Long-term NDVI dynamics in the basin of Lake Baikal

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Abstract. This paper presents an analysis of NDVI distributions and linear trends in the basin of Lake Baikal. Data of a thematic product MOD13Q1 of a MODIS spectroradiometer from 2000 to 2017 are used. Regression analysis is applied for more than 10 million time series. The slope coefficients and their statistical significance are calculated. Trends in surface air temperature and precipitation over the same period are also examined. It is revealed that the histogram of the number of pixels according to NDVI has a two-modal form, the maxima of which correspond to steppe and forest vegetation. 75.18% of the basin area has positive NDVI trends and 24.82%, negative ones. The negative NDVI trends are observed for steppe ecosystems of the Russian part of the basin, and for the steppes of Mongolia and forest ecosystems the trends are positive. For forest vegetation, the greatest and smallest values of trends are observed as a result of deforestation and forest restoration. The precipitation trends are positive in Mongolia and negative in Russia, which is consistent with the NDVI trends for steppes. Non-significant positive temperature trends are observed in the entire territory of the Lake Baikal basin. The seasonal dynamics of NDVI is highly correlated with air temperature and less correlated with precipitation. Preliminary data on the relationship between the width of tree rings and the forest NDVI have been obtained.

1. Introduction

The Lake Baikal basin is characterized by an exceptional diversity of ecosystems due to the natural conditions of the region located at the border of the boreal and arid regions of Eurasia. It is noted that the basin of Lake Baikal is one of the main strategic regions of the east of Russia and the north of Mongolia due to its position and potential [1].

The transformation of the terrestrial ecosystems of the region is facilitated by aridity, severity, and continentality of the climate with high annual and diurnal temperature ranges, the uneven nature of the wind regime and precipitation in the year seasons, the light texture of the soil and underlying bedrocks prevailing in many places, vast areas of bare and weakly fixed vegetation of the land, etc.

Arid climate in the area under investigation coupled with poor environmental management leads to significant vulnerability of the terrestrial ecosystems. This vulnerability is caused by negative natural-anthropogenic processes, such as degradation of vegetation, soil erosion and deflation, salinization, forest logging, and fires. These anthropogenic processes are intensified due to periodic tendencies to aridization in the climate system as a result of which there is not only an unfavorable change in the moistening conditions, but also a decrease in the productivity of the arable lands and pastures, which, in turn, affects the economy of the region. Our previous studies have revealed some peculiarities in the vegetation changes in different climatic zones of the region [2, 3].

The study of the response of the terrestrial ecosystems to climatic changes in the Lake Baikal basin is an urgent task for developing effective measures to mitigate the negative processes. The relevance of the topic is confirmed by the need to preserve the Lake Baikal – UNESCO World Heritage Site [4].

Such studies should be comprehensive, involving a variety of means and methods of remote sensing and ground control. To date, a significant amount of remote sensing data in various spatial, temporal, and spectral resolutions has been accumulated. The aim of this work is a regional assessment of the dynamics of the Lake Baikal basin vegetation cover on the basis of analysis of the MODIS NDVI trends.

2. Materials and methods

The initial data was the NDVI time series of the MODIS Terra thematic product MOD13Q1 [5]. The product is represented by 16-day raster composites of vegetation indices with a spatial resolution of 250 m. The size of the composite is 4800 by 4800 pixels, which corresponds to an area of 1200×1200 km on the earth's surface. In this work we used images obtained during the vegetative period from 2000 to 2016. NDVI is a widely used vegetation index that shows the amount of green phytomass and is calculated as the ratio of the reflection difference in the near infrared and red spectral range to their sum.

Preliminary processing of the data was carried out, consisting in restoring the erroneous or missing values and smoothing the NDVI time series. Incorrect values of the pixel are replaced by its average value for the entire period. The Savitzky-Golay filter is used to smooth the time series. The removal of the seasonal component of the time series is carried out using a moving average with a window width equal to the number of composites used per year [6]. The data obtained after preliminary processing was used to construct a linear regression model. In total, more than 10 million time series were processed.

Meteorological stations data was used to estimate long-term climate variations. For the correlation analysis of the NDVI and seasonal temperature and precipitation dynamics, the VEGA-PRO satellite service of the Space Research Institute of the Russian Academy of Sciences was used [7].

3. Results and discussion

Figure 1 presents the Lake Baikal basin NDVI map obtained by averaging the maximum annual values for the 17th period from 2000 to 2016. Analysis of the histogram of the NDVI values by the number of pixels revealed that the distribution has a two-modal appearance (Figure 2). To be more precise, the distribution has three maxima. The first maximum of the number of pixels is located in the negative semi-axis of the abscissas and characterizes water objects and glaciers. This maximum is excluded from consideration. In accordance with the shape of the histogram, we have identified 6 NDVI intervals, which will be considered below.
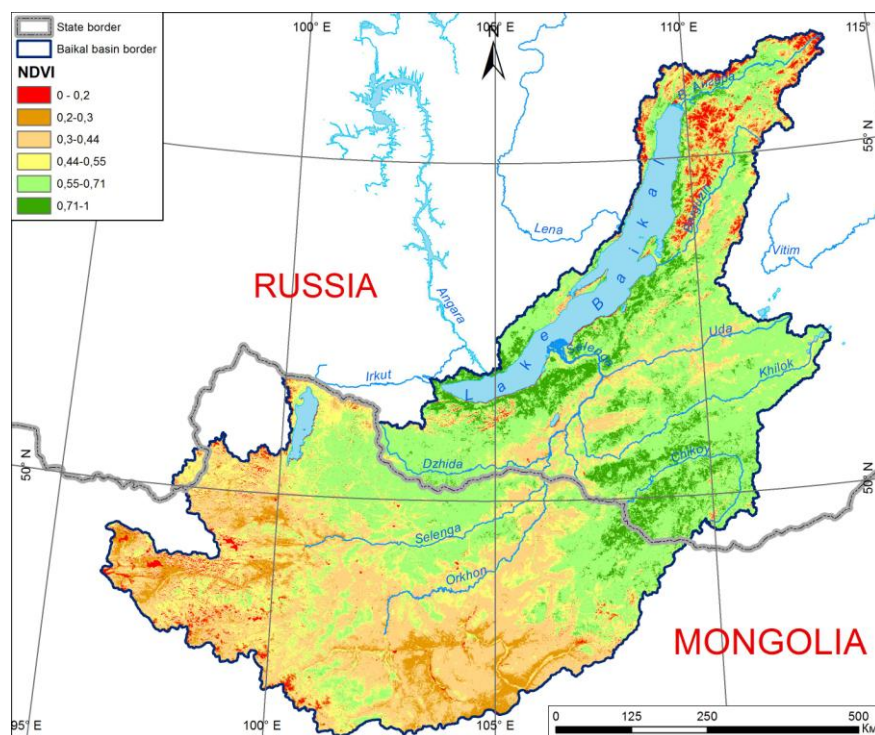

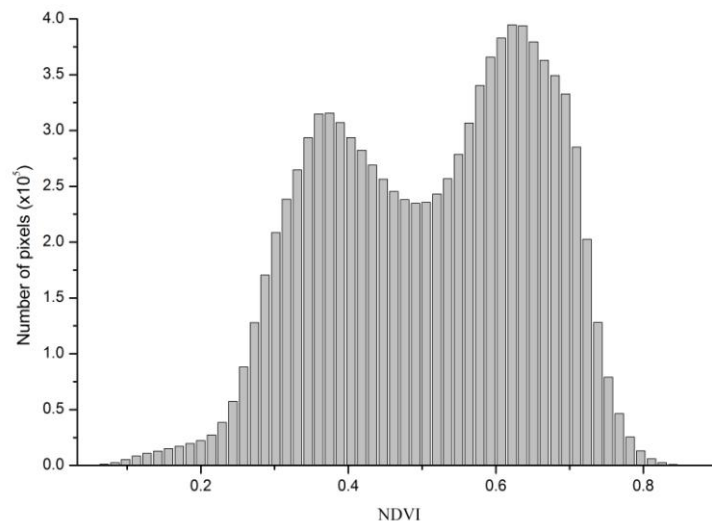**Figure 1.** Average NDVI map.

Figure 2. Histogram of NDVI.

Areas with NDVI values from 0 to 0.2 correspond to the earth's surface without vegetation and urban development. These are the top of the mountains with extremely sparse vegetation (or without it) of the Barguzin, Ikat ranges in the east, the Baikal range in the west and the Stanovoy highlands in the north, and the Khangai Ridge near the southwestern border of the basin. The sand massif of Mongolyn Els stands out clearly near the southern border of the basin. The NDVI from 0.2 to 0.3 characterizes strongly sparse vegetation. Areas with such vegetation are located mainly in the southern part of the basin in dry, deserted steppes of the Mongolian-Chinese phratry of formations. Also, these NDVI values are characteristic of the high altitude mountainous vegetation. The interval from 0.3 to 0.44 contains the first maximum of the distribution of the number of pixels by the NDVI and corresponds to the steppe type of vegetation, which occupies a significant part of the basin of Lake Baikal. In the NDVI interval from 0.44 to 0.55, a local minimum of the distribution between the two maxima is observed. It characterizes the ecotone zone at the border of the forest and steppe, i.e. it has a linear rather than an area distribution. In this biome, there is a combination of forest, steppe and meadow vegetation, pine woodlands and elm savannas. The next two intervals, from 0.55 to 0.71 and from 0.71 to 1, correspond to forest vegetation. Apparently, the interval from 0.55 to 0.71 is an indicator for light coniferous species; the second interval, from 0.71 to 1, characterizes dark coniferous vegetation or forests with a high projective covering with closed canopy.

As a result of satellite information processing, a spatial picture of the distribution of the NDVI linear trends for the Lake Baikal basin was obtained (Figure 3). Positive NDVI trends are observed for 75.18 % of the basin area, while negative trends, for 24.82 %. The area of the basin of Lake Baikal is 570 thousand km^2. Statistically significant trends ($p < 0.05$) are observed for 81.73 % of the basin area, of which 64.97 % for positive trends and 16.76 % for negative trends. An assessment of the NDVI changes was made for different types of vegetation within the investigated region. For analysis, a small-scale vegetation map of the Lake Baikal basin was used, the legend of which contains 96 classes [1]. Analysis of the distribution of the number of pixels by the values of the trend NDVI revealed that positive values of the linear trend prevail for all classes of vegetation.
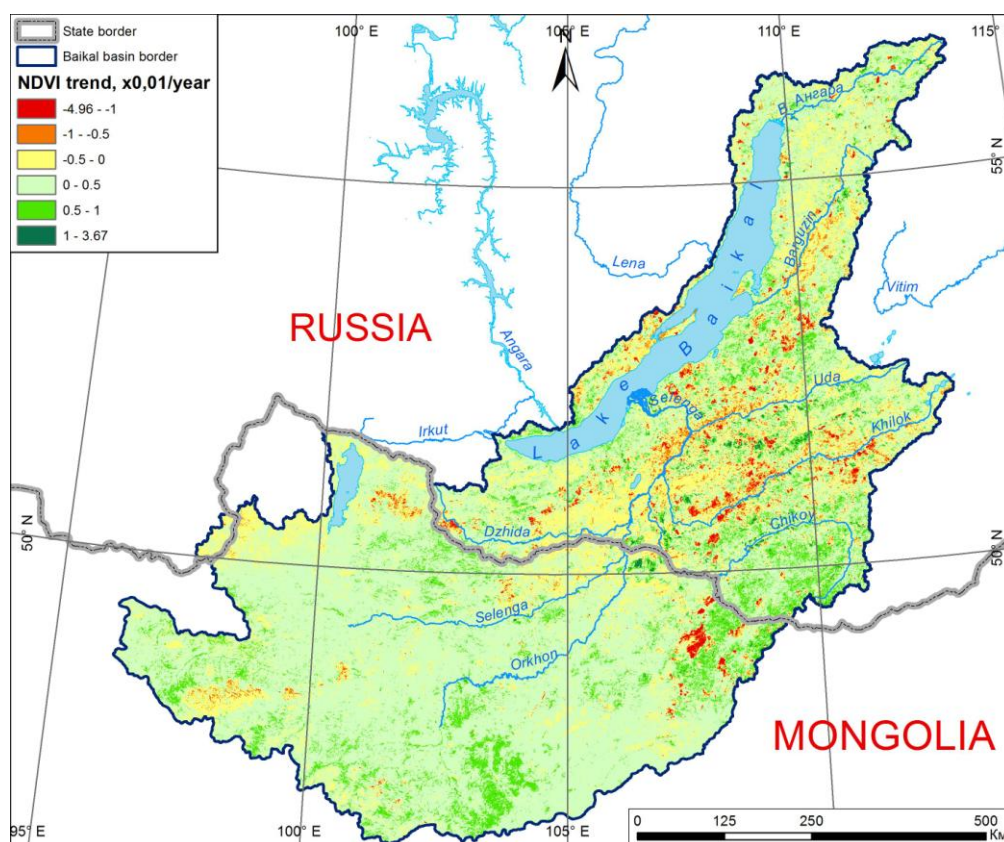
Figure 3. NDVI trend map.

Despite the fact that, in general, positive NDVI trends prevail for the majority of vegetation classes, solid zones with a negative trend in the steppe landscapes of the Western Transbaikalia are found, whereas in the steppe communities in Mongolia they show a positive trend. Coniferous forests of the Baikal region have positive values for the NDVI trend, but the presence of minimum and maximum trends is typical for forest ecosystems. According to visual verification using satellite images of ultra-high spatial resolution and field studies, it was determined that extreme NDVI trends are confined to areas of the natural and anthropogenic impact on forest ecosystems (deforestation, reforestation restoration, fires).

For spatial comparison of the NDVI trends with climatic variability in the Lake Baikal basin, an analysis of the meteorological parameters has been performed. The surface air temperature and precipitation trends are calculated from monthly data from 2000 to 2016 for 24 meteorological stations (Figure 3). It was found that in the Mongolian part of the basin the precipitation trends have positive values and for the Russian part, negative values, which agrees with the dynamics of the vegetation of the steppe zones. Practically for all meteorological stations there is a positive dynamics of the surface air temperature from 2000 to 2016; all temperature trends are not statistically significant.

The correlation analysis of the seasonal dynamics of the air temperature, precipitation, and NDVI for steppe, forest-steppe, and forest ecosystems was carried out. It was revealed that the NDVI correlation coefficient and temperature for steppes averaged 0.79, and for forest-steppe and forest, 0.84 and 0.77, respectively. The NDVI and precipitation have a correlation of 0.46, 0.56, and 0.54. For deforested areas, the correlation between the NDVI and meteorological parameters is very weak.

The relationship between the NDVI and tree-ring chronologies still remains unclear. During the expedition work in the summer of 2017 we established a dendroclimatic station on the southern branch of the Ulan-Bourgasy Ridge at the Verkhnaya Berezovka place. Measurements of the pine annual rings width, cross-dating, and indexing were carried out on a LINTAB 5 instrument using the TSAP

Win and RCSigFree software. Correlation analysis revealed a weak relationship (r = 0.24) between the tree-ring indices and NDVI. Nevertheless, the correlation coefficient with annual lag ($Year_{NDVI} - 1$) is 0.65. The reason for this is that the growth of tree rings in arid conditions is more dependent on the precipitation of the previous year. The highest coefficient of correlations (r = 0.5) in tree-ring chronology is observed with the sum of precipitation from September of the previous year to August of the following year. The obtained series of tree-ring chronologies allowed us to reconstruct the periods of low and high water content in the region.

4. Conclusions

In this study, spatial-temporal NDVI characteristics in Baikal region are presented. The distribution of the number of pixels of mean annual NDVI has a two-modal form, its maxima correspond to steppe and forest vegetation, and the minimum corresponds to forest-steppe vegetation. Linear trends of NDVI over a 17-year period have different directions: the negative trends are confined to the steppe type of vegetation of the Selenga middle mountains, the positive ones are observed in the Mongolian steppes and forest vegetation. The NDVI trends for steppe vegetation are co-directed with the precipitation trends. The greatest changes of NDVI are mainly due to the natural-anthropogenic impact on the forest ecosystems. The seasonal changes of NDVI have a strong correlation with air temperature and a weaker correlation with precipitation.

It is planned to organize field work to study the factors that influence the spatial-temporal dynamics of NDVI in the basin of Lake Baikal. Expedition work is planned to study the response of terrestrial ecosystems to climate change and anthropogenic impact.

References

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