Developing MODIS time series for monitoring vegetation conditions: preliminary results

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Keywords: MODIS, NDVI, vegetation monitoring

ABSTRACT: Satellite remote sensing imagery is being widely used in monitoring human induced or phenological changes in natural and agricultural environments. Inner-annual variations in vegetation conditions can be systematically studied with the use of frequently acquired data, thus offering the potential for operational monitoring of these changes. Such is the case of MODIS sensor, which provides daily images of the land surface and vegetation index products at various spatial resolutions. In this paper, 250 m MODIS daily images were used to generate 16-day composite NDVI time-series for five selected sites in Greece, representing different types of natural and managed vegetation. Specific objectives were to investigate the response of the composites to the seasonal changes of vegetation for the time period from May 2003 to October 2003, and whether variations between vegetation types are detected. Additionally, a comparison was conducted to examine the level of similarity between the 16-day NDVI composites produced and the standard MODIS VI products (MOD13Q1). The results displayed a relatively good response to phenological development and variations were described satisfactorily, while significant differences between the composites occurred for most of the test sites. The noise observed in the NDVI trends hindered a more precise vegetation analysis, however, the reduction or removal of irregularities is a subject for future work.

1 INTRODUCTION

Vegetation is one of the most important components of the ecosystems. Knowledge about variations in vegetation species and community distribution patterns, alterations in phenological cycles and modifications in the plant physiology and morphology provide valuable information about the climatic, edaphic and physiographic characteristics of an area (Jones et al., 1998). The constant changes of natural and agricultural environment, accelerated mainly by human activities, such as biomass burning, deforestation and land degradation, have posed the need for monitoring. Monitoring the condition of vegetation is of primary importance, especially in the Mediterranean region, as it is closely related with fire risk of natural vegetation and management of agricultural crops. Also, European directives and regulations dictate monitoring at
national or international scale aiming at the rational management of the ecosystems and prevention of future hazards.

Detection of land changes and examination of vegetation parameters have been usually conducted with in situ data collection. During the recent decades, satellite remote sensing has been widely used in monitoring terrestrial ecosystems at regional to global scales, due to its capability of providing synoptic information over wide areas with high acquisition frequency (Richards, 1993; Myneni et al. 1997) and has complemented field work measurements. Satellite data has been utilized for estimation of forest biomass (Jensen & Hodgson., 1985), for classification of agricultural land (Haack & Jampoler, 1994), for assessing the seasonal dynamics of tropical forest (Ferreira & Huete, 2004) and for fire risk assessment (Maselli et al. 2003).

The current monitoring of vegetation status with remotely sensed data has been performed with the utilization of vegetation indices, which are spectral transformations of two or more bands. The Normalized Difference Vegetation Index (NDVI) has been extensively applied in vegetation studies and is related to phenology and biophysical parameters, such as green cover, biomass, leaf area index, fraction of absorbed photosynthetically active radiation and productivity (Tucker, 1979; Sellers, 1985; Spanner et al. 1990; Baret & Guyot, 1991; Prince et al. 1995). Its strength lies in its ratioing concept, which reduces many forms of multiplicative noise (illumination differences, cloud shadows, atmospheric attenuation, certain topographic variations) present in multiple bands. However, the main disadvantage of the NDVI is the inherent nonlinearity of ratio-based indices and the influence of additive noise effects, such as atmospheric path radiances. The NDVI also exhibits scaling problems, asymptotic (saturated) signals over high biomass conditions, and is very sensitive to canopy background variations (Huete et al. 2002).

With the recent abundance of satellite data, even on a daily basis by sensors such as Terra/MODIS, NDVI time series have been utilized, often operationally, for monitoring phenological changes and vegetation conditions (Zhang et al. 2003; Gitas et al. 2004; Maselli, 2004). The Moderate Resolution Imaging Spectro-Radiometer (MODIS) onboard the Terra satellite, being an improved successor to NOAA-AVHRR, is designed to collect data in 36 spectral bands with a varying spatial resolution (250, 500, 1000 m), providing comprehensive data about land, ocean and atmospheric processes (Lillesand et al. 2004). It has to be mentioned that, due to frequent cloud cover and sensor–Sun–Earth geometric characteristics, the surface reflectance data needs to be composited in time and space to allow for temporal and spatial continuous monitoring of surface soil and vegetation dynamics with vegetation indices (Van Leeuwen et al. 1999).

The aim of this study is to investigate whether MODIS imagery can be used for monitoring inter-annual vegetation changes and explore its utility for operational applications. The specific objectives were to investigate:

(i) the response of MODIS NDVI composites to seasonal changes of vegetation condition,
(ii) the ability to detect variations between different vegetation types (natural and managed), and
(iii) the level of similarity between the 16-day NDVI composites created for this study and the standard MODIS products (MOD13Q1).
2 STUDY AREA AND DATA DESCRIPTION

2.1 Study area

The study area is the whole of Greece, a country that covers 131,000 km$^2$, and its vegetation cover is considered as typical Mediterranean. The phenological cycle of both natural and managed vegetation is repeated annually, comprising the phases of greenup, maturity, senescence and dormancy. Due to the diverse vegetation characteristics of the study area, five test sites (Figure 1), representing various types of natural and managed vegetation, were selected in order to perform this study in detail. The sites were selected to be as homogeneous as possible, covering approximately 680 ha each. A short description of the test sites is given below:

1. Taxiarhis test site is located at N40°26′01″, E23°30′06″, with mean elevation 850 m. Summers are warm and dry and winters are mild. Mean annual precipitation reaches 746 mm, unevenly distributed during November–December and May–June. Landscape is mountainous and forms seasonal streams, and no sources of surface water exist during the short period summers. Vegetation cover is mainly mixed forest, with deciduous and coniferous species, and small patches of agricultural vegetation.

2. Pertouli test site is located at N39°31′45″, E21°29′58″, with mean elevation 1100 m. Summers are warm and dry, winters are severe and mean annual precipitation is 1700 mm, but during the leaf-out and growing season (May–September) only 300 mm occur. Landscape is mountainous with numerous small basins, forming small streams.

Figure 1. Location of test sites.
of seasonal flow, and some springs of constant flow. Vegetation cover is coniferous forest were Abies Borisii Regis (fir) dominates.

3. Malakasa test site is located at N38°12′52″, E23°43′30″, with mean elevation 290 m. Mean annual precipitation is 450 m, distributed unevenly during autumn and winter months. Summer period is warm and dry, and winters are mild. Landscape is mildly undulating, and the numerous streams are of seasonal flow. Vegetation cover is mixed forest with shrubs.

4. Giannitsa test site is located at N40°42′12″, E22°27′50″, with mean elevation 12 m. Mean annual precipitation is 800 mm, and summers are warm and dry. The area is intensively agricultural and has a developed irrigation and drainage network. Terrain is flat, and vegetation cover consists mainly of annual crops (maize, cotton, alfalfa).

5. Kilkis test site is located at N40°43′34″, E22°35′24″, with mean elevation 65 m. Mean annual precipitation is 450 mm, distributed during winter and spring months. Winters are cold and summers are warm and dry. Vegetation cover is agricultural, except from narrow streams with natural vegetation. Main crops are winter cereals and irrigation activities are limited to sparse groundwater supply.

2.2 Data description

A series of MODIS/Terra images from the year 2003 was acquired from the Distributed Active Archive Center of NASA's Earth Observing System Data Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/). The time series included daily images from May 1st, 2003 to October 31st, 2003 (Julian days 121 to 304), since this time period represents best the growing season and phenological development of vegetation in the test sites. Furthermore, previous studies have shown that NDVI time-series of different vegetation during the non-growing season do not provide clear phenological separation (Ramsey et al. 1995; Senay and Elliott, 2000).

The data acquired refer to MODIS/Terra Surface Reflectance Daily L2G Global 250 m SIN Grid (MOD09GQK), which is a two-band product computed from the MODIS Level 1B land bands 1 and 2 (centered at 648 nm and 858 nm, respectively). It estimates surface spectral reflectance for each band as it would be measured at ground level if there were no atmospheric scattering or absorption. In addition, MODIS/Terra Vegetation Indices (VI) 16-Day L3 Global 250 m SIN Grid (MOD13Q1) products were acquired for the same period. The VI output file contains 16-day NDVI values and this product relies on surface reflectance series (MOD09), which are corrected for molecular scattering, ozone absorption, and aerosols (Vermote, et al. 2002).

3 METHODOLOGY

The methodology included initially the pre-processing of the data, so as to produce daily surface reflectance images of the study area. Next, daily NDVI images were generated and were used as input for the compositing followed by the analysis of the composite series and the comparison of the products.
3.1 Image pre-processing

The raw data had to be pre-processed in order to extract daily surface reflectance images covering the whole Greece. The first step was to import the raw data from their original Hierarchical Data Format (HDF) into a proprietary format to facilitate further processing by the software used. Since three images (tiles) were required daily to include Greece, the next step was to mosaic the tiles received into one image. The input tiles were all projected in the Sinusoidal coordinate system and contain map information, thus meeting the prerequisites for mosaicking. The image produced was then reprojected to the Greek Geodetic Reference System (EGSA87) and was subset to fit the map of Greece and exclude the neighboring countries, with the use of a vector file containing the boundaries of Greece. This preprocessing was applied to all the images of the time period studied, so a time series of MODIS surface reflectance daily images of Greece at 250 m resolution was created. The same procedure was conducted for the MODIS 16-day composite NDVI products (MOD13Q1).

3.2 Generation of daily NDVI images

The Normalized Difference Vegetation Index (NDVI), which is one of the most widely used vegetation indices, was utilized for the generation of the daily NDVI images. The red \( \rho_{\text{red}} \) and near-infrared reflectance \( \rho_{\text{NIR}} \), bands 1 and 2 respectively for the acquired MODIS data at 250 m, were used to calculate NDVI (Rouse et al. 1974; Tucker, 1979):

\[
\text{NDVI} = \frac{\rho_{\text{NIR}} - \rho_{\text{red}}}{\rho_{\text{NIR}} + \rho_{\text{red}}}, \text{ ranging from } -1 \text{ to } 1.
\]

A model was developed for this purpose and a threshold value of 0.2 was used to mask out clouds and non vegetated areas, such as infrastructure, water, snow, ice, rocky areas, that have lower or negative values compared to vegetated areas. The threshold value was estimated by using 150 points that were selected from sampled NDVI images to include vegetated and non-vegetated areas. From the NDVI time series created, the mean NDVI values were calculated for each test site and were presented in graphs (a sample is displayed in Figure 2). The large negative deviations in the values are evident in the graph and could be attributed to the effects of residual cloud, aerosol contamination or canopy background variations (Van Leeuwen et al. 1999; Huete et al. 2002). During the time period studied, the frequent appearance of clouds over the country was the main problem encountered when creating the NDVI series, causing additive noise effects.

3.3 Generation of the NDVI composites

The Maximum Value Composite (MVC) technique was selected to improve the stability of the NDVI time series data by smoothing the great variations (rapid increases and decreases) observed, and fill in missing values because of cloud cover. The MVC selects the maximum NDVI value on a per-pixel basis over a set composing period, designed to minimize atmospheric effects, including residual clouds and its main assumption is that the maximum NDVI represents best vegetation condition (White et al. 1997; Van Leeuwen et al. 1999). The 16-day time step was selected to avoid the frequent
3.4 Analysis of data series

Visual analysis was performed for the composite series that were plotted on a single graph to identify the trend of the vegetation index for each test site and investigate whether any variations occur among the different vegetation types. Additionally, the mean values of the MODIS standard products were calculated and recorded in a spreadsheet. Statistical correlation was conducted to examine the level of similarity between the standard products and the ones created for this study. Finally, paired t-tests were used to assess the statistical significance of observed differences.

4 RESULTS AND DISCUSSION

The examination of the daily NDVI images revealed that observed zero values can be attributed, almost exclusively, to the presence of clouds and cloud shadows over the areas of interest and that the threshold used was not sufficient in masking out clouds. This, along with the intense variations (abrupt increases and decreases) observed, led to ‘noisy’ NDVI trends, which did not facilitate interpretation of the vegetation growth. The generation of the composite series removed zero values and at the same time irregular variations were smoothed resulting in more notable trends (Figure 3). Moreover, the 16-day time step proved to be long enough not to include cloudy pixels for the compositing period.

4.1 NDVI’s response to seasonal changes

For natural vegetation sites, Taxiarhis site had reached mature phase by May and then NDVI dropped gradually until early September (Julian day 256), as warmer and drier weather conditions prevailed. NDVI increased during the next 30 days to drop again

Figure 2. Daily mean NDVI values for the test site of Giannitsa.
until the end of October. In Pertouli site, a slight delay in maturity peak appeared, due to the higher altitude, followed by a relatively steady trend throughout summer and a gradual decrease in autumn months, when vegetation senescence commences. For Malakasa site, vegetation displayed a negative trend until middle of August (Julian day 225), then NDVI increased until day 256, before it dropped again as expected.

In Giannitsa site, NDVI was steadily increasing, exhibiting a relatively late peak in early August (Julian days 208–225) before vegetation started to dry. Human induced irrigating activities at the study area are related with cash crop cultivation, causing a distinct delay in the phenological cycle of these crops. On the other hand, non-irrigated agriculture vegetation at Kilkis appeared to have reached maturity by late spring. The lack of irrigation and the early harvesting of crops are the main factors for the drastic drop of NDVI (days 144–170), whereas a slight increase during July could have been due to the development of sparse weed, after crop harvest.

4.2 Detection of variation between different vegetation types

The varying trends revealed a different response of the index for each site, allowing potential distinction between the different types of vegetation. These existing differences were more clearly pronounced when observations were examined as time-series and based on the fact that the phenological characteristics of each area are known. The comparison of NDVI trends and values only for a short period, does not allow clear distinction among the vegetation types. Indeed, the discrimination between the two dense forested areas and the irrigated one for the period from day 192 to day 224, becomes unclear.

The NDVI trends that were recorded and presented in graph are more or less in agreement with the expected phenological development of natural and managed vegetation of these sites for the time period examined. However, the use of the 16-day composites did not eliminate the observed noise, especially over the natural vegetation areas. Irregular NDVI increases that were observed during summer and early autumn could be attributed to local climatic conditions affecting vegetation condition. More specifically, in the high altitude areas, the frequent occurrence of late summer rainfall has an effect on vegetation condition, causing temporary NDVI increase, as the one
recorded in Taxiarhis site (days 256–288). Moreover, additive noise is possibly caused by sensor and sun view angle variations, since NDVI tends to increase with larger zenith angles, by residual aerosol contamination and by surface anisotropy effects (Cihlar et al. 1997; Van Leeuwen et al. 1999; Huete et al., 2002).

4.3 Comparison between the composite products

Regarding the MODIS standard products (MOD13Q1), their values calculated were plotted against the ones derived from the composites created and were presented in graphs (Figure 4). Visual examination of the graphs exhibits that the MOD13Q1 derived NDVI values are lower compared to the latter ones and trends are more similar for the irrigated agricultural area, while more variations are detected between trends for the other sites. The statistical correlation performed displayed the highest correlation coefficient for Giannitsa site ($R = 0.922$), being statistically significant at 0.05 level. The coefficients for the rest of the sites were lower, still positive but not statistically significant, with Taxiarhis site displaying the lowest $R$ value (Figure 4). Besides the correlation, a statistical comparison of their means was performed for each case using a paired t-test. The results demonstrated a non-significant mean difference for Giannitsa (0.123), whereas for Taxiarhis, Pertouli, Malakasa, Kilkis the differences in NDVI values were 0.13, 0.107, 0.203, and 0.153 respectively, and were significant at 0.05 level.

![Graphs showing comparison between composite products across test sites](image)

**Figure 4.** Comparison between the composite products across the test sites.
5 CONCLUSIONS

In this paper, multi-temporal NDVI composites were generated using a time-series of daily MODIS surface reflectance products and were utilized in monitoring vegetation condition. The results showed that MODIS NDVI responded to seasonal changes of vegetation, following the phenological development, and variations among the different types of vegetation were adequately described. The frequent appearance of clouds over the study areas necessitated the compositing procedure, however the persistent noise that was observed, did not permit a more precise description. Furthermore, from the statistical comparisons between our NDVI composites and the equivalent MOD13Q1 product that were performed, only the irrigated agricultural area displayed significantly high similarities and low differences. The removal of this noise was beyond the scopes of this study, but in future work, more sophisticated compositing methods and statistical filters should be utilized to minimize noise in the final products. Also, a challenging task could be to identify the optimal time step for monitoring vegetation condition. To conclude, MODIS data can be used for detecting phenological changes and the products derived can be employed for operational purposes, such as fire risk assessment, which is of primary importance in the Mediterranean area.

ACKNOWLEDGEMENTS

This study was funded by “Pythagoras”, a research grant awarded by the Managing Authority of the Operational Programme “Education and Initial Vocational Training” of Greece, which is partially funded by the European Social Fund – European Commission. The Civil Protection Agency of Greece is also gratefully acknowledged for its support.

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