A procedure to derive intra- and inter-annual changes on vegetation from NDVI time series. A case study in Spain.

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ABSTRACT

The NDVI time series are characterized by patterns like seasonality, trends and localized abrupt changes or discontinuities resulting from disturbance events. Therefore, they allow us to characterize vegetation dynamics on the basis of different temporal scales. In particular, the subtle, long-term changes convey relevant information on land degradation.

The objective of this work is to study the spatial patterns of vegetation activity over Spain and its temporal variability throughout the period 1989-2002. A multi-resolution analysis (MRA) based on the wavelet transform has been implemented on NDVI time series from the MEDOKADS database. The MRA decomposes the original signal as a sum of series associated with different temporal scales. Specifically, the intra-annual series is processed to define several key features in relation with the vegetation phenology. In contrast, the inter-annual component of the signal is used to detect trends by means of a Mann-Kendall test and map the magnitude of the land-cover change. Finally, a comprehensive identification of the areas presenting a negative value of the magnitude of change is carried out to select those linked to land degradation processes. Results show a major presence of these areas the Southeast of Spain.

Keywords: NDVI time series; vegetation dynamics; trend analysis; degradation.

INTRODUCTION

NDVI time series are usually non-stationary, i.e., they present different frequency components, such as seasonal variations, long-term and short-term fluctuations (de Beurs & Henebry, 2005). Our approach to study time series is based on the wavelet transform (WT). The fundamental idea behind wavelets is to analyze the signal according to different scales or resolutions. A WT uses local basis functions (*wavelets*) that can be stretched and translated with a flexible resolution in both frequency and time domains. In this paper, the Meyer orthogonal discrete wavelet has been selected. By means of a *multi-resolution analysis* (MRA) (Burke-Hubbard, 1998), the original signal $f(t)$ can be reconstructed from the approximation and detail components as:

$$f(t) = A_m(t) + \sum_{j=1}^{m} D_j(t), \qquad (1)$$

where m is the highest decomposition level considered. In the first level of the decomposition, $f(t)=A_1+D_1$, the signal has a low-pass filtered component, A_1, and a high-pass filtered component, D_1. In a second step, the approximation A_1 is split as $A_1= A_2+D_2$, and so on. The relationship $D_j=A_{j-1}-A_j$, gives us information about the portion of the signal that can be attributed to variations between the scales [j-1, j].

When dealing with NDVI time series, the MRA seems to be an adequate tool to decompose the signal into different temporal components (for example, the intra- and the inter-annual variation), thus allowing for the analysis of vegetation cover at several temporal scales (Percival et al., 2004). The intra-annual variation is associated with the seasonal changes, i.e. with the vegetation phenology, that is related to the vegetation canopy type and could be useful to map vegetation types. Conversely, the inter-annual variation can serve to detect both abrupt changes, such as those due to a fire, and subtle changes due to land degradation processes. In our particular case, where the Meyer wavelet is used and the time series has a sampling period of 10 days, the most informative components are (Martínez & Gilabert, 2009): (1) the variability component, $V = \sum_j^6 D_j$, which refers to the sum of the detail components up to level six and can be regarded as the total intra-annual variability, (2) the detail component D_5, which can be related to semi-annual variations typical of seasonal cycle, and (3) the A_6 component, which describes inter-annual changes changes. These three components are also time series.

In this work, the intra-annual component is processed to define several key features in relation with the vegetation phenology. On the other hand, the inter-annual component is mainly used to detect vegetation changes by trend analysis and to map the magnitude of the land-cover change. For the latter analysis, our hypothesis is that the seasonal changes act as a noise that is masking the possible trends in the signal. When this noise is eliminated by means of the MRA, the significance of the detected changes increases. Thus, if there exists a trend in the series, the MRA based on WT should allow for its identification.

METHODS

Data

A case study for Spain is presented to show the performance of this methodology using the 1 km resolution AVHRR/NDVI data from the MEDOKADS (*Mediterranean Extended Daily One-km AVHRR Data Set*) archive (Koslowsky, 2003), covering a time range from 1989 to 2002. Moreover, the 3-month Standardized Precipitation Index (SPI) and monthly-mean precipitation data are used to assist the comprehensive identification of the land-cover changes. These precipitation data were provided by the Spanish Meteorological Institute (Aemet) and by the *Universitat Autònoma de Barcelona* (UAB), respectively.

Experimental procedure

The methodology for studying vegetation dynamics using the MRA is divided in three steps. First, the MRA is applied to the NDVI imagery series to decompose the original series into the inter-annual (A_6) and intra-annual (V and D_5) series. The second step consists in deriving from the above series different key features, such as $\overline{NDVI}$, $NDVI_{min}$, $\Delta NDVI$ (amplitude of the annual phenological cycle), and t_{max} (date of maximum NDVI), which are related to vegetation phenology, and Q, which is quantified as the slope of the inter-annual component and considered as the magnitude of the land-cover change. Due to the autocorrelation, a *tau-b* Mann-Kendall with Sens' slope has been applied to ascertain the significance of the detected trends and quantify them through the slope Q.

The assessment of the methodology has been carried out first on some selected sites, belonging to six different vegetation canopies: (I) a broadleaf forest located in Galicia, (II) a coniferous forest located in central Cataluña that was affected by a forest fire, (III) a rice canopy located in the Albufera Natural Park, in Valencia, (IV) a non-irrigated crop area (cereals) in Albacete, (V) a sparse canopy (Mediterranean semiarid scrubland) located in Murcia region, and (VI) another sparse canopy (Alpha- steppes) located in Almería. Afterwards, the selected procedures have been applied on a per-pixel basis to map the selected key features and produce different images.

The third step consists in the comprehensive identification of the land-cover changes with negative Q, in order to identify those likely related to land degradation processes. For this purpose, the mean-NDVI image and the available precipitation data have also been considered.

RESULTS AND DISCUSSION

Figure 1 shows the intra- (V) and inter-annual (A_6) series for four of the selected sites. The intra-annual series shows the seasonal variation of each cover type. The rice canopy presents the most marked seasonality, whereas the range of the inter-annual component is lower for the sparse canopy, with vegetation cover linked to precipitation. The mean of the inter-annual series characterizes the average vegetation amount during the reported period, which is higher for the forested areas and lower for the sparse canopy. On the other hand, the shape of these curves is related to inter-annual changes experimented by the vegetation cover. The rice canopy, with a flatter curve, hardly shows a relevant trend. In case of the sparse canopy, more sensitive to precipitation, the inter-annual component presents a higher variability, with a general decrease of the vegetation amount, which is shown by the trend analysis in table 1. The coniferous forest also shows a decrease in the vegetation cover, which was caused by a large forest fire occurred in 1998.

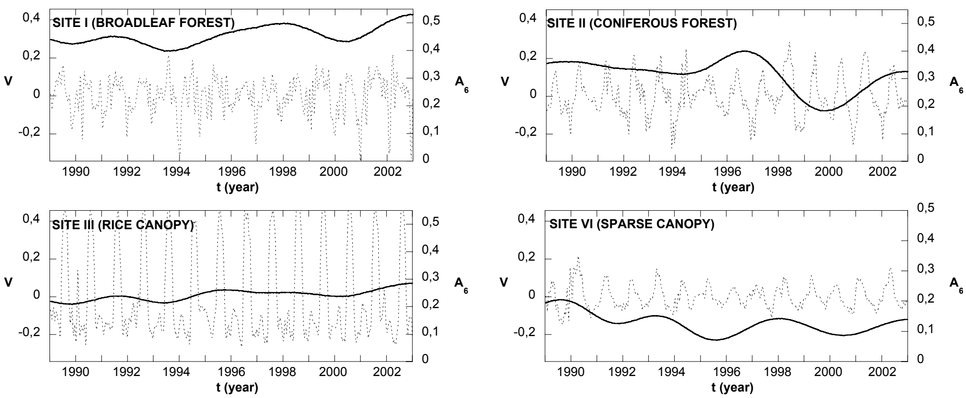

Figure 1. Decomposition of the NDVI time series into the intra-annual component V (dashed line and left-y axis) and the inter-annual component A_6 (bold line and right-y axis) for four selected sites.

Table 1. Key features for four of the selected vegetation canopies.

Canopy	$\overline{NDVI}$	$NDVI_{min}$	$\Delta NDVI$	t_{max}	$10^5 Q$
I (Broadleaf forest)	0.45	0.33	0.20	May	13.9 ± 1.6
II (Coniferous forest)	0.31	0.14	0.25	April	-15.5 ± 1.9
III (Rice canopy)	0.24	0.06	0.56	July	7.7 ± 1.2
VI (Sparse canopy)	0.19	0.05	0.14	March	-14.1 ± 1.5

When applying the MRA on a per pixel basis, a series of images can be calculated to study vegetation dynamics and to detect land-cover changes. Only the images related to the trend analysis are shown in figure 2. It is noticeable the dominance of the positive trends as opposed to only few areas with negative trends. Most of the positive trends coincide with broad stripes along Spanish major rivers, which might be related to an expansion of irrigation cultures. Some other areas showing an increase in the vegetation cover are located on the main mountain chains. A significant positive trend spot is also found in a marshland area (Marismas del Guadalquivir) mainly occupied by paddy fields. This is a consequence of the low NDVI values due to severe droughts in this area that were found in the first part of the studied time range. Negative trends are rather local and mostly concentrated along the

Mediterranean coast. These negative values map areas undergoing losses of vegetation, associated to different types of land-cover changes.

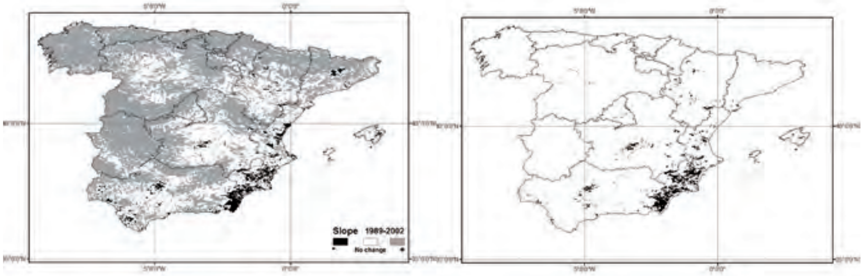

Figure 2. LEFT: Significant trends obtained from the Mann Kendall procedure (in grey: positive trends, in black: negative trends). RIGHT: Long-term changes associated to degradation processes (in black).

Areas satisfying four requirements (low $\overline{NDVI}$, *Q*<0, low precipitation and SPI-trend<0 values) are identified as affected by long-term land degradation processes. In fact, that means to consider land-degradation in arid and semi-arid environments, or what is also called dryland degradation. A major presence of these areas is located in southeastern Spain, particularly in Almería, Murcia and Alicante.

CONCLUSIONS

It has been shown the potential of the MRA to split the original NDVI series in components considered as source of intra- and inter-annual variability. Different key features can be calculated to quantitatively characterize the vegetation phenology and the inter-annual variability. The meaning of all these key features has been clarified by analyzing first some selected pixels on different biomes and after the whole image. In particular, the slope *Q* has been shown to be an efficient tool to quantify the magnitude of the change and to identify semiarid areas affected by land degradation processes.

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