STUDY OF DECIDUOUS NEEDLE-LEAVED FORESTS PHENOLOGY CHANGES IN SIBERIA

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INTRODUCTION

Phenological characteristics is potential indicators of climate changes effect on the vegetation cover condition[1-4] and other ecosystem components. The vegetation dynamics are influence on climate through changes of energy and water balance, as well as biogeochemical cycles. Remotely sensed vegetation indices are widely used to detect vegetation trends at large scales. Satellite-derived NDVI[5] is a better indicator for studying the vegetation condition and phenology changes of vegetation. The observed climate change is especially noticeable in the high northern latitudes and, in particular, in Siberia. Aim of this work is study of the long-term phenology changes of deciduous needle-leaved forests in Siberia on satellite data.

DATA AND METHODS

The land cover map of northern Eurasia[6] to select the areas of deciduous needle-leaved forests growth in Siberia was used. The lowland and plateau mask, which excludes elevations above 600 meters, was created using the elevation map[7] for selection the study area. The land cover map of northern Eurasia with using the created of lowland and plateau mask in the territory of Western and Eastern Siberia is presented (Figure 1a).

The five main types of vegetation according the legend of figure are presented in this map. The annual fluctuation of air temperature from winter to summer in some areas of Siberia reached is 100 degrees Celsius. As follows from Figure 1a, the severe climatic conditions of Siberia led to the widespread the deciduous needle-leaved forests characterized by high frost resistance. The dominant species of deciduous needle-leaved forests are Daurian and Siberian larch. The areas of larch growth are cover in two climatic zones - subarctic and temperate. In this regard, the study area (areas of deciduous needle-leaved forests growth) on subarctic (Figure 1b) and temperate (Figure 1c) zones was divided.

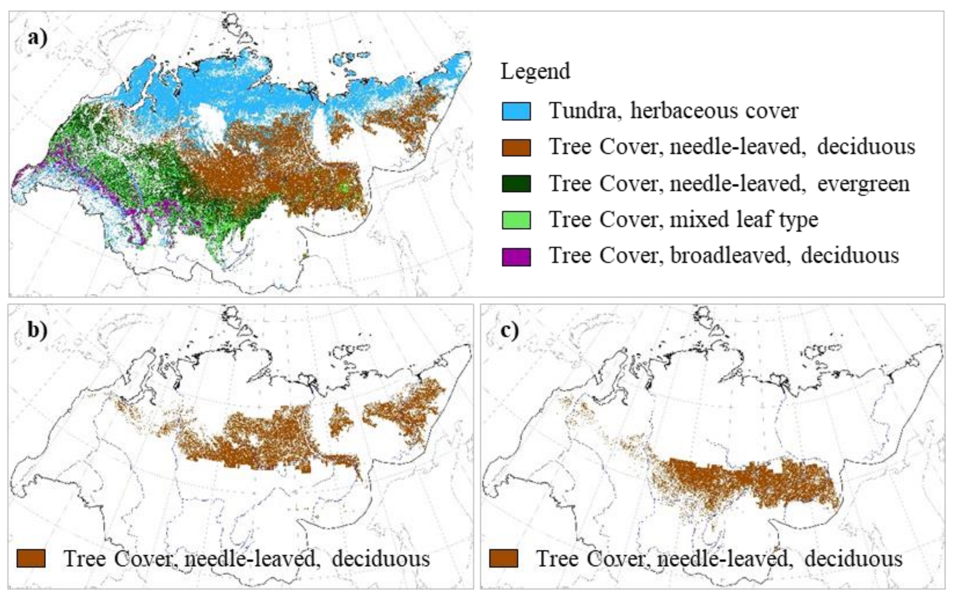

Figure 1. Areas of deciduous needle-leaved forests growth in Siberia: a) the vegetation map; b) subarctic zone; c) temperate zone.

Most long-term NDVI products based on datasets with multiple satellites. Therefore, the discontinuities in satellite time series caused by sensor changes etc. to introduce the significant uncertainties and artifacts for analyzing long-term trends. The paper[8] concludes that amongst the long-term AVHRR based datasets analyzed, the GIMMS3g is found to have the highest temporal consistency and at present state will be the most appropriate choice for NDVI trend analysis.

In this work the Global Inventory Modeling and Mapping Studies 3rd generation (GIMMS3g)[9] dataset was used to estimate of phenological parameters of deciduous needle-leaved forests such as the start of the growing season (SOS), the end of the growing season (EOS) and the length of the growing season (LOS). The GIMMS3g is 15-day NDVI maximum value composite with a spatial resolution of 1/12 degree and covering the period from 1981 to 2015. The year 1981 was excluded from our analysis in order to analyze only years with full data coverage. We pre-filtered the GIMMS3g dataset: NDVI values that were flagged as "snow" and "interpolated" in this dataset were excluded from the analysis. Because as the reliability of such interpolated NDVI values under snow or cloud conditions is unclear. The 15-day NDVI data of GIMMS3g were aggregated in the daily NDVI time series using the linear interpolated method. The SOS and EOS were calculated using the "Midpoint_{pixel}" method described in paper[10]. According this method, the SOS and EOS dates reached in the day of year (DOY) when NDVI exceeds locally tuned threshold 0.5 from $NDVI_{ratio}$[10] (1) in spring and autumn.

$$NDVI_{ratio} = \frac{\mathrm{NDVI}_{daily} - \mathrm{NDVI}_{\min}}{\mathrm{NDVI}_{\max} - \mathrm{NDVI}_{\min}} \quad (1),$$

were $NDVI_{daily}$ – the daily NDVI values. The $NDVI_{min}$ and $NDVI_{max}$ – is the minimum and maximum values of NDVI derived from daily NDVI time series.

The time-integrated NDVI values (TI-NDVI[11] – the sum of daily $NDVI_{ratio}$ values between SOS and EOS dates) during the growing season (1982-2015) was calculated. Similarly the Summer Warmth Index values (SWI[11]- the sum of daily average air temperatures above 0°C between SOS and EOS dates) during the growing season was calculated based on the ERA-Interim[12] reanalysis data. To analyze the relationship between the $NDVI_{ratio}$ and air temperature variations for the study period, their monthly average values were calculated for each year. The annual amount of precipitation was calculated based on Climatic Research Unit Time-series (CRU TS v.4.01)[13] data.

The statistical significance of trends of phenology and meteorology parameters was assessed using the Mann-Kendall trend test[14,15], a rank-based nonparametric test that is robust against seasonality, non-normality, heteroscedasticity and missing values. The Mann-Kendall test is one of the most widely used nonparametric tests to detect significant trends in vegetation remote sensing time series[16].

DISCUSSION

The daily $NDVI_{ratio}$ and the annual (1982-2015) values of SOS, EOS, LOS and TI-NDVI of deciduous needle-leaved forests in Siberia for each zone were calculated. The seasonal variations of $NDVI_{ratio}$ averaged over the first (1982-1991) and the last (2006-2015) decade of study period are presented in Figure 2a for subarctic zone and Figure 2b for temperate zone. The x-axis shows the day of year (DOY) and y-axis shows the $NDVI_{ratio}$ values. The dashed green lines in Figure 2a and Figure 2b are shown the $NDVI_{ratio}$ variations for 1982-1991, and the solid green lines in these Figures are shown the $NDVI_{ratio}$ variations for 2006-2015. The SOS/EOS and SOS*/EOS* dates is indicate as black dots in Figure 2a and correspond to 1982-1991 and 2006-2015*, respectively. The shaded area in Figure 2a and Figure 2b are shown the TI-NDVI (the sum of daily $NDVI_{ratio}$ values between SOS and EOS dates) from $NDVI_{ratio}$ variations of 1982-1991. As shown in Figure 2a, in the last decade (2006-2015) the beginning of the growing season came ~12/±4 days earlier than in the first decade (1982-1991). The end of the growing season in the last decade came ~7/±5 days later than in the first decade. In addition, there is a high $NDVI_{ratio}$ values during the beginning and the end of the growing season. The changes of $NDVI_{ratio}$ values for temperate (Figure 2b) zone is insignificant. The shift of SOS and EOS dates in this zone also insignificant: the SOS on 2/±5 days earlier and the EOS on 2/±2 days later.

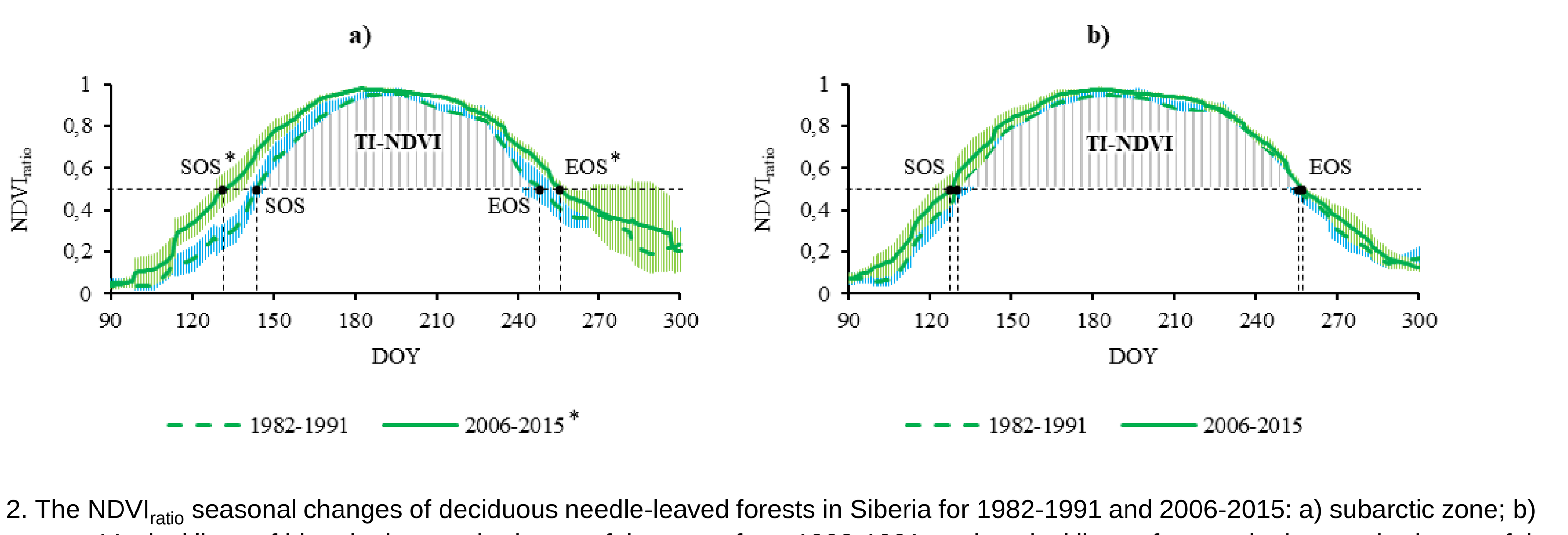

Figure 2. The $NDVI_{ratio}$ seasonal changes of deciduous needle-leaved forests in Siberia for 1982-1991 and 2006-2015: a) subarctic zone; b) temperate zone. Vertical lines of blue depict standard error of the mean from 1982-1991, and vertical lines of green depict standard error of the mean from 2006-2015.

Table 1 presents the trend values of phenology parameters of deciduous needle-leaved forests and average annual air temperature in subarctic and temperate zones for study period (1982-2015). Table 1 shows that the trend of SOS for subarctic and temperate zones is negative which indicate the earlier start of the growing season. At the same time, the trend of EOS for both zones is positive which indicate the later end of the growing season. However, the phenology trends in temperate zone is ~2–3 times lower as compared with subarctic zone. It should be noted the significant increase (~1.7°C/±0.8) of average annual air temperature for subarctic zone and the trend of temperature for temperate zone is negligible (~1°C/±1.1).

The correlation coefficients between annual air temperature and the length of the growing season (LOS) variations for study areas is 0.5. The annual amount of precipitation also increasing for study zones, but the correlation with LOS variations is low (R=0.3 for subarctic zone and R=0.27 for temperate). The influence of precipitation on vegetation is negligible because amount of precipitation in Siberia is generally low and the soil moisture content is in close relation to the seasonal permafrost thaw[17].

Table 1. The trend values of phenology (SOS, EOS and LOS) parameters of deciduous needle-leaved forests in Siberia in units of number of days and the trend values of average annual air temperature (T) in units of degree Celsius (°C) during 1982-2015 for subarctic and temperate zones. The standard error of the estimate, which is indicate a measure of the accuracy of predictions, is shown in brackets. Stars indicate the trend significant based on nonparametric Mann-Kendall test (p-value <0.01**, p-value <0.05*).

	The SOS trend	The EOS trend	The LOS trend	The T trend
Subarctic zone	-16 (±5)**	12 (±4)**	28 (±7)**	1.7 (±0.8)**
Temperate zone	-6 (±4)	4 (±3)*	10 (±5)*	1 (±1.1)

The interannual variations of TI-NDVI and SWI in areas of deciduous needle-leaved forests growth during 1982-2015 for subarctic and temperate zones are shown in Figure 3a and Figure 3b, respectively. The x-axis shows the year and y-axis shows the TI-NDVI values. The solid green lines in Figure 3a and Figure 3b are shown the TI-NDVI variations, and the solid red lines in these Figures are shown the SWI variations. The linear trends of TI-NDVI and SWI in these Figures are shown the dashed lines of the green and the red, respectively. The significant (p-value <0.01) positive trends of TI-NDVI and SWI for study zones (Figure 3a, b) are observed. From Figure 3a shown that the annual variations of TI-NDVI for subarctic zone are very changeable, however, there is a significant positive trend during the study period. It should be noted the significant increase of TI-NDVI since 2000: the TI-NDVI variations during 1982-1999 mainly range from 80 to 90, but the average TI-NDVI during 2000-2015 is ~100. One can see that SWI variations also are very changeable, but significant positive trend are clearly visible. Between TI-NDVI and SWI variations there is a high (R=0.85) correlation. The trends values of TI-NDVI and SWI for temperate zone (Figure 3b) is lower as compared with subarctic zone, and the correlation coefficient between their variations is 0.66.

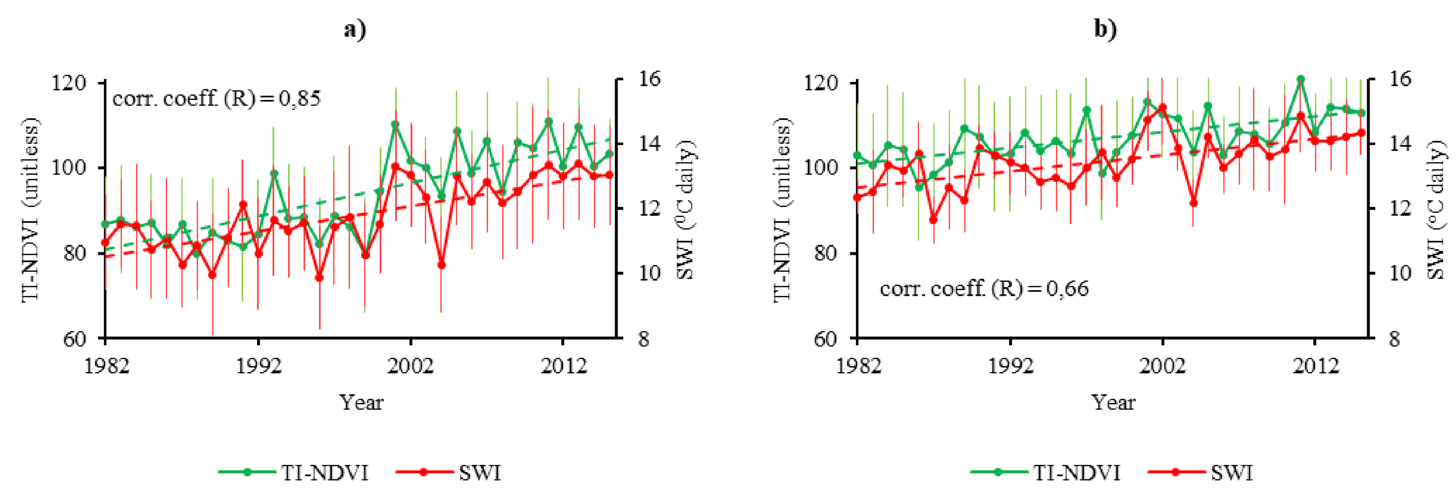

Figure 3. Variations of TI-NDVI and SWI values in areas of deciduous needle-leaved forests growth in Siberia for 1982-2015: a) subarctic zone; b) temperate zone. Vertical lines of green/red depict field standard deviation of TI-NDVI/SWI from fields of subarctic (a) and temperate (b) zones.

For analyze the relationship between $NDVI_{ratio}$ and surface air temperature their monthly averages for each zone during 1982-2015 were calculated. The correlation coefficient values between $NDVI_{ratio}$ and surface air temperature for each month (from March to November) are presented in Figure 4a for subarctic zone and Figure 4b for temperate zone. The x-axis shows the month and y-axis shows the correlation coefficient values. The blue diagram shows the negative correlation coefficient, and the red diagram shows the positive correlation. It should be noted that the high correlation in study zones only in beginning of growing season is observed. As shown in Figure 4a, there is a high (R>0.8) correlation coefficient in May and June for subarctic zone. For temperate zone (Figure 4b) the high correlation (R>0.8) in May is observed. An analysis of $NDVI_{ratio}$ and air temperature variations in these months during 1982-2015 showed the positive trends for each zone. For subarctic zone: the increase of $NDVI_{ratio}$ values in May and June is 26% and 13%, respectively; the increase of temperature values in this months is 2.8°C and 2.4°C, respectively. For temperate zone, the increase of $NDVI_{ratio}$ in May is 10% and increase of temperature values is 1.9°C.

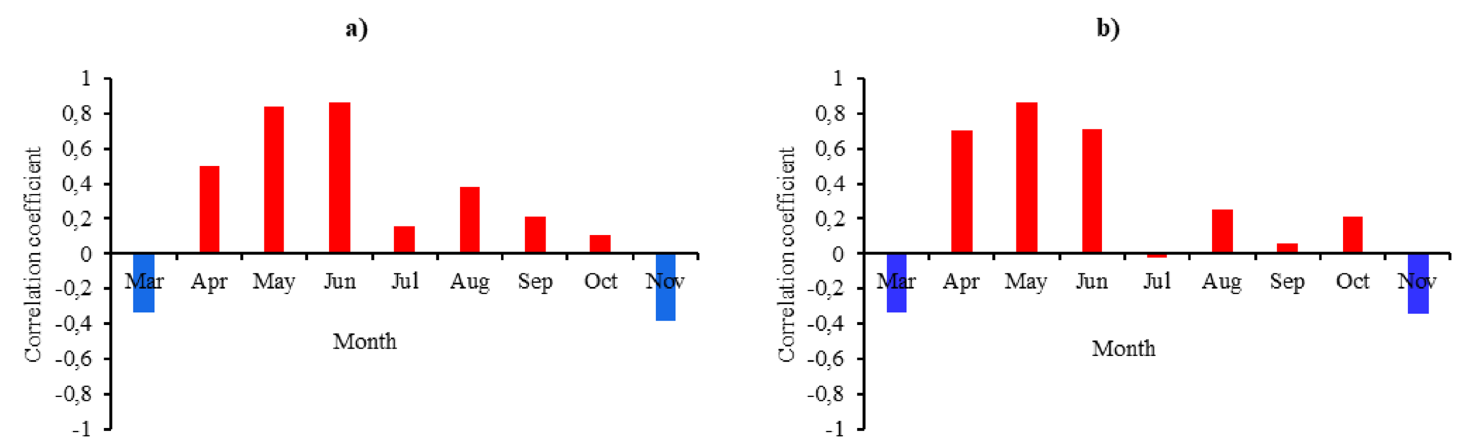

Figure 4. The correlation coefficient values between variations of monthly mean values of $NDVI_{ratio}$ and air temperature for 1982-2015: a) subarctic zone; b) temperate zone.

CONCLUSIONS

An analysis of phenology variations of deciduous needle-leaved forests in Siberia during 1982-2015 showed the significant increase of the length of growing season on ~28/±7 days in subarctic zone and in temperate zone on ~10/±5 days. The increase of the length of growing season is due to the earlier of beginning and the later of the end of growing season. At that time, the shift of dates of the start of growing season in both zones is greater than the shift of dates of the end. Perhaps this is due to a close relationship (R>0.8) between $NDVI_{ratio}$ and surface air temperature variations only in beginning of growing season because the correlation in the end of growing season is weak. The phenology trends of deciduous needle-leaved forests during the study period in subarctic zone is ~2–3 times higher as compared with temperate zone. For same time, there is a significant increase (~1.7°C/±0.8) of average annual air temperature in subarctic zone but the trend of temperature in temperate zone is negligible. The significant increase of the time integrated NDVI values in both zones are observed and their variations a close relation with changes of summer warmth index values: there is a high (R=0.85) correlation in subarctic zone and moderate (R=0.66) correlation in temperate zone. The trend values of the time integrated NDVI and the summer warmth index in subarctic zone are also higher as compared with temperate zone. There is a positive trend of the annual amount of precipitation values in subarctic and temperate zones, but their correlation with phenology variations is low.

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