Digital Monitoring of the Environmental Situation of the Baikal Natural Territory

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Abstract

The paper presents the results of research obtained within the framework of a large scientific project "Fundamentals, methods and technologies of digital monitoring and forecasting of the ecological situation of the Baikal natural territory". The project is aimed at creating new methods and technologies for integrated environmental monitoring and forecasting based on digital platforms that collect, store, process, analyze large arrays of heterogeneous spatial and temporal data, as well as a set of mathematical and information models, services and machine learning methods and their validation for the Baikal Natural Territory.

Keywords

Digital monitoring, forecasting, digital platforms, web-services, machine learning

1. Introduction

The Baikal Natural Territory (BNT) is a complex natural complex, where Lake Baikal, recognised by UNESCO as a World Natural Heritage Site, is located. The ecological situation in the BPT is not favourable. Large cities and industrial centres located in the southern part of the BNT are sources of air, water and soil pollution, which in turn affects the health of the population. In addition to environmental problems of anthropogenic nature, there are dangerous geodynamic processes in the BNT (seismicity, landslides, rockslides, mudflows, etc.), as well as problems with the state of boreal forests (including epidemiological damage, spread of pests, natural fires, climate change, etc.). The development of means and methods of comprehensive geo-ecological control is an important task for the conservation of Lake Baikal ecosystem and the whole BNT.

A consortium of 16 institutes of the Siberian Branch of the Russian Academy of Sciences was formed to implement the project aimed at developing new methods and technologies for integrated environmental monitoring and forecasting based on digital platforms. Consortium members have extensive practical experience in studying changes in the hydrosphere, lithosphere, biosphere, atmosphere, human health under the influence of natural and anthropogenic factors, as well as in applying mathematical methods and information-computing technologies to solve complex scientific and applied problems.

In 2024, research continued in the direction of developing a set of methods, mathematical and information models for analysis and forecasting of the Baikal natural territory development on the basis of a digital platform, which will significantly accelerate scientific research due to intellectualization, interoperability of services and their compositions.

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2. Digital platform for environmental research

To implement digital environmental monitoring of the Baikal natural territory, the ISDCT SB RAS has developed a digital platform [1-3] (Fig.1), which unites researchers from scientific institutes, employees of departmental organizations and provides them with support for integrated analysis of monitoring data, forecasting and development of recommendations for the conservation of Lake Baikal and adjacent territories. Modern approaches to the creation of digital platforms [4, 5] are usually based on the use of service-oriented architecture (SOA) [6]. This architecture allows to implement a unified information environment supporting algorithmic mutually beneficial relationships of a significant number of independent participants of any process (e.g., environmental monitoring). Within SOA, each participant provides the results of its activity in the form of services, which allows instant access to data and processing methods without the need for coordination. SOA significantly speeds up research. To unify services in the digital platform, the Web Processing Service (WPS) standard [7], which regulates the service call protocol and metadata exchange, is used by the Open Geospatial Consortium [7].

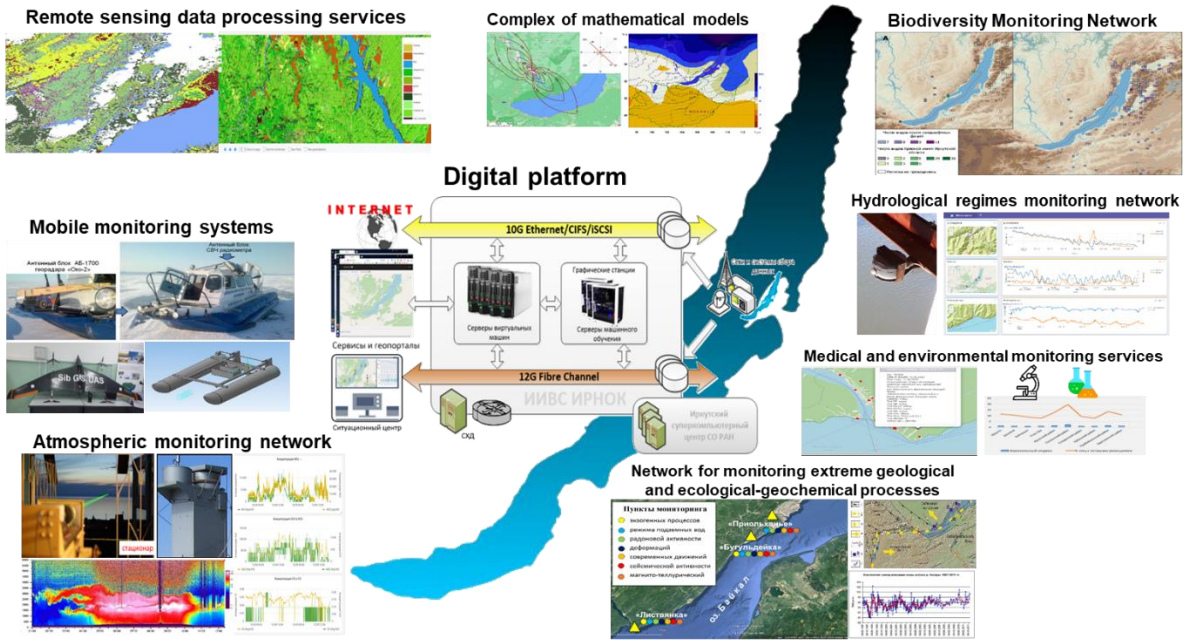

Figure 1: Digital platform for environmental research

The digital platform developed under the project acts as an integrating framework for digital environmental monitoring, is an environment for accumulation, exchange and management of data in a structured form, as well as a system for calling business functions with services of participants of the digital ecosystem (monitoring participants) connected to it through technological interfaces. The digital platform of environmental monitoring consists of three basic components: instrumental, infrastructural and application digital platforms. The Instrumental Digital Platform (IDP) provides access to the participants of the digital ecosystem of monitoring to the development and debugging of applied information and software-hardware, providing them with tool services for processing spatial and temporal data and their interfaces. The IDP includes tools for creating three main types of components embedded in a common environment:

1. development of WPS services and their compositions designed for software data processing, realizing software interoperability standards;
2. creation of data exchange services that provide and make available thematic data collection;
3. deployment of geoportals providing access to thematic data and services.

The IDP contains tools for creating generic geoportals and services in a cloud data center environment. Creation is based on pre-configured virtual machine templates. For WPS services there

are templates with Zoo project [8], 52°North Web Processing Service systems that simplify realization of WPS standard.

The Infrastructure Digital Platform (InfDP) provides the creation of applied hardware and software monitoring tools, thematic WPS services of data processing and distributed data storage based on a high-performance information and analytical environment, service-oriented and end-to-end technologies. The InfDP contains means of data delivery, processing, storage, as well as InfDP deployment infrastructure, services (software solutions based on PPI), means of development, debugging and integration of services. In order to solve the project tasks, a computing infrastructure is deployed on the basis of the IICN IREC [9], which provides all project participants with the ability to store large volumes of multiformat spatial and temporal data, high-speed access to them and the ability to perform high-loaded calculations. The infrastructure consists of a 10G-Ethernet-based high-speed data transmission network connected storage system based on Infortrend EonStor GS 1000 Gen2 (736 TB of capacity), high-performance storage system based on HPE MSA 2060 (27 TB of capacity), high-speed storage area network (SAN) operating on the basis of Fibre Channel 12G protocol, computing cluster of 15 servers with NVidia RTX- 3080, 3090 GPUs (for machine learning). On the basis of the main infrastructure components, using VMWare vSphere 7 virtualization system, a cloud platform was formed, consolidating network and computing resources with resources of data storage systems (network) and flexibly providing them for all systems and services of the project.

The applied digital platform (ADP) operates processed data at the level of a separate group or type of monitoring as a whole, as well as supports the algorithmic exchange of services between independent participants of the digital ecosystem using a unified information and analytical environment and technological infrastructure. The ADP consists of a digital monitoring geoportal, data provision services and thematic WPS services.

3. Monitoring technologies based on Earth remote sensing data

The project pays special attention to monitoring methods based on Earth remote sensing (ERS) data processing. A considerable amount of information has been collected: Sentinel-2 satellite images of the Irkutsk Region and the Republic of Buryatia for three years occupy more than 57 terabytes (21 thousand images). To organize a convenient search for space images and quick access to them, a remote sensing data catalog was created, a possibility to display images on the map and support for acquisition of space images of the Earth's surface from various sources was implemented. The images are stored in IICN IREC storage, their registration is performed by the developed data acquisition components. Image search with regard to sensor, cloud cover, position and date is implemented.

To organize environmental monitoring in large areas, a technology and Web-service (Fig.2) for classification of multispectral space images Sentinel-2 has been developed [10]. Classification of space images is carried out using the ResNet50 neural network. The technology allows to define a set of classes (surface types), prepare a training sample, verify and classify a large number of images. The training sample is generated using the Web interface based on Sentinel-2 satellite images and field surveys. As input data, the neural network accepts 13 Sentinel-2 channels and a channel built on the basis of local binary patterns to account for textural characteristics. Characteristic feature classes are identified for the BPT: Bogs, Bare Rock, Grassland, Clearings, Transitional Forest/shrubs, Coniferous Forest, Riparian Forest, Deciduous Forest, Mixed Forest, Clouds, Cropland, Residential Area, and Water. 134 space images of BNT were marked, the number of polygonal objects - 2246 pieces, the area of more than 5900 square kilometers. The average classification accuracy amounted to 95%. The developed Web-service allows to increase the efficiency of monitoring of large territories. Classification technology can be used to solve actual problems of large natural areas, in particular, to analyze changes in the forest fund (logging, fires, restoration dynamics), assess the impact of climate change on the landscape, analyze the dynamics of development, inventory of agricultural land, etc.

Figure 2: Example of the result of space images classification

4. Web services for environmental monitoring

The project has created a number of services that solve demanded tasks for the environmental monitoring of BPT. All services are implemented using the components of the instrumental digital platform and support the developed interfaces and data exchange services, which allows simplifying the integration of services and solving complex tasks. The developed services are embedded in the CP and can be applied by users for different tasks. Transaction costs, in this case time costs, are reduced due to the allocation of computing resources that are in constant access, reduction of human participation, standardization of the protocol of service invocation, etc. The created services realize modern methods of data processing and provide unique data of ecological monitoring of BNT. The following thematic services were developed to support digital environmental monitoring of the BNT and Lake Baikal:

- Monitoring service based on remote sensing data processing;
- Biodiversity monitoring service;
- Service for monitoring of hazardous geological processes;
- Atmospheric pollution monitoring service based on data from reference stations;
- Atmospheric pollution monitoring service based on Sentinel-5P satellite data (Fig.3);
- Thunderstorm activity monitoring service;
- Service for monitoring pollution of aquatic ecosystems;
- Service of forest fire risk analysis and forecasting;
- Service for registration of bites by ixodal ticks;
- Service for assessing the impact of forest fires on respiratory organs;
- Service of identification and assessment of changes in the state of vegetation cover;
- Service "Gas and aerosol impurities".
- Service "Generalized data of automatic atmospheric control stations"
- Service "Concentration of substances affecting respiratory organs"; Service "Concentration of substances affecting respiratory organs"
- Service "Atmospheric pollution index";
- Service "Catalog of earthquakes";
- Service "Fault Field";
- Service "Forest-pathological monitoring";
- Service "The burning of the forest";
- Service "Felling (forest)";
- Service "Phthalates content in water of Selenga River delta channels";

- Service "Level of pH (degree of acidity) in water by seasons";
- Service "Water turbidity by seasons of the year";
- Service "Dissolved oxygen content in water by seasons of the year";
- Service "Content of heavy metals in bottom sediments by seasons of the year";
- Service "Content of heavy metals in water by seasons of the year".

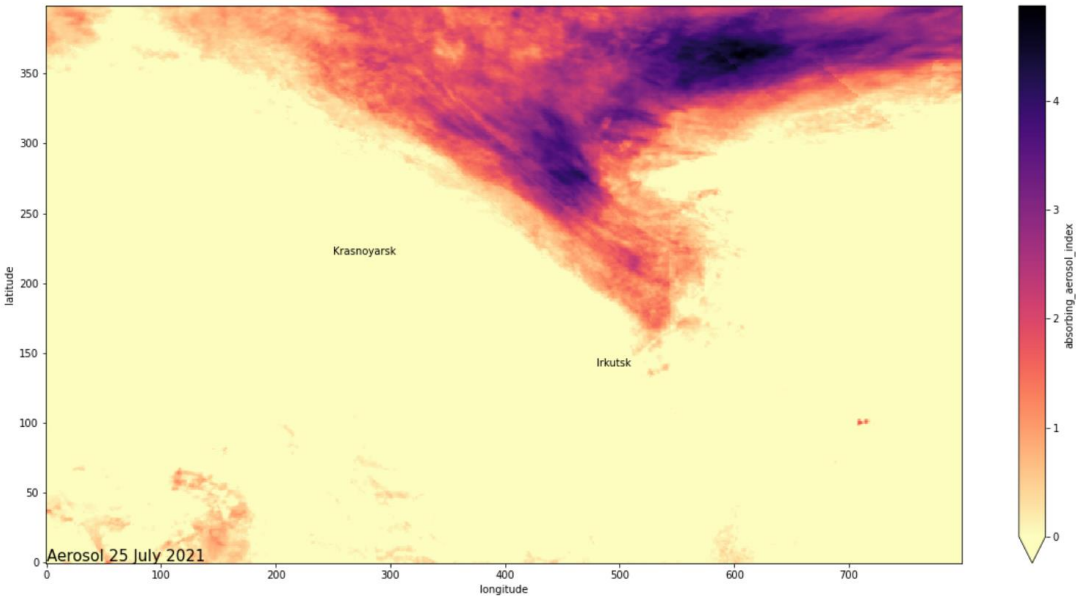

Figure 3: Example of the result of space images classification

5. Conclusion

The results obtained within the framework of the project are primarily of fundamental nature and open new opportunities in the field of development of digital technologies to support large-scale studies in large areas, processing of remote sensing data, mathematical modeling of environmental processes, monitoring and forecasting of natural and anthropogenic emissions in the atmosphere, monitoring and forecasting of hydrological regimes of water bodies, monitoring of dangerous geological processes, monitoring of biodiversity, medical and scientific research, and monitoring of biodiversity. The complex of program components is actively used in practice. More than 200 data services and more than 40 data processing services have been created. 5 different geoportals oriented to different subject areas and teams were deployed. Based on the created services, service compositions were formed, combining data services, processing and publishing services. The created digital platform for environmental monitoring of BNT is an environment for accumulation, exchange and management of data in a structured form, as well as provides the call of analytical functions with the services of participants of the digital ecosystem (monitoring participants) connected to it through technological interfaces.

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