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Application of NOAA AVHRR satellite images for studying various environmental and climatic conditions in Polish forests

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Abstract: The main objective of the presented work is to make an evaluation of the applicability of low-resolution satellite data for studying the condition of Polish forests being under impact of various climatic and environmental factors. NOAA AVHRR images were used in the work; vegetation indices derived from these images were combined with meteorological parameters obtained from weather stations. Six forest study areas representing different climatic and environmental conditions were used in the research work. The results of the study revealed that there are statistical relationships between remote sensing based indices derived for forest areas from low-resolution satellite data and temperature information characterizing climatic conditions, especially in the first part of the growing season. These findings were confirmed both in the spatial context – in various climatic zones – and in the temporal context.

Keywords: climate change, forest monitoring, low-resolution satellite data, vegetation index

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1. Introduction

Forests are one of the most important terrestrial ecosystems; it is recognized that they can respond to climate changes and natural / man made disturbances in a non-linear way (Lambin et al., 1997). The impact of disturbance factors is region / site dependent, hence there is a need to investigate this problem in the regional scale. Monitoring of the impact of climate changes on vegetation development with the use of remote sensing has been reported in recent publications (Stow et al., 2004; Lhermitte et al., 2011; Li et al., 2013; Hawinkel et al., 2015; Krishnan et al., 2015; de Moura et al., 2015). Most often the authors used for monitoring purposes Normalized Difference Vegetation Index (NDVI), widely recognized as an indicator of vegetation condition. Multi-scale satellite images have been used for research work, starting from high-resolution images (Landsat type) down to low-resolution satellite data (MODIS, NOAA AVHRR, SPOT Vegetation) (Jepsen et al., 2009; Bokhorst et al., 2012; Ivits et al., 2012; Griffiths et al., 2014; Hermosilla et al., 2015). Various approaches to analysis of time series based on satellite derived indices were applied, in order to derive proper information on their usefulness for climate change monitoring, including time series segmentation (Jamali et al., 2015).

The goal of the presented work is to evaluate the usefulness of low-resolution NOAA AVHRR data for monitoring Polish forests representing various environmental and climatic conditions. In order to achieve the goal of the research work a detailed spatial and temporal analysis of meteorological parameters was carried out in combination with spatial and temporal variability of vegetation indices derived from satellite images. Two vegetation indices – NDVI and VCI (Vegetation Condition Index) – were analysed in conjunction with a meteorological database, containing temperature and precipitation data, using a statistical method of regression analysis. The outcome from statistical analysis reveals good relationships between remote sensing based and meteorological parameters, thus enabling the authors to draw conclusions on stress conditions in Polish forests.

2. Study area

In order to cover various environmental conditions in Poland six forest study areas were selected for the research work. Four forest areas – Augustowska Forest, Bialowieska Forest, Knyszynska Forest and Borecka Forest – are located in northeastern Poland. This part of Poland is under the influence of a continental climate, characterized by the impact of polar air masses, a shorter vegetation period and large temperature fluctuations. The four forest areas differ in forest site characteristics of species compositions: Augustowska and Knyszynska forests represent mainly coniferous forests (pine and spruce stands), while Bialowieska and Borecka Forests include large areas of deciduous and mixed stands (with hornbeam, oak, alder and birch as the main species).

Two other study areas are located in southern and southwestern Poland. Forests in Beskid Zywiecki Mountains are situated in the zone of continental climate zone with the impact of the tropical zone, while forests in Karkonosze Mountains belong to the zone of maritime climate zone with the impact of tropical air masses. Both southern study areas are located in mountainous regions, with two dominant species – spruce and beech.

The location of all study areas is presented in Figure 1.

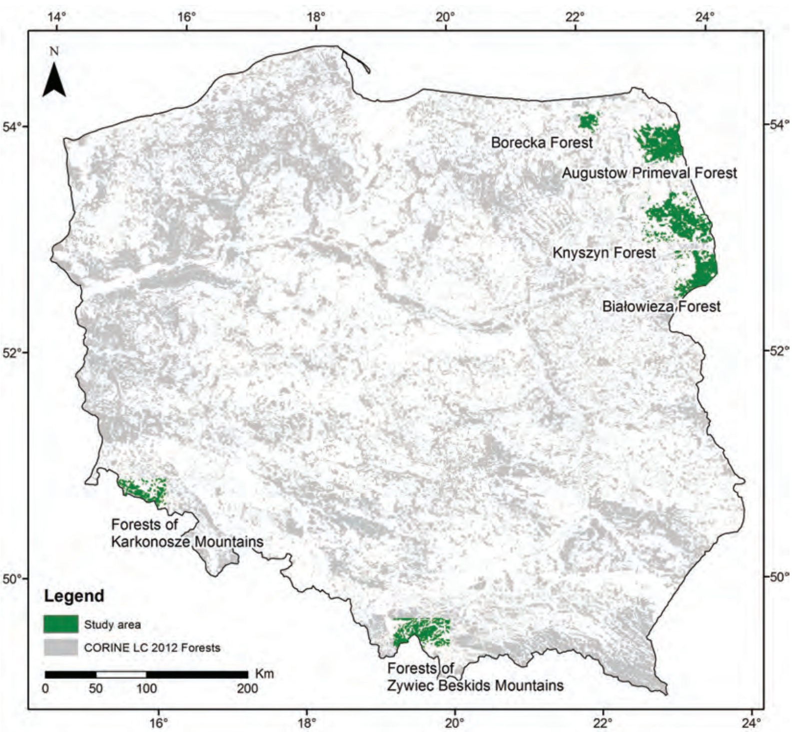

Fig. 1. Location of forest study areas

3. Materials and methods

1-km NOAA AVHRR images were used as the basic material for the research work. The images collected by a receiving station installed at the Institute of Geodesy and Cartography, Warsaw, Poland were pre-processed geometrically and radiometrically, including an atmospheric correction algorithm; next a cloud screening procedure was conducted applying the split-window technique and individual images were composited to produce 10-day cloud-free composites. Next values of two vegetation indices – Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI) – were extracted from the regions of interest: six forest areas located in southern, southwestern and northeastern Poland. The values were collected both for the whole forest areas and for 1-km test sites representing homogeneous tree stands.

At the next stage of the work NDVI time series were generated for each study area, covering the vegetation period (April – September) for the dataset comprising NDVI images from 1997 to 2015. Preliminary analysis of these series revealed a problem of quite high fluctuation of NDVI values within the vegetation period, which had to be analysed and accounted for prior to the next stage of the work – comparison of changes of remote sensing based indices with changes of meteorological parameters for the study areas. Therefore, two approaches of smoothing NDVI time series were applied in order to remove noise existing in original values due to non-precise cloud removal and changeable atmospheric conditions – a method of noise reduction based on the Savitzky-Golay filter (Bojanowski et al., 2009) and a method applying the spline technique. Moreover, in order to reduce fluctuations of NDVI values the study was conducted with the use of parameters describing short-term changes in atmosphere (temperature and humidity). The first results of the study revealed, that there is a relation between major changes in the atmosphere and abrupt NDVI decline. As a result of that study it was found that the smoothing method based on the Savitzky-Golay filter renders more precisely the NDVI run within the vegetation period, preserving subtle changes and removing abnormal ones.

The research was also conducted to determine whether NDVI values derived from low-resolution satellite images for the large forest areas, which include mixed forest information (e.g. deforestation patches, boundary mixed pixels, etc.) can be representative for dominant tree stands. The study included a comparison of the vegetation index derived from:

– the forest mask which encompassed the whole forest study area, as defined by CORINE Land Cover map, assuming that boundary pixels which include more than 50 % of forest belong to the forest mask,
– 1-km homogeneous test sites distributed with the forest study area as a mean NDVI value obtained from 8–12 sites.

The analysis was carried out for all six study areas located in northeastern and southern Poland. The results of the study proved that NDVI values derived for forest masks are compatible with means from 1-km test sites, whereas individual test sites can slightly deviate from that pattern. Compatibility of both NDVI curves, derived from 1-km test sites and from the whole forest polygons, is presented in Figure 2, using as an example the Borecka Forest test site.

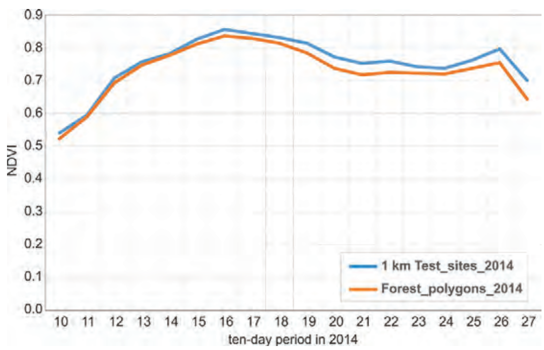

Fig. 2. Comparison of NDVI curves derived from eight 1-km test sites and from the whole forest area

At the next stage meteorological data were compiled from weather stations adjoining study areas: air temperature and precipitation (including information on snow appearance). These data were analysed in order to find anomalous weather periods, which could affect the condition of tree stands within study areas. As a result of the analysis three years which differ greatly in meteorological conditions were selected for comparative analysis – 2006, 2013 and 2014. The year 2014 was characterized by a mild winter, with temperatures above 0 from mid-February, reaching a maximum temperature at the beginning of August and gradually decreasing until the end of October. There were three precipitation peaks within the vegetation period – in ten-day periods 14, 19–20 and 23. In contrast, in 2006 and 2013 winters were quite long – with the air temperature below 0 until the beginning of April and with snow coverage, followed by a rapid temperature increase to the end of July / beginning of August. In 2013 there were three precipitation peaks within vegetation period – in ten-day periods 15, 16, 20 and 26, while there were two in 2006 – in ten-day periods 15 and 23. The graph demonstrating air temperature changes for northeastern forests in 2006, 2013 and 2014 is presented in Figure 3.

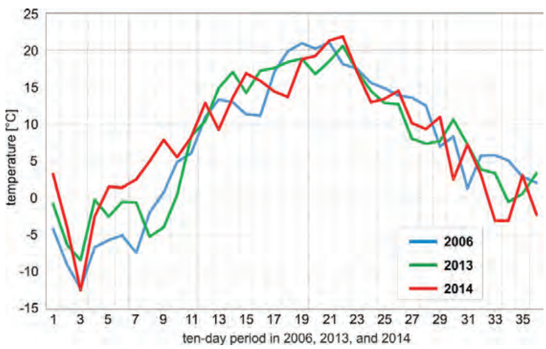

Fig. 3. Air temperature changes for northeastern forests in 2006, 2013 and 2014

4. Results and discussion

At the next stage of the works NDVI indices derived from NOAA AVHRR data collected in the 2000 – 2015 period were computed for forests located in six study areas: four in northeastern Poland – Bialowieska Forest, Knyszynska Forest, Augustowska Forest, Borecka Forest – and two located in southern Poland – Beskid Zywiecki and Karkonosze. The thorough analysis of NDVI curves was performed in two aspects:

– in the spatial context,
– in the temporal context.

Analysis of NDVI runs for study areas located in various geographical regions in northeastern and in southern Poland revealed quite important differences, caused both by different climatic conditions and environmental aspects. In the case of high temperatures at the end of winter and beginning of spring (2014) NDVI for forest study areas located in southern Poland begins from lower values due to the later start of the growing season in the Beskid and Karkonosze mountains. It is next compensated by favourable temperature conditions, reaching in ten-day periods 15-16 (May – June) similar values to the remaining forest areas. Forests in mountainous regions are more sensitive to NDVI fluctuations due to more variable climatic conditions. The lowest NDVI values in the mid-growing season are observed for Augustowska and Knyszynska Forests, which are the study areas more influenced by the continental climate than the remaining ones. NDVI changes for all study areas in 2014 are presented in Figure 4.

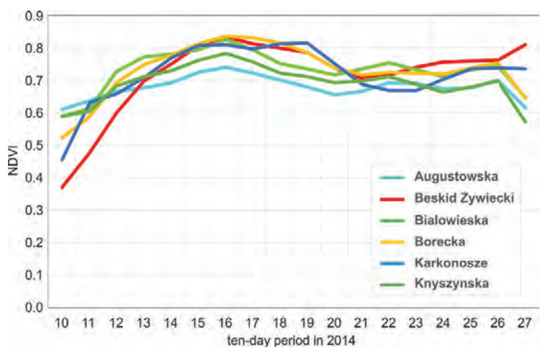

Fig. 4. NOAA NDVI changes for all forest study areas in 2014

A different situation of NDVI runs is observed in the case of the "cold" year, represented by low temperatures at the end of winter / beginning of spring (2006). In this case NDVI values for all study areas are low at the beginning of the growing season (the lowest one for the Karkonosze test site), reaching quite similar values in the mid-growing season. In the second part of the growing season – ten-day periods 20-27 (July – September) – test areas represented predominantly by mixed forests (Bialowieska and Borecka Forests) reveal higher NDVI values then the remaining ones. Again, lower

NDVI values can be observed for Augustowska and Knyszynska Forests, influenced by a more continental climate. NDVI changes for all study areas in 2006 are presented in Figure 5.

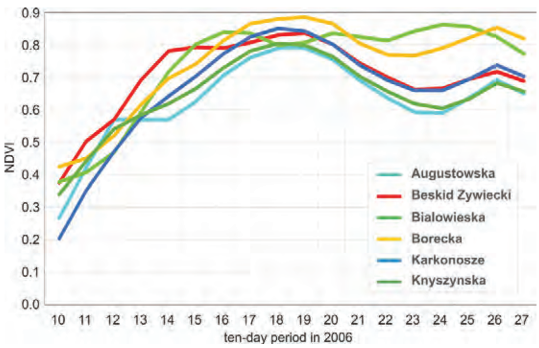

Fig. 5. NOAA NDVI changes for all forest study areas in 2006

Analogous analysis was conducted in the temporal aspect. NDVI curves were compared for particular forest test sites in the consecutive years 2000 – 2015. Analysis of the variability of NDVI values throughout the growing season revealed quite important differences, depending on the year represented by specific meteorological conditions. Three years representing different meteorological conditions at the beginning of growing season – 2006 and 2013 characterized by low temperatures at the end of winter / beginning of spring and 2014 when the growing season was preceded by a mild winter (temperatures in March above 0ºC) – were selected for illustration purposes. Analysis of NDVI in these years for northeastern forests revealed low values at the beginning of the growing season 2006 and 2013, as compared to 2014, for all three forest areas. Lower NDVI values existed until ten-day periods 15–16 (end of May / beginning of June); they also appeared in the case of 2013 at the end of the growing season. Comparison of NDVI changes for northeastern forests is presented in Figures 6 and 7.

In order to support analysis of NDVI changes an additional parameter characterizing the forest condition – Vegetation Condition Index (VCI) – was also applied. VCI is based on present and historical values of NDVI; it is expressed by the formula:

$$VCI = (NDVI_i - NDVI_{min}) / (NDVI_{max} - NDVI_{min})$$

where $NDVI_i$ means NDVI value in the *i* ten-day period, $NDVI_{max}$ and $NDVI_{min}$ are the maximum value of NDVI and the minimum value of NDVI in the historical database, respectively.

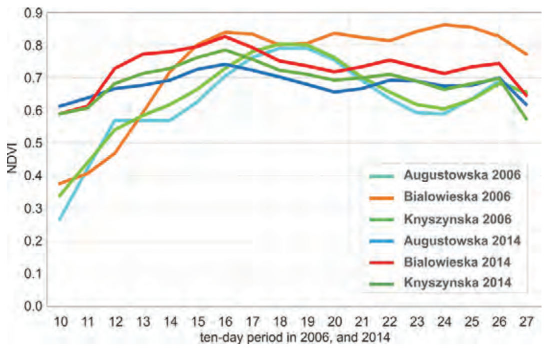

Fig. 6. Comparison of NDVI changes for northeastern forests – 2006 and 2014

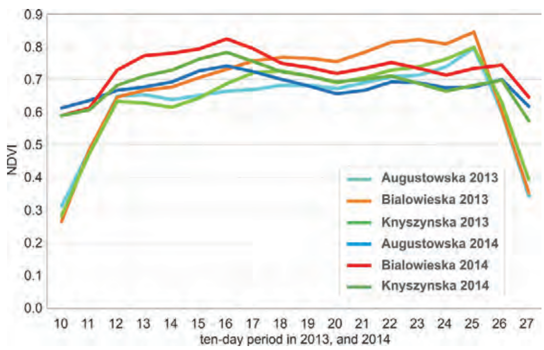

Fig. 7. Comparison of NDVI changes for northeastern forests – 2013 and 2014

The Vegetation Condition Index has been computed for all years in the 2000 – 2015 period and for all forest study areas. The results of analysis of VCI curves support those obtained from NDVI analysis – in the first part of vegetation seasons 2006 and 2013 (until ten-day period 17 – mid-June) VCI values were much lower than those observed in 2014. A comparison of VCI changes for northeastern forests is presented in Figures 8 and 9.

As thorough comparison of NDVI and VCI curves pointed out that there are some relationships between the character of meteorological conditions and values of vegetation indices, at the next stage of the works the quantitative assessment of these relations was conducted, through statistical analysis of remote sensing based and meteorological datasets. Various parameters derived from these datasets were applied:

– mean temperature for the winter period (January – March);
– mean temperature in March;
– mean temperature in the third ten-day period of March;
– NDVI / VCI value in the first ten-day period of April;
– NDVI / VCI value representing curve in the first six ten-day periods (April – May);
– NDVI / VCI value representing curve in the whole growing season.

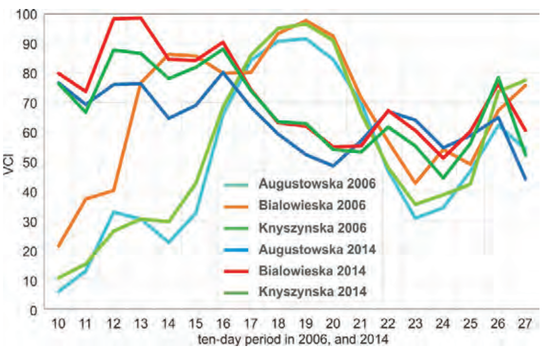

Fig. 8. Comparison of VCI changes for northeastern forests – 2006 and 2014

It was assumed that air temperature in wintertime and at the beginning of the growing season can have a significant impact on vegetation development, as expressed by vegetation indices. The detailed correlation analysis between temperatures and NDVI / VCI indices revealed that there is quite a strong correlation between mean air temperature in March and value of NDVI, represented by the area under the NDVI curve in the first six ten-day periods of the growing season. A high correlation coefficient appears for 5 study areas (except the Beskid Zywiecki test site). These findings are confirmed by correlation analysis between mean air temperature in March and the Vegetation Condition Index.

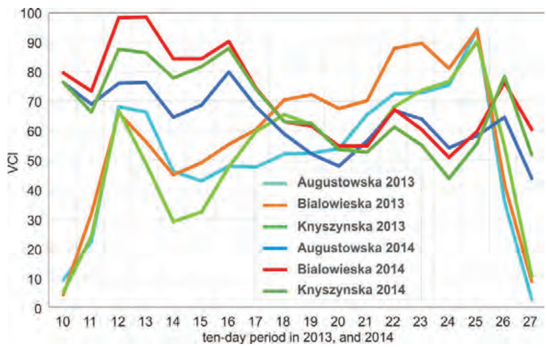

Fig. 9. Comparison of VCI changes for northeastern forests – 2013 and 2014

Slightly lower correlations were obtained between mean air temperature in the third ten-day period of March and the sum of vegetation indices in the first six ten-day periods, whereas correlations between mean winter temperature and the sum of NDVI / VCI are not so evident (exist only for some forest areas).

Table 1. Results of correlation analysis between air temperatures and NDVI / VCI derived from the first six ten-day periods of the growing season

Name of test area	Winter		March		March 3rd ten-day period	
	NDVI	VCI	NDVI	VCI	NDVI	VCI
Augustowska Forest	**0.51**	**0.55**	**0.64**	**0.67**	**0.50**	0.47
Bialowieska Forest	0.39	0.28	**0.63**	**0.53**	**0.53**	0.42
Knyszynska Forest	0.45	0.44	**0.66**	**0.50**	**0.58**	0.32
Borecka Forest	**0.64**	**0.73**	**0.86**	**0.87**	**0.51**	0.45
Beskid Zywiecki	0.13	0.31	0.30	0.45	0.14	0.16
Karkonosze	**0.61**	**0.50**	**0.67**	0.49	0.32	0.16

Significant correlation was not found between air temperatures and NDVI values derived from the area under the NDVI curve in the whole vegetation period.

In the case of relationships between air temperatures in wintertime / March / end of March and NDVI / VCI in the tenth ten-day period (first ten-day period of the growing season) these correlations were somewhat lower compared to previous ones, but still exist, especially in the arrangement NDVI / VCI versus air temperature in the third ten-day period of March.

There are some differences in correlation coefficients between particular forest areas; the highest coefficients were obtained for Borecka Forest (r = 0.87), while the lowest for Beskid Zywiecki (r = 0.30). Results of the correlation analysis are presented in Table 1 and in Figure 10.

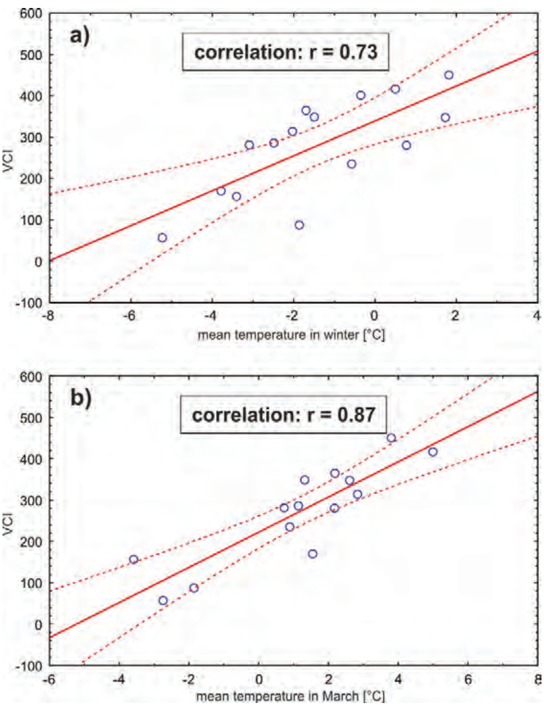

Fig. 10. Correlation graphs: a) for mean temperature in winter, b) for mean temperature in March (Borecka Forest)

5. Conclusions

The aim of the presented work was to evaluate the applicability of low-resolution satellite data for studying various environmental and climatic conditions in Polish forests. The results of the work revealed that both aspects of forest variability can be to a large extent monitored with the use of vegetation indices derived from NOAA AVHRR images. Forest areas located in various climatic regions – under the impact of continental climate in northeastern Poland and under the impact of the maritime climate in southwestern Poland are characterized by different NDVI curves, especially at the beginning and end of the growing season. General species composition within the study areas – dominance of coniferous or deciduous / mixed forests – also has a visible impact of NDVI levels.

Study of relationships between meteorological parameters and vegetation indices derived from NOAA AVHRR images also led to the conclusion that there is quite a significant relation between these two types of data. Both indices – Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI) – derived from the first part of the vegetation season correlate well with temperatures existing in wintertime, especially at the end of winter (in March). It means that low-resolution satellite data can be applied for monitoring stress conditions at the beginning of the growing season. Nevertheless, it should be mentioned that a significant impact of unfavourable conditions expressed by low winter / early spring temperatures is not observed for the study areas, while analysing vegetation indices in the whole growing season. It implies the conclusion that Polish forests located in both climatic zones are quite resistant to anomalies of temperature at the onset of the vegetation season.

The results of this study indicate further research which will be based on high-resolution satellite data; these data will enable more detailed analysis of relations between climatic conditions, environmental aspects and indices derived from EO images, taking into account variability of species and sites within the study areas.

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Zastosowanie obrazów satelitarnych NOAA AVHRR do badania warunków środowiskowych i klimatycznych w polskich lasach

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Streszczenie: Głównym celem prezentowanej pracy jest ocena możliwości wykorzystania niskorozdzielczych obrazów satelitarnych do badania kondycji drzewostanów w polskich lasach, będących pod wpływem różnych czynników klimatycznych i środowiskowych. W pracy zostały wykorzystane obrazy satelitarne NOAA AVHRR; wskaźniki roślinności określone na podstawie tych obrazów zostały porównane z parametrami meteorologicznymi otrzymanymi z naziemnych stacji pogodowych. Badania przeprowadzono dla 6 obszarów leśnych reprezentujących różne warunki klimatyczne i środowiskowe. Wyniki prac wykazały, iż istnieją statystyczne zależności pomiędzy wskaźnikami roślinności określanymi na podstawie niskorozdzielczych obrazów satelitarnych a temperaturą powietrza charakteryzującą warunki klimatyczne, zwłaszcza w pierwszej części okresu wegetacyjnego. Wnioski te zostały potwierdzone w aspekcie przestrzennym – w różnych strefach klimatycznych oraz w aspekcie czasowym.

Słowa kluczowe: zmiany klimatyczne, monitoring lasów, niskorozdzielcze obrazy satelitarne, wskaźnik roślinności