SPOT-VGT NDVI AND NDWI TRENDS 1998-2005 AS INDICATORS OF RECENT LAND COVER CHANGE PROCESSES IN NORTHERN EURASIA

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ABSTRACT

The Boreal and Tundra ecosystems of the mid-high latitudes provide sensitive indicators of environmental impacts both of climate change and human activities. A number of studies have emphasized changes and trends in Eurasia due to drivers of natural and human induced land cover dynamics, in particular for the period 1982-1999. The investigations of this study focus on the very recent years of 1998-2005 and cover the whole boreal ecosystems of Northern Eurasia with its geographical dimensions of 42°N to 75°N and 5°E to 180°E. The study focuses on linear trends from 1998-2005 using inter-annual and inter-seasonal trends in the SPOT-VGT mosaics.

Significant trends could be detected in the NDVI and NDWI time series from 1998-2005. The trends differ by season (spring, summer, fall), land cover type and latitude. The spring trends show significant positive NDVI regression slopes and strong negative NDWI slopes over the evergreen needleleaf-, needleleaf/broadleaf-, and mixed forests of the Russian and Scandinavian boreal zone, which indicates an onset of the vegetation green-up dates (NDVI trends) over eight years linked with earlier snowmelt (NDWI trends). Similar vegetation dynamics can be exposed in the fall. Positive NDVI slopes over nearly all vegetation classes indicate a longer durance of the vegetation period. Contrary trends were detected in the tundra. The tundra ecosystems of the northern Eurasia latitudes seemed to be affected by trends of negative NDVI and positive NDWI slopes. The significant trends could be acquired in the prostrate shrub tundra followed by sedge and shrub tundra. This may be explained by earlier snowmelt from higher temperature anomalies since the last eight years. The estimates over these mainly climate controlled processes can be consolidated by analyzing the surface temperature anomalies from 1998 to 2005. In comparison with the base from 1951 to 1998, positive surface temperature anomalies are observed particular in spring and fall season. The analysis of the summer NDVI trends with GLC2000 cropland classes on Oblast level in Russia point at hot spots of agricultural land changes in the south-western part of Russia.

INTRODUCTION

Northern Eurasia is a hot spot in global environmental change. There are significant temperature anomalies [1], [2], [3], and there is no doubt that climate change is the major force of environmental change [4]. In addition, land dynamics are driven by socio-economic changes in the Former Soviet Union (FSU). Decreasing agricultural subsidies [5], [6], cause wide natural succession and afforestation processes potentially acting as carbon sinks [7]. Cross-border comparisons of landscape pattern in Eastern Europe [8], and European Russia [9], the analysis of fire frequency and pattern [10], [11], and logging pattern [12], have recently emphasized the human impact on Northern Eurasia’s land cover characteristics.

Despite such major processes, their effects and representation in distinct land cover characteristics are still not sufficiently understood. Of particular interest are their temporal character-
istics, their comprehensive nature and consistency for the whole of Northern Eurasia, and to have an up to date for the very recent years. Building upon previous analysis using long-term NOAA-AVHRR satellite time series data [13], [14], [15], the aim of this paper is to present the most recent indicators of land-cover change in Northern Eurasia for 1998-2005. We apply seasonal SPOT VGT mosaics and a regression technique to observe linear trends in the NDVI and NDWI and use them as change indicators. The trends are discussed and analyze using a suite of ancillary remote sensing data products, i.e. a land cover map, a digital elevation model, a burnt area database, and a freeze-thaw product. The investigation area covers the boreal ecosystems of Northern Eurasia with its geographical extent of 42°N to 75°N and 5°E to 180°E.

DATA AND METHODS

The satellite data have been provided through the TerraNorte Information System (http://terranorte.iki.rssi.ru). Seasonal averaged mosaics from 1998-2005, derived from maximum NDVI images of SPOT-VGT S-10 products [16] for the seasons spring (March-May, begins in 1999), summer (June-August) and fall (September-November) were used for a multi-annual trend analysis. Land-cover data were provided from the SPOT-VGT derived Global Land Cover Map of the year 2000 (GLC2000, [16]). Surface temperature data (GISTEMP) from the NASA Goddard Institute for Space Studies (GISS) were used to compare land cover change trends with recent temperature anomalies in Northern Eurasia. Global datasets with a cell size of 2°×2° degree grid are available on the GISS website (http://data.giss.nasa.gov/gistemp/maps, [3]. The study did focus on trend analysis, however, used a SPOT VGT based Burnt Area Inventory Database for Boreal Ecosystems 2000-2005 (BIS) [11]. The fire activity assessed by the Burnt Area Inventory Database for the Boreal Ecosystems [11] should be mentioned as major land cover change process in Northern Eurasia. Forest fires which are often triggered by human activities cover large areas of forest cover. Fire events cause temporally abrupt land disturbances and areas burnt 2000-2005 were excluded from the trend analysis.

Data from Shuttle Radar Topography Mission (SRTM) from the Global Land Cover Facility (GLCF, available at http://glcf.umd.edu/data) were used to analyze the NDVI/NDWI trends in terms of height dependence. Data of the duration of the thaw/freeze alternation period over the SIBERIA-II region derived by the operational scanning dual spot beam scatterometer on-board the QuikSCAT satellite using diurnal difference indicator [17] were used to analyze SPOT-VGT trends in terms of climate controls on snow melting onset in the Siberian tundra and taiga ecosystems.

To detect significant positive and negative trends in the SPOT-VGT seasonal mosaics from 1998 - 2005, a temporal trend analysis using the ordinary least squares (OLS) regression technique on the basis of a linear regression model (Y = a + bX + ε) as presented by Fuller [18] and Zhou et al. [15] is applied on the dataset. The trends are analyzed on a confidence level of 95% using standard t-test. NDVI (\(\lambda_{\text{Nir}} - \lambda_{\text{Red}} / \lambda_{\text{Nir}} + \lambda_{\text{Red}}\)) and NDWI (\(\lambda_{\text{Nir}} - \lambda_{\text{Swir}} / \lambda_{\text{Nir}} + \lambda_{\text{Swir}}\)) were computed and regressed over eight years time (1998-2005). For each pixel slope of the linear regression (in NDVI or NDWI unites) and R² values (in %) were extracted. Only the significant trends of either increasing or decreasing NDVI or NDWI signals were compared with the GLC2000 to see land cover types are most affected and susceptible. Comparisons with temperature anomalies, digital elevation models, and changing freeze/thaw patterns were performed to visualize seasonal patterns of NDVI/NDWI trends and provide a deeper understanding of processes ongoing.

RESULTS AND DISCUSSION

Significant trends appear as sub-continental and regional patterns differing with season and land cover type. Figure 1 summarizes the eight years SPOT-VGT NDVI time series reflect the main land change indicators in Northern Eurasia. Positive NDVI trends on croplands in sum-
mer indicate socio-economic driven processes of land cover change. The Northern Eurasia boreal forest ecosystems show significant positive NDVI trends in spring and fall. Increasing temperatures trigger an onset of vegetation greening in the major forested land cover types and at least a lengthening of the active photosynthetic period of vegetation. In the entire tundra ecosystems significant trends in spring were mapped indicating earlier snow melting and an onset of daily thaw and freeze alteration period. Increasing surface temperatures in the high latitudes are the main trigger for this process. The fire activity assessed by the Burnt Area Inventory Database for the Boreal Ecosystems [11] should be mentioned as major land cover change process in Northern Eurasia.

**Figure 1: Recent land-cover trends in Northern Eurasia 1998-2005 derived from SPOT-VGT seasonal mosaics.**

**Climate Controls on Vegetation Phenology**

It is evident that there is a direct relationship between recent temperature anomalies and the vegetation activity within the recent eight years. The comparison of GISS surface temperature trends derived from global stationary data by season from 1998-2005 with SPOT-VGT NDVI trends shows similar spatial patterns from both temperature anomalies and SPOT-VGT trends. A temperature-response of the whole Russian Taiga and Scandinavian boreal forests is visible for spring. The same development can be recognized in the fall season, where the strongest NDVI trends follow the high-temperature pattern in central Siberia. Negative NDVI trends, in relation to temperature increase in spring, are visible in all tundra ecosystems in Northern Eurasia. Negative NDVI trends are apparent due to decreasing temperatures as observed in spring for Western Russia, Mongolia, and China. A positive summer NDVI trend, corresponding to areas with negative temperature trends, can be seen in the European Russia. This change perhaps reflects more socio-economic driven processes of land cover change and will be discussed in more detail later.

All boreal forest types of Eurasia exhibits positive NDVI trends in spring and fall. The zonal mean GLC2000 land-cover trends, as shown in Figure 2, help analyzing the NDVI/NDWI trends in terms of land-cover and ecosystem dynamics. Most affected are needle-leaf forests...
classes and broadleaf/needle-leaf mosaic classes with mean annual NDVI increase of 0.0006 – 0.0022. NDWI shows reverse slopes within the forest classes. Similar trends with a slighter bias of the NDVI/NDWI trends were recognized in the wetland classes bogs and marshes, palsas and riparian vegetation. Positive NDWI in conjunction with negative NDVI slopes were detected in the entire circum-polar tundra regions in northern Siberia and Scandinavia as well as the mountain tundra regions.

Higher temperatures and earlier snow melting are responsible for a longer growing season in high latitudes [13], [19]. The NDVI data derived from NOAA-AVHRR showed an increased biosphere activity in latitudes about 35°N. Myneni et al. [13] describes the NDVI increase in Eurasia for a geographical band extending from Spain across Asia to the western Pacific Ocean, which is comparable with the summer trends in this study. Further studies done by Zhou et al. [15] were able to manifest the long-term NDVI trends in the northern hemisphere. The correlation of the most recent SPOT-VGT trends with long term NDVI time series data reinforces the hypothesis that climate is the major driver of land cover change.

Climate control mechanisms on vegetation phenology using NDVI datasets on a global scale has been estimated by a number of studies [20], [21]. As a consequence of increasing temperatures the vegetation greening moves northwards and the onset of the phenological dormancy moves in a southern direction. The use of SPOT-VGT data by Delbart et al. [22] proves to be advantageous to detect the timing of the biospheric activity of different vegetation types.

![Mean GLC2000 Land cover Trends Spring 1999-2005](image)

Figure 2: Land-cover trends in Northern Eurasia (42°N to 75°N and 5°E to 180°E) derived from zonal mean values of NDVI and NDWI regression slopes (points) and $R^2$ (bars) for GLC2000 land cover classes: ENF=Evergreen Needleleaf Forest, DBF=Deciduous Broadleaf Forest, NBF=Needleleaf/ Broadleaf Forest, MF=Mixed Forest, BNF=Broadleaf/Needleleaf Forest, DNF=Deciduous Needleleaf Forest, BDS=Broadleaf Deciduous Shrubs, NES=Needleleaf Evergreen Shrubs, HG=Humid Grasslands, S=Steppe, BM=Bogs and Marshes, PB=Palsa Bogs, RV=Riparian Vegetation, PST=Prostrate Shrub Tundra, SET=Sedge Tundra, SHT=Shrub Tundra, C=Croplands, FNM=Forest-Natural Vegetation Mosaic, FCM=Forest-Cropland Mosaic, CGM=Cropland-Grassland Mosaic.
Agricultural abandonment as driver of Land Cover Change

Significant positive NDVI trends in the summer season over the mainly agricultural used Chernozem Zone in Russia as well in the former Soviet Nations like Ukraine, Belarus, and the Baltic states indicate land use changes originated through post-Soviet land use change. Large-area agricultural land abandonment processes are causing re-naturation and natural afforestation transitions in former agriculture dominated regions. The comparison of the summer NDVI trends with the loss of arable land (1997-2003) derived by agricultural statistics on Oblast level shows a correlation of up to 45% (Figure 3). Comparisons with multi-temporal Landsat data showed natural succession on former agricultural land is in particular located at remote areas, along river lines, forests and along the state and Oblast borders. Cross-border comparisons of post-Soviet land-use change as well as affects on biodiversity, as done by Kümmerle et. al. [8] and Radelov [9] for Eastern Europe have demonstrated such processes and should to be analyzed on coarse scale analysis.

Indication of Snowmelt onset in the Tundra

The negative NDVI and positive NDWI trends within the northern hemispheric tundra ecosystems may be related to temperature effects and an earlier onset of snow melting. The trends in spring give averaged information between March and May; the time where the vegetation period begins for the Taiga region. The main time of intensive snow melting for the Tundra is from May to July and thus the observed spring trends do no represent vegetation activity. Earlier snowmelt raises the surface water content causing a stronger NIR and SWIR channel absorption and a positive NDWI and negative NDVI trend. Figure 4 shows a clear dependence of NDVI/NDWI trends and topography. The scatter plots of NDVI regression slope versus height based on SRTM-DEM show a correlation between elevation and trends. The NDVI shows a linear relationship of decreased trend occurrence with higher elevation. The more prominent in the low elevation floodplains confirm the presence of surface water as driver of the observed trend signal.

According to McCloy et al. [24], further studies have to set their focus on data synergies between existing coarse scale global NDVI data products like Pathfinder, FASIR, and GIMMS. Also in terms of accuracy assessment and harmonization purposes multiple data use can be useful. The comparative analysis of trends derived from SPOT-VGT and other coarse scale satellite data would minimize systematically errors and inaccuracies. The transmission of data inaccuracies within multiple data applications should be avoided in future global change studies.

The recent calibration problems concerning the VEGETATION-2 instrument should be mentioned. The over-estimated calibration coefficients of the RED and NIR bands for the VGT-2 sensor, used for sensor degradation correction can affect an NDVI decrease of up to 10% within three years [25], which potentially influences NDVI time series estimates. However, the SWIR band calibration coefficient is well estimated compared to the other bands. This study uses averages values over three month both from the VGT-1 and VGT-2 sensor. We observe positive and negative trends over eight years that vary for different seasons. A significant effect of the calibration error would be of “global nature”. Thus the global calibration problem will not impact whether there is a trend or not but may have an effect for the strength of the trend (i.e. overall NDVI increase) without change the relative change pattern.
Figure 3: Positive NDVI trends between 1998-2005 derived from SPOT-VGT on croplands indicate the succession of natural vegetation on former agricultural fields as a post-soviet process. The comparison between the area loss derived by agricultural statistics [23] on Oblast level shows a correlation of up to 45%.
Figure 4: Significant trends were detected in the northern Siberian Tundra. Positive NDWI trends (a) and an lengthening of the period of daily thaw and refreeze between (b) 2000 and 2003 [17] indicate an onset of the snowmelt season. The dependence of NDVI trends and topography are displayed in the subset of the Verkhoyansk Range and the delta of the Lena River between 123°E-128°E and 75°N-71°N (c) and the scatter plot of spring NDVI regression slope vs. SRTM-DEM elevation data (d).

REFERENCES


12 Stibig, H.J., and Bucha, T., 2005: Feasibility study on the use of medium resolution satellite data for the detection of forest cover change caused by clear cutting of coniferous forests in the northwest of Russia., Luxembourg: Office for Official Publication of the European Communities, EUR 21579 EN, June 2005, pp.42.


23 Rosstat, 2004: Agriculture, hunting and forestry in Russia. Moscow.
