THE USE OF VEGETATION INDICES IN THE EVALUATION OF VEGETATION PHENOLOGY BASED ON MERIS DATA: THE CZECH REPUBLIC CASE STUDY

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ABSTRACT

This article focuses on utilization of vegetation indices for vegetation phenology analysis based on multitemporal MERIS data. The model data set contained imagery acquired during the vegetation season of the year 2009 and it covered most of the area of the Czech Republic. Databases LPIS and GlobCover were used for spatial delimitation of the observed vegetation types. Firstly, a methodology of processing multitemporal MERIS data for atmospheric and geometric corrections is presented. The main part deals with the evaluation of spectral characteristic of the forest species and agricultural crops by means of vegetation indices. Results showed that the MTCI index is well related to the changes of chlorophyll concentration and it is a suitable measure for chlorophyll estimation from MERIS data. Indices fCover and LAI are very sensitive to the quantity of vegetation cover (biomass). Perspectives of the research regarding the planned missions of the satellites Sentinel 2 and Sentinel 3 are given in conclusion.

Keywords: vegetation phenology, remote sensing, MERIS, vegetation indices, land cover

1. Introduction

Remote sensing is one of the most important data sources for monitoring state and changes of the land cover. Till now, many satellites and sensors with different resolutions suitable for variety of land cover monitoring tasks have been launched. Within all sensors those with high temporal resolution play an important role. The temporal resolution specifies the revisiting frequency of a satellite sensor on a specific location. If this frequency is between 1 to 3 days, it is specified as high temporal resolution sensor. The disadvantage of such sensor might be lower spatial resolution especially in case of sensors with continuous, global coverage scanning.

The MEdium Resolution Imaging Spectrometer (MERIS) installed on the ENVISAT satellite (Figure 1) with the spatial resolution of 300 m and temporal resolution of 1 day represented significant progress, for example in comparison with the scanner VEGETATION 2 installed on the satellite SPOT 5. With the same temporal resolution, MERIS offered more than three times higher spatial resolution. Moreover, MERIS collected data with relatively high spectral resolution using 15 spectral bands. Detailed information about MERIS data, sensor's properties, calibration and possible applications are available on the website http://envisat.esa.int/instruments/meris/, from which the data can be also downloaded. Unfortunately communication with the Envisat satellite was lost on 8 April 2012 and the end of the mission was consequently declared by ESA (https://earth.esa.int).

The primary purpose of the MERIS data was mapping chlorophyll and determining characteristics of the oceans or inland waters (e.g. Zibordi et al. 2013). Due to the global coverage and excellent temporal resolution, MERIS data have been used in change detection, especially changes of vegetation cover and its state.

There are many studies focused on vegetation mapping based on MERIS data. Rama-Rao (2008) tested possible utilization of MERIS images for classification of agricultural crops. Schlemmer et al. (2013) find bands 3, 4, 5, 6, 7 most suitable for vegetation monitoring. Authors of this study also indicated wavelengths, where changes in vegetation were most visible. The Red Edge band 6, where very steep increase in the reflectance is noticeable, showed to be the most useful. Zurita-Milla (2008) studied possibilities of combining MERIS and LANDSAT Thematic Mapper (TM) data for classification of heterogeneous land cover forms. Such a fusion takes advantage of both high spectral and temporal resolution of MERIS and higher spatial resolution of TM. The study uses "fully linear unmixing" method, where each classified category within one pixel is unmixed.

Dash et al. (2007) used MERIS data and vegetation indices MGVI (MERIS global vegetation index) and MTCI (MERIS terrestrial chlorophyll index) for vegetation classification. These two indices were developed for MERIS scanner and, according to the authors, enable discrimination between vegetation classes better than by using only a single spectral band of MERIS data. Štych et al. (2014) and Malíková (2010) evaluated reflectance of the vegetation in the Czech Republic based on MERIS data and spectral curves of the forest areas and chosen agricultural crops. Brodsky et al. (2008) deal with a crop classification using MERIS data in the Czech Republic.

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Fig. 1 Satellite ENVISAT.
Source: ESA.

High temporal and spectral resolution of MERIS data enables use not only for classification of the land cover but also for analysis the physiological changes of vegetation. Vegetation indices are then suitable indicators of research of qualitative factors of vegetation.

A solution to these problems can be seen in the selected studies, which dealt with potential of vegetation indices developed for determining contents of chlorophyll and nitrogen in plants from the MERIS data. The index NDVI (Normalized Difference Vegetation Index) was frequently used, however, according to Dash et al. (2007), there are some significant limits for using NDVI for monitoring vegetation, e.g. the disregard of structure of the surface, reflectance of the soil and partly even chlorophyll content. Chlorophyll content is a basic factor influencing spectral characteristics of vegetation. It is different for each vegetation type and for each vegetation phase. Thus, it can be used as a suitable measure for creating maps of vegetation cover. The use of MERIS data enabled development of new vegetation indices, which are focused on, for instance, more exact estimation of biomass or leaf chlorophyll content. The index called Meris Green Vegetation Index (MGVI) can be mentioned as one of these indices. Maximal sensitivity to state and changes of the health condition of vegetation is fundamental to empirical derivation of this index. MGVI should determine the extent of the land vegetation and its condition (Gobron et al. 1999, Gobron et al. 2008). It has been proved that the MGVI index is a reliable indicator of content of green mass in a pixel, in some cases more reliable than the frequently used vegetation index NDVI (Gobron 1999). Dash et al. (2007) studied the relationship between vegetation indices and chlorophyll content and they presented a formula for this calculation. Chlorophyll content closely related to the values of vegetation indices MTCI and MGVI, which are derived from MERIS data. Gobron et al. (2007) compared results of the index fAPAR (fraction of Absorbed Photosynthetically Active Radiation) calculated from different data products, for example from sensor MERIS or SeaWiFS. They concluded that the MGVI index strongly correlates with the fAPAR index. Small differences depend on geographical conditions or different calibration of each sensor.

Vegetation indices are traditionally used for determining phenological phases of plants. At present, there are several data sources suitable for determination of phenological phases. The MODIS sensor located on the satellite Terra (Clerici 2012; Ivitis et al. 2009) or sensor AVHRR (Advanced Very High Resolution Radiometer) located on the satellite NOAA can be mentioned as examples of such sources.

Determination of the length of the vegetation period based on remote sensing data can be done during the vegetation season by time curves (in this case, a time curve means function of the selected vegetation index in dependence on its time course during the calendar year) derived from the vegetation index, which is calculated from a temporal sequence of the imageries from chosen sensor. Two key points SOS (Start of Season) and EOS (End of Season), which give beginning and end of the vegetation season, must be set on the time curve. Ivitis et al. (2009) and Celrici (2012) discussed a definition of these points by use MODIS data. Beurs and Henebry (2013) used a method of thresholding of the time curves of the chosen vegetation indices for finding the SOS and EOS points. Based on the mentioned methodology the internet application (http://tethys.dges.ou.edu/EVI/#) was created. It determines beginning and end of the vegetation season based on chosen value of the NDVI index or possibly EVI (Enhanced Vegetation Index) (Tucker 1979). Zhang et al. (2003) and Aurdal et al. (2005) defined each phenological phase of vegetation according to development of NDVI values. Each phenological phase was defined as the following:

1. green-up – beginning of photosynthetic activity,
2. maturity – maximum of the leaf area,
3. senescence – period, when photosynthetic activity and leaf area begin decrease steeply,
4. dormancy – photosynthetic activity is approaching zero.

Setting the exact length, the beginning and the end of phenological phases based on vegetation indices can be specific for a particular locality considering different geographical and climate conditions.

In this work the potential of multitemporal MERIS data for analysis of vegetation spectral characteristics by chosen vegetation indices is studied. The aim of the presented study is to evaluate the differences of spectral characteristics of the selected land cover types by using combination of data from the MERIS sensor and LPIS (Land Parcel Identification System, http://www.lpis.eu). Several forest types (coniferous, mixed and deciduous) and agricultural crops (oil seed rape, maize, cereal crop, hop and grassland) are investigated. The studied time period is the vegetation season of the year 2009. The changes of spectral characteristics of vegetation are evaluated based on the selected vegetation indices. Following the results of the spectral characteristics of vegetation, problems of determining particular phenological phases of the selected vegetation types are discussed.

2. Methods and data

This study deals with spectral behaviour of forest (coniferous, mixed and deciduous) and agricultural crops (oil seed rape, maize, cereal crop, hop and grassland). It is based on analysis of the MERIS data acquired in period between April 2009 and September 2009 covering almost the entire area of the Czech Republic. According to the available meteorological data, in 2009 nor temperature extremes nor extreme rainfalls occurred. MERIS data products Level 1 generally marked MERIS_FRS_1P were used. Data were provided by the receiving station of the satellite ENVISAT installed at the Faculty of Science of Charles University in Prague. For the purposes of this study, 6 images were selected (Table 1) with the primary requirement of low percentage of cloud cover (lower than 10%). The year 2009 was chosen mainly because of availability of the database LPIS, which was the second significant data source. LPIS is an information system, which is mainly used for records of agricultural land in the Czech Republic. The primary aim of the creation and maintenance of this system is to provide data about the use of agricultural land, including simple administration and to check complying with conditions of application for agricultural subsidies (http://www.lpis.cz). For the purposes of this study a spatial database in shapefile format containing necessary data about each soil unit was obtained from the Ministry of Agriculture of the Czech Republic. A soil unit represents a basic unit of records of the minimum area of 0.1 ha. Thus, geometrical and attribute data from LPIS provided information about the crops and area of the soil unit.

Tab. 1 The list of used imageries from the sensor MERIS.

Image acquisition		ID of image
Date acquisition acquisition	Time (UTC)	
21.4.2009	9:39:13	37336
3.5.2009	9:59:38	37508
14.6.2009	9:42:10	38109
17.7.2009	9:04:47	38581
20.8.2009	9:36:24	39068
1.9.2009	9:56:46	39240

Source: Receiving station of satellite data, Faculty of Science, Charles University in Prague.

The GlobCover database was used for definition of the masks of basic forest areas. This database was also used as a reference for determination of basic forest types, because it was created from the same type of data (MERIS). The database contains 22 landscape types according to the system LCCS and 63 categories of the regional database GlobCover. This database is the result of the classification of data composition from the period December 2004 – June 2006 and it is available on the website http://ionia1.esrin.esa.int/. In the case of agricultural crops, plots were determined from the LPIS database. Examined plots of observed vegetation types were created based on both LPIS and GlobCover database.

Data MERIS were processed in the freeware BEAM 4.7 (Basic ENVISAT (A) ATSR and MERIS), which supports MERIS data and AATSR data from the satellite ENVISAT as well as data from the sensors MODIS, AVHRR, AVNIR, PRISM and CHRIS/Proba. The internal format *.N1 as well as the widespread formats such as GeoTiff, NetCDF including vector format *.shp are supported.

Atmospheric corrections were made by the internal modules SMILE and SMAC on the BEAM platform. These algorithms are designed for atmospheric correction in a semiautomatic mode. In the case of module SMAC input parameters concerning visibility are based on concentration of aerosols (Aerosol Optical Depth – AOD) in the earth's atmosphere for a given time figure. Further, the module requires specification of the type of the area (continental, desert) and defining the mask. The other parameters are calculated automatically. Data about concentration of aerosols in the atmosphere were acquired from portal GIOVANNI (http://disc.sci.gsfc.nasa.gov/giovanni). Correction of irradiance and reflectance was calculated by the SMILE module. Process of atmospheric correction is given by summarization of the two above mentioned components – SMAC and SMILE (BEAM HELP 2009). Accuracy of the atmospheric corrections was verified on principle of the darkest object that means on the values of the chosen pixels of vast water bodies.

Geometric corrections of the input data were done using orthorectification. Orthorectification on the BEAM platform is an automatic process without manual inputting tie points. The tie points are included in products MERIS 1P and the digital elevation model GETASSEA30 (Global Earth Topography and Sea Surface Elevation at 30 arc second edition) is available in SW BEAM as a separate product. All imageries were transformed into the system of UTM coordinates. A resampling with the pixel size of 300 × 300 m was made by the nearest neighbour method.

An important step during the processing of the MERIS data was to mask cloud cover. When pictures without cloud cover were not available, the cloud cover had to be removed. The masks of cloud and snow covers were created by the tool CLOUD PROBABILTY, which is implemented in BEAM software. The creation of the masks was made by thresholding histogram and visual interpretation.

The selected vegetation indices were chosen for observing development of spectral behaviour of vegetation, respectively phenological phases. All vegetation indices were calculated by the tools VEGETATION PROCESSOR, NDVI PROCESSOR and FAPAR PROCESSOR, which are the parts of software BEAM. VEGETATION PROCESSOR uses neuron networks and works with 11 spectral channels of the sensor MERIS, except bands 1, 2, 11 and 15. Following indices were calculated:

1) NDVI (Normalized Difference Vegetation Index)

Without doubts, NDVI is the most frequently used vegetation index. This indicator presents vitality of vegetation on the earth surface and its values are correlated with a number of chosen quantities such as volume of biomass, health state of the vegetation or vegetation cover (Carleson and Ripley 1997).

The general formula for the calculation:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

(note: NIR = 10th spectral band; RED = 6th spectral band of MERIS data)

This index values are ranging from −1 to +1, value 0 means that the particular pixel does not contain any green vegetation. On the contrary, values reaching 1 represent healthy and dense vegetation (Solano et al. 2010).

2) MGVI (MERIS Global Vegetation Index)

This index uses information from the blue, red and NIR spectrum. The information from the blue part of the spectrum minimizes the influence of atmospheric effects. The index MGVI is able to detect many features of the vegetation cover such as physiological state and vitality of the vegetation (Gobron et al. 2005). The index MGVI is calculated based on the information contained in the spectral band with the wavelength of 442 nm and it is combined with the wavelengths of 681 nm and 865 nm. The methodology for exact empirical determination of MGVI is described in works by Verstraete and Pinty (1996), Govaerts et al. (1999), Gobron et al. (1999) or Rahman et al. (1993).

3) MTCI (MERIS Terrestrial Chlorophyll Index)

This index represents characteristics of a pixel on the wavelengths 0.6–0.7 μm using spectral bands 8, 9, 10 of sensor MERIS (ratio between differences of the bands 10–9 and 9–8; see formula). In these spectral bands is visible steep increase in reflectance on the border between areas of pigment absorption and high reflectance. The increase in spectral reflectance is noticeable, especially in the direction from the 8th to the 10th spectral band (Dash, Curran 2007):

$$MTCI = \frac{R_{Band10} - R_{Band9}}{R_{Band9} - R_{Band8}} = \frac{R_{753.75} - R_{708.75}}{R_{708.75} - R_{681.25}}$$

R is spectral reflectance respective spectral bands.

Index MTCI is sensitive to the chlorophyll content in plants and that is why it is used for analysis the state and changes in concentration of this pigment in plants and is related to the characteristics of vegetation such as physiological state, phenological phases and others. MTCI seems to be the most suitable index for estimation of content of chlorophyll from the MERIS data (Dash and Curran 2003 or Dash and Curran 2007).

4) fAPAR (fraction of Absorbed Photosynthetically Active Radiation)

It is a fraction of photosynthetically active radiation absorbed by vegetation. This index gives the quantity of radiation absorbed by the surface with wavelengths 0.4–0.7 μm and depends on the structure of the surface and the angle of incidence of the Sun radiation. The values are ranging from 0 to 1 (Gobron et al. 2008), where value 1 represents a high absorption of Sun radiation. It is suitable for analysing seasonal and inter-annual changes of the vegetation (Gobron et al. 2005).

5) fCover (fraction of Green Vegetation Coverage)

This index determines vegetation coverage of the area. It assumes values between 0 (bare land) and 1 (fully covered vegetation). This index is a suitable alternative of traditional used vegetation indices for the monitoring of green vegetation, as it is basically independent on leaf and soil optical features and the angle of incidence radiation (Global Land Service 2014). The principle of fCover is depended on spatial structure of the vegetation coverage, for example, orientation leaf, index of leaf area, and layout of single plants (Bacour et al. 2006).

6) LAI (Leaf Area Index)

LAI is a quantitative proportion of the leaf density, which reflects the state of the vegetation. LAI expresses leaf coverage, which is the total area of the upper side of the leaves per horizontal area unit. LAI can be derived from NDVI (Chen and Cihlar 1996). It is a quantitative indicator of the total leaf area, which can absorb radiation necessary for processes of photosynthesis (Dobrovolný 1998).

7) LAIxCab

LAIxCab expresses leaf chlorophyll content, with the possibility to calculate the chlorophyll content on both leaf and surface levels. The values of LAIxCab are obtained by multiplying LAI by the content of the leaf chlorophyll (Cab) and they range from 0 to 300 g/m^2.

The values of the used vegetation indices represent the average values of individual pixels under the masks. The mean value was calculated for all the examined plots of observed vegetation types in the Czech Republic. The plots were delimited by the reference database GlobCover and LPIS. The plots for forests were created based on GlobCover database and the polygons made by selection of the data LPIS were used for masks for each agricultural crop type. The size of the smallest unit of the studied polygon in GlobCover and LPIS was defined to 900 × 900 m that means minimally 9 pixels of the size 300 × 300 m. The minimum size of areas was 81 ha. Consequently, average values of vegetation indices were calculated by statistic functions in SW BEAM under these masks (plots). The total number of the analysed plots was in hundreds and total number of pixels in thousands. The largest number of monitored pixels was noticed for forest areas, the noticeably lower number of plots was for the agricultural crops such as hop. Geographical characteristics of the examined plots were very different. Plots were located in different types of landscape: lowlands, hilly places or mountains areas. Forests (coniferous, broad-leave and mixed forest) and agricultural crops (maize, cereal crop, oil seed rape, hop and grassland) were the evaluated categories in this study. In the Figure 2 selected observed areas (areas of interest) of grassland are shown.

3. Results

The result part focuses on evaluation of the differences of the spectral responses of vegetation types during vegetation season 2009. Similarities and differences in the values of the studied indices are presented with regard to assessment of particular phenological phases of the studied crops and forest. The results should indicate applicability of different vegetation indices or their combinations for detection of vegetation types and determination of their phenological phases. The results focuse on the comparison of values of the studied vegetation indices during the observed period and on the evaluation of their suitability for distinguishing between the given crops and forest species.

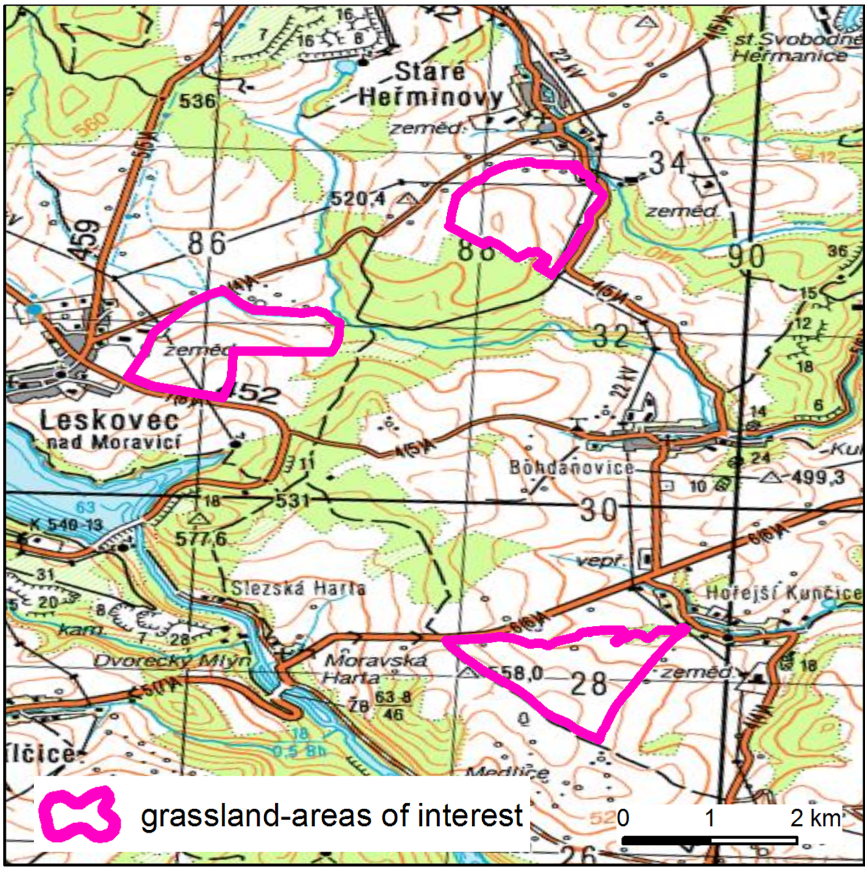

Fig. 2 Areas of interest of grassland in Jeseníky Mountains.
Source: Czech National Geoportal and own calculation.

Firstly, the development of all calculated vegetation indices for the chosen crops was evaluated. Figure 3 represents the development of the found values of all studied vegetation indices for maize. There is an obvious difference in the result values, when the values NDVI, MGVI and fAPAR ranged within 0–1, the values of the other indices, on principle, assumed higher values. Analysing the values changes during the observed period, index MTCI showed in the case of maize a significant increase of the values from April with maximum in July. After that, the value of MTCI begins to decrease, what could indicate the fact that the plant switch to the period of senescence, when maize ripened and did not show so high photosynthetic activity. Lower photosynthetic activity could be also seen in the values of fAPAR (Figure 3), which were lower during August and September than in July. Also indices fCover and LAI, which should reflect the quantity of green cover and the size of the leaf area respectively, showed the highest values in July. Generally, it can be concluded that in the case of maize, the curves of the values of the evaluated indices reach their maximums approximately at the same time. Both types of indices: 1) indicating photosynthetic activity (concentration of pigments) and 2) indicating vegetation coverage reach their highest values approximately at the same period. The very similar course of the development curves was obviously seen at LAI, LAIxCab and MTCI. The values of fCover and MGVI corresponded at lower value level. The development of NDVI was the least noticeable without bigger extremes.

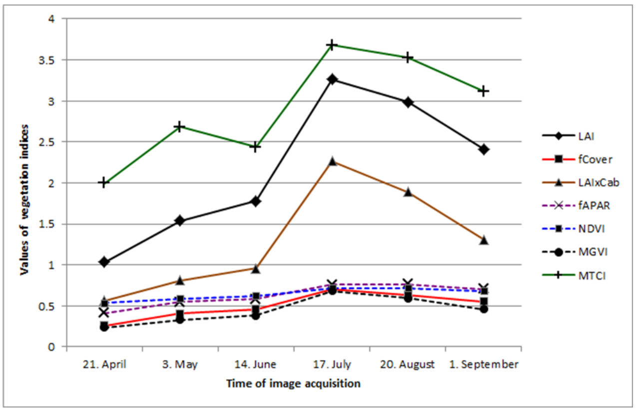

Fig. 3 The development of vegetation indices for maize during the observed period in 2009.
Source: Own calculation.

In case of oil seed rape, the curves of the evaluated indices were different. Development of the values LAI and LAIxCab is, in principle, similar, however with a more different course in comparison with values MTCI (Figure 4). In the primary phase index MTCI, which is sensitive to content of chlorophyll, reached the highest values. There was a decrease in the following period i.e. May. In this period oil seed rape is mostly in the phase of the characteristic yellow blooming and, according to the results, index MTCI should reflect this fact. The values of LAI reached its maximum in July, after that the values sharply decreased. This could be caused by the harvest of this crop, which naturally decreases the level of LAI representing the leaf area. The indices NDVI, MGVI, fCover and fAPAR also decreased in this period; their values were on much a lower level.

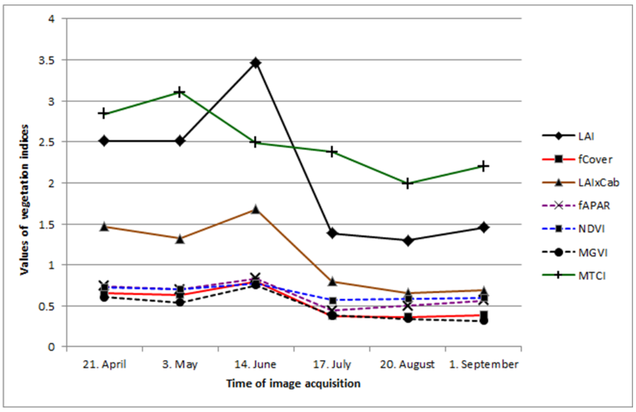

Fig. 4 Development of vegetation indices for oil seed rape during the observed period in 2009.
Source: Own calculation.

Certain differences in the course of the curves of vegetation indices could be also found at grassland (Figure 5). The indices expressing size of leaf area and vegetation coverage (LAI and fCover) reached the highest values during summer, after that there was noticeable a decrease in the values. Indices MTCI, NDVI and the values of fAPAR showed a similar two-peaked course of the curve with a decrease in the values in high summer. The decrease in values of LAI and fCover in summer could be influenced by the mowing of grassland, the decrease of MTCI could be caused by hot and dry summer weather, which could affect spectral characteristics.

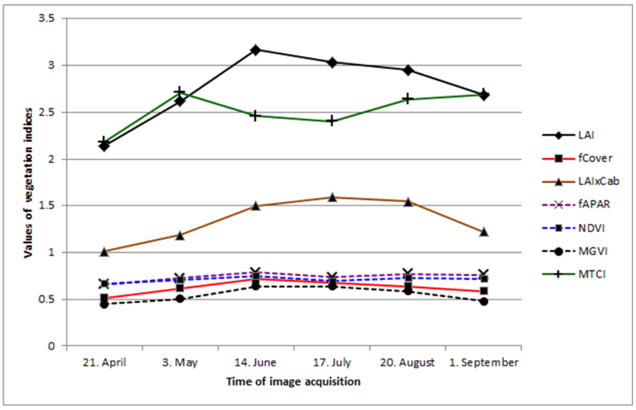

Fig. 5 The development of vegetation indices for grassland during the observed period in 2009.
Source: Own calculation.

Based on the analysis and comparison of the curves of the values of chosen vegetation indices, the values NDVI (Figure 6) in most cases confirmed generally known curves of the phenological phases. There was noticeable early vegetation maximum of oil seeds rape, later for the cereal crop and in the following weeks the maximum for maize occurred. A very heterogeneous character of the grassland makes impossible to find the obtained results significant. Forests can be considered as very heterogeneous biotops as well. But the obtained results of the NDVI index (Figure 6) did not differ from many other studies; in summer coniferous forest reached lower values than deciduous and mixed ones (see Boyd et al. 2011).

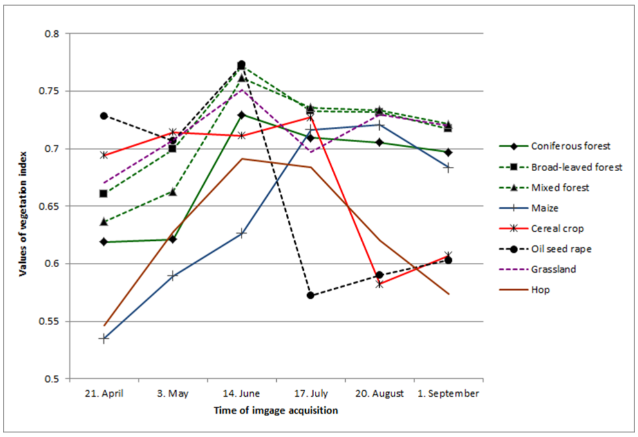

Fig. 6 The development of vegetation index NDVI in 2009.
Source: Own calculation.

The curves of the value of index MTCI are presented in Figure 7. In cases of forest areas the growth of the values during the entire studied period, with the clear maximum in July, for mixed forest could be seen. Cereal crop and hop reached their maximum in July, then for cereal crop there was a significant decrease in the following period, which could detect the harvest season. The courses of values for oil seed rape, maize and grassland were described above.

From comparing the curves of NDVI and MTCI for the evaluated crops, there was obviously wider range of the values MTCI than NDVI. The values NDVI showed slow increase and decrease with maximum in June and July. Except for cereal crop and oil seed rape, in the case of which there was a steep decrease in value in summer period probably as a result of their harvest.

The obtained results are in agreement with the results of the study (Boyd et al. 2011), which experimentally confirmed higher values MTCI at the mixed forest and generalizes comparison of NDVI and MTCI by conclusion that MTCI is much more sensitive to differences in content of chlorophyll and NDVI reflects changes in vitality and up to some point even the volume of biomass of the vegetation (Boyd et al. 2011).

The results of the index fCover (Figure 8) are worth more detailed analysis, as in principle they express extent of the coverage of the vegetation. In the cases of particular types of forest, naturally, for deciduous forest was noticed higher value for this index than for coniferous forest. Grassland also reached high values and consequently coverage. This index also showed a steep increase of the phenological phase followed by a steep decrease of oil seed rape. Cereal crop confirmed earlier harvest than in the case of maize. Before its harvest in July, cereal crop reached a high value in the index fCover.

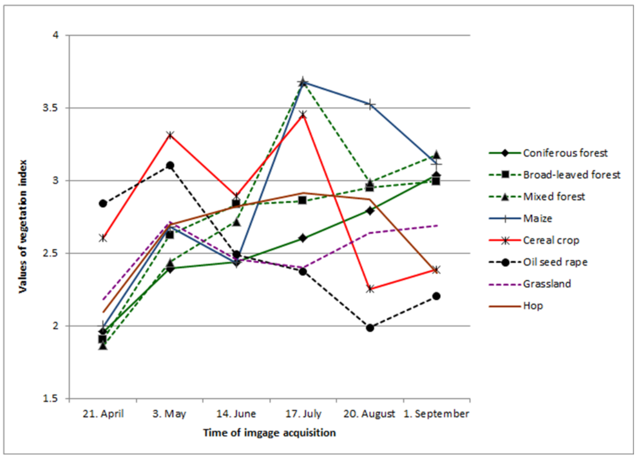

Fig. 7 The development of vegetation index MTCI in 2009.
Source: Own calculation.

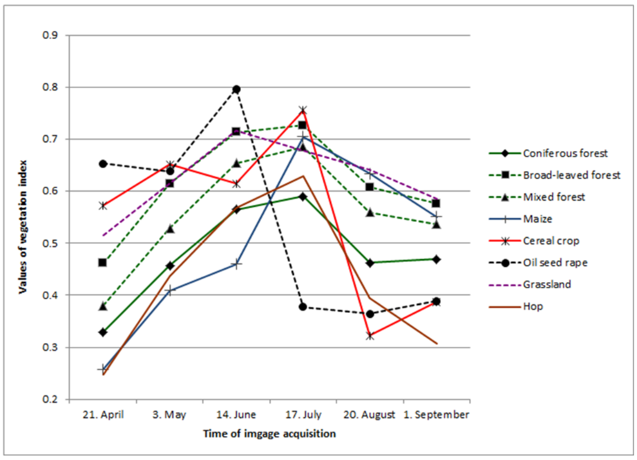

Fig. 8 The development of values of fCOVER in 2009.
Source: Own calculation.

4. Conclusions and discussion

This study based on MERIS data showed a relevant potential of using this data and vegetation indices for the evaluation of phenological phases. Calculation and comparison of the results of the selected vegetation indices showed strong and weak sides of the used methods. Generally, it can be said that specifically designed indices for the MERIS sensor brought relevant results based on which particular types of vegetation and development of their phenological phases were possible to be distinguished more accurately and in details. The data from the MERIS sensor can be successfully used for monitoring of spectral characteristics of many vegetation types. MERIS data have the advantage over Landsat or Spot for example, which is higher number of bands existing in the area between red and infrared part of the spectrum called red edge. This fact is proved by higher sensitivity of the vegetation indices based on these bands. Vegetation indices MTCI and MGVI, using spectra in the area of red edge for their calculations, brought relevant results. This work determined curves of values of MTCI, when cereal crop, maize or mixed forest reached high values in high summer. These results are in accordance with the results of similar studies, e.g. Štych et al. (2014); Malíková (2010) or Boyd et al. (2011). MTCI well reflects changes of chlorophyll concentration and in comparison with other indices, which express vegetation coverage or leaf area (LAI or fCover), showed a slightly different course of the curve. In comparison with NDVI, index MTCI showed much wider range of values, what was the most noticeable in the case of forest areas. The comparison of the values of MTCI and NDVI was done also by Dash and Curran (2003) who noticed a much higher range of the values of the MTCI index and they considered this index most suitable for the estimation of chlorophyll with the use of MERIS data.

The combination of data MERIS and LPIS seemed to be very suitable for further research of spectral characteristics of agricultural crops. On the contrary, presented methodology based on data only from one year and must be critically judged. Using the GlobCover database as reference information of forest is discussable as well. The accuracy of classification of forest was calculated for this global database. These aspects could affect the results of this study.

Generally valid rules based on these results cannot be defined. For future research it would be desirable to analyse spectral curves during a multi-year period with detailed research and an explanation of the reached values of the used vegetation indices. High heterogeneity of some observed vegetation types, such as forest and cereal crop must be also considered. Development of the phenological phases in different climate zones and zones with different altitudes can be shown in the resulting curves. A disadvantage of the chosen methodology is observing crops in all area of the Czech Republic, where vegetation types from different climate zones are combined. Another study, which would deal with development of vegetation indices in particular climate zones and their differences, would be suitable.

As for the technical side of the method, significant advantage in case of the use of data MERIS is freeware platform of software BEAM, which was designed by European Space Agency directly for processing these data. However this software must be used carefully, especially if the default set-up of some tools is used. Default setting of the tool NDVI processor, which calculates the NDVI based on 6 and 10 bands, can serve as an example. This chosen combination is arguable, as the 6th spectral channel of the MERIS sensor does not sufficiently cover the required red band. The center of wavelengths of the 6th spectral channel varies around 620 nm, so it is on the border between the green and red band. The chosen 6th channel for calculation of index NDVI is arguable and the index should most likely be calculated as a combination of the bands 7(8) and 10. This fact was proved also experimentally, when the denominator of the fraction (red spectral band) should include wavelengths around 700–720 nm (see Clevers, Gitelson 2013).

Despite the ending of the ENVISAT mission in 2012, studies based on MERIS data can be considered useful as in the future launched the satellites Sentinel 2 and Sentinel 3 will provide data with similar properties (Donlon et al. 2012). Satellites Sentinel 2 and 3 should offer even better parameters for the study of vegetation, as they will combine conditions of high temporal resolution with quality spatial resolution (20 m) (Schlemmer et al. 2013). Data from Sentinel satellites should be more sensitive in the red edge area. It will enable more advanced monitoring and detection of particular types of vegetation (Clevers, Gitelson 2013). Spectral bands n. 5 (705 nm) and 6 (740 nm) of the satellite Sentinel 2 should represent the red spectral band better (Schlemmer et al. 2013). Spectral channel n. 11 with the center of the wavelengths of 709 nm of the satellite Sentinel 3 should also reliably cover the red part of the electromagnetic spectrum and as a result it is again very well suited for using for correct determination of the border red edge, see Schlemer et. al. 2013 or Clevers and Gitelson 2013. In the future, a wide use of the data products which come from these two satellites can be expected not only for study of phenological phases of the vegetation, but also for other research tasks such as detection of changes of land cover, determination of the condition of vegetation or estimation of biomass.

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RESUMÉ

Využití vegetačních indexů v hodnocení fenologických fází vegetace v Česku na základě dat MERIS

V této studii je zkoumán potenciál využití vegetačních indexů pro účely výzkumu fenologického chování vegetace na území České republiky pomocí multitemporálních dat MERIS. Hodnocení proběhlo ve vegetační sezoně roku 2009 a k prostorovému vymezení sledovaných vegetačních typů bylo využito databází LPIS a GlobCover. Použitá metodika prokázala schopnost monitoringu fenologického chování lesní a zemědělské vegetace hlavně díky vhodnému časovému a spektrálnímu rozlišení použitých dat MERIS. Obecně lze konstatovat, že specificky navržené indexy pro sensor MERIS přinesly relevantní výsledky, na základě kterých bylo možno podrobněji a přesněji rozlišit jednotlivé typy vegetace a průběh jejich fenologických fází. Studie potvrdila silný výzkumný potenciál kombinace dat MERIS a LPIS. Kombinace těchto zdrojů se jeví jako velmi vhodná pro další výzkum spektrálních charakteristik zemědělských plodin. Pro budoucí výzkum by bylo žádoucí sledovat spektrální křivky ve víceletých periodách s detailnějším průzkumem a vysvětlením dosažených hodnot použitých vegetačních indexů. Přestože provoz družice ENVISAT, na které byl umístěn sensor MERIS, byl ukončen v roce 2012, lze považovat studie založené na těchto datech za užitečné, jelikož data podobných vlastností budou poskytovat v budoucnu vypuštěné družice Sentinel 2 a Sentinel 3. Lze tedy očekávat široké využití datových produktů, které pocházejí z těchto satelitů, nejen pro studium fenologických fází vegetace, ale také pro další výzkumné úlohy, jako jsou detekce změn land cover, určování zdravotního stavu vegetace či odhady biomasy.

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