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APPLICATION OF REMOTE SENSING DATA FOR THE ASSESSMENT OF THE UJUK MOUNTAIN BOREAL FORESTS (THE TYVA REPUBLIC, RUSSIA)

ABSTRACT. This paper discusses some issues related to assessment and monitoring of forests in southern Siberia. This study aims to evaluate the response of southern boreal forests to climate warming at local scale. Estimating the impacts of climate change on mountain boreal forests requires a more complete accounting of tree growth/climate interaction. We used both remote sensing and field data. Field measurements were made from the upper to lower timberline of dark deciduous forest in 2005 and 2012. The remote sensing datasets were generated from LANDSAT scenes of different dates (19.08.1988, 25.06.1992 and 18.08.2011). For estimation of forests changes, we used values of NDVI (Normalized Difference Vegetation Index) and NBR (Normalized Burn Ratio).

KEY WORDS: climate change, mountain forests, cedar sapling, wildfires, boreal forest dynamics.

INTRODUCTION

Tyva is situated within the boundary latitude of boreal forests in the southern part of Southern Siberia Mountains. The forests are located in a transitive zone between the boreal and arid zones, and present great interest for study. These boreal forests represent a unique natural biome; they are located in mountain chains and are composed of cedar or mixed larch-cedar stands.

Mixed-conifer forests are common throughout the mountain zone. Landscape plays an important role for trees survival under harsh climatic conditions. North-facing slopes have closed-canopy Larch (*Larix sibirica Ledeb*.), Siberian Pine (*Pinus sibirica Du Tour*), and Spruce (*Picea obovata Ledeb*.) stands; whereas south-facing slopes have more open Larch (*Larix sibirica Ledeb*.) stands. For mountain forests of Tyva, cedar forests have crucial importance in the formation of stable mountain forest ecosystems and they perform very important ecological functions (climate-controlling, water-regulating, anti-erosion, and soil-protective) in the specific conditions of the Central Asia.

The most important feature of the modern climate is global warming. Climate warming is detected from meteorological observations. This paper discusses some issues related to changes in the vegetation cover occurring under the influence of current climatic trends a forecast for its dynamics in boreal forest. Assessment of the impacts of climate change on mountain boreal forests requires a more complete accounting of tree growth/climate interactions.

Specifically, this paper discusses some issues related to changes in the vegetation cover occurring under the influence of current trends of climate change and its dynamics of the Ujuk Mountain range.

MATERIALS AND METHODS

Study area

The test area is located in southern boreal forests in Central Tuva (Fig. 1). The Ujuk Mountain range is the southern branch of the Western Sayan Mountains. Larch (*Larix sibirica*) and Siberian Pine (*Pinus sibirica*) cover most of this mountain range, however other Spruces (*Picea obovata*) can also be found in patches in the area. Deciduous stands such as Birches (*Betula pendula, Betula microphylla*) and poplar (*Populus laurifolia*) cover the areas at lower elevation. The forests represent a low-height (15 m), woody vegetation ecosystem at the dry timberline (285 mm mean precipitation). The sample plots of the transect were established at randomly selected sites of varying altitudes (900 and 1700 m a.s.l.). Within the study sites, forest types are confined to a fairly definite range in elevation, including a narrow belt consisting of Larch and Birch (900–1200 m) and light and mixed coniferous (1200–1400 m) and dark-coniferous species (1400–1700 m). The complex relief of the mountains causes strong climatic contrasts between the sunny and dry south-facing slopes and the shaded and wetter north-facing slopes. Increase of active temperature has been an important factor for mountain coniferous forests growth in the recent decades.

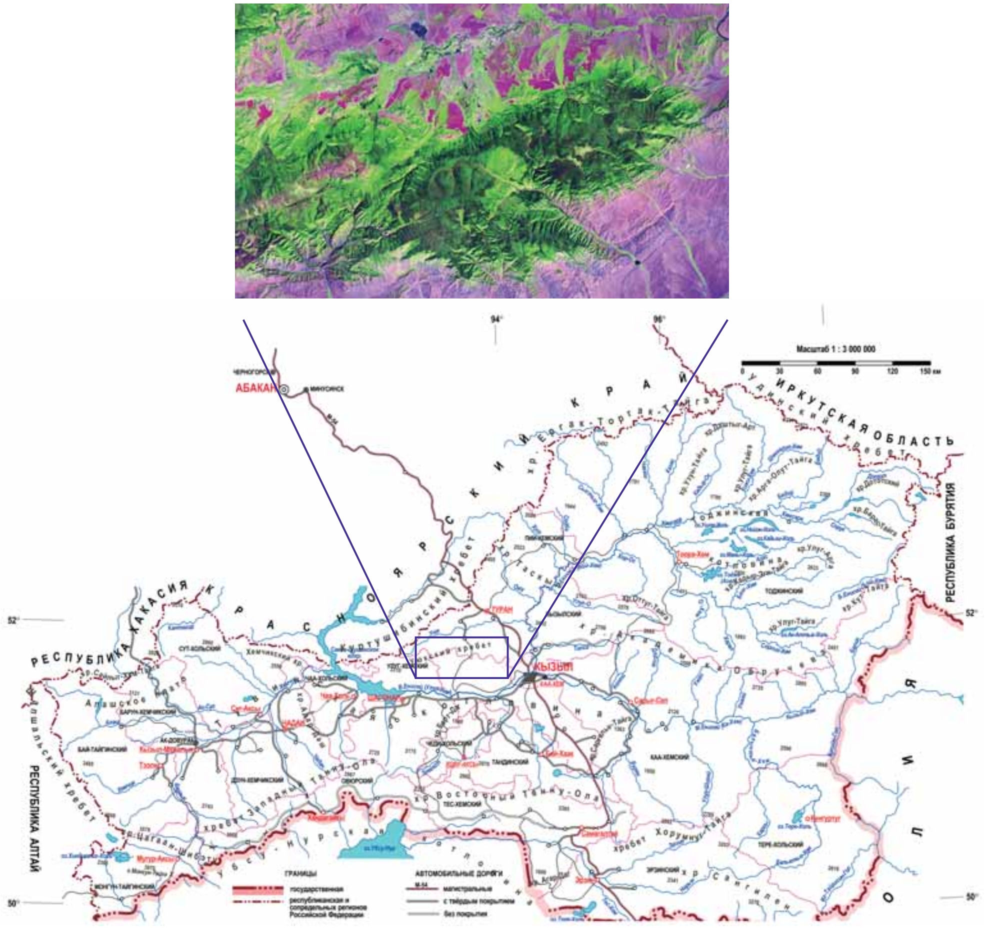

Fig. 1. Location map of study area — Ujuk Mountain range. Map of the Republic of Tyva: based on the [Atlas..., 2005]

Meteorological data were obtained from the Turan station (52.15°N, 93.92°E, 862 m a.s.l.), the annual total precipitation is 306 mm (near of the Ujuk Mountain range). Mean annual temperature is –4.1 °C with sharp seasonal and daily fluctuations. The mean temperature of the coldest month of January is –29.8 °C. The temperature of the hottest month of July is +16.9 °C. Precipitation is about 300 mm per year depending on altitude and mainly falls in summer (70 %).

According to the Turan weather station, the sum of effective temperature (ΣT > 5 °C) was 2178.9 °C and active temperature (ΣT > 10 °C) — 2017.1 °C in 2011–2013. The sum of effective temperatures was 1841 °C and sum of active temperatures — 1487 °C according to "Types of mountain forests of Southern Siberia" (1980).

Methods

Remote sensing method. LANDSAT multispectral images represent an important tool for analysis, estimation, and monitoring of boreal region forests. LANDSAT–5, 7 (TM/ETM +) satellite images were used in this study. Free-of-charge satellite images were obtained from the GLCF (Global-Land-Cover-Facility) homepage: http://www.glcf.umiacs.edu/data/. The satellite images were taken on 19.08.1988, 25.06.1992 and 18.08.2011.

Vegetation Indices (VIs) represent combinations of surface reflectance at two or more wavelengths designed to highlight a particular property of vegetation. The Normalized Difference Vegetation Index (NDVI) is one of the most frequently used VIs. NDVI was calculated for the study area. This index was applied to monitor the quality of the environment and its changes. NDVI is defined as the ratio of the difference between the spectral reflected near-infrared band and visible band and the sum of both (Rouse et al., 1974):

$$NDVI = NIR - RED / NIR + RED,$$

where NIR and RED are the spectral values of the two channels of the LANDSAT range reflected in the near-infrared and red parts of the spectrum, respectively. The main feature of the NDVI index is that it allows identifying areas with problem vegetation. The forest dynamics was successfully traced by satellite imagery taken at intervals of several years.

In the process of determination of the boundaries of the burned areas, we have used the Normalized Burn Ratio (NBR) to assess the areas of fire. NBR (LANDSAT imagery) was used to highlight the burned areas and to index the severity of a burn. The formula for the NBR is very similar to that of NDVI except that it uses the near-infrared and the short-wave infrared 2 spectrums (Key, Benson, 1999):

$$NBR = NIR - SWIR2 / NIR + SWIR2,$$

where NIR and SWIR2 are the spectral values of the two channels of the LANDSAT range reflected in the near-infrared and medium infrared part of the spectrum, respectively. For a given area, NBR is calculated from an image just prior to the burn and a second NBR is calculated for the image immediately following the burn. The burn extent and severity is assessed by taking the difference between these two index layers:

$$\Delta NBR = NIR_{prefire} - NIR_{postfire}.$$

Field method. Traditionally, forest dynamics monitoring is performed with the help of field studies. Our field measurements were made from the upper to lower timberline of dark deciduous forest in 2005 and 2012 (Fig. 1a). We used the monitored sample plots in the transects. The sample plots of the transects were established at randomly selected sites of varying altitudes (between 900 and 1700 m a.s.l.).

From four to eight plots were established every 100–400 meters in each altitudinal interval. To identify the pattern of shoot elongation, cedar saplings were sampled in about 100 plots across the transects. The height growth patterns of cedar saplings at the low and upper dark-tree line and the below and above the dark-tree line boundaries were examined over their life span, using leader shoot elongation measurements.

RESULTS AND DISCUSSION

Satellite imagery integrates changes in all parts of the range; therefore, at least some field assessment is usually necessary. The ground-based data on cedar saplings at below of the low and above of the upper boundaries of dark coniferous forests were examined, using leader shoot elongation measurements. The annual shoot elongation measurements of cedar saplings show that good elongation (5–13 cm) is observed in the lower part of forest at 980–1200 m a.s.l.; at 1200–1400 m a.s.l. it is 3–10 cm; and at 1400–1680 m a.s.l. the average growth is 4 –11 cm (Fig. 2a). The annual shoot elongation of cedar saplings decreases with the increase of the elevation of the mountain range (r2 = 0.3; p = 0.0024). The average age of saplings is 21 yrs and the maximum is 49 yrs, which coincides with the beginning of climate warming in the region (Fig. 2b). Negative impacts of climate warming were recorded at 1300–1680 m a.s.l. in wet exposures (eastern, northern, northeastern), where the boreal forest does not have time to adapt to the new moisture conditions, which leads to it is being covered with lichen, thus, leading to oppression.

To detect changes below the low and above the upper dark-tree lines, we carried out calculation of the normalized vegetation index NDVI images. Image differencing (dNDVI) is one of the most accurate methods of change detection. Figure 3 presents the NDVI images for 19.08.1988 (a), 25.06.1992 (b), and 18.08.2011 (c). A lighter area stands out on the dNDVI image (Fig. 3d) surrounded by the dark strip on the lower part of the northern macroslope of the range, which corresponds to the expanding cedar saplings below the coniferous forests. The NDVI values corresponding to the expansion of the lower dark-tree line are 0.2–0.3. The width of the zone of expansion ranges from 0.6 to 2.3 km. White tones correspond to the areas with altered vegetation; in the central part of the range, burned areas clearly stand out (a white

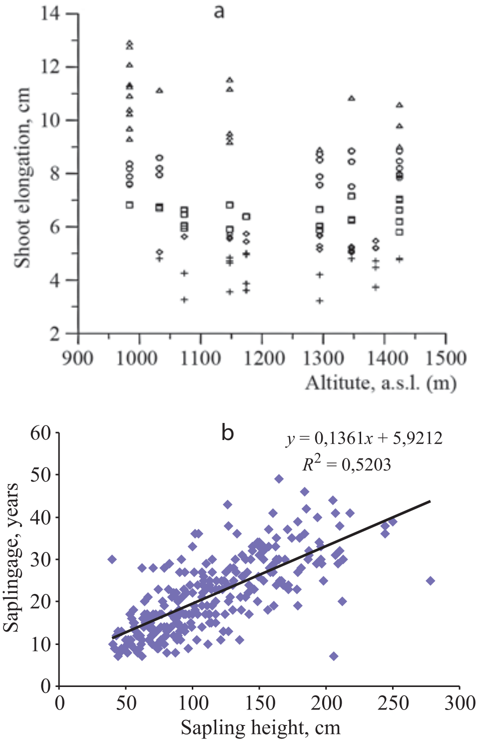

Fig. 2. The dependence of the (a) shoot elongation on altitude and (b) the age of cedar sapling on height

spot in the middle of the range). The results also indicate negative trend values of NDVI. In 2011 (Fig. 3c), the forests' area decreased in proportion to the burned area.

However, NDVI is inaccurate where fires occur after vegetation has died as well as in the areas that had little vegetation before the disturbance. The NBR differencing bands NIR and SWIR2 have high accuracy in detection of forest harvest. The difference between pre-fire and post-fire NBR is now the primary method for mapping large remote burned areas.

Figure 4 presents a collection of the NBR images for the years 19.08.1988 (a), 25.06.1992 (b), 18.08.2011 (c), and dNBR (d), where the boundaries of burned areas are clearly distinguished. The autumn of 2007 was marked by extreme heat, drought, and disasters brought by nature fires (forests, steppe, and tundra). Therefore, due to wildfire, forest areas had a marked decrease.

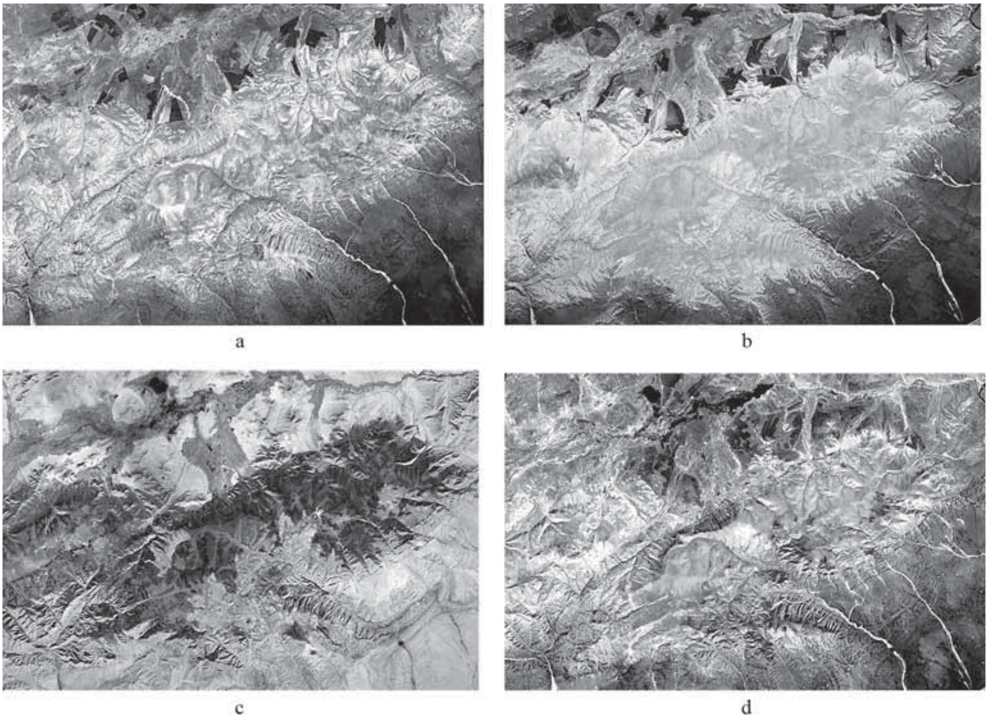

Fig. 3. The NDVI images: 19.08.1988 (a), 25.06.1992 (b), 18.08.2011 (c), dNDVI (d)

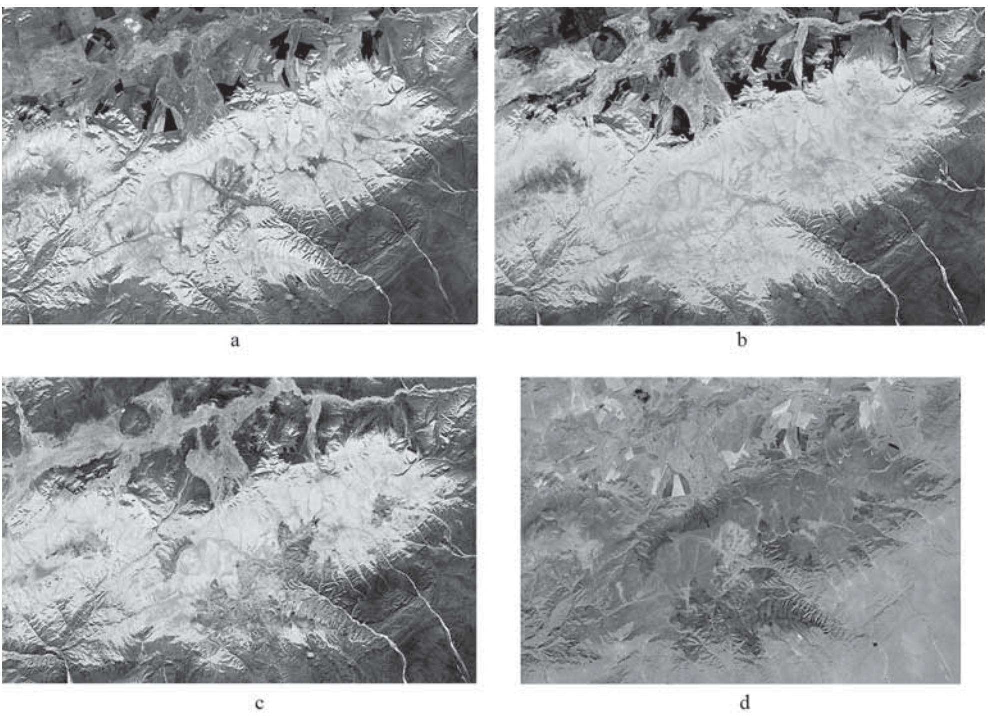

Fig. 4.The NBR images: 19.08.1988 (a), 25.06.1992 (b), 18.08.2011 (c), dNBR (d)

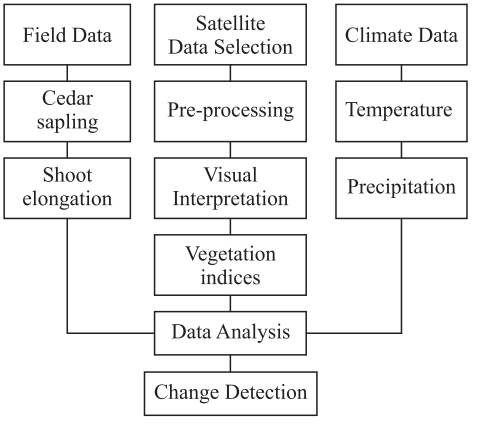

Fig. 5. Workflow for change analysis

Wildfire growth has modified mountain forests in the study period. The extreme weather conditions were observed in the Tyva Republic in 2007 with anomaly mean temperature of 2.98 °C. In 23 years (from 1988 to 2011) in the entire territory of the Ujuk Mountain range, there were 21362 hectares of burned area.

The diagram of the overall work-flow adopted in the present study is presented in Figure 5.

CONCLUSIONS

The general approach used in this investigation is as follows. We calculated the local rates of changes based on the LANDSAT data. The time series analysis was performed with a series of images, related to the change of the Ujuk Mountain range forests.

We assessed changes of the forest ecosystems dynamics in the Tyva Republic under the influence of climate impact in the recent decades. Increasing air temperature during vegetation period was an important factor for coniferous forests. Climate change impacts mountain boreal forests in various ways, including: change of the timberline of dark coniferous forests, especially at the bottom and top borders; with increased wildfire occurrence and area burned.

Research of the forest ecosystems dynamics (changes of vegetation index of the Ujuk Mountain Range) was based on long–term of data (1988–2013) of LANDSAT data. We used NDVI (Normalized Difference Vegetation Index) and NBR (Normalized Burn Ratio) vegetation indices.

Thus, it can be concluded that the vegetation indices are effective for information on shift trends of dark deciduous forest, even in the growing season. These indices clearly distinguished change of boreal forests (shift at the lower tree-line of the dark deciduous forest) caused by the natural stress factors (climate change) and anthropogenic impacts (fire). dNDVI can be used to measure the expansion of the dark deciduous forest with the onset of climate warming in the region. The 2002 and 2007 fire seasons led to seriously damaged forest area.

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Khulermaa B. Kuular received her PhD degree from V.N. Sukachyov Institute of Forest RAS SB. Her primary research interests are in the area of remote sensing methods in analysis of boreal forest, dynamics of mountain forests influenced by climate change and wildfires factors.
Main publications: Peculiarities of climate in the Tyva Republic in the 20th and 21st centuries (2015); Estimation of burned areas of the Ujuk Mountain Range using LANDSAT data analysis (2013).