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Object-based delineation of homogeneous landscape units at regional scale based on MODIS time series

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ABSTRACT

Landscapes can be described by seasonal and spatial patterns linked to vegetation type and phenology, environmental conditions, and human activities. The objective of this work is to propose and test an approach for delineating homogeneous landscape units at a regional scale by using only Earth observation data. We used MODIS (Moderate Imaging Spectroradiometer) images from 2007 to 2011, acquired over the whole continental French territory at 250 m spatial resolution. The data set includes time series of the Enhanced Vegetation Index (EVI) and time series of five Haralick texture indices. A principal components analysis (PCA) allowed us to choose the most representative indices (spectral and textural) and dates to be used in the region-growing segmentation. Different combinations of input data, as well as different segmentation parameters, were tested and compared using unsupervised evaluation methods. These methods were used to analyze the radiometric homogeneity of the regions and the radiometric disparity between regions when changing the homogeneity criterion of the segmentation. The best segmentation results obtained included three EVI images, together with three images of the texture 2nd moment, corresponding to the average of the months of April, July and December from 2007 to 2011. The optimum homogeneity criterion for the region-growing segmentation using this combination of variables was 15. We believe this method is applicable at other scales and other data sets for vegetation and biodiversity studies, and for habitat mapping.

Introduction

Landscapes are valued for a variety of reasons and provide a series of important functions, such as providing natural resources, wildlife habitats, economic benefits, scenery and open spaces, as well as possessing cultural heritage (European Environment Agency, 1995). Landscapes are the result of long-term interactions between nature and the human action and are thus continuously changing. These changes are leading to a loss of landscape character that alarms citizens and policy-makers (Mücher et al., 2010). In this context, it is important to delineate landscape units for identifying the different existing landscapes, their characteristics and importance, and the changes they are suffering. The European Landscape Convention (Council of Europe, 2000) states in Article 6 the importance of identification and assessment of European landscapes.

Landscape maps are a tool for different policy implementations, including environmental assessments and monitoring agri-environmental measures. Landscape mapping starts with the delineation of landscape units followed by the characterization of these units in terms of environmental variables (e.g. climatic variables, soil properties, land cover, etc.). Having an objective and repeatable methodology for delineating landscape units on large territories using Earth observation (EO) is an important contribution to landscape mapping. This is especially useful for avoiding the problem of integrating regional maps, where political limits do not correspond to landscape limits, and where the delineation methodologies may be different from a region to the other.

Landscape mapping is usually performed from geographic data, such as topography, parent material, climate, and land cover (cf. European Landscape Classification, LANMAP Mücher et al., 2010). The combination of data is performed using segmentation techniques that allow user-oriented and automatic data processing. Frequently, the use of EO data in landscape mapping is restricted to land cover mapping. Newton et al. (2009) expressed that landscape ecology must progress beyond the simplistic approach of thematic mapping and the derivation of two-dimensional pattern metrics.

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The use of time series of vegetation indices allows identifying the vegetation types through their seasonal pattern (phenology), and human activities through land cover changes (Maxwell et al., 2002). On the other hand, texture indices are linked to the arrangement of the different components in the landscape (Myint and Lam, 2005). The use of texture indices alone or in combination with vegetation indices has led to high classification accuracies, especially at medium (Landsat: Paneque-Gálvez et al., 2013; Reschke and Hüttich, 2014; Rodriguez-Galiano et al., 2012) to very high spatial resolution (VHR) (IKONOS: Agüera et al., 2008; Kayitakire et al., 2006). The application to coarse spatial resolution is less common, although some studies have already shown good results using MODIS images (Tsaneva et al., 2010; Vintrou et al., 2012a).

The pixel-based approach is useful when the objects of interest are smaller than the size of the spatial resolution (Blaschke et al., 2014). When the objects are composed of several pixels, an object based approach is more suitable. The object-based image analysis (OBIA) has been found especially useful when using HR and VHR images (Blaschke, 2010). However, OBIA can be applied at different spatial resolution images for identifying homogenous regions. For example, recent studies presented OBIA applications on medium resolution Landsat satellite images for wetland mapping (Dronova et al., 2012) or field crop mapping (Vieira et al., 2012). OBIA was also used to segment 250 m spatial resolution MODIS images for mapping land units (Vintrou et al., 2012a).

The segmentation results are frequently judged either by a human evaluator (Zhang et al., 2008), thus making the evaluation subjective, or using ground data. We believe that these types of evaluation are difficult when dealing with large areas (national to global scale) mapped using coarse spatial resolution imagery. Unsupervised methods have been developed to overcome the difficulty of evaluating segmentation results when there is no reference. They are based on the measurement of both intra-segment homogeneity and intersegment heterogeneity. The first unsupervised evaluation index was proposed by Borsotti et al. (1998), who developed an index that analyses the homogeneity of the segments. In the domain of remote sensing, Espindola et al. (2006) proposed a method to maximize intra-segment homogeneity and intersegment heterogeneity. This method includes two terms: the intra-segment variance of the regions and Moran's autocorrelation index, which measures how similar a region is to its neighbours (Fotheringham et al., 2000). The best segmentation is the one that combines the lowest intersegment Moran's index with the lowest intra-segment variance. Subsequently, Johnson and Xie (2011) adapted the method of Espindola et al. to multiband images. Drăguţ et al. (2010) proposed another unsupervised method based only on the intra-segment variance. Zhang et al. (2012) proposed an unsupervised evaluation method including measures of intra-segment homogeneity and intersegment heterogeneity and compared it, and other unsupervised methods, to a supervised method by applying them to a multispectral QuickBird image. They obtained a good agreement between the performances of their unsupervised index and the supervised one. The difference between the methods lies in the variables used to measure homogeneity and heterogeneity.

The objective of this work is to propose and test an approach for delineating radiometrically homogeneous regions (considered as landscape units) at a national scale based on coarse resolution satellite EO data, OBIA techniques, and unsupervised evaluation methods. We focused on the French continental territory as part of a project that seeks to identify agro-ecological infrastructures from EO data. The guiding principle of this work is the hypothesis that the use of time series of vegetation indices together with texture indices offers a complete data set for delineating land units showing a certain homogeneity in terms of environmental and human conditions. Consequently, the radiometrically homogeneous regions identified can be considered as landscape units. The regionalization results can be used in other studies, e.g. for enhancing land cover classification results or for landscape mapping. Moreover, the methodology proposed can be applied to other scales and EO systems for example for habitat mapping studies.

The procedure for delineating radiometrically homogeneous regions over the French territory consists of objectively identifying: (1) the best combination of satellite-derived variables (spectral, temporal and textural) and (2) the best image segmentation parameters. The method was applied to a set of monthly Enhanced Vegetation Index (EVI) MODIS image time series (250 m spatial resolution) and to their corresponding texture images.

Data and methods

A diagram showing the different methodological steps described in this chapter is shown in Fig. 1.

Image data set preparation

MODIS satellite data and pre-processing

MODIS time series from the TERRA satellite were chosen because they show a good compromise between temporal and spatial resolution allowing having monthly time series at national scale. The MOD13Q1 product was chosen. This product provides 16-day atmospherically corrected composite images at 250 m spatial resolution, including two vegetation indices (NDVI: Normalized Difference Vegetation Index; and EVI). For covering the French continental territory (550,000 km^2) three tiles are needed: h17v04, h18v03 and h18v04. The images of the MOD13Q1 product were downloaded for the period of 2007-2011 from the NASA website (http://reverb.echo.nasa.gov/reverb). The EVI index is preferred to the NDVI, as it corrects for some disturbances caused by the particles in the air and by the ground cover below the vegetation (Gao and Mas, 2008). The EVI data product also does not become saturated as easily as NDVI when viewing areas with large amounts of chlorophyll (Bisquert et al., 2011; Gao and Mas, 2008).

The quality band was used to mask those pixels that did not have reliable information due to clouds, fog, snow or other types of interference. Afterwards, a mosaicking of the three tiles was performed to obtain an image covering the entire French continental territory.

Because the landscape is continuously changing due to long-term interactions with climate and human activities (urbanization, deforestation, protected areas, etc.), the period used for the study is crucial. This period should be short enough for not integrating the long-term interaction. On the other hand the use of a single year period could be highly influenced by the conditions of that particular year. Using an average over a period of five normal years (not having extreme climatological events) is a compromise between natural inter-annual variability (mainly due to climate) and mid-term trend (mainly human activity). In this study, 12 monthly images were obtained, each as the average image of the same month from the five individual years (2007–2011) (Fig. 2).

Calculation of texture images

Five texture indices (Haralick et al., 1973) were calculated from the monthly averaged images: homogeneity, contrast, dissimilarity, entropy and 2nd moment. The texture indices were obtained using ENVI software (Exelis Visual Information Solutions, Boulder, Colorado). For calculating the texture indices, three parameters had to be set: window size, moving direction, and quantization level of digital numbers.

The optimal window size for calculating the texture is the one offering the highest variance while having the smallest window size. To select it, we calculated the semi-variogram that measures the spatial correlation between samples in close proximity