



Seasonality of vegetation types of South America depicted by moderate resolution imaging spectroradiometer (MODIS) time series

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ABSTRACT

The development, implementation and enforcement of policies involving the rational use of the land and the conservation of natural resources depend on an adequate characterization and understanding of the land cover, including its dynamics. This paper presents an approach for monitoring vegetation dynamics using high-quality time series of MODIS surface reflectance data by generating fraction images using Linear Spectral Mixing Model (LSMM) over South America continent. The approach uses physically-based fraction images, which highlight target information and reduce data dimensionality. Further dimensionality was also reduced by using the vegetation fraction images as input to a Principal Component Analysis (PCA). The RGB composite of the first three PCA components, accounting for 92.9% of the dataset variability, showed good agreement with the main ecological regions of South America continent. The analysis of 21 temporal profiles of vegetation fraction values and precipitation data over South America showed the ability of vegetation fractions to represent phenological cycles over a variety of environments. Comparisons between vegetation fractions and precipitation data indicated the close relationship between water availability and leaf mass/chlorophyll content for several vegetation types. In addition, phenological changes and disturbance resulting from anthropogenic pressure were identified, particularly those associated with agricultural practices and forest removal. Therefore the proposed method supports the management of natural and non-natural ecosystems, and can contribute to the understanding of key conservation issues in South America, including deforestation, disturbance and fire occurrence and management.

1. Introduction

The description of the Earth's surface has traditionally involved the identification and characterization of land use and land cover classes, with emphasis on their location and their spatial arrangement. Remote sensing has been a useful tool for conducting these tasks due to, among other factors, the synoptic view of large geographic regions and the lower associated costs, when compared to other data acquisition methods.

In spite of these advantages, analyses using remote sensing techniques have prioritized the understanding of space and have often used a

single date or “snapshot” approach. Traditionally, less attention has been given to time and, in particular, to the high-frequency dynamics of several land cover types. Reasons include the limited availability of high-quality chronosequences of remotely-sensed images and the lack of adequate methodological approaches to process this type of data. The increasing availability of time series of satellite images, specifically provided by MODIS sensor, and the potential contribution of these images to environmental management and conservation emphasize the need for the development of specific approaches to properly deal with the unique nature and volume of these data (McCloy, 2010).

Time series analyses address pressing issues involving the temporal

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characterization of land cover. These issues include the identification of types and patterns of changes in time and the incorporation of seasonality and phenological cycles of vegetation into analyses (Lunetta et al., 2006; Wardlow et al., 2006). Many of these investigations have focused on regional and continental scales, incorporating products derived from one or more remote sensors onboard satellites orbiting the Earth. Examples of these applications include the Advanced Very High Resolution Radiometer (AVHRR, NOAA), Vegetation (SPOT) and Moderate Resolution Imaging Spectroradiometer (MODIS Terra and Aqua) (Lunetta et al., 2006; Wardlow et al., 2006; Han et al., 2004; Reed et al., 1994; Batista et al., 1997; Moulin et al., 1997; Schwartz et al., 2002; Hall-Beyer, 2003; Lasaponara, 2006). In particular, MODIS products have received significant attention from the scientific community, motivated by improvements in system design, data processing and product distribution. The geolocation accuracy of MODIS pixels, combined with the daily global coverage, moderate spatial resolution (0.25–1 km), rapid availability of various products, and cost-free status (Lobell and Asner, 2004) of the sensor support time-series analyses and the use of MODIS products for monitoring temporal changes of biophysical parameters of vegetation (Xie et al., 2008; Justice et al., 2002).

Vegetation mapping presents valuable information for understanding the natural and man-made environments through quantifying vegetation cover from local to global scales at a given time point or over a continuous period (Wolfe et al., 2002). Vegetation indices (VI) are arguably the most used remote sensing products applied to regional and global studies of land use and land cover changes. Patterns of variations in VI values have been used to investigate physiological and structural seasonal changes in vegetation over large areas, including the identification of time of dormancy and the duration of vegetation cycles (Lunetta et al., 2006; Wardlow et al., 2006; Han et al., 2004; Reed et al., 1994; Batista et al., 1997; Moulin et al., 1997; Schwartz et al., 2002; Lasaponara, 2006). A large number of studies and operational applications have traditionally used the Normalized Difference Vegetation Index (NDVI), considering its simple formulation and its ability to describe biophysical properties of vegetation (Huete et al., 2002). However, the biophysical limitations of NDVI when estimating structural vegetation parameters over dense canopy are well known in the remote sensing literature (Huete et al., 2002; Huete, 1988; Baret and Guyot, 1991; Gao et al., 2000). Then the images derived from spectral mixing models representing fractions of vegetation and other target types have been presented as an alternative to overcome some of VI limitations. Among other advantages, vegetation fractions offer a physically-based representation of vegetation conditions and are less prone to saturation when representing dense canopies, when compared to NDVI (Elmore et al., 2000). Lobell and Asner (2004) demonstrate the importance of subpixel heterogeneity in cropland systems, and the potential of temporal unmixing to provide accurate and rapid assessments of land cover distributions using coarse resolution sensors, such as MODIS.

South America accounts for around 12% of the Earth's land surface, being one of the most physically and biologically diverse regions on the planet. The large meridional extent of the continent, coupled with its topographic features and other physiographic characteristics, result in considerable climatic variability. The climate of South America ranges from equatorial at its northern fringe to icy-cold polar in the south. As a result, the continent is home to multiple biomes and ecoregions, including the largest remnant of tropical rainforest on the Earth, arid deserts and permanent ice caps (Olson et al., 2001). South America also accounts for nearly a quarter of the world's potentially arable land, representing around 12% of the current cropland and 17% of all pasturelands (Gómez and Gallopin, 1991). The continent is under strong pressure for land occupation and resource utilization, resulting in several high-biodiversity areas currently being threatened.

In this context, this work has the objective to present a new toolset for environmental managers and decision makers by presenting and showing the applicability of a novel method to provide information for policy definition and environmental monitoring. The method supports

the representation and analysis of land use and land cover dynamics, particularly the dynamics associated with high-frequency temporal variations in land cover classes and vegetation. The primary objective of this work was to verify the ability of time series of vegetation fractions derived from a linear spectral mixing model (LSMM) to represent and to describe seasonal changes in land cover and vegetation disturbance over highly-diverse terrestrial landscapes at a continental scale. Although the study considered the spatial representation of those fractions, we were particularly interested to know how the proposed method would perform when representing temporal variability, including seasonal and phenological changes of different land cover types and particularly relevant vegetation typologies. We showed the potential of the proposed approach over biomes of South America using approximately nine years of images acquired by the MODIS sensor onboard the Terra platform. Therefore the method proposed is very important for providing information related to the international effort to prevent the vegetation dynamics pattern in a global scale toward to improve our understanding on global climate change.

2. Material and methods

2.1. Study area

South America covers an area of about 18 million km² arranged between the Latitudes 11° N to 55° S and longitude 34° W to 82° W. The relief of this continent can be divided into three parts, the East comprises the low altitude plateaus with the basins of the main Brazilian rivers. To the West is the Andes mountain range with altitudes whose peak reaches approximately 7000 m. Between the mountains and the low plateaus of Brazil extends to Central South American Depression, formed by Plains with excerpts flooded as the Orinoco River in Venezuela, the Mamoré-Beni in Bolivia and in Brazil, Paraguay and Argentina. Due to this variation of Latitude and altitude are large climatic variations found in the region, particularly the equatorial climates with high temperatures, small thermal amplitudes and abundant rainfall; the temperate climate appears to the extent that there is an increase of latitude towards to the South Pole, including the subpolar climate in the far South of the continent. Also present are the semi-desertic and desert climates. Due to the combination of these physical characteristics, the vegetation that covered the region is very diverse, but points out that 51% of the this area was covered by forests (Olson et al., 2001; Ross, 2016).

Vegetation cover is complex, especially in the plateaus and in the areas that occur differences in precipitation. Tropical moist forests are quite extensive, covering the Amazon basin. A semicircular zone of temperate forests of Araucaria is part of the Southern Brazilian plateau, while the cold forest extends over the Central Southern Chilean Andes, and tropical forests comprise the staple Chaco region. There are vast areas of grassland and savannah. In Northeastern Brazil, under a semi-arid climate, the caatinga and corresponding to the tropical climate, extend the Cerrado of central Brazil. The steppe vegetation of altitude cover large portions of the inter-andinos plateaus of Ecuador and Northern Peru, while the pampas present the same vegetation type. The desert vegetation predominates largely in the Pacific coast, in South Central Peru, Northern Chile, and Northeastern Argentina. (Cia., 1999)

We demonstrate the usefulness of the proposed remotely-sensed based method to represent spatial and temporal vegetation variability in South America by identifying and sampling areas representative of a diverse conditions over the continent. Sampling took into account the MODIS dataset analyzed and previous field experiences of our research team and aimed to represent: (a) different vegetation types and densities; (b) seasonal pattern variability; and (c) different histories of disturbance and land use patterns. Samples include: areas along the interface between ecoregions; areas inside ecoregions; and agricultural areas (Fig. 1).

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