Information system for processing, analysis, and storage of the data of optical measurements in the stratosphere

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The purpose, structure, and principles of the information system for processing, analysis, and storage of the data of optical measurements in the stratosphere are considered. The system is still under development and is intended for revealing the processes and regularities connected with the ozone and ozone layer in the stratosphere. Various data are used for analysis and processing: the lidar sounding data (altitude distributions of the ozone, temperature, and aerosol scattering ratio), the passive sounding data (total ozone content, distribution and total content of nitrogen dioxide), as well as different model data. We present a functional block diagram of the system and consider the interrelations of the composing subsystems. The operation algorithm and the interface of the system are described. The prospects of development and further improvement of the system are considered including the use of the World Wide Web.

Introduction

The change of climate on the planet attracts an increasing attention to the study of climate formation factors. The investigations carried out in recent years have shown that the stratosphere gives a considerable contribution to the climate processes. The change of gas composition and aerosol overburden of the stratosphere lead, in the final result, to climate changes. Regardless of the investigations lasting for many years, the problem on interaction and behavior of different components of the stratosphere remains in the focus. To solve this problem, it is necessary to use new highly accurate measurements, perfect mathematical methods and algorithms, as well as to create information systems and databases.

Vast experimental material has been compiled at the Siberian lidar station of the IAO (which is the only one to the east of Ural) by use of both active and passive sounding techniques in recent years. The measurement data obtained by laser sensing methods (tropospheric and stratospheric profiles of the ozone, temperature, and aerosol scattering ratio at several wavelengths[1]) in combination with the data of passive methods (the total content of O_3 and NO_3 and profiles of NO_2) allow the new regularities in the evolution of various atmospheric processes over Tomsk to be revealed.

The study of altitude distribution and dynamics of the atmospheric aerosol, temperature, and gas composition (O_3 and NO_2) is important in solving a number of problems connected with the effects of these components on the radiation transfer, photochemical processes, and others. At the same time, the effect of some atmospheric processes (for example, synoptic processes) on these components can also be studied.

In this connection, we have started the development of an information system (IS). The system will allow us to accumulate, process, and analyze various experimental information (the data of laser and passive sounding, profiles of gas components and their total content, values of meteorological parameters in the near-ground layer, and others) in order to reveal temporal and spatial regularities in the behavior of the stratospheric components studied.

Description of the information system

The necessity to create an IS containing different experimental data (temperature, aerosol, and gas components of the atmosphere) and other various parameters (temperature of the near-ground layer and temperature profile, total ozone content (TOC), ozone in the near-ground layer and ozone profile, and others) is caused by complicated interrelations of these parameters in the atmosphere.[2–4]

In developing such an IS, the following aims were stated: 1) developing the IS with a suitable and easy-to-use (friendly) interface; 2) filling the IS with modern and traditional techniques of experimental data processing and methods of analysis (Fourier analysis, statistical, spatiotemporal statistical, and correlation analysis) of both measured and "processed" data (ozone profiles, temperature and aerosol scattering ratio, and the total content of ozone and nitrogen dioxide); 3) creating archives of experimental and "processed" data for their joint use in solving the problems in geophysics; 4) creating a versatile IS in order to solve a sufficiently wide range of both the inverse problems and problems in the geophysical analysis; 5) providing for an easy and fast access to different experimental and "processed" data.

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The block diagram of the IS (Fig. 1) consists of the following computer codes: 1) the "Calendar" program for search and retrievals from the database of measured or processed values for their subsequent use; 2) the database; 3) the program for processing the retrieved information; 4) the program for the statistical analysis of data; 5) the programs for making up reports and printing them out.

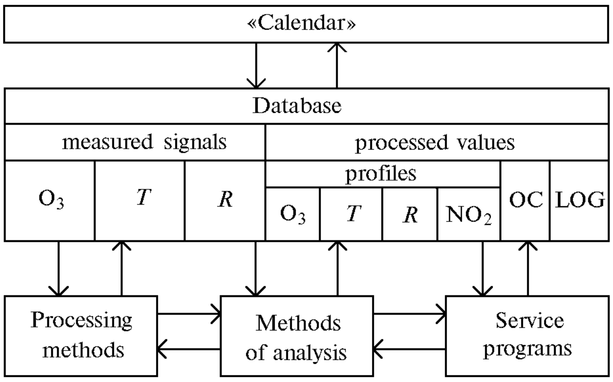

Fig. 1. Block diagram of the information system.

The programs of the IS, which realize the diagnostics of performed operations and calculations, allow one to localize and interpret the errors in operations or calculations for their timely detection and removal.

Let us consider a functions of every block of the IS and their interaction. The "*Calendar*" *program* is the program of read and write operations and control over the information flows on the path from the database to the "active" block (the block whose programs may be called for by a user). The present IS version contains a simple and clear structure of storage of the information (*the database*) on the "processed" data on the profiles of ozone, temperature, aerosol scattering ratio, measured signals from the ozone, temperature, and aerosol. The data on processing the parameters are stored in the files of the block "LOG". It allows one to browse profiles and other results, as well as the information on the methods and parameters used in calculating these data. In the block "TC" the information on the total content of gas components of the atmosphere (total content of ozone in the stratosphere from lidar data or data of an M–124 photometer, and the total content of NO_2 obtained from interpretation of the data on sky brightness at zenith) is stored.

The next, by its importance, block is the *block of lidar signal processing* yielding the profiles of ozone, temperature, and aerosol scattering ratio.

Consider some parts of the experimental data processing block in a more detail. Determination of the ozone profile from the lidar echoes obtained with a differential absorption lidar reduces to the problem of differentiating the function $f(z)$ (Ref. 5):

$$f(z) = \frac{1}{2} \ln \frac{U_{\rm off} - U^{\rm b}_{\rm off}}{U_{\rm on} - U^{\rm b}_{\rm on}} + \psi(z); \qquad (1)$$

$$\psi(z) = \frac{1}{2} \ln \frac{\beta_{\rm on}(z)}{\beta_{\rm off}(z)} - [\tau_{\rm on}(z) - \tau_{\rm off}(z)], \qquad (2)$$

where $U_{\rm off}(z)$ and $U_{\rm on}(z)$ are the echo signals recorded from the height z at the wavelengths $\lambda_{\rm on}$ and $\lambda_{\rm off}$; $\beta_{\rm on}(z)$ and $\beta_{\rm off}(z)$ are the backscattering coefficients at the wavelengths $\lambda_{\rm on}$ and $\lambda_{\rm off}$ (in our case these are 308 and 353 nm); $\tau_{\rm on}(z)$ and $\tau_{\rm off}(z)$ are the optical thickness of the atmosphere due to molecular scattering, aerosol extinction, and interfering gases (SO_2 and NO_2); $U^{\rm b}_{\rm off}(z)$ and $U^{\rm b}_{\rm on}(z)$ are the signals due to the background noise.

The function $\psi(z)$ in Eq. (2) must be determined from an independent experiment or taken from model representations. The concentration of ozone is determined from the equation

$$\rho(z) = [1/2K(z, T)]\ t\ (z), \qquad (3)$$

where $t\ (z)$ is the regularized analog of the derivative $f'(z)$ of the function $f(z)$; $K(z, T) = K_{\rm on}(z) - K_{\rm off}(z)$ is the differential cross section of the absorption by O_3; T is the temperature.

To decrease the finite error in the processed echo signals, the procedure of "compression" of signals[5] is provided in the program. This procedure implies an increase in the lidar altitude strobe by summing up readouts from adjacent (by the height) strobes and finding an average after that. The decrease of fluctuations of a lidar signal at large heights is attained by this procedure.

For analysis and processing of echo signals, the problems concerning the distortions of signals in the photodetector of a lidar operated in the photon counting mode[7–10] and molecular aerosol correction of signals arise. To solve these problems, it is necessary to know the profiles of aerosol ($\alpha_{\rm a}$, $\beta^{\rm a}_{\pi}$) and molecular scattering coefficients ($\alpha_{\rm m}$, $\beta^{\rm m}_{\pi}$), which are calculated either based on the model profiles of temperature and preasure[11–13] or on the experimental profiles and solution of the inverse problem (it is known that the problem of differentiation of the empirical functions is an ill-posed problem[14]).

At present, to solve the problem of differentiating function (1), different methods are used. A comparison of three methods can be found in Ref. 6: the method of spline functions, regularization method, and method of optimal parameterization. It is shown that at present most acceptable, from these three methods, is the method of spline functions. In the IS developed we use the method of spline functions realized in the Spline software package.[15]

Next, among the methods of lidar signal processing, we select the method of reconstruction of the aerosol scattering ratio, which is the basic characteristics in describing vertical distribution of the atmospheric aerosol. Reconstruction of the aerosol vertical stratification (using the aerosol scattering ratio)

$$R(h) = [\beta_m(h) + \beta_a(h)]/\beta_m(h) \quad (4)$$

is carried out within the framework of a single-wavelength sounding technique most often used in practice (at the wavelength of 353 nm) with calibration of a signal against the molecular scattering.[16,17]

The laser method of acquiring temperature data is based on the use of molecular light scattering. In the absence of the effects of resonance scattering and at low concentration of aerosols in the atmosphere, the backscattering coefficient $\beta_m \gg \beta_a$ and the echo signal is simply related to the molecular scattering coefficient α_m, which, in its turn, is proportional to the density of the atmosphere. The air temperature is calculated by use of the hydrostatics equation and the equation of state based on the data of the air density of the atmosphere. Solution of the lidar equation for the molecular scattering coefficient is found neglecting the aerosol scattering; the general form of the solution is given in Ref. 18.

The following block "*programs of statistical analysis*" is intended for revealing the geophysical regularities in the atmospheric processes of interaction of different components (gases and aerosol) with ozone. To reveal these regularities, it is necessary to calculate, using statistical methods, the time dependence of TOC and to follow up its relation to the aerosol load of the atmosphere, the height of the ozone profile maximum, temperature stratification, and others.[19–21]

Revealing of the regularities in the ozone distribution with height, search of trends and cycles of change of the distribution parameters must answer the questions on the dynamics of the profiles of ozone and others components of the atmosphere. It is possible to study the interrelations between the meteorological parameters in the near-ground layer and the parameters of the ozone or temperature profile.

The block of methods for analysis allows one to construct average profiles and altitude matrices of covariance between physical parameters of the atmosphere too. This information, in its turn, can be then used in processing of different experimental data using methods of statistical (optimal) parameterization.[6]

The last block "*service programs*" is intended for visualization of the measurement data and results of processing and analysis in the form of a table or plot. The mode of "report" formation is provided for suitable representation of calculations and analysis.

Description of the software

The first, or initial, cycle of the program includes the following stages:

1) selection of objects for processing (files with the data of a certain sounding session); 2) processing of objects in the off-line mode with the default parameters of the configuration file, for example, the parameters of compression, differentiation, and smoothing; 3) the presentation of the obtained results in a graphic or table form.

Thus, the user selects, from "Calendar", the files for the days when the sounding sessions were carried out and confirms the choice, and the program performs Steps 2 and 3. When Step 3 is completed, the altitude profiles of the ozone concentration are plotted on the screen. Then, the user can choose viewing the values of the optical thickness and model profile, plotting isolines, changing the processing parameters, and adding (removing) the objects. When the processing parameters are changed, the program recalculates the data and presents them on the graphic element that is a chart (chart-scheme). Thus, a direct effect of that or another calculation parameters on the final result is clearly demonstrated. After every iteration the user can save the obtained results or load the results saved earlier for comparison and further processing. The basic work panel of the system is shown in Fig. 2.

Originally, the development of the system was planned using Microsoft Visual ”asic 4.0. ”ut during the development of the system, disadvantages of this language became clear: non-optimal code created and the absence of sufficient built-in facilities to work with the Internet. Therefore, we decided to use Microsoft Visual ”asic 5.0 in late 1997. To this moment the conceptual development of the system has been finished. At present the system is developed on the object-oriented base. In particular, an object is a set of data, methods, and parameters relating only to one file (session) of initial data.

All processing procedures are contained in dynamically loaded libraries, what simplifies considerably their change when finalizing the operation development and debugging a package at the usage stage. The object of data enters the procedures as a parameter. The retrieval of data for processing is simplified considerably due to capabilities of the object-oriented programming.

The processing procedure retrieves necessary data and parameters from an object and applies corresponding operations to them. The obtained results are recorded in the data area of an object which are assigned for this purpose. The out parameter appears also as a returned input parameter and, being an object in the sense of the object-oriented programming, contains also a technique for validating correctness of the recorded data.

After completion of operations with an object at the level of processing methods and algorithms, the object enters the subsystem of graphic display of data. Here plots are constructed for every object on the graphic elements.

At present, debugging and checkout of the existing set of data processing methods are carried out.

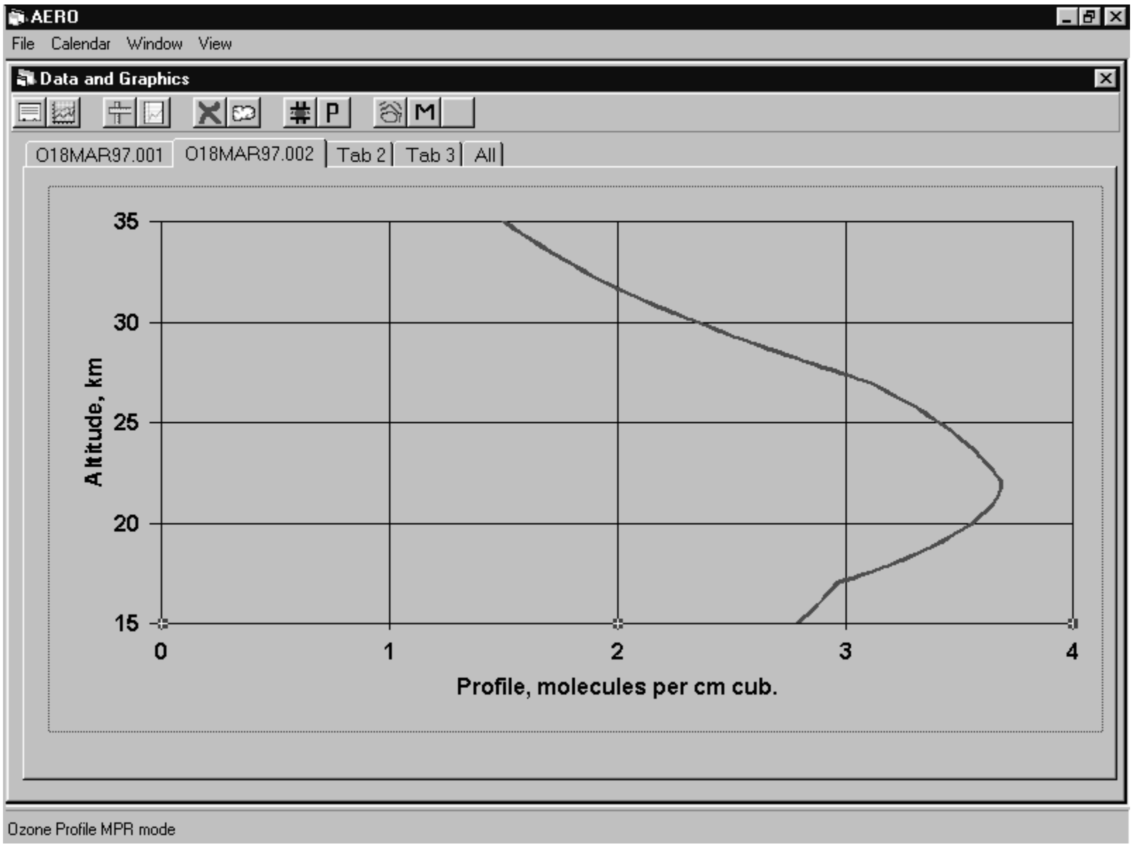

Fig. 2. Basic panel of the system. Ozone concentration profile.

In the future it is planned to extend the capabilities of the system by incorporating statistical correlation analysis, graphic representation, comparison with other gases and data obtained from other sources.

Since the problem of global monitoring of the environment becomes an urgent research, the information system considered will be supplemented, at its development, with a possibility of receiving and transferring data using World Wide Web, TCP/IP protocols, and client-server technologies.

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