

Landsat imagery evidences great recent land cover changes induced by wild fires in central siberia^{*}

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Abstract. The article discusses the methods of satellite image classification to determine general types of forest ecosystems, as well as the long-term monitoring of ecosystems changes using satellite imagery of medium spatial resolution and the daily data of space monitoring of active fires. The area of interest of this work is 100 km footprint of the Zotino Tall Tower Observatory (ZOTTO), located near the Zotino settlement, Krasnoyarsk region. The study area is located in the middle taiga subzone of Western Siberia, are presented by the left and right banks of the Yenisei river.

For Landsat satellite imagery supervised classification by the maximum likelihood method was made using ground-based studies over the last fifteen years. The results are the identification of the 10 aggregated classes of land surface and composition of the study area thematic map.

Operational satellite monitoring and analysis of spatial information about ecosystem in the 100-kilometer footprint of the ZOTTO tall tower allows to monitor the dynamics of forest disturbance by fire and logging over a long time period and to estimate changes in forest ecosystems of the study area. Data on the number and area of fires detected in the study region for the 2000-2014 received in the work. Calculations show that active fires have burned more than a quarter of the footprint area over the study period. Fires have a significant impact on the redistribution of classes of land surface. Area of all types of vegetation ecosystems declined dramatically under the influence of fires, whereas industrial logging does not impact seriously on it.

The results obtained in our work indicate the highest occurrence of fires for lichen forest types within study region, probably due to their high natural fire danger, which is consistent with other studies. The least damage the fire caused to the wetland ecosystem due to high content of moisture and the presence of a large number of fire breaks in the form of open water.

Introduction

Currently it is considered that one of the main factors of the Earth climate warming is the increased concentration of greenhouse gases in the atmosphere, including carbon dioxide (CO₂). Siberian ecosystems, comprising about 1/5 of the world's forested area, are the most

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powerful reservoir of carbon and play an important role in the global carbon cycle affecting the Earth's climate [1].

Forest fires as an integral factor of forest ecosystem dynamics make a significant contribution to carbon emissions into the atmosphere. During the last few decades the incidence of fires in boreal forests has increased [2]. A number of studies forecast a further increase in fire frequency due to global climate change [3-5]. Thus, an important task is evaluation of changes in the atmosphere caused by CO₂ emissions from forest fires.

This problem can be solved by integrating data from atmospheric research, ground-based observations and remote sensing. This work is part of research where joint analysis of following data is performed: state of the atmosphere obtained on the ZOTTO international observatory measuring mast; field studies for the mast coverage area; status of the underlying surface defined by satellite images.

The paper deals with the classification of satellite images to determine the main types of the underlying surface that have similar characteristics of the phytomass carbon stock, as well as analysis of long-term dynamics of the forest ecosystem status for the study area.

The study area is determined by the location of the ZOTTO international observatory (302 m height), which is installed near the Zotino settlement (Krasnoyarsk region territory, 60°48'N 89°21'E). Continuous monitoring of the greenhouse gas concentrations, radiation and meteorological parameters in the surface layers of the atmosphere are conducted at the measuring mast. [6]. The area of interest of this work is 100 km footprint of the ZOTTO. The study area is located in the middle taiga subzone of Western Siberia, are presented by the left and right banks of the Yenisei river. Major factors affecting forests in this area are wild fires and deforestation.

Classification of satellite images

Landsat ETM+ multispectral satellite imagery obtained during the 2000 vegetation period were used to identify the main types of the land surface. All Landsat images passed standard pre-processing including radiometric and geometric correction. Classification of satellite images for mapping land cover types is one of the main applications of remote sensing data [7]. Joint use of satellite and ground-based data improves the classification accuracy and allows to more accurately determining the spatial location of land cover types [8].

For Landsat imagery supervised classification by the maximum likelihood method was made. The maximum likelihood method is the most commonly used and most accurate for mapping the underlying surface [9]. As training sample for supervised classification were used ground data collected during field work in the years 2000-2014. These data consist of 350 permanent plots located in the most representative sites of forest stands. For these plots using the methods of enumerative inventory were specified characteristics of forest stands as well as based on these data body wood and wood-waste carbon content was calculated. All ground-based data is stored in the information system Forest, consisting of DBMS, GIS and the web server, enable remote data access at <http://forest.sfu-kras.ru> [10, 11].

The total area of the study is 3140 hectares. As a result of satellite data analysis for the ZOTTO footprint were specified 10 aggregated classes of land surface. Thematic map of land cover of the study area was obtained based on these classes. It was found that the forested area is about 76% of the study area. In 2000, a dominant position on the investigated territory is occupied by dark coniferous forests (spruce, fir, cedar forests) – 48 %. Deciduous forests (birch and aspen), formed on the felling and burned areas cover 12 % of the territory. About 16% of the study area is the pine biogeocenosis, represented by lichen and moss pine forests.

Wetland ecosystems occupy 11%, recent felling and scars occupy 3 and 5 % of the territory, respectively.

Monitoring of forest ecosystems

Satellite data of medium spatial resolution are widely used for forest ecosystems monitoring [12, 13]. In our work to study long-term changes in vegetation cover, we used Landsat ETM+, TM and OLI images. More than 20 scenes obtained from Landsat series satellites in the period from 2000 to 2014 were used. Distinctive feature of the Landsat program is the inheritance of spectral bands that provides continuity and compatibility of data obtained by different satellites of the Landsat series during the entire period of the program.

Identification of the felling and fire scars based on the values of spectral brightness of the Landsat images. As it is known, the change in the physiological status of vegetation leads to changes in their spectral characteristics [14]. This is achieved by reducing the absorption of sunlight by chlorophyll, and as a result, an increase in reflectance in the visible region of the electromagnetic spectrum. As well leaf tissue damage leads to lower reflectance in the near infrared region [15, 16]. These properties of vegetation are used for interpretation of satellite images.

When identifying forest areas damaged by fires, used the following criteria: spectral characteristics in the visible and infrared bands on the post-fire Landsat image; spatial features (presence of sharp boundaries); the presence of active fire polygons (hotspots) in the archive of the Krasnoyarsk center of space monitoring. The polygons of the active fires are calculated daily during the fire season by Terra, Aqua/Modis satellite data. For the detection of active fires threshold algorithm of Kaufman, based on the specifics of the fire radiation in the middle and far infrared range is used [17].

Results

Table 1 presents data on the number and area of fires detected in the study area over the years 2000-2014. As can be seen from table 1, the total area damaged by fire during the period of study is 852 560,28 ha. Some areas were affected by fire more than once. After excluding this areas the total area damaged by fire decreased to 830 037,61 ha. Thus, over the past 15 years, the fire damaged about 26% of the study area.

Table 1. The number and total area of fires in the years 2000-2014

Year	Area, ha	Number of fires
2000	8 025,12	3
2001	702,00	1
2002	0	-
2003	2 133,83	3
2004	6 606,16	8
2005	1 610,27	4
2006	73 412,47	22
2007	467,50	2
2008	653,60	1
2009	0	-
2010	0	-
2011	18 271,99	18
2012	711 063,53	33

2013	23 708,90	8
2014	5 904,91	9
Total for 2000-2014	852 560,28	112

As shown in table 1, two peaks of fire activity during the study period were observed, in 2006 and 2012. During the 2006 fire season more than 2% of the study area was damaged by fires, and 23% was damaged in 2012 fire season. Fires occurring in the last 15 years have made a significant contribution to the structure of forests and have led to an appreciable change of space occupied by vegetation ecosystems at the study area.

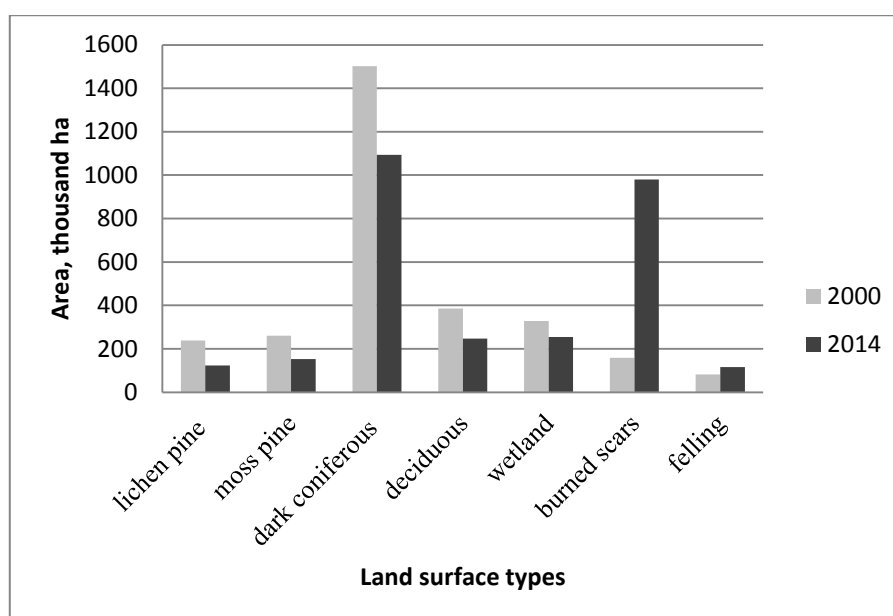


Figure 1. Changes in the ecosystem structure in 2000-2014 over the study area

As can be seen from figure 1, the area of burned scars for the investigation territory significantly increased in the period from 2000 to 2014 and has reached 980 thousand hectares. The area of felling has increased from 82 to 117 thousand hectares. Area of all types of vegetation ecosystems have declined: for lichen pine forests from 239 to 123 thousand hectares; for moss pine forests from 260 to 153 thousand hectares; for dark coniferous from 1502 to 1094 thousand hectares; for deciduous from 386 to 248 thousand hectares; for wetland ecosystems from 328 to 255 thousand hectares. Maximum numerical reduction is observed for dark coniferous, are dominant for this territory.

Conclusions

Thus, operational satellite monitoring of the investigated territory enables to assess the dynamics of forest disturbance by fire and logging over a longtime period and to estimate changes in forest ecosystems caused by these disturbance. In the course of the work were defined 10 significant classes of the underlying surface within ZOTTO 100 km footprint. Thematic map of the study area was composed by means of Landsat images supervised classification with the help of field data. Based on satellite data, it was found that the area of fire scars over the study period (from 2000 to 2014) has increased significantly, and currently is about 30% of the territory. Industrial logging does not cause significant damage to forest ecosystems of this territory: the total area of the felling at the moment is about 4%. The

reduction of the area of all vegetated ecosystems was detected: lichen pine forests had lost 49% of its original area; moss pine forests – 41%, deciduous forests – 36%, dark coniferous forests – 27% and wetland ecosystems – 22% of their original territory.

It is known that the burning of forests is influenced by a number of factors such as forest type, stand age, moisture, wind speed, etc. [18, 19]. The results obtained in our work indicate the highest occurrence of fires for lichen forest types within study region, probably due to their high natural fire danger, which is consistent with other studies. The least damage the fire caused to the wetland ecosystem due to high content of moisture and the presence of a large number of fire breaks in the form of open water.

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