Development of a database of regional satellite information and software for its processing at the Institute of Atmospheric Optics SB RAS

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We present a general description of the information and software system developed at the Institute of Atmospheric Optics (IAO) SB RAS based on the regional archives of digital satellite (MODIS, NOAA) information and the software for primary and thematic processing of this information. The system to be developed is intended for solution of a wide range of problems in remote sensing of atmospheric and Earth's surface parameters from space, as well as for investigation into the spatial and temporal variability of the environment in Western Siberia. The program block of the system is based on both commonly known and original, developed at the IAO, software for processing satellite data.

Introduction

Specialists from the Institute of Atmospheric Optics (IAO) SB RAS are now actively developing the information and software system,[1–7] intended for solution of a wide range of problems in remote sensing of the atmospheric and surface parameters from space, as well as for investigation into the spatial and temporal variability of the environmental parameters in Western Siberia. The information block of the system consists of the databases, compiled from the digital information of various satellite systems (AVHRR, ATOVS, MODIS, SPOT, TOMS). The data are obtained for the territory covering Novosibirsk, Tomsk, Omsk, Tyumen, and Kemerovo Regions, as well as Altai Krai of Russia, and a part of Kazakhstan (Fig. 1).

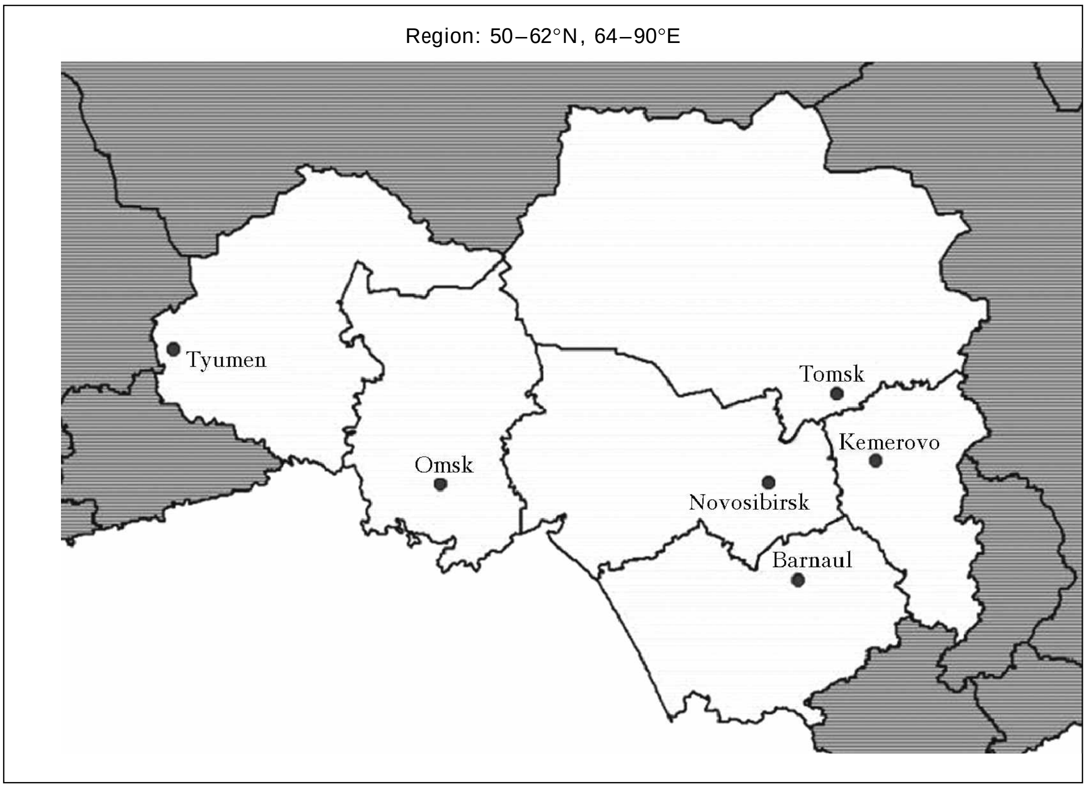

Fig. 1. Map of the distribution of regional satellite information.

Today the databases include two types of the satellite information:

– MODIS Atmosphere Products archive, accessible through the Internet;

– the archive of the NOAA satellite information, including AVHRR and ATOVS data.

The program block of the system is developed based on both the commonly known and original software for processing satellite data. The software used for primary and thematic processing of measurement data from AVHRR was developed at IAO. Primary and thematic processing of ÀTOVS data is performed by AAPP and ICI packages, adapted for the PC platform.

1. Information basis of the databases

1.1. MODIS Atmosphere Products data

The MODIS Atmosphere Products data are the results of reconstruction of optical and meteorological parameters of the atmosphere from the measurement data of MODIS (Moderate Resolution Imaging Spectroradiometer), installed aboard TERRA and AQUA satellites (http://modis.gsfc.nasa.gov/). This spectroradiometer conducts global measurements in 36 spectral channels (from 0.405 to 14.385 μm) with the spectral resolution of 1000, 500, and 250 m. Consumers of this information can get the data of primary processing of different-level measurements and the results of their thematic processing: vertical profiles of the atmospheric aerosol characteristics, water vapor and ozone column densities, cloudiness characteristics, surface temperature, surface reflectance, vegetation indices, etc.

In compiling the database of MODIS measurements, we used, as a source of data, the archives of the NASA Goddard Distributed Active Archive Center (DAAC), which distribute these data free of charge through the Internet, by mail on magnetic carriers, or by the ftp protocol through network communications. At the first stage, we determined three key types of the MODIS Atmosphere Products data:

1) MOD04 – aerosol characteristics;

2) MOD05 – integral water vapor in the atmosphere;

3) MOD07 – vertical profiles of geopotential, atmospheric temperature and humidity.

The MODIS Atmosphere Products data are organized in files (granules), which are briefly described in Table 1.

Along with the basic characteristics, listed in the Table, the granules include geolocation and time parameters, parameters of observation geometry, characteristics of sun position, cloud masks, characteristics of the quality of reconstructed parameters.

1.2. NOAA data

Now NOAA satellites carry two sets of measuring instrumentation:

1) AVHRR radiometer for space monitoring of the surface and cloudiness parameters in five visible and IR spectral channels (nadir FOV = 1 km);

2) ATOVS (Advanced TIROS Operational Vertical Sounder).

The main purpose of ATOVS is to obtain global and regional data on the vertical profiles of geopotential, atmospheric temperature and humidity, water vapor and ozone column density. The ATOVS instrumentation includes a 20-channel HIRS/3 IR radiometer (FOV = 19 km), a 15-channel AMSU-A MW radiometer (FOV = 48 km), and a 5-channel AMSU-B MW radiometer (FOV = 16 km).

Table 1. Brief description of MODIS Atmosphere Products data

Type	Spatial resolution, km	Basic parameters	Mean number of granules a day (for a region)	Granule size, Mb	Data accumulated for 2000–2003, Gb
MOD04	10×10	*type of aerosol*; *aerosol optical depth* (λ = 0.47, 0.55, and 0.66 μm); *Angström index*; *mass concentration*	6	11	96
MOD05	1×1	*integral water vapor*	9	20	236
MOD07	5×5	*surface*: temperature, pressure *vertical profiles*: geopotential, temperature, dew point; *integral ozone,* *integral water vapor*	9	30	378

A center for acquisition and processing of NOAA satellite information, fabricated by ScanEx (http://www.scanex.ru/), has been operated by the Institute of Atmospheric Optics SB RAS since 1998. It records the NOAA data in the SCANEX/RAW format. A file of about 70 Mb consists of a title and telemetry data, containing the results of AVHRR and ATOVS measurements, as well as the data of the spaceborne processor. The telemetry data are recorded frame by frame (HRPT minor frame[8]) as a bitstream just after the title.

As a result of operation of this center, an about 600 Gb archive of AVHRR and ATOVS data has been accumulated for the territory of Western Siberia.

2. Basic software

2.1. Software facilities for processing MODIS data

The MODIS data are stored in the HDF-EOS 2 format (Hierarchical Data Format for storing data from the Earth Observing System (EOS)). The HDF-EOS format and the basic software for storage and processing of information in this format were developed at the National Center for Supercomputing Application's (NCSA), University of Illinois, Urbana-Champaign (http://hdf.ncsa.uiuc.edu/index.html). The software is a library of functions for creating, accessing, and processing the basic structures of the HDF-EOS format, whose interface is implemented in C and FORTRAN.

To record, read, analyze, and visualize data in the HDF-EOS format, companies developing software for remote sensing, as well as various research teams and individual scientists, have developed both commercial and freeware programs. The main feature of these programs is that they are intended for the operation in the UNIX operating system on 64-bit Sun, IBM, Alpha, SGI, and other workstations. However, most Russian centers for acquisition and processing satellite information employ personal computers. This circumstance restricts the application of the most program packages intended for processing of multispectral and hyperspectral images.

For processing MODIS data, we used the following commonly known software products, operating on a PC platform in the Windows operating system:

– ENVI (the Environment for Visualizing Images);
– HDF Explorer Lite;
– Multispec;
– hdfeos2bin.pro.

For validation and statistical analysis of MODIS Atmosphere Products data, we have developed the software (MODIS-AP), which executes the following functions:

1) reads granules and selects the arrays of reconstructed atmospheric parameters and the arrays of parameters of observation geometry;

2) selects the values of the reconstructed atmospheric parameters corresponding to a given level of quality;

3) selects the data for a given spatial area;

4) analyzes comparatively the time-matched satellite and ground-based measurements of optical and meteorological characteristics of the atmosphere (validation of satellite information);

5) analyzes statistically the spatial and temporal variability of data in the region under study.

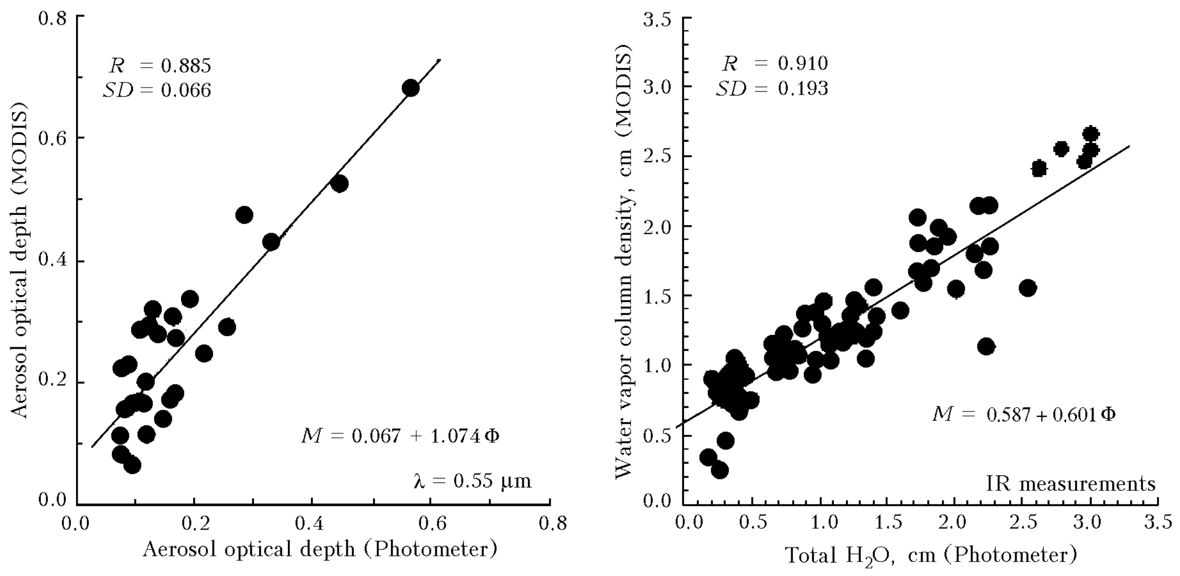

Fig. 2. Results of validation of MOD04 and MOD05 (Level 2) data; Tomsk Region, May–September 2002.

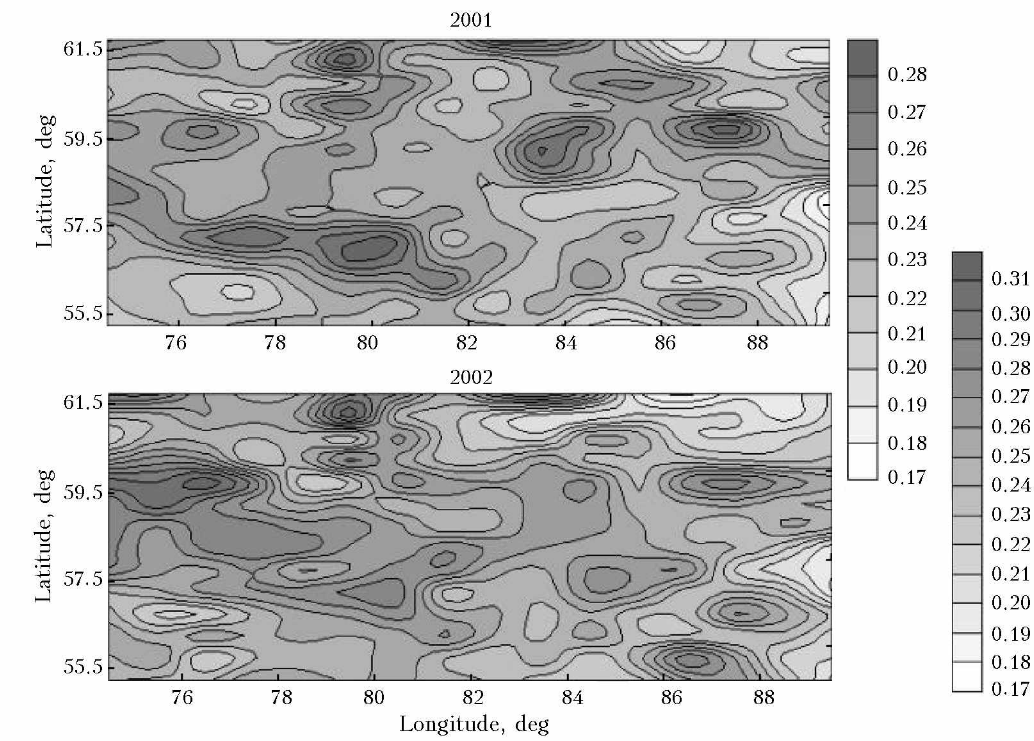

Fig. 3. Spatial distribution of the time-averaged AOD (λ = 0.55 μm) in the Tomsk Region.

During the execution of Item 2, for any type of the files we faced the discrepancy between the information and specification contained in it. In particular, Fill Value can differ from the value specified. In addition, the correspondence between the values of the reconstructed parameters and the characteristics of reconstruction quality (Quality Assurance Flags) can break.

Figures 2 and 3 show examples of the results validation and statistical analysis of MOD04 (Level 2) and MOD05 (Level 2) data for Tomsk Region in 2002 (May–September). For validation of the satellite data, we used photometric measurements of the spectral aerosol optical depth and the water vapor column density in the atmosphere (such measurements are regularly carried out at IAO SB RAS[9]).

The analysis the data shown in Fig. 2 suggests quite good correlation between the MODIS data and the data of ground-based photometric measurements.

In analyzing the data on the spatial distribution of the aerosol optical depth (AOD) for 2001–2002 over Tomsk Region (Fig. 3), the fact is worth noting that these distributions have similar structure despite they are quasihomogeneous (within $\pm$ 0.05). The correlation coefficient between the data for 2001 and 2002 is rather high: R = 0.70. In the future, we plan to study the cause for this fact.

2.2. Software tools for processing of NOAA / AVHRR data

The software developed at the IAO SB RAS for the primary and thematic processing of AVHRR data executes the following functions:

– reads the files of the satellite digital telemetry information, decommutates this information;

– calculates the calibration coefficients for the AVHRR IR channels;

– calibrates the AVHRR measurements, recalculates them into albedo (channels 1, 2, 3a) and brightness temperature (channels 3, 4, 5);

– analyzes the quality of the satellite measurements; automatically searches and rejects bad scans and bad pixels;

– performs the geographic reference of images on the basis of the SGP4 library and the files of orbital data in the TLE-NORAD format;

– performs the linear interactive correction of the calculated geographic reference of images on the basis of a set of reference points and contour lines;

– processes the time series of clear-sky satellite images and draws the spatial distribution of the surface albedo in AVHRR channels 1 and 2 (visible spectrum) for the territory under study;

– reconstructs the aerosol optical depth in AVHRR channels 1 and 2 and draws the spatial distribution of the aerosol optical depth;

– obtains the file of the spatial distribution of clouds over a satellite image;

– detects hot spots (high-temperature anomalies) on the surface with the aid of satellite measurements taking into account the optical and meteorological state of the atmosphere and the observation geometry.

The practical application of this software is illustrated in Refs. 10–12.

2.3. Software tools for processing of NOAA / ATOVS information

For a preliminary processing of the ÀTOVS data, foreign scientists widely use the AAPP (ATOVS and AVHRR Processing Package) program package, developed by Meteo France in cooperation with EUMETSAT (http://www.eumetsat.de). Thematic processing of the ÀTOVS data (reconstruction of vertical profiles of the atmosphere) is now usually carried out with the use of one of the following two packages: ICI (Inversion Coupled with Imager), developed by Meteo France (http://www.meteorologie.eu.org /ici), or IAPP (International ATOVS Processing Package), developed by CIMSS (Cooperative Institute for Meteorological Satellite Studies) University of Wisconsin-Madison (http://cimss.ssec.wisc.edu/opsats/polar/iapp/IAPP.html).

As in the case with HDF-EOS files, the packages for primary and thematic processing of ÀTOVS data have been developed for operation in the UNIX operating system on 64-bit workstations. As was already mentioned, most of the Russian centers for acquisition of the satellite information employ personal computers. Thus, for processing the ATOVS data in Russia, it is needed either to develop new software or to apply the PC-adapted versions of AAPP, ICI, and IAPP. Today we do not know any Russian or foreign organizations developing and distributing ĐÑ versions of the packages for primary and thematic processing of the ATOVS data. In the Russian scientific literature there are only few publications (Refs. 13 and 14) reporting the results of using the PC adapted versions of the AAPP and IAPP packages in the Planeta Scientific Research Center of Space Hydrometeorology (Moscow). All the circumstances mentioned above forced us to develop PC-adapted versions of the AAPP and ICI packages at the Institute of Atmospheric Optics.

The AAPP package is intended for preliminary processing of the HRPT data; the results of its operation are entered in the form of L1d file, which is then used by the ICI or IAPP programs.

The processing of data in the HRPT format includes four main stages: 1) decommutation, 2) geographic referencing, 3) calibration, and 4) creation of the cloud mask. These stages are shown in the flow chart in Fig. 4.

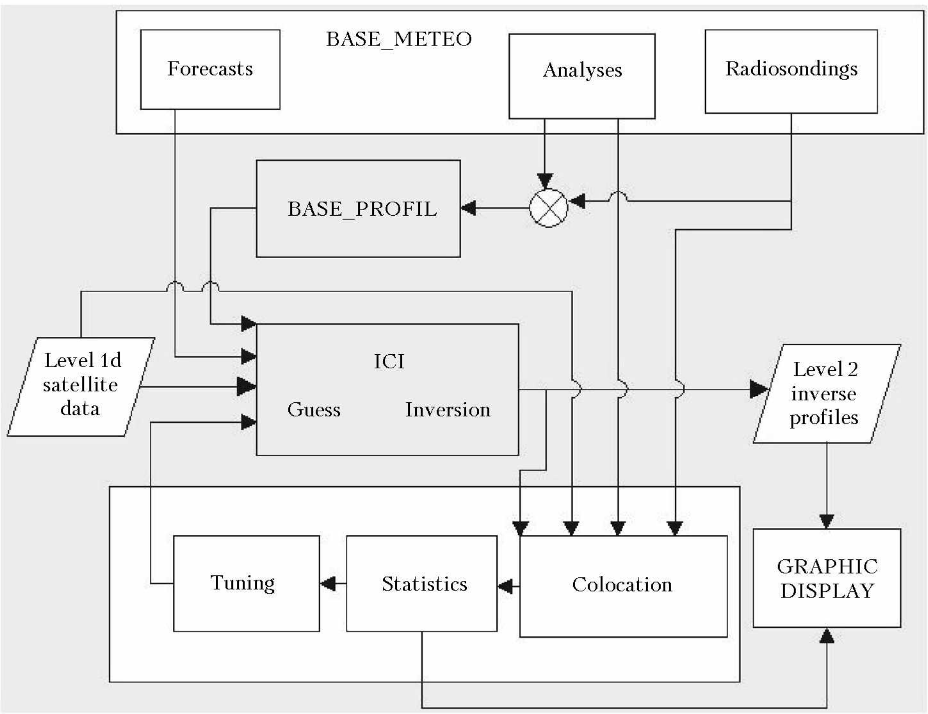

Fig. 4. Flow chart of AAPP package.

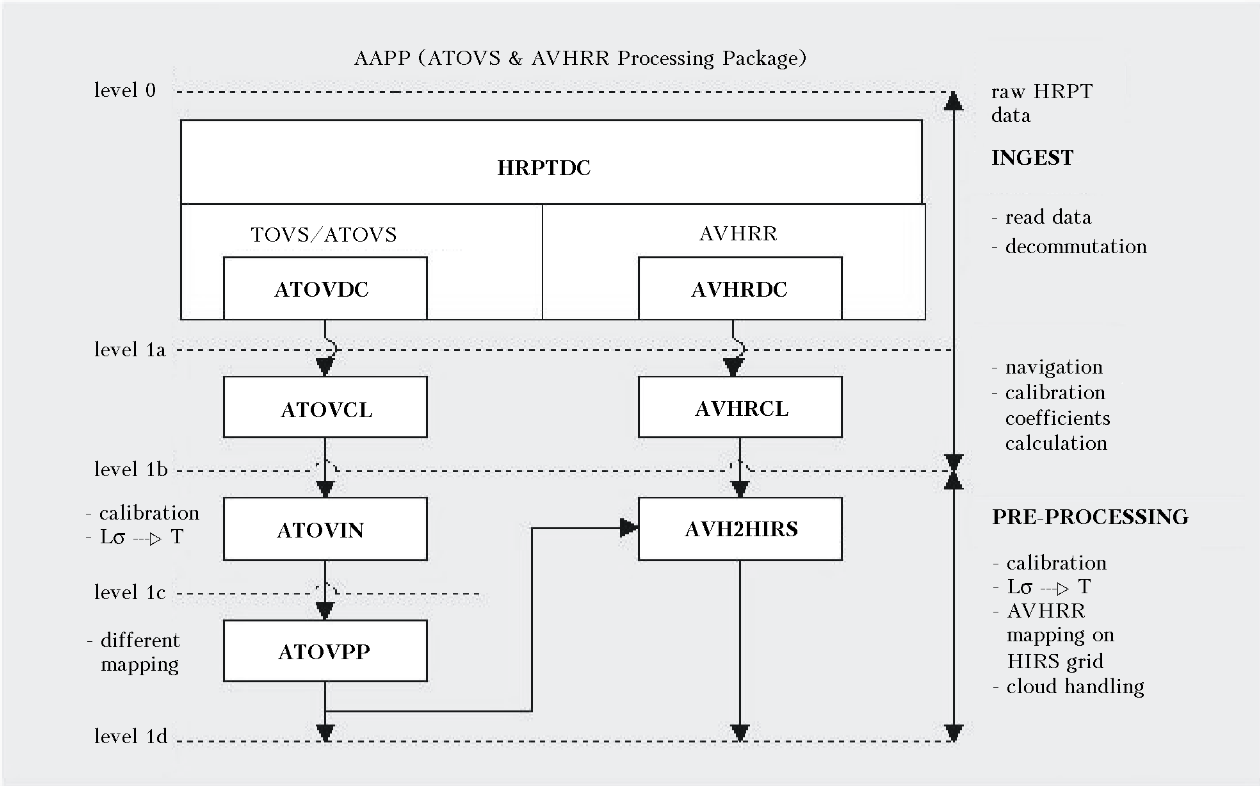

Fig. 5. Flow chart of ICI package.

Table 2. Results of verification of ÐÑ version of the ICI package v3.0.

Time (GMT)	Number of profiles	Temperature, K	Humidity, %
01:05	1285 / 2	–0.001, 0.026	0.019, 0.742
02:46	1680 / 4	0.000, 0.046	0.000, 0.677
04:27	1259 / 3	0.000, 0.031	–0.025, 1.400
10:59	1008 / 6	0.000, 0.037	–0.010, 0.749
12:35	1708 / 8	–0.001, 0.064	–0.003, 1.829
14:47	1736 / 9	0.001, 0.073	–0.003, 1.477

In the operation process, working files in the L1a, L1b, and L1c formats are created. At the final stage, the package creates the cloud mask and the file in the L1d format.

We have adapted the AAPP v3.5 package for operation on a PC with the use of the FORTRAN g77 compiler and the Linux operating system. The results of verification of the PC version of the AAPP v3.5 package showed a good 4agreement with the test data for the files of all formats (L1a, L1b, L1c, L1d).

The ICI package processes L1d files, created by AAPP, in order to reconstruct the vertical profiles of the atmospheric parameters (geopotential, temperature, and humidity) at 40 altitude levels from 1000 to 0.1 hPa. The ICI flow chart is shown in Fig. 5.

As a result, ICI creates a binary file, containing the results of reconstruction of the vertical profiles and integral characteristics of water vapor and ozone content in the atmosphere.

For operation on a PC, we have adapted the ICI v3.0 package using the Intel Fortran 8.0 compiler and the Linux operating system. The verification of the PC version was carried out on the basis of the test data enclosed in the ICI v3.0 package. These data include 8676 vertical profiles of the atmosphere in the geographic region of 20–75°N and 50°W–50°E, reconstructed from the data of six NOAA-16 images for March 30, 2001.

For every image, Table 2 presents the following parameters:

– time of measurements (GMT);

– total number of profiles and the number of reconstructed profiles, different from the test data;

– statistical characteristics (mean and rms deviation) of the absolute difference between data for temperature profiles;

– statistical characteristics (mean and rms deviation) of the relative difference between data on the humidity profiles.

It can be seen from Table 2 that the verification of the PC version of ICI v3.0 showed quite good agreement between the test data and the results of reconstruction of the vertical atmospheric profiles.

Figure 6 shows an example obtained by processing the NOAA/ATOVS data for Tomsk Region with the PC version of the AAPP&ICI packages.

In the process of realization of the PC versions of the AAPP and ICI packages for operation with the data of the Russian centers for acquisition and processing of satellite information, the problems of different representation of data on workstations (Sun, IBM, Alpha, SGI) and personal computers were solved and peculiarities of data format for different centers were taken into account.

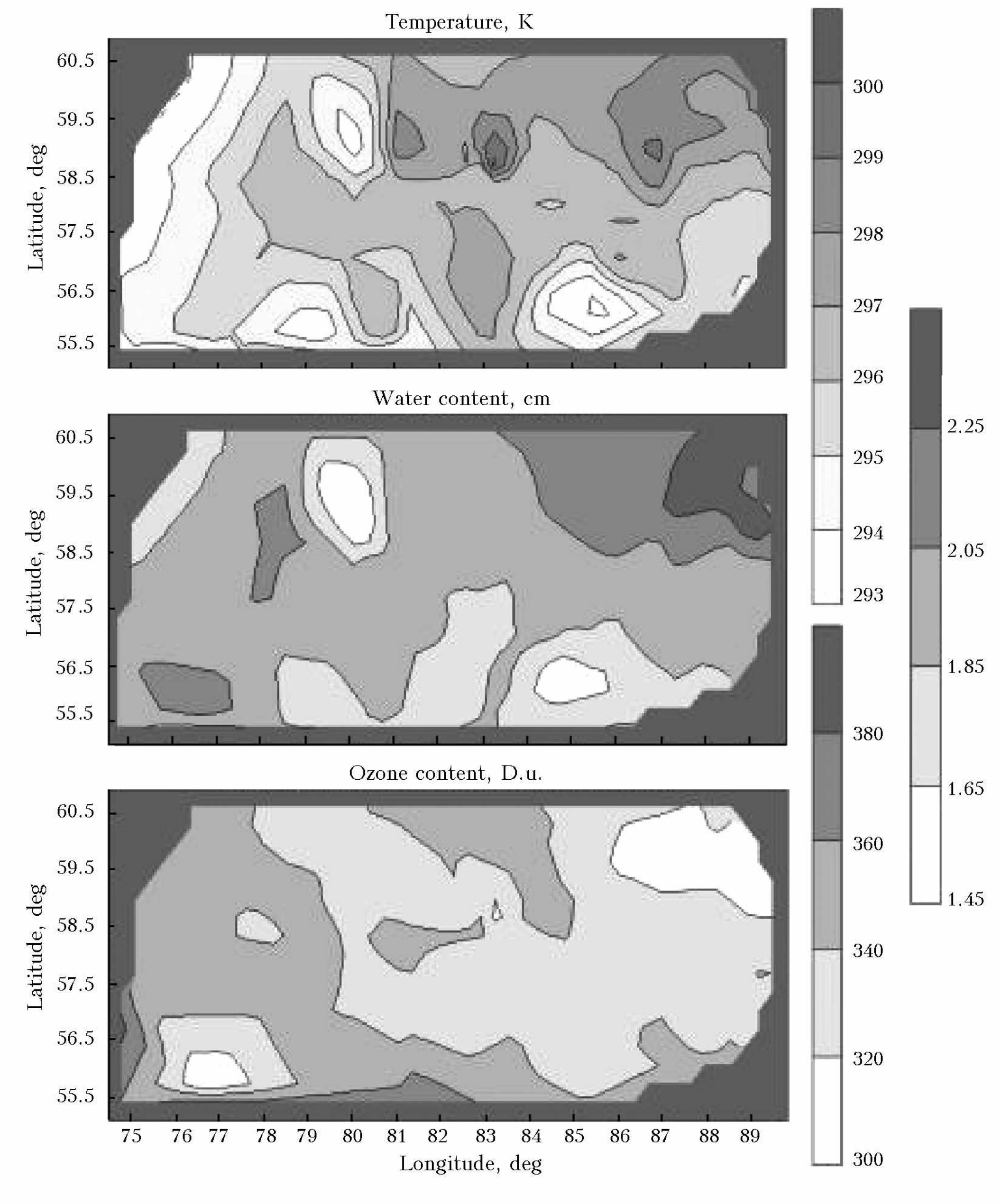

Fig. 6. Example of processing of ATOVS/NOAA-17 data for the Tomsk Region (June 24, 2003, 04:56 GMT).

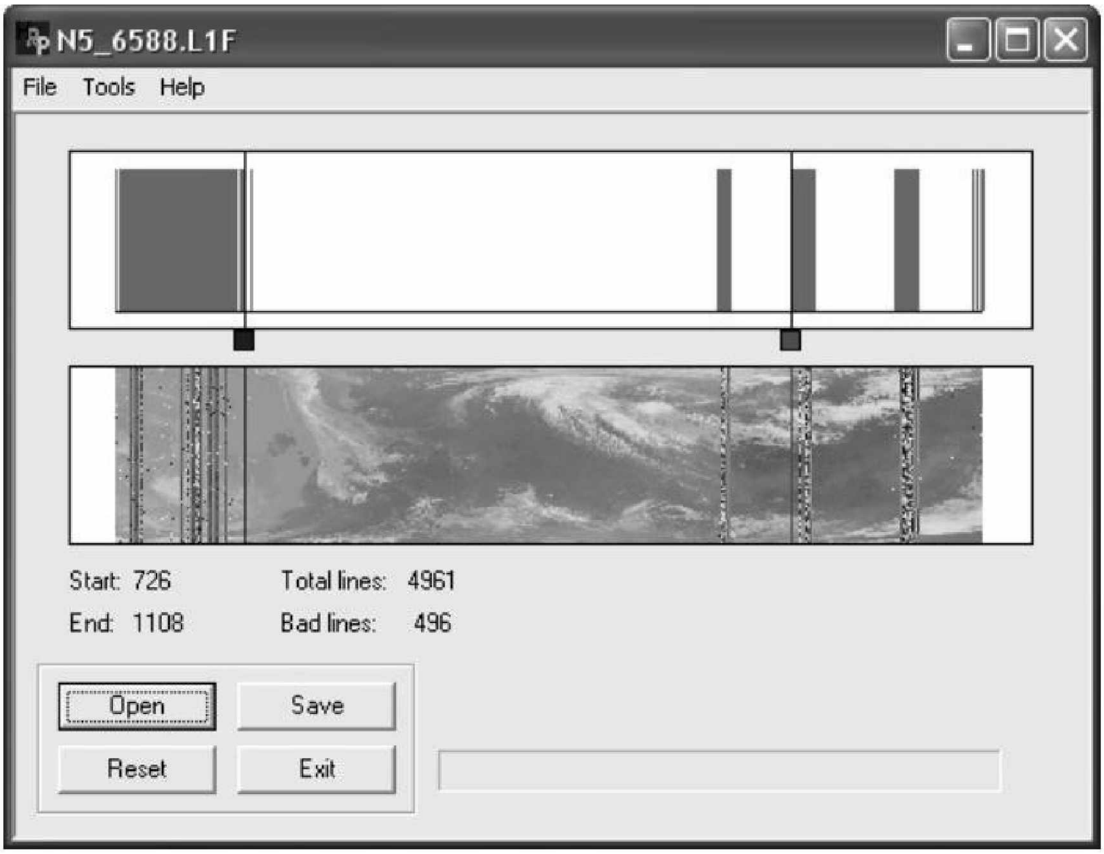

Fig. 7. Main window of the HRPQuality program.

Another urgent problem was the presence of bad scans, caused by problems during information transmission or failures in onboard instrumentation, in satellite images. This problem leads to unstable or incorrect AAPP operation, and when the number of bad scans exceeds some amount (~ 50–100), the information processing stops at the stage of decommutation or calibration of satellite measurements.

To solve this problem, we have developed the Windows-application HRPQuality, which outputs the information about the number of bad scans and their distribution over the image. In addition, the user can remove bad scans on the edges of an image. Then the application converts the files of the satellite information into the AAPP input format.

The main window displays the plot and two markers, indicating the number of cut-off lines from the beginning (left marker) and from the end of the file (right marker), as well as the buttons, which serve to open and save files, to close the application, to reset the marker positions, and to change the scale of the plot. The main window of the HRPQuality application is shown in Fig. 7.

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