3.3.1. INFORMATION SYSTEM OF OPERATIONAL DATA IN NTs OMZ (TERRA-MODIS DATA PROCESSING)

The main components of the information system of the Earth remote sensing satellite data, which is under development in NTs OMZ in cooperation with FIRE RAS, are described. The main accent is made on the subsystems for data storing and data access in application to the MODIS TERRA data processing.

Introduction

A large amount of information which is receiving by means of Earth remote sensing satellites requires an adequate information system for data processing, cataloguing and archiving of this information and the retrieval results. The data collected in the information system may be used as for operational as for fundamental scientific and applied investigations [1–3].

The main elements of the information system are the subsystems for storing data and for data access. These subsystems must provide a required level of reliability of data keeping and efficiency of data access. As a rule such systems are directed to requirements of the end user. So, this information system must have a simple, comfortable and easy to use interface, which provides for user all required functions, but at the same time it must not permit to do any unhallowed tasks.

Information received from Earth remote sensing satellites is stored in the centers for data processing and storing. Now in Russia there are several centers, such as http://smis.iki.rssi.ru/archive — IKI RAN; http://ire.rssi.ru/cpssi — CPSSI IRE RAS, Fryazino; http://sputnik.infospace.ru/catalog_eng.html - SRC “Planeta”; http://ckm.iszf.irk.ru/satdata — Regional center ISZF SO RAS, Irkutsk and other. Data stored in these centers usually have some thematic orientation.

An integral part of the data processing and storing centers is information system, including modern hardware and software tools for reliable and long time storing the data and corresponding graphical interfaces, which allow user to query and to obtain required information [2, 4].

One of such centers for data processing and storing the space information is the Research Center for Earth operative monitoring (NTs OMZ) of the Russian Space Agency (Roscosmos). Information system creating in NTs OMZ is oriented to provide the solution of general tasks, which are in responsibility of the Federal level Earth remote sensing center. In particular there are: management of the State archive of Earth remote sensing data and providing users with the possibility to search and receive required information [5].

In this paper the main attention is made on description of the operation of NTs OMZ information system on processing, cataloguing and archiving the data from MODIS device on the USA satellite TERRA. Polar orbiting satellite TERRA was launched December 18, 1999. MODIS device is a medium resolution scanning spectroradiometer with 36 spectral channels in 0.4–14.4 μm band (http://modis.gsfc.nasa.gov/).

Brief description of the information system

Information system in NTs OMZ includes the following functional subsystems:

- satellite data acquisition and archiving in operational archive;
- data processing to level 1b[1] (radiometrically corrected and calibrated in physical units at full instrument resolution as required);
- cataloguing the information in the specially developed data base (DB);
- creation of long live archive on the DLT tapes;
- creation of the data exchange system via Internet.

Information system infrastructure consists of complex of catalogues of satellite data archives and software and hardware means for catalogue and ancillary information exchange. This infrastructure allows making search of the general and detailed information, and after that to order the required data in frame of the same system.

At present time in NTs OMZ there are archive end electronic catalogue of the data received from Russian and foreign Earth remote sensing satellites. There is a possibility for remote access to the catalogue via communication channels and Internet. Now the creation of the software and hardware complex for long time data archive and cataloguing support is under completion.

The data from TERRA satellite are receiving in NTs OMZ in the mode of direct downlink and are storing in the operational archive. The data are in the PDS format (product data set). For the data processing a software package IMAPP (International MODIS/AIRS Processing Package) is used. It is developed in Wisconsin University under NASA support and is standard for MODIS data processing. This software converts the data from raw format level 0 to the standard products of level 1a and 1b. This converting includes also calibration and geographic referencing of the data.

Software components of the NTs OMZ information system

In NTs OMZ information system the Oracle data base management system (DBMS) is used.

The developed data base consists of two main parts. The first one is used for storing the descriptions of data collections of satellite data, and the second one for storing detailed descriptions of all minimal portions of archived data (granules).

Data processing, cataloguing and archiving of the received information is conducted in the automatic regime. Specially developed software for these purposes includes:

1. Software for data exchange between computers of the system:
   a. ftpx — data transfer from operation archive server to the data processing subsystem;
   b. ftpput — data transfer from data processing subsystem to the archive;
2. Software for registration of input satellite data entered into data processing subsystem;

[1] According to the definition suggested by EOSDIS and adopted by CEOS.

3. Software for cataloguing the data entered into long time archive;

4. Software for making backup copies of data collections and recording them into magnetic tapes (DLT)

Software components 2–4 and IMAPP package are managed by special supervision program MODIS_OMZ.pl.

Software tools providing data search and data order functions are installed in Web server NTs OMZ (http://sun.ntsomz.ru/data_new) and are the integral part of the whole information system http://www.ntsomz.ru.

Data request subsystem of the NTs OMZ information system

One of the main user requirements to the information system is decreasing of the time costs on data search and data obtain. In application to the satellite data the important condition of the search system is a requirement to provide querying all the data sets included into information system simultaneously. To provide such possibility a data request subsystem has special user interfaces (access gateways) to the descriptions of archived data. These gateways allow organizing process of search, view graphical primitives and order required data in the same graphical interface. The important feature of data request subsystem as general is provision users with actual information about archived data. This is possible because user interface has direct connection to the data catalogue, content of which is synchronized with archive descriptions. Moreover data search system not allowed to make user contradictory request even at the beginning stages.

For a detailed search, it is required to define the following attributes:

- **Geographic region** — geographical coordinates of the interest region defined by rectangle with longitude (±180°) and latitude (±90°);
- **Date-Time** — data and time of the beginning and the end of interested measurements;
- **Project** — project name (name of the program or mission) in frame of which measurements were conducted (values are selected from a valid list according to archive content);
- **Instrument** — instrument name, data from which are stored in the granules (values are selected from a valid list according to archive content).

As a search result, user at first receives list of data sets and, after that, a list of granules matched to selected search criteria.

Each granule, obtained as a search result, has so called browse images (NASA) or quick look (ESA). Browse images are mostly intended for visual control of data quality as for measurement quality (such as sun angle, cloudiness conditions, etc.) as for data distortions in process of data downlink, and other. User interface allow viewing these browse images and select requested granules according to the results of visual analyses.

In conjunction with a search and visual control of data quality, interface of data request subsystem allows user to make an order on selected granules immediately after data search and selection process in the same working session.

Order creation includes two actions:

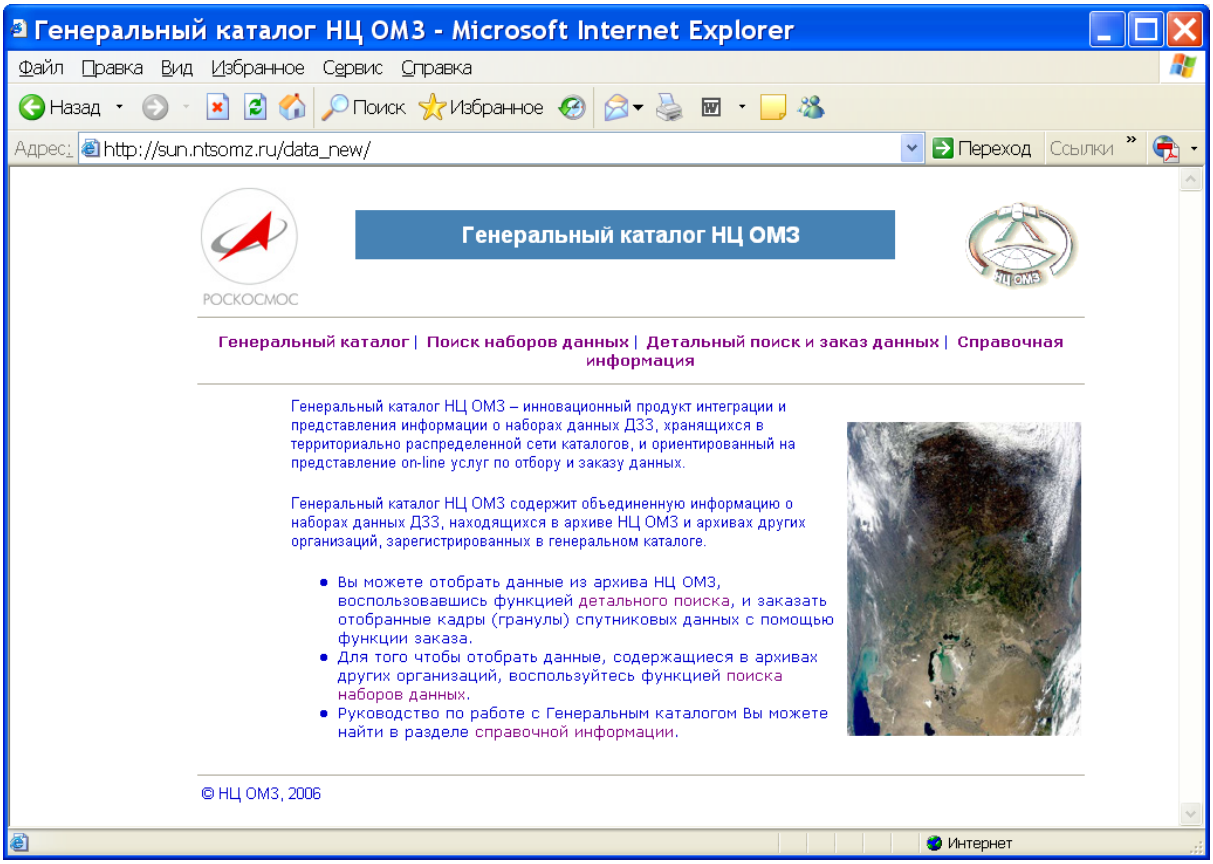
1) selection of data transfer option;

2) registration of contact information about user.

Selection of data transfer option includes a choice of the media type for recording a requested data and preferable data format. Created order is automatically transferring to the data archive. Simultaneously a request for order confirmation is send to user via e-mail. As a rule, order begins to execute in archive only after receiving an order confirmation from user.

Data request subsystem is developed with use of free of charge software packages and libraries available for Solaris operation system. The basic part of it is Web server Apache with PHP module. PHP module has enough flexibility to dynamically generate a request forms, presentation of search results forms and has internal tools for Oracle database access. Moreover it allows using graphical library for dynamic generation of the images, for drawing a vector elements (polygons, cycles, etc.) and text comments on images. Used software packages and libraries exist for other computer operation systems such as Windows and Linux. So, such configuration allows transferring the developed software to another computer platform with minimal cost, mostly associated with a configuration tasks.

The main page of data request subsystem is presented in figure.



3.3.2. INVESTIGATION OF THE SOLAR WIND USING RADIO SOUNDING METHOD

The statistical processing and analysis of the materials of the coronal sounding experiments carried out in the years 1991–2002 with the spacecraft

GALILEO and ULYSSES provided a new information on the solar wind for the heliocentric distances between 6 and 80 solar radii for the equatorial and polar regions and different phases of the 11-year cycle of the solar activity [1–18].

1. The reliable data were originally obtained on the outer scale of the turbulence of the solar wind [1–3]. It is shown that the turbulence outer scale increases with the increasing heliocentric distance according to the power law dependence which is close to the linear dependence. At heliocentric distances about 6 solar radii the outer scale of the turbulence may be as high as $0.7 \cdot 10^6$ km for the equatorial regions while in the polar regions it is 2…3 times greater than in equatorial regions [3]. The model of the solar wind turbulence has been developed in which the turbulence outer scale is determined by a random ensemble of interacting Alfven and magnetosonic waves. It is shown that it is formed due to competition between the linear amplification of the Alfven waves in the irregular moving solar wind plasma and the nonlinear transfer of turbulent energy to higher frequencies. It is shown that the main processes responsible for the formation of the inertial interval of the spectrum are three-wave decay processes involving Alfven and magnetoacoustic waves [1].

2. It is established a fundamental feature of the solar wind – the turbulence regime and plasma flow at low heliolatitudes does not change practically during the solar activity cycle [6, 10, 11, 13, 16, 17]. The nonlinearity of the forms of the turbulence spectra can be explained by a tolerance of the equatorial magnetic fields of the Sun distinct from strongly changing with time magnetic fields of the polar regions. The analysis of the temporal power spectra of the frequency fluctuations of the sounding signals shows that the spectral index of the three dimensional spatial spectrum of the solar wind which is generated by low-latitude coronal regions has a value about 3.1…3.2 in the region of the formation and initial part of its acceleration at heliocentric distances about 10 solar radii [6, 10, 11, 13, 16, 17]. At very small heliocentric distances (less than 6 solar radii) the temporal spectra of the frequency fluctuations demonstrate a sharp decrease of the spectral density at fluctuation frequencies of 0.04…0.06 Hz which correspond to spatial scales of 1500÷…2500 km [6]. At the transition of an established motion (heliocentric distances are larger than 20 solar radii) the temporal spectra fall more steeply down and spectral index of the spatial spectrum increases up to 3.5…3.7 [6, 10, 11, 13, 16, 17]. The features of the radial evolution of the turbulence spectra can be explained by a physical model of the turbulence, in which the turbulence is formed by an ensemble of the interacting Alfven and magnetosonic waves tolerated by the plasma flows. The regime change is determined by a relative contribution of slow and fast magnetic sound, namely, in the regions of the formation and acceleration the electron density fluctuations are connected predominantly with slow magnetic waves and cascade processes are absent. In the region of the established motion the main contribution is connected with fast magnetic sound waves and power turbulence spectra are formed at the expense of cascade processes to the small-scale part of the spectrum [13].

3. It is established that the observations of the signals of the spacecraft occulted by the Sun and a registration of the radio wave characteristics at several

ground stations provides a possibility to obtain an information on a generation on the solar surface of plasma perturbations: coronal mass ejections, transients, shock waves and other plasma formations. The spectral and correlation analysis of the frequency fluctuations demonstrates that the radio sounding technique can provide a detection of the plasma formations propagating from the Sun. Besides, this method is an effective one for a prediction of the events which will be taken a place in the near-Earth space. The detection of the plasma perturbations along the radio ray path can be realized by an increase of the frequency and amplitude fluctuations and also by a behavior of the temporal spectra and cross-correlation functions of the frequency fluctuations observed at several ground station simultaneously. At the increase of the fluctuation intensity connected with the passage of the large-scale plasma formations is observed an increase of the spectral indices of the temporal power spectra of the frequency fluctuations, is registered a decrease of the cross-correlation function width and a change of position of its maximum at the temporal axis. These factors demonstrate a difference of the solar wind characteristics for the quiescent and perturbed conditions in the interplanetary space. This statement holds true for spatial spectrum of the plasma turbulence, plasma velocity and a spread in irregularities velocity [15].

4. The spectral analysis of the amplitude fluctuations of the signals of the S- and X-bands (2.3 and 8.4 GHz, respectively) had given an information on the dependence of the spectral density of the amplitude fluctuations on heliocentric distance [9, 18]. It is established that the transition of the fluctuations into regime of the saturated fluctuation occurs at distances about 16 solar radii for S-band signals and distances about 7 solar radii for X-band signals. The cross-correlation analysis of the amplitude fluctuations of signals of S- and X-bands detects a presence of the time lags which are connected with differential refraction in the irregular plasma of the solar wind.

The estimates of the velocity of the solar wind irregularities were obtained using the obtained time lags. The typical values of the velocity are about 80-100 km/s for heliocentric distances 6…8 solar radii.

5. The cross-correlation analysis of the materials of coronal sounding experiments obtained at two widely spaced ground stations permitted to detect the two-velocity structure of the solar wind at heliocentric distances between 20 and 40 solar radii [16]. A model of the generation of the irregularities of the solar wind was proposed in which the irregularities are formed locally by slow magnetosonic waves, which propagate to the Sun and in opposite direction relative to the moving solar wind plasma. The resulting velocity relative to the radio ray path can be both a sum of velocities and a difference of the velocities of the solar wind and sound. The obtained result can provide a new technique of the magnetic sound study.

6. A new method of the estimation of the turbulence outer scale was developed on the basis of the effect of the enhancement of the radio wave fluctuations at the double propagation in irregular plasma [7, 12]. It is shown that the enhancement effect is registered in the coronal sounding experiments with occulted by the Sun spacecraft only in such cases when spacecraft as transponder of the signals, received from the ground station transmitter, is situated at small

distances from the layer of the scattering irregularities of the solar corona. In this case the time of signal propagation from the scattering layer to spacecraft and from spacecraft to scattering layer is substantially less than time of changing of the irregularities which intersect the radio ray path. This time is determined by the irregularities velocity and maximum scales of the irregularities (their outer scale). The obtained values of the turbulence outer scale is found to be close to values found with an use of other technique.

3.3. DEVELOPMENT OF RADIO OCCULTATION TECHNIQUE FOR GLOBAL MONITORING OF THE EARTH ATMOSPHERE AND IONOSPHERE BY USE OF SATELLITE-TO-SATELLITE LINKS

Radio-holographic technique is elaborated for retrieving the spatial distributions of physical parameters at different altitudes in the Earth atmosphere and ionosphere with global coverage by use of the GPS occultation signals in links GPS satellites — German CHAllenging Minisatellite Payload (CHAMP) satellite [1–15]. Radio-holographic technique allows to heighten by an order of magnitude the vertical resolution for retrieving the altitudes profiles of temperature, density and pressure in the atmosphere and electron density in the ionosphere from radio occultaion (RO) experiments [1, 2, 8]. General Inverse Operator is developed for inversion of the radio holograms of the GPS occultation signals registered in satellite-to-satellite links [1, 2].

The radio-holographic technique, as applied to analysis of RO measurements, allows to evaluate the vertical gradients of refractivity and to observe wave structure at the 10–40 km altitudes in the atmosphere with global coverage [3–7]. The amplitude variations of GPS occultation signals can be considered as radio-holographic images of wave structures in the atmosphere [2–4, 6–14]. The new technique was applied to measurements provided during CHAMP RO mission, and have been used to find parameters of wave structures with vertical periods in the 0.8–4 km interval at the 10–30 km altitudes in the upper troposphere and stratosphere in the tropical areas and middle latitudes. From amplitude variations of GPS occultation signals, measured by the CHAMP satellite, the altitude dependence of the phase and amplitude of internal waves in the atmosphere have been revealed [2–4, 6, 9–11, 13]. The geographical distributions and seasonal dependence of the atmospheric wave activity with global coverage for period 2001–2003 years have been revealed [6]. An asymmetry in distribution of the wave activity at the 12 km level in the atmosphere has been found. The maximal wave activity occurs in the summer polar region. At the 14–16 km levels the wave activity is centered in the moderate latitudes both in the Northern and Southern Hemisphere. At 18 and 20 km levels, most of the internal wave's activity is concentrated in the equatorial areas. The local seasonal dependences are clear for some regions, e.g. Siberia at the height of 14 km in the winter, with a low wave activity and a high wave activity in the summer [6]. In the case of the atmospheric gravity waves (GW), the potrait of GW can be revealed

from the measurements of the amplitude variations of GPS occultation signals [2, 6, 9–11]. The portrait of GW consists of the altitude dependences of the horizontal wind perturbations and intrinsic phase speed [2, 6, 9–11]. The application of this and other new techniques will generate a more extensive body of information on wave structures and natural processes in the atmosphere and ionosphere [14, 15].

Comparative investigations of the altitude dependence of the amplitude and phase variations of RO signals in the decimeter and centimeter frquency bands have been provided in different areas of the Earth by use of satellite-to-satellite links.

The vertical profiles of the spectral index p of the spatial spectrum of fluctuations of refractivity have been obtained. It is shown, that at the 4–8 km height interval in the troposphere the measured value p is equal to 3.5 in 70 out of 100 cases of measurements, that are in fair good accordance with the theoretical value p relevant to developed turbulence [16–19]. The value of the outer scale of the tropospheric turbulence Λ_{max} is evaluated as equal to 1.4 km. In the stratosphere at the 14–20 km altitude interval the measuered value p is equal to 4.4 [16–19]. This value does not be connected with turbulence effect and can correspond to irregular layered structures in the atmosphere. Only in 20 % of measuerements the spectral index p corresponds to developed turbulence in this height interval. It is shown that the RO method is effective for global monitoring of the small-scale irregularities in the atmosphere [16–19].

Analysis of the CHAMP RO measurements in the lower ionosphere indicated the connection of the geographical and seasonal distributions of the cases with strong amplitude variations of the GPS RO signals with solar activity [14, 15, 20]. Therefore it is shown the broad possibilities of RO method for comprehensive complex investigation of connections between solar activity and natural processes in the ionosphere and mesosphere and for global monitoring of irregularities in the ionospheric plasma [14, 15, 20].

The experimental investigation of the absorption of the centimeter radio waves by clouds and water vapor has been provided and the attractive potentialities of RO method for monitoring of the vertical distribution of water vapor and clouds has been demonstrated [21].

The problems and results of the remote sensing of media and space radio physics are considered and summarized in specialized monographs [22, 23].