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Satellite Monitoring System for the Krasnoyarsk Territory Area Based on Small Satellites Use

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The satellite monitoring system for the Krasnoyarsk Territory area is proposed. The main feature of proposed system is its implementation at three levels: space, low altitude and ground levels. Each level assumes the use of data compatible spectrophotometric equipment for subsequent integrated interpretation. The development of ground system for control, data acquisition, processing and distribution is assumed.

Keywords: monitoring system, small satellite, unmanned aircraft, imaging hyperspectrometer, Earth remote sensing, agriculture, forestry, inland waters, emergency situations, land, forest fires, floods, land utilization, predictions, ecology, biological productivity, man's impact.

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Система спутникового мониторинга территории Красноярского края на основе использования малых космических аппаратов

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Предлагается система спутникового мониторинга территории Красноярского края. Основной особенностью этой системы является реализация ее на трех уровнях: космическом, маловысотном и наземном. На каждом из уровней предполагается использование информационно совместимой спектрофотометрической аппаратуры для дальнейшей комплексной интерпретации. Предполагается разработка наземной системы управления, сбора, обработки и распространения информации.

Ключевые слова: комплекс мониторинга, малый космический аппарат, беспилотный летательный аппарат, видеогиперспектрометр, дистанционное зондирование земли, сельское хозяйство, лесное хозяйство, внутренние водоемы, ледовая обстановка, чрезвычайные ситуации, почвы, пожары.

Actuality

The Krasnoyarsk Territory area is characterized by the following main factors:

- large area;
- low population density;
- large quantity of natural resources;
- complexity of negative natural and anthropogenic factors dynamics fast control.

High potential existing in Krasnoyarsk Territory for development of various domains of human economical activity requires the application of appropriate technologies to control the processes occurring within this area.

The main feature of such technologies is the correspondence between applicable approaches and extension of the area, as well as speeds of processes occurring within this area.

At the present time such technologies could include the space methods for the Earth remote sensing and the up-to-date information technologies.

The space facilities could include:

- System of efficient spacecrafts applicable for registration of the Earth surface passive and active radiation in different ranges of electromagnetic spectrum.
- Space data acquisition system with data transmission to ground receiving centers.
- System of processed data storage and transmission to users: agriculture and forestry, Ministry of emergency situations, environmental services etc.

Main directions of satellite information technologies development

The main direction of information technologies development consists in development of methods of radiometric data interpretation to parameters applicable for end users.

At the present time there is a number of developments concerning the remote sensing systems for different areas. Some of them are quite specific topically and relate to a very particular direction, for example, forest fires direction. Some of them, generally, relate to territorial peculiarities of controlled objects, as for example, systems developed by Chinese colleagues. Some of the systems are general-purpose, such as those based on use of equipment similar to MODIS, and due to their generality not always take into account the territorial peculiarities.

On the basis of the above, the creation of space monitoring system which would take into account the peculiarities of Krasnoyarsk Territory, and capable of express timely data output for various consumers located within this area, could be considered quite actual objective. Such data type could be used by the Territorial Administration for management decisions, as well as by the Ministry of emergency situations systems, located in Krasnoyarsk Territory, for quick response to emergency situations, agricultural vegetation and silva status assessment etc.

Peculiarities of the Krasnoyarsk Territory area

The Krasnoyarsk Territory area is characterized by extremely diverse natural conditions connected with latitudinal peculiarities. These are plain regions in Khakassia border, boreal forests, forest-tundra and tundra, shelf zone in the North border of the Territory, water bodies of different types, deep-water storage basins, large and small lakes etc.

Each of these object types requires application of specific interpretation methods. Thus, it is evident that in order to take into account the territorial peculiarities and for on-line data access, the development of space monitoring system adapted to the region peculiarities represents the actual problem.

Such a system could be the system based on use of small satellites being developed in the JSC "Academician M.F. Reshetnev "Information Satellite Systems". The multichannel visible spectrum scanner and the scanner operating in infrared range could be used as a payload.

Problems in creation of the Krasnoyarsk Territory space monitoring system

- Possibility of unilateral data access stopping or restriction by the side of operator (owner) of the Earth remote sensing system space segment in case of political background change (due to use of foreign Earth remote sensing satellites by the Russian Ministry of emergency situations);
- Technological dependence of a consumer (for example, the Ministry of emergency situations structures) from a service provider (foreign operator representative at the territory of Russian Federation);
- At the present time the lifetimes of many domestic Earth remote sensing satellites in use are expired or will be expired in the near time;
- Lack of system approach or its limitation in the frame of acquisition, processing and distribution of the data being received during monitoring;

- Limitation of available space systems and unmanned aerospace systems (UAS) for surveillance which would allow providing the data on specified region with required quality and high accuracy;
- Limitation of available space instruments, UAS instruments, dedicated ground centers and mature technologies to process the hyperspectral images which would allow to obtain high-quality Earth remote sensing data;
- Limitation of possibility to obtain the high resolution images and dependence of their quality on shooting height and natural conditions;
- Limitation of shooting operationability and details which are required in specified conditions of data acquisition;
- insufficient operationability and frequency of the Earth remote sensing data obtaining for some regions of the Russian Federation territory;
- lack of possibility to observe the high-latitude regions of the Russian Federation territory in the real-time mode with high and average spatial resolution.

Three-level monitoring system features

The proposed space monitoring system will obtain the data on the Earth surface status in three simultaneous ways:

- obtaining the data from the Earth remote sensing small satellite (ERS small satellite);
- detailed shooting of required Earth surface areas using unmanned aircraft;
- use of the ground data collector system (GDCS).

Based on this approach the three-segment (multilevel) monitoring system (small satellite, unmanned aircraft, GDCS) will be developed.

It assumes technological development for obtaining high-quality data using imaging hyperspectrometer (30 channels), panchromatic channel (1) and infrared spectrometer (1 channel) accommodated on the small satellite.

The equipment operating on different segments will allow performing shooting of different Earth areas at different heights, performing calibration and integrated data processing. This approach provides wide surface coverage using the upper satellite segment (small satellite), on the one hand, and on the other hand, possibility of detailed study of detected deviations and particularly important objects using the segments of lower level (unmanned aircraft, DCS). There is a possibility to use not only the monitoring mode, but also to follow supposed changes of natural environment, to test prediction results etc.

The spatial resolution of modern optical-to-electrical systems of commercial spacecrafts reaches from 100 to 0,5 m, depending on carrier height and on-board equipment complexity.

Resolutions of images obtained from unmanned aircrafts can be measured in centimeters, the advantage is their use in any weather conditions (including under clouds). It is possible to use them for housing development control in population aggregates, in case of locality changes requiring prompt analysis, decisions and measures (locality seasonal changes, eg. flooded areas due to river flood etc.).

Based on integrated use of data being obtained from different shooting levels the common technology of processing these data will be created. The consequence of such approach is data quality improvement, as well as extension of its application field.

Thus, the conclusion is that the proposed three-level system will allow obtaining the high-accuracy data on the Earth surface objects in the real-time mode, which couldn't be obtained using the Earth remote sensing systems of Russian Federation known at the present time.

Structural units of the three-level system

The creation of small satellites is one of important trends of the world space technology progress. Their obvious advantages are small dimensions and relatively low cost, as well as possibility to implement a tandem launch of several small satellites, that still much more reduces costs for implementation of specific space project. The small satellites are irreplaceable for development of new engineering and technological solutions, scientific experiments performance, especially if they require a certain operationability, which is achieved due to reduction of the small satellite manufacturing time [1–3].

At the present time the JSC “ISS” performs the activities on creation of the advanced Earth remote sensing small satellite – “ISS-55” based on the multipurpose micro series space platform – “HT100-01”.

Small satellite creation objectives

The Earth remote sensing small satellite of high spatial resolution and multispectral shooting “ISS-55” is intended for multiregion remote sensing of the Earth surface for the purpose of:

- obtaining the high-quality images in visible and infrared ranges of electromagnetic spectrum;
- providing the on-line information transfer via radio channel;
- information processing and delivery to wide range of users.

The information obtained from the small satellite “ISS-55” could be used for performance of the following tasks:

- Monitoring of emergency situations: flood control and assessment of consequences, informational support management in emergency situations;
- Agriculture: inventory of agricultural holdings, identification of different types of crops, pedology, hydrology, meteorology, agricultural disasters prevention, yield prediction and agricultural potential analysis;
- Land utilization: topographic and subject mapping, urban extension monitoring, pasture observation, animals distribution and migration monitoring, land cadastres drawing up, natural resources cadastres drawing up;
- Forestry: forests destruction control, determination of afforestation types and dominant species, timber reserves assessment, forests mapping, quantitative assessment of standing crop, forestry, woodlands water regime monitoring;
- Water resources monitoring: ice and atmosphere interaction analysis, ice temperature and thickness measurement, detection and classification of snow cover areas, determination of snow cover characteristics, determination of snow water equivalent, groundwater indirect detection, flood monitoring, water quality control.

The small satellite “ISS-55” under development is based on the new multipurpose space platform – «HT100-01». This platform uses the active, triaxial attitude determination and control subsystem, the main loop of which is designed on the basis of star trackers and control drive wheels. Such an engineering solution allows using the satellites on the “HT100-01” platform basis to perform tasks of

high-accuracy shooting of the Earth surface in different optical and radio ranges, as well as to perform, if necessary, the satellite repointing for shooting of objects that are not covered by the satellite-covered area. The platform on-board subsystems are designed based on devices and equipment manufactured in Russian Federation. The platform provides creation of satellites with the launch mass of about 150 kg, and the payload mass in this case is not less than 50% of the satellite total mass, which completely conforms to the best world analogues.[4,5]

Main technical and functional performances of the small satellite “ISS-55”

The first small satellite «ISS-55» will not comprise the propulsion subsystem, on the subsequent small satellites the thermocatalytic Orbit control propulsion unit will be installed, that will increase the small satellite Lifetime up to 5 years.

The small satellite «ISS-55» in operational configuration is presented in Fig. 1.

The small satellite “ISS-55” can be launched into operational orbit by single launch (including concurrent launch), as well as by tandem launch as part of several small satellites unit.

Table 1. Main technical performances of the small satellite “ISS-55”

Parameter	Parameter value
Platform mass, kg	Up to 60
Payload mass, kg	Up to 75
Platform EPS power (mean per turn), W	Not less than 150
Embodiment	Unpressurized
Orientation type	3-axial, active
ADCS accuracy, deg.	
- roll	0,5
- pitch	0,5
- yaw	0,05
Attitude control accuracy with an error in each axis, deg./s	0,0004
Satellite turns velocity when performing the shooting scenarios, deg./s	1,5
Repointing angle, deg.	±45
Data transmission speed	
- along command radio line, kb/s	2,5
- along target radio line, Mb/s	10 (S), 120 (X)
Lifetime, years	1
Operational orbit height, km	450
Operational orbit inclination,°	97
Launch vehicles	
- single launch	LV «Start-1»
- tandem launch	LV «Angara-1.2», LV «Rokot», LV «Soyuz-2-1B»



Fig. 1. Small satellite «ISS-55» in operational configuration

Small satellite «ISS-55» payload equipment

The main equipment of the small satellite is the optical-to-electrical equipment (OEE) of high spatial resolution with resolution capability of less than one meter. In addition to main equipment for detailed observation the multispectral shooting system (MSS-M) of average spatial resolution with resolution capability of less than thirty meters is installed. It includes the Fourier-imaging spectrometer (FIS) and the Infrared shooting system (IRSS). Both equipment sets are developed and manufactured by the JSC “PELENG”, Republic of Belarus.

Multispectral shooting system (MSS-M)

The MSS-M should provide hyperspectral and panchromatic shooting of the Earth surface areas in visible and near IR spectrum ranges, target data generation, including video information and necessary overhead and telemetry information, as well as storage and transmission of generated data to the small satellite radio line (RL) [6].

The MSS-M should include:

- Fourier- imaging spectrometer (FIS);
- Infrared shooting system (IRSS);
- Control and synchronization unit (CSU);
- Interunit cables set.

The main technical performances of the MSS-M for specified shooting conditions are presented in the Table 2 [7].

Structurally, the MSS-M represents the base with two shooting systems (FIS and IRSS) and the CSU accommodated on it. The FIS and the IRSS are connected with the CSU by means of interunit cables.

FIS

The FIS consists of an optical module and an optical-to-electrical converter (OEC). The optical module of the FIS generates the Earth surface interference image in the photodetector plane of the OEC. The FIS optical module consists of an interferometer and a focusing lens. The interferometer provides interference image generation, and the focusing lens transfers the interference image to the

Table 2. Technical performances of the MSS-M

Parameters of the MSS-M	Infrared shooting channel	Panchromatic shooting	Multispectral shooting
Pixel projection to the Earth in nadir, m	30	15	30
Capture bandwidth in nadir, km	28	30	30
Spectral channels quantity	1	1	30
Operating spectral range, nm	1550-1700	450-900	450-900
Mass, kg	25		

Table 3. Main performances of the CSU

Parameters	Value
Memory, GB	24
Target data interface	RocketIO
Target data flow, Mb/s	150
Dimensions, mm	150×150×70
Power, W	18
Mass, kg	3

photosensitive plane of image receiver. The OEC converts the image into the video data digital flow and transfers it to the CSU. The FIS uses the CMOS photodetector of visible and near IR ranges.

The IRSS consists of an objective lens and an OEC. The IRSS represents the IR camera of 0,9 – 1,7 μm range. To generate the specified spectral range (1,55 – 1,7) the light filter is used. The photodetector is the InGaAs linear photodetector. The OEC of the IRSS converts the IR image into the video data digital flow and transfers it to the CSU.

CSU

The CSU is intended for MSS-M interaction with the satellite, FIS and IRSS control, video information reception from FIS and IRSS, video information storage and target information transmission to the satellite radio line. The main performances of the CSU are presented in the Table 3.

The MSS-M provides following states and modes of operation:

- initial state – the MSS-M switched-off (no power),
- ready state – the MSS-M switched-on, initialized and synchronized with on-board equipment. The MSS-M is waiting for a flight task array transmission;
- MSS-M data recording mode – the MSS-M performs shooting and data recording in the memory device of the CSU;
- MSS-M data output mode – the MSS-M performs reading of specified data from the memory device and transmits it to the RL;
- MSS-M service mode – to perform activities concerning MSS-M testing, memory load data reception from the satellite OCS, and other activities.



Fig. 2. MSS-M external view

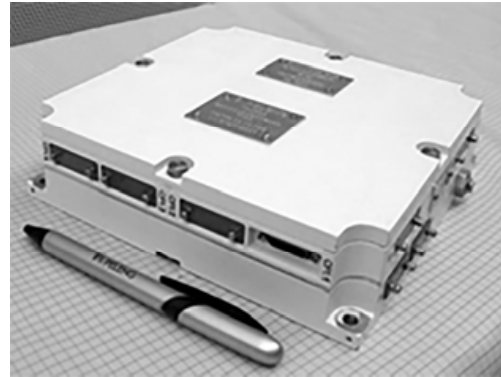


Fig. 3. CSU external view

The MSS-M external view is presented in Fig. 2, and the CSU external view is presented in Fig. 3.

The small satellite with on-board MSS-M shall perform the following tasks:

- Forests breed and age grading;
- Woodlands biological status monitoring;
- Ecological systems status monitoring (swamping, desertification, salinization, territorial pollution and their consequences);
- agricultural objects status evaluation;
- evaluation of the Earth surface hydrocarbon pollution level;
- basins ecological status evaluation;
- evaluation of coastline and sea coastal waters pollution;
- topographic mapping and maps updating.

Optical-to-electrical equipment (OEE)

The optical-to-electrical equipment for the small satellite should provide shooting of the Earth surface areas in visible spectrum range, in panchromatic and multiregion channels, target information generation (including video information, necessary overhead and telemetry information), as well as target information recording and storage in the memory device with following reading from the memory device and target information transmission to the target information transmission radio line [8].

The OEE should include:

- optical-to-electrical module (OEM) including:
 - objective lens;
 - two optical-to-electrical units;
 - objective lens housing, including mirror cube, electric heaters and temperature sensors.
- central processor unit;
- interunit cables set;
- MLI set;
- container set;

- operational documentation package.

The main technical performances of the OEE are presented in the Table 4 [9].

Description of planned activities

Development of concept, design principles and methods for unified space monitoring system including:

Earth remote sensing small satellite (intended for space monitoring of the Earth surface):

- module of service systems:
- on-board control subsystem;
- electric power subsystem;
- thermal control subsystem;
- attitude determination and control subsystem;
- propulsion subsystem;
- navigation and motion control subsystem;
- structure;
- mechanical devices;
- payload module:
- optical-to-electrical equipment (OEE);
- multichannel Fourier-imaging spectrometer;
- infrared equipment.

Unmanned aircraft (intended for monitoring of the Earth surface without distortions due to the atmosphere, with high spatial resolution):

- hyperspectrometer;
- data reception/transmission equipment;
- navigational equipment.

Ground data collector system (intended for obtaining spectral characteristics of ground objects):

Table 4. Main technical performances of the OEE

Parameter	Value
Spectral ranges number	
- in panchromatic channel:	1
- in multiregion channel:	3
Operating spectral range, nm.	
- in panchromatic channel:	450-900
- in multiregion channel:	450-690
Geometric resolution* in nadir shooting, not more, m	
- in panchromatic channel:	0,9
- in multiregion channel:	3,6
Capture bandwidth* in nadir, not less, km	7,2
OEM dimensions, not more (without MLI), mm	1490 × 745 × 520
Total mass, not more, kg	61 (with body mass of <25)
Lifetime, not less, years	1,0

- cross-country capacity vehicle;
- data reception/transmission equipment;
- small-size portable spectrophotometer.

Scientific and technical tasks and proposed approaches for their performance

- Development of general concept for unified multispectral monitoring system creation, for the Russian Federation regions, based on the three-segment system of satellites and unmanned aircrafts using the spectral measuring equipment, ground systems for data acquisition, processing and distribution to all administration levels.
- Analysis of structure of the Krasnoyarsk Territory and Russian Federation areas multispectral monitoring system based on the three-segment monitoring system.
- Feasibility analysis and deployment alternatives for the advanced multispectral on-line monitoring system to be used for the benefit of the Russian Federation regions taking into account its necessary integration with available ground segment for space data reception and processing.
- Development of on-line monitoring instrument based on the three-segment system of satellites and unmanned aircrafts using the spectral measuring equipment and ground data collector systems developed by industrial enterprises of Russia and Belarus.
- Development of ground spectrophotometric system using mobile vehicles and unmanned aircrafts for space data calibration and in order to perform autonomous tasks for the benefit of agricultural, forest and other subjects of economical activity.
- Development of ground infrastructure on the basis of leading research institutions for reception and processing of space and ground data.
- Implementation of data reception and processing natural experiment on the Krasnoyarsk Territory area in cooperation with research institutions of Belarus.
- Development of new software and algorithmic tools for target interpretation of satellite and ground data.

Purpose and fields of application of expected scientific (scientific and technical) result, way and activities to deliver the result to users

The Russian Federation area monitoring system being developed based on use of a small satellite with on-board imaging hyperspectrometer and infrared spectrometer will allow obtaining timely and up-to-date information on crops status and yield, land utilization status in agriculture, woodlands and herbage status, assessment of man's impact on natural complexes etc.

The obtained information will be received by interested institutions from the information reception and processing center via dedicated channels, and in case of public data – via the global network – the Internet.

The possible users of results of this activity are administrative bodies and subjects of economical activity.

The possible users are interested in obtaining the results of the activity, so the result will be requested without delay.

The developed system could be used as the educational basis in order to prepare the specialists in the Earth remote sensing domain.

The system being developed contributes to improvement of the Russian space industry competitive ability at the international market of the Earth remote sensing services.

The research results should be used in Russian Federation.

The possible users of services provided by the system being created:

Ministries and state departments of Russian Federation (Ministry of emergency situations,

- Ministry of Agriculture, Ministry of forestry, etc.);
- executive authorities in Russian Federation regions;
- regional centers of space services and information analysis centers;
- mineral resource industry enterprises , agricultural, forestry and fishery enterprises;
- separate organizations and private persons.

To implement the project the material and technical basis of the partners could be used, including the equipment of the Satellite Control Center of the SibSAU and the Branch resource center of collective use “Spacecrafts and space systems” of the SibSAU and the JSC “ISS”. As well as scientific results and developments obtained in the Institute of biophysics under Siberian Branch of Russian Academy of Sciences and presented in Fig. 4–6 [10–33].

The proposed research corresponds to the priority direction “Transport and space systems” and is a part of subject plan for research and development included in the Strategic Research Program of the technological platform “National Information Satellite System” (TP NISS) for the period from 2012 to 2020 years.

Conclusions

The paper presents the actuality of creating the satellite monitoring system for the Krasnoyarsk Territory area based on small satellites use taking into account its peculiarities connected with extension of the area and diversity of its natural complexes.

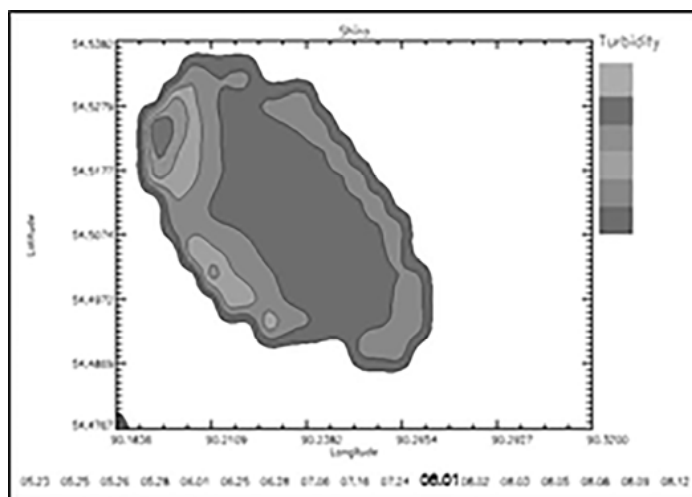


Fig. 4. Inland waters research. Turbidity dynamics in surface waters of the lake Shira (August scrap)

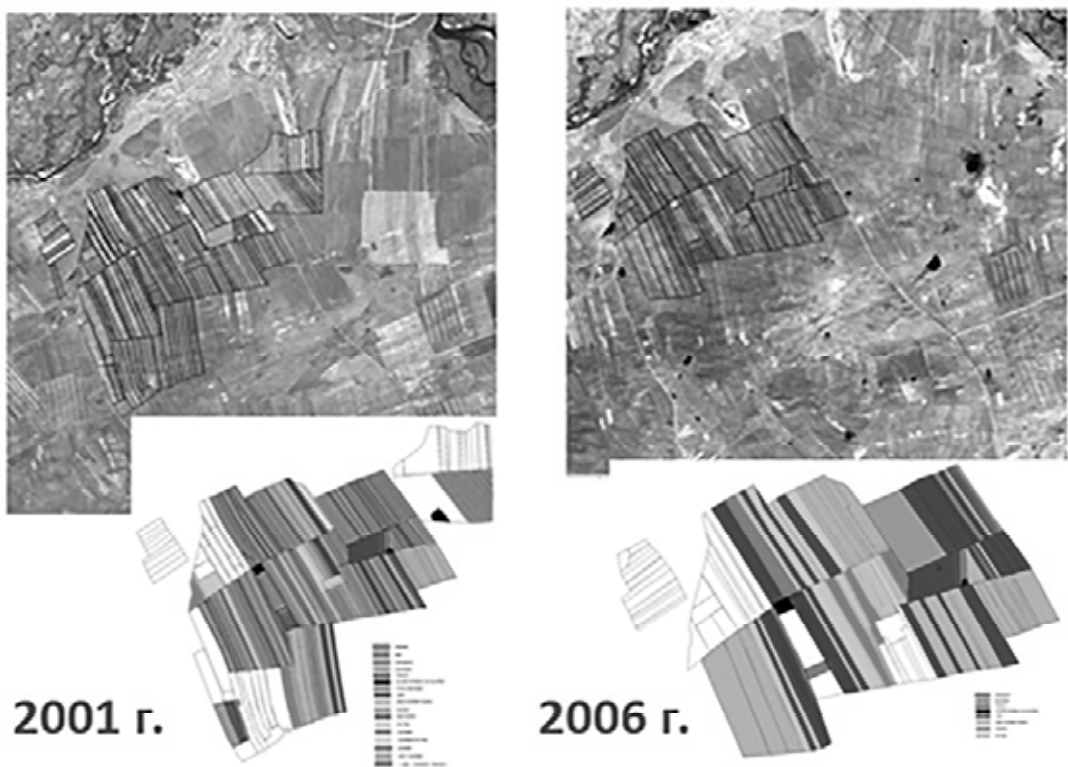


Fig. 5. Schematic maps of crop rotations for the region of Khakassia. Sets of successive images allow estimating the land utilization changes

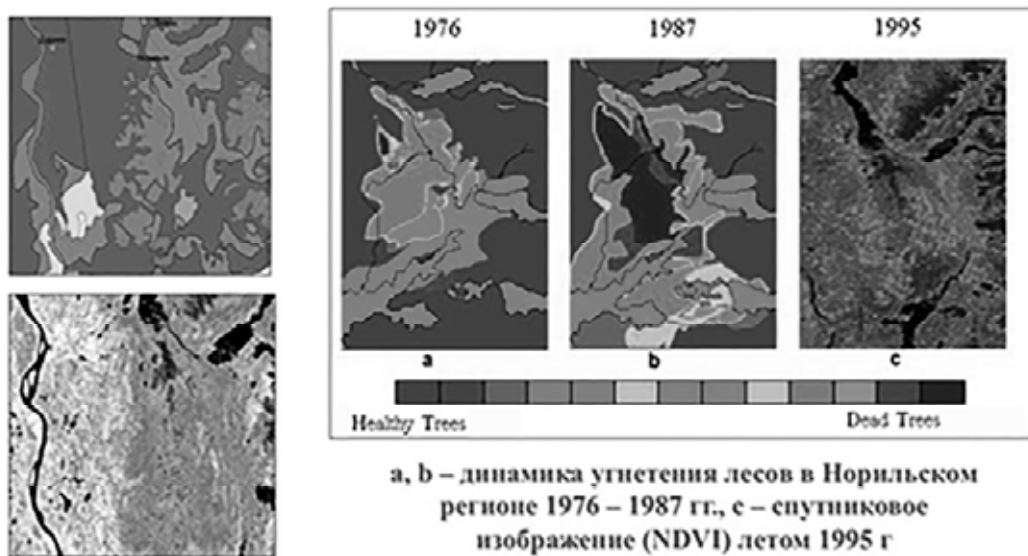


Fig. 6. Forests dynamics in the region of Norilsk. The obtained results include proper materials. Materials of prof. V. Kharuk (1976, 1987)

The scientific and technical problems being solved during the integrated space monitoring system creation are presented.

The necessity of three levels of the system is shown: space, low altitude, unmanned and ground calibration levels.

The paper presents the structure of tasks performed by the monitoring system for the benefit of different levels of the Krasnoyarsk Territory area subjects: administrative bodies, Ministry of emergency situations, forestry and agriculture, ecology etc.

The scientific and technical potential providing the creation of effective space monitoring system is shown.

The scientific potential providing the target subject processing of satellite data for use in different economic structures of Krasnoyarsk Territory is shown.

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