Forest monitoring and analysis based on Earth observation data services

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Abstract. The paper presents an overview of thematic services providing Earth observation based products for forest monitoring. The authors analyzed both global and regional (in particular - Russian) forest services including input satellite data, output thematic products and features of data access. Based on gathered information, the main advantages and limitations of existing services were highlighted. The results of performed research confirm the need to develop the system integrating data from various forest remote monitoring services for the efficient and timely analysis of forests (especially - in cross border regions).

1. Introduction
To perform a reliable analysis of forests state, areal monitoring data are required, since, due to the continuity and complex mosaic of the forest cover, point observations do not provide the required amount of information. Today, one of the most effective methods of forest vegetation areal monitoring is Earth remote sensing (ERS) from space.

The main areas of using ERS for the forest cover analysis are:
- obtaining new data on the analyzed objects and (or) processes (including the use of remote sensing data as the only available source of information);
- obtaining additional information about objects and (or) processes in combination with other monitoring methods;
- verification of results obtained by other survey methods;
- using as a spatial (cartographic) basis for visualization of monitoring / analysis results.

At the same time, the amount of data used can vary from individual images and (or) thematic products created on their basis obtained for specific dates and intended for a one-time analysis of objects, to time series of images and (or) thematic products for object monitoring and analyzing the dynamics of changes over a period of time.

With regard to forest vegetation, existing ERS technologies allow observation in a wide spectrum of electromagnetic radiation with different spatial and temporal resolutions. Depending on the electromagnetic spectrum used for the analysis of forest vegetation, the following imaging techniques can be used:
- optical imaging using the light spectrum (visible, near and middle infrared), which allows obtaining the optical characteristics of objects (their spectral brightness);
• infrared imaging, which transmits the temperature characteristics of objects;
• radio imaging (microwave radiometric and radar).

Multi- and hyperspectral optical imaging is the most commonly used type of imaging, in which sounding is carried out simultaneously in several spectral channels. The difference is in the number of spectral channels used: from 3-5 to 12 for multispectral imaging to several hundred for hyperspectral imaging [1, 2]. However, this type of imaging has a significant limitation. It depends on the state of the cloud cover, therefore, even with a high frequency of surveys of a certain area, the total number of usable images (for example, for the summer season) may turn out to be significantly lower than the number of survey cycles performed. In addition, to solve most of thematic problems (including monitoring of forest cover), optical survey must be carried out in good lighting conditions of the investigated area. Unlike optical sensing, radio imagery provides data regardless of cloudiness and illumination of the Earth's surface (which is especially important for areas with a low percentage of sunny days). Thermal infrared imaging does not depend on lighting conditions; however, this type of sensing is hampered by the presence of cloud cover. Therefore, the joint use of various types of data is becoming more and more popular, which makes it possible to compensate for the individual disadvantages of individual methods [3-6].

In order to obtain the required characteristics of the forest cover from original satellite images, it is necessary to perform their preliminary processing (radiometric, atmospheric, and geometric correction, etc.), as well as thematic processing. Methods of thematic processing of remote sensing data for the purpose of monitoring and analyzing forest vegetation include:
• calculation of vegetation indices - combinations of values of spectral brightness coefficients in separate spectral channels (for optical data) or values of radio signal backscattering coefficients at different polarizations (for radar surveys) [7];
• various satellite images classification methods - dividing image pixels into groups (clusters) based on the similarity of spectral characteristics (with preliminary formation of training samples or without) [8-10];
• radar interferometry - processing of radar data time series to assess the dynamics of vegetation [11];
• radar polarimetry - processing of radar data obtained in different polarizations;
• polarimetric interferometry - a combination of interferometric and polarimetric processing of radar data [12];
• texture analysis of radar images - segmentation of radar images based on their texture features [13];
• joint analysis of data obtained in different spectral channels (data fusion) [3-6, 9].

The listed methods of remote sensing data processing make it possible to determine a wide range of qualitative and quantitative characteristics of forests: the biomass volume, stand density and height, crown diameter, species composition and forest age, as well as the dynamics of changes in these characteristics [14]. Based on remote sensing data, forest use is monitored, including identification of violation of forest legislation (areas of illegal logging). Space imagery is also used to monitor emergency situations, in particular, forest fires, often being the only available source of operational spatial data on the disaster area due to the impossibility or limited use of other observation methods (ground-based or unmanned aerial vehicle imagery).

Despite potentially high applicability of remote sensing data in monitoring and analysis of forest vegetation, the actual use of space imagery materials for solving specific practical problems is currently very limited. This is caused, first of all, by the existing difficulties in obtaining and processing space data, namely, the lack of convenient tools for automating the ordering, receipt and use of satellite remote sensing data. Today, for the effective use of space data, a specialist in the field of forestry, environmental management or emergency situations must have a high level of knowledge and a wide range of practical skills in the area of processing and interpreting imagery from space.
An effective way to bridge the current gap between the available volume of remote sensing data from space (and thematic information products built on their basis) and the end users (specialists from various fields of professional activity) is to develop tools that provide convenient access to space imagery materials and the possibility of simplifying them for solving specific practical problems. In this regard, one of the main trends in the development of remote sensing in general is the development of methods and tools for simplified access to data, the so-called thematic remote sensing services [15]. The article provides an overview and analysis of the most popular remote sensing services aimed at monitoring and analyzing forest vegetation.

2. Methods and Materials

2.1. Review of existing services in the field of forest management based on the use of remote sensing data

The main international services for monitoring and analyzing the state of forest vegetation are the following:

1. Copernicus Land Monitoring Service (CLMS) [16].
2. European Forest Fire Information System (EFFIS) [17].
3. Forestry Thematic Exploitation Platform (Forestry TEP) [18].
4. Fire Information for Resource Management System (FIRMS) [19].
5. Global Forest Change [20].
6. Global Forest Watch [21].

Copernicus Land Monitoring Service is one of the services for thematic use of remote sensing data, developed within the European program of global satellite monitoring Copernicus. The service is based primarily on data from European satellites: Sentinel, SPOT, and PROBA-V. Examples of thematic products obtained from space imagery for analyzing the state of vegetation are: Fraction of photosynthetically active radiation absorbed by the vegetation (FAPAR), Fraction of green vegetation cover (FCOVER), Leaf Area index (LAI), Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI), Vegetation Productivity Index (VPI), Burnt Area, etc. The products listed have global coverage. Data on forest cover density and forest type are also available for Europe, obtained from imagery of the Resourcesat-2, SPOT 4/5 and RapidEye satellites.

The European Forest Fire Information System developed under the Copernicus program is part of the Emergency management service (CEMS) [22]. EFFIS provides access to fire hazard class maps based on such indicators as: Fire Weather Index (FWI), Initial Spread Index (ISI), Build Up Index (BUI), Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), Drought Code, etc. The service also allows you to receive information about current fires and burnt areas, obtained from the MODIS and VIIRS satellite data. In addition to the results of satellite monitoring, the service provides data for forecasting fire hazardous weather: temperature and rain anomaly maps, the source of which is the European Center for Medium-Range Weather Forecasts (ECMWF) [23].

Forestry TEP is one of the platforms for thematic use of remote sensing data developed by the European Space Agency. This platform provides access to space imagery (Sentinel, Landsat), and also includes the following functionality: mapping vegetation changes using Sentinel-2 data; mapping vegetation types (land cover) using Sentinel-1 and Sentinel-2 data, the Random Forest algorithm and training sample; biomass assessment according to Sentinel-1 data; calculation of vegetation indices, etc. [18].

The Fire Information for Resource Management System was developed by the National Aeronautics and Space Administration (NASA) and provides access to operational and archived data on fires (hot spots) obtained from MODIS and VIIRS satellite imagery.

Global Forest Change provides access to maps showing the dynamics of changes in forest areas over the years and built on the basis of data from Landsat satellites [24].
Access to data from FIRMS and Global Forest Change is also carried out on the Global Forest Watch platform, which also includes data from the forestry ministries of a number of states, results of an analysis of the negative effects of forest decline, and other data [21].

Examples of Russian services are:
1. "Map of fires" [25].
2. "VEGA-Science" [26].
3. Information system for remote monitoring of the Federal Forestry Agency ISDM Rosleskhoz [27].
4. GIS "Cascade" [28].
5. Service TerraTech "Forestry Monitoring" [29].
6. "Service of hazardous natural phenomena" [30].

Service "Map of fires" was developed by SC "Scanex" and is a dynamic map of fires (in the form of hot spots) on the territory of Russia. The service is based on the use of data from MODIS satellites (product MOD14A1 Thermal Anomalies / Fire) and VIIRS. The global coverage of this data is provided by the aforementioned FIRMS system.

"VEGA-Science" is an information service developed by the Space Research Institute of the Russian Academy of Sciences (IKI RAS) and focused primarily on the analysis of vegetation on the territory of Russia and neighboring states. The service provides access to long-term archives of space imagery materials (from the Landsat, Sentinel - 1/2/3, MODIS-Terra / Aqua, Suomi - NPP, NOAA 20, Proba-V satellites) and the thematic products obtained on their basis. The latter include the results of calculating vegetation indices and their use for analyzing the state of vegetation; the results of analyzing the fire situation (points of occurrence of fires, size of burnt areas, etc.), maps of agricultural areas, maps of forests by prevailing species, etc. [14]. Also on the basis of "VEGA-Science" the development of the service "VEGA-Les" has been declared, intended for monitoring and analysis of forest cover (and including the basic functionality of "VEGA-Science") [31].

Technologies developed at the IKI RAS are also used in the Remote Monitoring Information System of the Federal Forestry Agency (ISDM-Rosleskhoz) for monitoring wildfires and their consequences [27, 32]. For this purpose, the system, along with ground and aerial observation data, uses space imagery from Landsat, Sentinel-2/3 / 5P, Meteosat, NOAA. MODIS-Terra / Aqua, “Electro-L”, “Meteor-M” “Resurs-P”, “Kanopus-B”. Among the open data of the system are: Landsat, MODIS-Terra / Aqua and "Meteor-M” composite images, maps of forest and non-forest fires based on MODIS-Terra / Aqua and VIIRS-NPP data, daily summary report on forest fires (thermal anomalies) based on the results of space monitoring, cards of individual fires, etc.

GIS "Cascade" is a system for space monitoring of emergencies of the Ministry of Emergencies of Russia, providing data on fires (forest and non-forest), while the FIRMS service is used as one of the sources. For a number of territories, thematic products are available, including data on hot spots combined with images from the Terra / MODIS satellite.

"Forestry Monitoring" is one of the branch geoinformation services, the development of which has been announced by the Russian company "TerraTech". According to the developer company, the service is aimed at providing industry-specific information to forestry organizations for monitoring forest use and identifying changes in the forest fund (clear-cut areas, fires, windfalls, dead stands).

The possibility of obtaining data on fires, confirmed by the Ministry of Emergency Situations, and on hot spots detected by satellite data, is also declared in the Service of Natural Hazards, the developer of which is Space Communications LLC together with Russian Space Systems JSC [30].

3. Results and Discussion
Analysis of existing solutions in the field of thematic remote sensing services showed that such systems and services have the following main advantages:

- areal nature of data, efficiency and regularity of their delivery (in comparison with the results of ground monitoring);
- possibility of obtaining ready-made thematic products without the need for additional processing (as opposed to services that provide satellite imagery source materials);
possibility of obtaining data in an automated / automatic mode based on web technologies and using standard protocols (in comparison, for example, with the results of ground monitoring). However, there is a number of restrictions on the use of these services:

1. Spatial coverage of thematic products (for Russian users): for example, a significant part of Copernicus services cover predominantly the territory of Europe (in some cases, including the European part of Russia).
2. Limited access to a number of services (for example, Copernicus Emergency Service).
3. Limited set of tools for working with data: most services provide, as a rule, access to data without the possibility of additional processing on the site of the service itself. To use platforms with an extended set of functions and tools (Thematic Exploitation Platforms (TEPs) [33], Copernicus Data and Information Access Services (DIAS) [34], Copernicus Research and User Support (RUS) Service [35]), the user needs special knowledge and experience in the analysis and interpretation of remote sensing data and application of GIS technologies.
4. Limited opportunities for sharing data from Russian and foreign satellites: despite the fact that Russian services provide access to data from space agencies of other countries, and, in particular, to data from Sentinel and Landsat satellites, there are no tools for their integrated processing.
5. The lack of integrated processing of remote sensing and other heterogeneous data (for example, the results of ground observations, surveys from UAVs, modeling, etc., including data from other thematic services).
6. Not all services offer the possibility of automated data retrieval (in particular, Russian ones).
7. Difficulties in working with data due to complicated interface of the services themselves.

Thus, despite the constant improvement of thematic remote sensing services in general and in the field of forest management in particular, most of the issues related to delivery of thematic data required for the forest cover analysis to the end user remain open. The key problem is integration of various data sources (based on remote sensing services or their use) for a comprehensive analysis of the forest cover. In this regard, the urgent task is to develop systems for simplified interaction with remote sensing data providers and thematic products built on the basis of such data (including joint analysis of heterogeneous data).

This confirms the relevance and timeliness of the InnoForestView project within the framework of the South-East Finland – Russia cross-border cooperation program 2014-2020 [36], aimed at the development and implementation on the Russian and Finnish sides of a unified innovative information system designed to solve the problems of analysis and forecasting the consequences of the impact of negative natural and anthropogenic factors on forests in the border areas.

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