda}(y_{i-1})e^{-\alpha h}\,dh.$$

Hence, for the aerosolic scatter coefficient in i layer we define:

$$(12)\qquad \sigma_{a\lambda}(y_{i-1})=\frac{\Delta\tau_{a\lambda_i}\,\beta_i}{e^{-\beta_i y_{i-1}}-e^{-\beta_i y_i}}.$$

The relationship between $\sigma_{a\lambda}(y_{i-1})$ and $\sigma_{a\lambda}(y_{i-2})$ is given with:

$$(13)\qquad \sigma_{a\lambda}(y_{i-1})=\sigma_{a\lambda}(y_{i-2})\,e^{-\beta_{i-1}y_{i-1}}.$$

For the last layer (where we may assume lack of powerful aerosolic layers) $\beta_n=1/H_0$, H_0 is the height of the isothermal atmosphere. For the other layers β_i is determined by (1). The method provides for high-accuracy definition of $\sigma_{a\lambda}(h)$ into the upper atmospheric layers, where the contribution of the multifold scatter is insignificant also for spectral range, distinguished by lack of absorption from molecules of gas with variable density (O_3, H_2O). The altitudinal adjustment of the spectrometric record when scanning the horizon is made by comparing the ratio between the atmospheric transmission

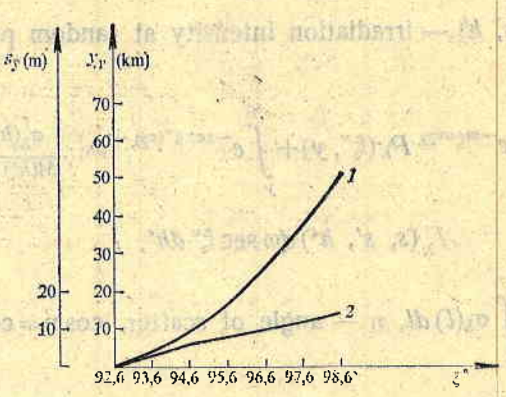

Fig. 2. Variation at the height of sight and the resolution in altitude in dependence on the fast performance, equipment sensibility and solar zenith angle. *1* — y_v; *2* — s_y

function in the i th layer and that at $y_x = y_{\min}$ in the spectral range 0.76 μm and the ratio of the registred intensities within the same spectral range [2]. The method allows for precise altitudinal adjustment, since the transmission function of the oxygen is computed with high accuracy. It is necessary to make complex measurements in the optical and near IR ranges, as well as of the natural irradiation in the radio range for the spectral ranges specified with water vapour absorption. This allows to determine the integral water content required for the computations of the transmission function in the studied atmospheric layer.

The altitudinal resolution at nadir measurements in the terminator area depends on the fast performance and the sensitivity of the measuring equipment. Figure 2 shows the variation at the height of sight y_x and the resolution in altitude $s_{y_i} = y_{v_i} - y_{v_{i-1}}$ in dependence on the fast performance, the measurement equipment sensitivity and the zenith angle ξ of the sun. From the ratio of the registered intensity in two sequential moments for the optical thickness in the layer y_{v_i}, $y_{v_{i+1}}$ we obtain:

$$\Delta\tau_{a\lambda_i} = \frac{1}{m_\xi - 1} \ln \frac{I_{i\lambda} \int_{y_i}^{y_{i+1}} P_\lambda(\varepsilon, l)\, dl}{I_{i+1,\lambda} \int_{y_i}^{y_{i+1}} P_\lambda(l)\, dl} - \int_{y_i}^{y_{i+1}} \sigma_{R_\lambda}(l)\, dl. \tag{14}$$

The coefficient of the aerosolic scattering $\sigma_{a\lambda}(h)$ and β_i are computed on the basis of dependencies similar to (10)-(13).

The values obtained for the spatial and vertical dependencies of $\sigma^0_{a\lambda}(h)$ are used as input values for the solution of the transmission equations (1), (3), (4), (6) by the Monte Carlo simulating modelling method. The determined values of the spectral and vertical dependencies of $\sigma_{a\lambda}(h)$ are obtained by minimization of the functional:

$$\sum_{i=1}^{m} (\widetilde{I}_{i\lambda} - I^k_{i\lambda}(\sigma^k_{a\lambda}(h)))^2 = \delta, \tag{15}$$

where $\widetilde{I}_{i\lambda}$ is the measured value in point $i(s_i, y_i)$, $I^k_{i\lambda}$ the value obtained for the intensity in the numerical modelling of the respective equation of transmission after the Monte Carlo method, where $\sigma^k_{a\lambda}(h)$ varies according a determined law, $\sigma^k_{o\lambda}(h) = \sigma^{k-1}_{a\lambda}(h) - f(\delta)$, k — number of iteration.

The proposed radiation experiment is partially realized aboard the SALYUT-6 [4] orbiting station, while the complex version between visible, near IR and radio ranges was made aboard METEOR-PRIRODA within the BULGARIA-1300-II project [3].

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Комплексный спутниковый эксперимент по исследованию оптических свойств аэрозоля в атмосфере

В. Д. Петрова

(Резюме)

Рассмотрены возможности спутникового радиационного эксперимента, позволяющего определить спектральный и пространственный ход основных оптических характеристик аэрозоля: коэффициент рассеяния, индикатриса рассеяния и оптическая толщина.

Предложенный эксперимент частично реализован на станции „Салют — 6“, причем комплексирование видимого, ближнего ИК и радиодиапазона сделано на ИСЗ „Метеор — Природа“ по проекту „Болгария — 1300“.