REMOTE SENSING OF DECIDUOUS FORESTS: A MULTI TEMPORAL APPROACH

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Orientador
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SUMMARY

ABSTRACT

OLIVEIRA, Thomaz Chaves de Andrade Oliveira. **Mapping deciduous forests:** A multi-temporal approach. 2009 Dissertação (Mestrado em Manejo Ambiental) - Universidade Federal de Lavras, Lavras, MG.[1]

This work investigates whether Deciduous vegetation of Minas Gerais, in the Cerrado Biome, have differences in geographically different areas. This was accomplished through the use of Normalized Difference Vegetation Index (NDVI) time series data. Its objective was to find out if these differences exist and to quantify these differences. Four different geographical locations covered by deciduous forests and other neighbor vegetation were chosen for the analysis. This study was conducted in two chapters where chapter 01 quantifies the annual shifts of phenology curves of Deciduous Forests in the different regions and chapter 02 applies different denoising algorithms to time series of NDVI data and compared the results of vegetation classification as input to artificial neural networks. It was concluded that there are annual shifts in the annual curve among deciduous forests localized in different geographical areas of Minas Gerais state. Time signatures of NDVI can be used with success to map Deciduous Forests, however the results do not conclude which of the two filtering techniques best generates the vegetation signatures.

RESUMO

OLIVEIRA, Thomaz Chaves de Andrade Oliveira. **Mapping deciduous forests:** A multi-temporal approach. 2009 Dissertação (Mestrado em Manejo Ambiental) - Universidade Federal de Lavras, Lavras, MG.[1]

Este presente trabalho tem o objetivo principal de pesquisar se as florestas deciduais de Minas Gerais situadas em áreas geográficas distantes possuem diferenças entre as mesmas. Isso foi possível através da utilização de séries temporais do Índice de Vegetação de Diferença Normalizada (NDVI), para quantificar as diferenças. Foram escolhidas quatro diferentes localizações separadas geograficamente, onde encontram-se florestas decíduas e outros tipos de vegetação. Este trabalho foi conduzido em dois capítulos onde o capítulo 01 quantifica o deslocamento temporal anual da curva da fenologia das florestas deciduais de diferentes regiões. O capítulo 02 aplica diferentes algoritmos de remoção de ruído para séries temporais de NDVI e compara os resultados através da classificação da vegetação com a utilização das séries temporais filtradas como entrada de dados em uma rede neural artificial. Na conclusão geral do trabalho, pode-se concluir que: existe um deslocamento temporal na curva anual de fenologia entre as florestas decíduas que se situam em áreas geográficas diferentes. Assinaturas temporais de índices de vegetação NDVI podem ser utilizadas com sucesso para mapear as florestas decíduas de diferentes localizações, no entanto, não evidenciam a melhor entre as técnicas de filtragem de dados.

GENERAL INTRODUCTION

The Cerrado Biome in the Minas Gerais state-Brazil is one of which is in constant threat to deforestation. One of the phytophysiognomies within this biome that needs special attention is the Deciduous Forest. It is characterized by an alternating cycle of dry and wet seasons. By which 70 % of its leaves are off in the dry season (Oliveira-Filho & Ratter, 2006). The peculiarities of this vegetation involve special treatment when mapping land cover due to this variation on "greenness" throughout time. Since 'objects' that have similar spectral reflectance present problems when mapping with single date remote sensing images, when mapping this vegetation, incorrect results may appear in some locations. This work's objective was to generate time information based on time series of Normalized Difference Index that will help map this forest type. The time series used in the study were collected during 2003, 2004 and 2005, all the results were conducted in four different locations.

This study was motivated by setting up the following questions surrounding the deciduous forests:

1) Do geographically distant deciduous forests have annual shifts in their phenological cycles during the year?

2) Can MODIS filtered NDVI (Normalized Difference Vegetation Index) time series generate precise mapping to deciduous forests in different regions?

3) Which of two filtering techniques (HANTS Fourier Analysis) and Wavelet Filtering produces the best filtered time series for mapping this phytophysiognomy.

To answer these questions this work was organized in the following sequence:

General Introduction

CHAPTER 01 Analysis of Temporal NDVI profiles on different geographical occurrences of Deciduous Forests in the Brazilian Cerrado

The Objective of this work is to answer the question 01, it uses harmonic analyses to calculate the annual shift of the phonological curves of each geographical separated area.

CHAPTER 02 Mapping Deciduous forests using time series of filtered MODIS NDVI and Neural Networks

This chapter answers questions 02 and 03, where NDVI time series of four different geographical regions were filtered with the HANTS algorithms and Wavelet temporal algorithms, the resulting data sets were input to classification in an artificial neural network.

General Conclusions

Chapter 01

Analysis of Temporal NDVI profiles on different geographical occurrences of Deciduous Forests in the Brazilian Cerrado

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Abstract: *This work investigates whether geographically distant deciduous forests have different timing in their phenological cycle during the year. The study was conducted in the state of Minas Gerais in the Cerrado biome. Four different geographical locations covered by deciduous forests were chosen for the analysis. A MODIS NDVI data set was chosen to deliver the results because of its high time resolution. The harmonic analysis based HANTS algorithm was used to generate the time profile of each location. The mean value of phase from the first harmonic was used to characterize the annual shift of vegetation phenology for each one the four regions of interest. Results show the existence of a time gap in the annual curves of NDVI of each of the four locations.*

Keywords: Remote Sensing, MODIS, NDVI, time series, HANTS, harmonic analysis

1 Introduction

The Cerrado biome of tropical South America covers about two million squared kilometers, representing almost 22% of the Brazilian territory. The biome was named after the vernacular term of its predominant vegetation type, a fairly dense woody savanna of shrubs and smalls trees. The term “cerrado” (Portuguese for half-closed, closed, or dense) was probably applied to this vegetation because of the difficulty of traversing it on horseback (Oliveira-Filho & Ratter 2002). The constant threat to the Brazilian Cerrado has lead to the necessity of strategies and measures to promote the monitoring and mapping of this biome. The Cerrado has a large biodiversity but it’s fragmentation throughout the years has lead to the losses of exemplars from this biome (Oliveira 2004).

One of the phytophysiognomies within this biome that needs special attention is the Deciduous Forest. It is characterized by an alternating cycle of dry and wet seasons. More than 70 % of deciduous forests leaves are off in the dry season (Oliveira-Filho, 2006). The period of dryness occurs from mid April till September. The wet season starts in October and goes up to March. This leads to an intensified variation of greenness in vegetation and landscape characterization throughout time. The variation of greenness of the semi-deciduous forests is not so intense, due to their occurrence in regions of intensified humidity (Oliveira, 2004). These differences can be observed in Figure 1.

Mapping land cover by means of remotely sensing data has been an area of growing research interest throughout the past decades. Its complexity, peculiarities and state of the art concerning computational aids and processing routines differ a lot from past conventional cartographic tools. Developments in computer science have aided a better information extraction from remotely sensed images, as well as an effective use of geographical information systems to store, analyze and present all sorts of land cover information (Carvalho, 2001).

Some objects on the Earth´s surface reflect the electro-magnetic energy in the same way when sensed with a multi-spectral scanner. In the present case, it is difficult to differentiate deciduous and semi-deciduous forests when leaves are on using single date remote sensing. Nevertheless, 'objects' reflectance may vary according to growth stage, phenology, humidity, atmospheric transparency, illumination conditions etc. These characteristics led to a search for alternative features to enable the discrimination of land cover classes with similar reflectance behavior (Carvalho et al., 2004).

(a) **(b)**

FIGURE 1 (a) Deciduous forest, (b) semi-deciduous forest - Source Oliveira (2004)

These features, especially temporal information, are very useful for characterizing deciduous forests in the Cerrado biome, due to their pronounced dynamics. This can be noticed in the official forest map of Minas Gerias state, carried out by Carvalho (2008), (which was done with lower time resolution Landsat TM images) that does not capture small deciduous forests fragments present in the region of the Triângulo Mineiro, western Minas Gerais. In the coordinates of 19º09'10''S , 50º39'10''W, for instance, there is a 25ha fragment of dry Deciduous Forests on the margins of Rio Paranaíba, in fazenda Bonanza, municipality of Santa Vitória (Oliveira-Filho et al., 1998). Research however, suggests that remotely sensed time series data could possibly improve misclassification and the accuracy of mapping deciduous forests (Oliveira, 2004).

According to Jensen (2000), timing is very important when attempting to identify different vegetation types or to extract useful vegetation biophysical information (e.g. biomass, chlorophyll, characteristics) from remote sensed data. Multi-temporal satellite images composites are now of standard use in land cover classification of large areas at regional and global scales (Carrão et al., 2007).

The objective of this work was to find whether geographically distant deciduous forests have different timing in their phenological cycle during the year, leading to an annual shift in their cycle. The answer to this question could further improve the accuracy of forest mapping in the State of Minas Gerais.

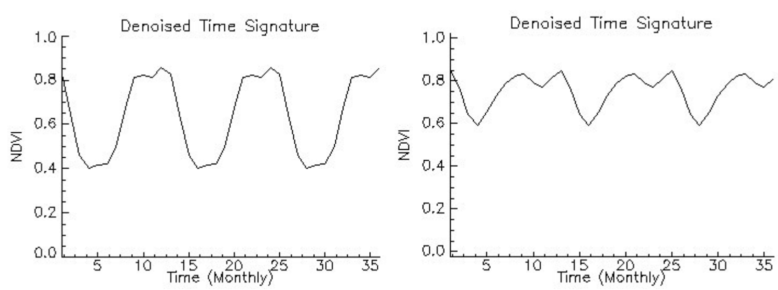
2 Methods

2.1 Vegetation Indices

Temporal information used in this study comprised time series of *vegetation indices*, viz. the Normalized Difference Vegetation Index (NDVI). Since the 1960's, scientists have extracted and modeled vegetation biophysical variables using remotely sensed data. Much of the effort has gone into the development of vegetation indices – defined as dimensionless radiometric measures that function as indicators of relevant abundance and activity of green vegetation, often including leaf-area-index (LAI), percentage green cover, chlorophyll content, green biomass, and absorbed photosynthetically active radiation (APAR). There are more than 20 vegetation indices in vigor. A vegetation index should maximize sensitivity to plant biophysical parameters; normalize or model external effects such as sun angle, viewing angle, and the atmosphere for consistent spatial and temporal comparisons; normalize internal effects such as canopy background variations. A vegetation index may preferably couple with a measurable biophysical parameter such as biomass, LAI, or APAR (Jensen, 2000).

Vegetation dynamics indicate important short and long-term ecological process. Continuous temporal observations of land surface parameters using satellite reveal seasonal and inter-annual developments. Vegetation indices have been extensively applied to characterize the state and dynamics of vegetation, in particular multiple NDVI datasets of the Advanced Very High Resolution Radiometer (AVHRR) instrument used during the last 25 years (Jensen, 2000; Coldiz et al., 2007).

Different vegetation types exhibit distinctive seasonal patterns on NDVI variation (Yu et al., 2004). Vegetation profiles of deciduous and semi-deciduous forests are illustrated in figure 2. In most cases, different types of vegetation have different phenological patterns. For example, evergreen plants will have a more steady temporal dynamics throughout the year when compared to tropicalplants that loose their leaves (Bruce et al., 2006).



Deciduous Forests time signatures　　　　Semi-Deciduous forests time signature

FIGURE 2 Denoised NDVI time series Deciduos and Semi-deciduous Forests

Spatial and temporal variability in vegetation indices arise from several vegetation related properties, including LAI, canopy structure/architecture, species composition, land cover type, leaf optics, canopy crown cover, understory vegetation, and green leaf biomass (Huete et al., 2002).

2.2 The MODIS Sensor

In the present study, NDVI time series from the Moderate-resolution Imaging Spectroradiometer (MODIS) were used. MODIS data products offer a great opportunity for phenology-based land-cover and land use change studies by combining characteristics of both AVHRR and Landsat, including: moderate resolution, frequent observations, enhanced spectral resolution, and improved atmospheric calibration (Galford et al., 2007). The AVHRR sensor was originally designed for meteorological applications, and has only two spectral bands (red and near-infrared) that can be used to generate spectral indices of vegetation. The new generation MODIS sensor has a number of advantages over AVHRR, including more spectral bands that can be used for vegetation analysis (Yu et al., 2004).

2.3 MODIS Vegetation Indices

MODIS vegetation indices are appropriate for vegetation dynamics studies and characterization. They are found to be sensitive to multi-temporal (seasonal) vegetation variations and to be correlated with LAI across a range of canopy structure, species composition, lifeforms, and land cover types. The MODIS-NVDI demonstrates a good dynamic range and sensitivity for monitoring and assessing spatial and temporal variations in vegetation amount and condition. The seasonal profiles provided by the MODIS-NDVI outperform in sensitivity and fidelity the equivalent AVHRR-NDVI profiles, particularly when the atmosphere has a relatively high content of water vapor (Huete et al., 2002).

2.4 Data set

Due to the widespread occurrence of deciduous forests in the state of Minas Gerais and its large extent, 586.528 km², four different areas of interest were chosen so that time signatures of geographically separated forests could be compared. These locations were primarily chosen because of known occurrences of Deciduous forests according to the Treeatlan data base (Oliveira-Filho, 2009) (Figure 2). A set of temporal images from the Landsat TM sensor were used as auxiliary data. The Landsat images from each location were acquired in the dry and wet seasons in order to identify fragments of deciduous forests through visual interpretation.

The NDVI time series were derived from the MOD13 product, which has a spatial resolution of 250m, and 16-day compositing period.

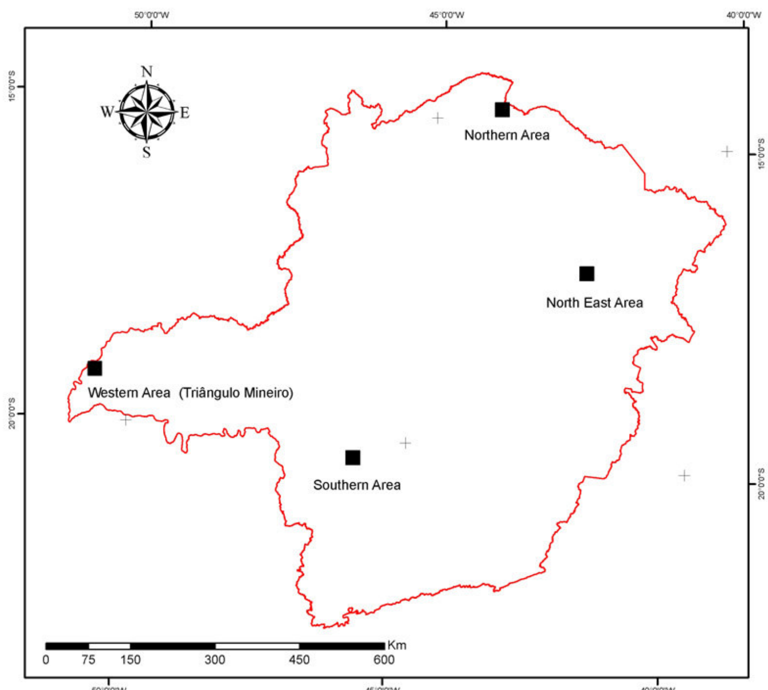


FIGURE 2 Locations of Deciduous Forests

The original images were preprocessed using the MODIS Reproduction Tool (MRT). The data set was sampled to 23 values per year, approximately two images per month. This dataset included the years of 2003, 2004, and 2005.

2.5 MODIS compositing Methods:

The presence of factors apart from land surface characteristics such as cloud contamination, atmospheric variability, and bi-directional reflectance affect the stability of the satellite derived NDVI. Thus compositing methods have been developed to eliminate these effects. The compositing Method for the AVHRR NDVI data source is the MVC (Maximum value composite), which selects the maximum NDVI value on a per pixel basis over a set of compositing period (Wang et al., 2004).

The MODIS compositing method operates on a per-pixel basis and relies on multiple observations over a 16-day period to generate a composite Vegetation Indice. Due to sensor orbit overlap and multiple observations, a maximum of 64 observations may be collected in a 16 compositing period. Once all the 16 days of observation are collected, the MODIS VI algorithm applies a filter to the data based on quality, cloud, and viewing geometry. Only the higher quality cloud free, filtered data are retained for compositing. (Huete et al., 2002).

At regional and larger scales, variations in community composition, micro and regional climate regional, climate regimes, soils, and land management result in complex spatio-temporal variation in phenology. Further, some vegetation types exhibit multiple modes of growth and senescence within a single annual cycle. Therefore compositing methods need to be sufficiently flexible to allow for this type of variability. (Zhang et al., 2003).

2.6 Fourier Transform

The Fourier Transform has been traditionally used to solve differential equations in Mathematics and Physics. Its main objective is to approximate a function in the time domain by a linear combination of harmonics (sinusoids) (Morettin, 2006). The most basic property of the sinusoids that makes them suitable for the analysis of time series is their simple behavior under a change in time scale (Bloomfield, 1976).

Fourier analysis have been used for denoising and curve fitting in MODIS vegetation index data sets (Wang et al., 2004; Yu et al., 2004; Bruce et al., 2006; Colditz et al., 2007). If the original time series is discrete rather than continuous, the Discrete Fourier transform (DFT), which requires regular spacing on samples within the temporal domains, should be applied (Wang et al., 2004). Eq 1 depict the DFT: The original signal, x[n], which has N samples. The transformation will create two vectors containing N/2 values each where ReX is the Real part vector and ImX is the imaginary part vector of the transformation, k is the index of these transformation vectors. Eq 2 depicts the inverse fourier transform or synthesis equation in discrete time, where the original signal [x] can be completely resynthesized from the ImX and the ReX vectors.

$$\mathrm{ReX}[k] = \sum_{i=0}^{N-1} x[i] \cos(2\pi k i / N) \tag{1}$$

$$\mathrm{ImX}[k] = \sum_{i=0}^{N-1} x[i] \sin(2\pi k i / N) \tag{2}$$

$$x[i] = \sum_{k=0}^{N/2} \mathrm{Re}\,\overline{X}[k] \cos(2\pi k i / N) + \sum_{k=0}^{N/2} \mathrm{Im}\,\overline{X}[k] \sin(2\pi k i / N) \tag{3}$$

EQUATIONS 3, 4 AND 5 Fourrier analys equation in discrete time, Equation (5) sysnthesis equation in frequency domain – Source Smith (1998)

The algorithm chosen to implement the Discrete Fourier Transform was the HANTS algorithm (Harmonic Analysis of Time Series) (Verhuef, 1996;

Roerink et al., 2000). The algorithm was developed to deal with time series of irregularly spaced observations and to identify and remove cloud contaminated observations. Since the NDVI time series of this study were acquired through compositing, the pixels have different acquiring dates that lead unequal time spacing.

HANTS considers only the most significant frequencies expected to be present in the time profiles (determined, for instance, from a preceding FFT analysis), and applies a least squares curve fitting procedure based on harmonic components (sines and cosines) (Verhoef, 1996; Roerink et al., 2000). For each frequency, the amplitude and phase of the cosine function is determined during an iterative procedure. Input data points that have a large positive or negative deviation from the current curve are removed by assigning a weight of zero to them. After recalculation of the coefficients on the basis of the remaining points, the procedure is repeated until a predefined maximum error is achieved or the number of remaining points has become too small. (Roerink, et. al. 2000).

The algorithm runs starting in the upper left block with the original NDVI time series which are used as input in the FFT and the frequencies that contain biophysical features (usually mean, annual and half-year signal) are selected from the Fourier spectrum. The inverse transforms the spectrum back into a filtered NDVI time-series afterwards. A comparison between the filtered NDVI time-series and the original NDVI time-series is then made and this is accomplished by subtracting the corresponding values of each time series. Each value below a user defined threshold is removed from the time series and considered cloudy, and then are replaced by values in the filtered NDVI time-series. (Figure 3). Replacing values in the NDVI time-series makes the average of the entire profile larger making a next iteration necessary, so the NDVI time-series is searched again for possible cloud contaminated NDVI observations. This process continues until no new points are found. Many different phenological indicators have been defined in various satellite-based studies. The advantage of the HANTS algorithm is that the output consists of a completely smoothed NDVI profile which is convenient for calculating derivatives. (De Wit, 2005) The calculations of derivates are important to estimate the start of growing season and senescence (Sakamoto et al., 2005).

The version of HANTS used was implemented in IDL by De Wit (2005) and is under the GNU General Public License.

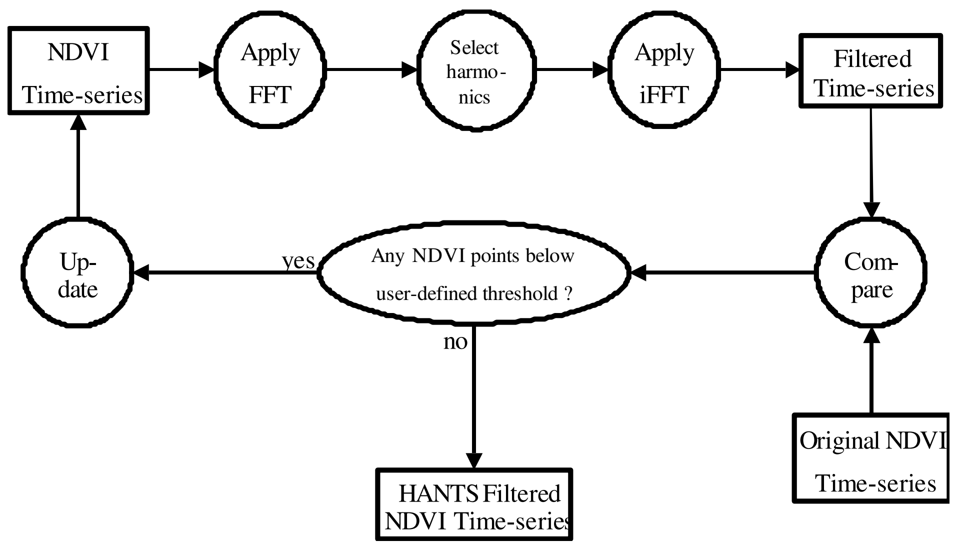


FIGURE 3 The HANTS algorithm - Source (De Wit, 2005)

Among the resulting files, the algorithm outputs a FFT file which has a complex number pair, that is, the Fourier transform of each pixel location regarding its NDVI time series.

2.7 Calculation of amplitude and phase

Harmonic analysis can be used aiming at reducing the dimensionality of the data. Another advantage is that each pixel is treated individually, being independent from the rest of the image. It is also possible to choose the period of analysis relating to the frequency of the studied phenomenon, thus this technique is appropriate to deal with noise originated from cloud contamination in the time series and from noise resulting from pre-processing that is not periodic. The magnitude and phase of a waveform can be calculated from the complex number resulting from the FFT. The magnitude corresponds to half of wave's peak value, and the phase corresponds to the shift from the origin to the wave's peak value from 0 to Π (eq. 6 and 7) (Lacruz & Santos, 2007).The amplitude/phase vector corresponds to the polar form of the DFT (Smith, 1998). The output of the HANTS algorithm contain the complex form for each harmonic (eq. 3, 4 and 5) and the mean value of the time series (this value was also used for discussion and comparison among the different areas).

Since the content in the original FFT prior to the transformation to the polar form is not intuitive (Smith, 1998), equations 6 and 7 were used to compute the amplitude and phase of each harmonic. Coldiz et al. (2007) suggest that only the amplitude and phase of the first three harmonics depict biophysical parameters. Some authors, such as Yu et al. (2004), state that forest classification can be carried out in the amplitude/phase space. Previous work by Oliveira et al. (2009) suggests, however, that information is lost in the dimensionally reduction and efficient forest classification is not possible in a rich and complex environment such as the Cerrado.

$$Cj = \sqrt{Aj^2 + Bj^2} \tag{4}$$

$$\phi = \tan^{-1} \frac{B_j}{A_j} \tag{5}$$

EQUATIONS 6 AND 7 Calculation of amplitude (equation 1) and phase (equation 2) for to the polar form of the DFT

2.8 Phase Statistics of NDVI of Deciduous Forests

After the calculation of amplitude and phase of each harmonic of the original NDVI images (which uses equation 4 and 5) of different locations, a subset of the original images was generated. Equation 4 calculated the amplitude of first harmonic. The phase was calculated using eq 5. A subset containing only the pixels corresponding to the occurrences of Deciduous Forests. Statistics was computed to the phase of the first harmonic so that annual shifts of deciduous forests of different geographic locations cold be quantified. Each phase value ranges from $-\pi$ to π, where 2π corresponds to a full year cycle. The phase values were multiplied by 182.5, which correspond to half year, in order to calculate annual shifts in days.

3 Results

Results in table 1 explicit differences in the phase of the annual frequency of the NDVI value of the deciduous Forests of Minas Gerais. These results can be very useful for future vegetation classification and to quantify the geographic differences among apparently similar fragments of this phytophysiognomy.

The largest time shift was observed for the Triângulo Mineiro Region (Western Minas Gerais) which is on average 13.45 days ahead in the annual cycle when compared to the Northern region. This difference could be explained by the fact that the Deciduous Vegetation in this region is mixed with other phytophysiognomies such as the Savanna resembled "Cerradão" and other formations. The mean value of this phytophysiognomy´s time series does not differ substantially from the others (Table 1). These similarities in the mean NVDI time series value confirm that deciduous forests do not have discrepancies in their amplitude value suggesting that the analyzed forest fragments are not mixed with other vegetation that have higher mean NDVI value such as the semi-deciduous forests.

TABLE 1 statistics of harmonic analysis of the four different study areas

Region	**Fundamental harmonic's phase mean value**	**Phase value expressed in days shifted value**	**Time series mean value**
North East	1.04325	60.6	0.687018
North	1.035954	60,2	0.641661
South	1.141607	66.2	0.735416
West (Triângulo Mineiro)	1.267896	73.65	0.685943

Previous work from Sakamoto et al. (2005) rely on the use of derivates and wavelet transforms to obtain the days of harvest and plantation of paddy rice in Japan with the use of MODIS NDVI images. Changes in cropping system, management, and climate make the times-series collected over agricultural areas closer to non stationary signals, which are better handled by the wavelet transform. In the case of native forests that exhibit a stationary behavior, our FFT approach is most suitable.

The proximity in results regarding mean value of the phase in the North and the Northwest areas (table 1) can be partly explained by the geographical proximity of the areas, thus reinforcing that there is a shift in the annual cycle of the deciduous forests due to geographical differences. The Southern area also has a 6 days shift in the average phase value of the annual NDVI frequency and thus also reinforces our hypothesis.

4 Conclusions

This research suggests that there is an annual shift in the phenological curve of the Deciduous forests of Minas Gerais that are geographically distant, however these differences are not great in value. Different regions demonstrate different annual shifts in the time profile of their deciduous forests of about half month. However, the spatial resolution of the MODIS sensor limit its application resulting in few pixels to calculate statistics on small forest fragments such as the West region of Triângulo Mineiro. The combined use of MODIS NDVI time series and higher spatial resolution sensors, ground truth data and Geostatistics might improve the discrimination of deciduous forests in Minas Gerais.

5 References

BLOOMFIELD, P. **Fourier analysis of time series**. New York: J.Wiley, 1976. 257p.

BRUCE, L.M.; MATHUR, M.; BYRD JUNIOR, J.D. Denoising and wavelet-based feature extraction of MODIS multi-temporal vegetation signatures. **Geoscience & Remote Sensing**, v.43, p.170-180, 2006.

CARVALHO, L.M.T. **Mapping and monitoring forest remnants**: a multi-scale analysis of spatio-temporal data. 2001. 140p. Thesis (Doctor in Resources Conservation and Production Ecology)-Wageningen University, Wageningen.

CARVALHO, L.M.T. de; CLEVERS, J.G.P.W.; SKIDMORE, A.K.; JONG, S.M. de. Selection of imagery data and classifiers for mapping Brazilian semideciduous Atlantic forests. **Internacional Journal of Applied Earth Observation and Geoinformation**, Enschede, v.5, p.173-186, 2004.

CARVALHO, L.M.T.; SCOLFORO, J.R. **Inventário florestal de Minas Gerais**: monitoramento da flora nativa 2005-2007. Lavras: UFLA, 2008. 312p.

CARRÃO, H.; GONÇALVES, P.; CAETANO, M. Contribution of multiespectral and multitemporal information from MODIS images to land cover classification. **Remote Sensing of Environment**, New York, v.112, n.3, p.986-997, 2007.

COLDITZ, R.R.; GESSNER, U.; CONRAD, C.; ZYL, D. van; MALHERBE, J.; NEWBY, T.; LANDMANN, T.; SCHMIDT, M.; DECH, S. Dynamics of MODIS time series for ecological applications in southern África. In: INTERNATIONAL WORKSHOP ON THE ANALYSIS OF MULTITEMPORAL REMOTE SENSING IMAGES, 14., 2007, Leuven, Belgium. **Proceedings**... Leuven: Multitemp, 2007. p.18-20.

GALFORD, G.L.; MUSTARD, J.F.; MELILLO, J.; GENDRIN, A.; CERRI, C.C.; CERRI, C.E.P. Wavelet analysis of MODIS time series to detect expansion and intensification of row-crop agriculture in Brazil. **Remote Sensing of the Environment**, New York, v.112, n.2, p.576-587, 2007.

HUETE, A.; DIDAN, K.; MIURA, T.; RODRIGUEZ, E.P.; GAO, X.; FERREIRA, L.G. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. **Remote Sensing of Environment**, New York, v.83, n.1, p.195-213, Nov. 2002.

JENSEN, J.R. **Remote sensing of the enviroment**: an earth resource perspective, retune hall series in geographic information science. New Jersey: Upper SaddleRiver, 2000. 544p.

LACRUZ, M.S.P.; SANTOS, J.R. Monitoriamento da paisagem de unidades de conservação. In: RUDORFF, B.F.T.; SHIMABUKURO, Y.E.; CEBALLOS, J.C. (Org.). **O sensor MODIS e suas aplicações no Brasil**. São José dos Campos: Parêntese, 2007. cap.13, p.173-183.

MORETTIN, P.A.; TOLOI, C.M. **Análise de séries temporais**. 2.ed. São Paulo: E.Blucher, 2006. 433p.

OLIVEIRA-FILHO, A.T. **TreeAtlan 1.0**: flora arbórea da Mata Atlântica e domineos adjacentes: um banco de dados envolvendo geografia diversidade e conservação. Available at: <http://www. treeatlan.dcf.ufla.br/>. Access in: 10 Jan. 2009.

OLIVEIRA-FILHO, A.T.; CURI, N.; VILELA, E.A.; CARVALHO, D.A. Effects of canopy gaps, topography and soils on the distribution of woody species in a central Brazilian deciduous dry forest. **Biotropica**, Washington, v.30, n.3, p.362-375, 1998.

OLIVEIRA-FILHO, A.T.; RATTER, J.A. **The Cerrados of Brazil**: ecology and natural history of a neotropical savannah. New York: Columbia University, 2002. 121p.

OLIVEIRA- FILHO, A.T.; SCOLFORO, J.R.; CARVALHO, L.M.T. **Mapeamento e inventário da flora nativa e dos reflorestamentos de Minas Gerais**. Lavras: UFLA, 2008. 46p.

OLIVEIRA, L.T. **Fusão de imagens de sensoriamento remoto e mineração de dados geográficos para mapear as fitofisionomias do bioma Cerrado**. 2004. 131p. Dissertação (Mestrado em Manejo Ambiental)-Universidade Federal de Lavras, Lavras.

OLIVEIRA, T.C.A.; OLIVEIRA, L.T.; CARVALHO, L.M.T.; MARTINHAGO, A.Z.; FAUSTO, W.; LIMA, L.P.Z. Separabilities of forest types in amplitude-phase space of multi-temporal MODIS NDVI. In: SIMÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO, 16., 2009, Natal. **Anais**... Natal, 2009. No prelo.

ROERINK, G.J.; MENENTI, M.; VERHOEF, W. Reconstructing Cloudfree NDVI composites using Fourier analysis of time series. **International Journal of Remote Sensing**, Basingstoke, v.21, n.9, p.1911-1917, 2000.

SAKAMOTO, T.; YOKOZAWA, M.; TORITANI, H.; SHIBAYAMA, M.; ISHITSUKA, N.; OHNO, H. A crop phenology detection method using time-series modis data. **Remote Sensing of Environment**, New York, v.96, p.366-374, 2005.

SMITH, S.W. **The scientist and engineer's guide to digital signal processing**. San Diego: California Technical, 1998. 626p.

VERHOEF, W. Application of harmonic analysis of NDVI time series (HANTS). In: AZZALI, S.; MENENTI, M. (Ed.). **Fourier analysis of temporal NDVI in the Southern African and American continents**. Wageningen: DLO Winand Staring Centre, 1996. p.19-24. (Report 108).

WANG, Q.; TENHUNEM, J.; DINH, N.Q.; REICHSTEIN, M.; VESALA, T.; KERONEN, P. Similarities in ground and satellite-based NDVI time series and their relationship to physiological activity of a Scots pine forest in Finland. **Remote Sensing of Environment**, New York, v.93, n.2, p.225-237, 2004.

WIT, A. de; SU, B. **Deriving phenological indicators from spot-vgt data using the *Hants* algorithm**. Wageningen: Centre for Geo-Information, 2005.

Available at: <http://www.vgt.vito.be/vgtapen/pages/fullpapers/Dewit_full.pdf>. Access in: 15 dez. 2008.

YU, X.; ZHUANG, D.; CHEN, H.; HOU, X. Forest classification based on MODIS time series and vegetation phenology. In **International Geoscience and Remote Sensing Symposium**, 4., 2004, Toulouse. Annual publications of… Toulouse, 2004. p. 2369-2372.

ZHANG, X.; FRIEDL, M.A.; SCHAAF, C.B. Monitoring vegetation phenology using modis. **Remote Sensing of Environment**, New York, v.84, p.471-475, 2003.Oliveira,

T. C. A. (2009) , Oliveira L. T.,Carvalho L.M. T. , , Z. Martinhago, A. Z. , Fausto W. Acerbi Júnior, Lima, L. P. Z., Separabilities of Forest Types in Amplitude-phase Space of multi-temporal MODIS NDVI Anais do IVX Simósio Brasileiro de Sensoriamento Remoto, no prelo

Sakamoto, T. ; Yokozawa, M. ; Toritani, H. ; Shibayama M. ; Ishitsuka N.; Ohno H. (2005) A Crop Phenology Detection Method Using Time-Series Modis Data; **Remote Sensing of Environment**, New York, 96 366 – 374

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Chapter 02

Mapping Deciduous forests using time series of filtered MODIS NDVI and Neural Networks

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Abstract: ***Multi-temporal images are now of standard use in remote sensing of vegetation during monitoring and classification. (Jensen 2000) Temporal vegetation signatures (i. e., vegetation indices as functions of time) generated, poses many challenges, primarily due to signal to noise-related issues Bruce et al. (2006). This study investigates which methods best generate smoothed curves of vegetation signatures on MODIS NDVI time series. The filtering techniques compared were the HANTS algorithm which is based on Fourier analyses and Wavelet temporal algorithm which uses the wavelet analysis to generate the smoothed curves. The study was conducted in four different regions of the Minas Gerais State. The smoothed data were used as input data vectors for vegetation classification by means of Artificial neural networks. A comparison of the results was ultimately discussed in this work where results were encouraging, with no better of the two filtering techniques.***

Resumo: Imagens multi-temporais de uso essencial no Sensoriamento Remoto, para o monitoramento e classificação da vegegetação. Jensen (2000) Assinaturas temporais da vegetação possuem muitos desafios na sua utilização devido a elevada relação sinal/ruído Bruce et al. (2006). Este estudo investiga é o melhor entre dois métodos para se gerar assinaturas temporais suavizadas de vegetação NDVI sendo essas originadas do sensor MODIS. As técnicas de filtragem utilizadas foram o algoritmo baseado em Fourier HANTS e algoritmo

Wavelet Temporal que utiliza análise Wavelet.. Os estudos foi conduzido em 4 diferentes conjuntos de dados, correspondente á áreas separadas geograficamente no estado de Minas Gerais. As séries temporais foram usadas como entradas de dados para classificação da vegetação através de métodos computacionais automatizados. Essa mesma foi feita através das redes neurais artificiais. O resultado dessa classificação foi discutido posteriormente nesse trabalho com resultados promissores onde não houve melhor entre os métodos de filtragem comparados

Keywords: remote sensing, signal processing, time series, wavelets analysis, NDVI, MODIS, Fourier.

Palavras Chave: Sensoriamento Remoto, processamento de sinais, análise wavelets, NDVI, MODIS, Fourier

1 INTRODUCTION

Mapping land cover by means of remotely sensed data has been a research of growing interest in the past decades. Its peculiarities and state of art of computer aided methods and studies go beyond conventional cartographical tools. (Carvalho, 2001). The advances of computer science, engineering, and all sciences surrounding remote sensing, continue to present new technologies to map land cover.

Some objects on the Earth´s surface reflect the electro-magnetic energy in the same way when sensed with a multi-spectral scanner, in addition 'objects' reflectance may vary according to growth stage, phenology, humidity, atmospheric transparency, illumination conditions, etc. These drawbacks led to a search for alternative attributes to enable the discrimination of land cover classes with similar reflectance behavior. (Carvalho et al., 2004)

These attributes, especially temporal information, are very useful for characterizing deciduous forests in the Cerrado biome, due to their pronounced dynamics. This can be noticed in the official forest map of Minas Gerias state, carried out by Carvalho (2008), which does not capture deciduous forests fragments present in the region of the Triângulo Mineiro, due to the time of acquisition of the available images. For example, there is a 25ha fragment of dry Deciduous Forests on the margins of Rio Paranaíba, in fazenda Bonanza, municipality of Santa Vitória (Oliveira-Filho et al., 1998), which was misclassified as semideciduous forest. Research however, suggests that remotely sensed time series data could possibly improve misclassification and the accuracy of mapping deciduous forests (Oliveira, 2004).

The main objective of this work is to develop an efficient methodology to map the deciduous forests present in the Cerrado biome based on the use of temporal attributes. Our research seeks to find whether MODIS filtered NDVI (Normalized Difference Vegetation Index) time series can generate accurate mapping to deciduous forests in different regions. This study also has the goal of testing which of two filtering techniques produces the best map. For generalization purposes, the process of filtering and mapping were conducted in four geographically different regions, thus resulting in four different data sets for comparison purposes. The filtering techniques utilized were wavelet filtering and the Discrete Fourier Analysis using the HANTS algorithm. The filtered time series were used as input vectors for each pixel location on artificial neural networks, both for training and classification, generating vegetation classification maps.

2 METHODS

2.1 Analysis of Vegetation Temporal Signatures

According to Zhang et al. (2003), field-based ecological studies have demonstrated that vegetation phenology tends to follow relatively well defined temporal patterns. For example, in deciduous vegetation and many crops, leaf emergence tends to be followed by a period of rapid growth, followed by a relatively stable period of maximum leaf area. Different types of vegetation have different temporal growth patterns (i.e., different growth and senescence rates)

(Bruce et al., 2006). Vegetation dynamics indicate important short and long-term ecological process. Continuous temporal observations of land surface parameters using remote sensing reveal seasonal and inter-annual developments. Vegetation indices have been extensively applied to characterize the state and dynamics of vegetation, in particular multiple NDVI (*Normalized Difference Vegetation Index*) datasets of the Advanced Very High Resolution Radiometer (AVHRR) instrument used during the last 25 years. (Jensen, 2000; Coldiz et al., 2007).

Different vegetation types exhibit distinctive seasonal patterns on NDVI variation (Yu et al., 2004). A vegetation index should maximize sensitivity to plant biophysical parameters; normalize or model external factors such as sun angle, viewing angle, and the atmosphere for consistent spatial and temporal comparisons; normalize internal effects such as canopy background variations; and couple with measurable biophysical parameters such as biomass, LAI, or APAR (Jensen, 2000).

Spatial and temporal variability in vegetation indices arise from several vegetation related properties, including LAI, canopy structure/architecture, species composition, land cover type, leaf optics, canopy crown cover, understory vegetation, and green leaf biomass (Huete et al., 2002).

2.2 The MODIS Sensor

The EOS (Earth Observing System), leaded by NASA, has the objective of studying the Earth's global changes, its processes and to promote its continuous observation. Their sensors were designed to operate for a long period of time. TERRA was the name given to the first platform launched by the EOS, which marked the development of remote sensing scientific methods by incorporating various sensors that collect different types of data. The MODIS (Moderate-resolution Imaging Spectroradiometer) is the most important sensor aboard the TERRA platform. Its concept has its origin in various predecessors by which the most important is the AVHRR (Advanced Very High Resolution

Radiometer) aboard the NOAA (National Oceanic and Atmospheric Administration), from 1978 until 1986. (Soares et al., 2007)

The AVHRR sensor was originally designed for meteorological applications, and has only two spectral bands (red and near-infrared) that can be used to generate the spectral indices of vegetation. The new generation MODIS sensor has a number of advantages over AVHRR, including more spectral bands that can be used for vegetation analysis (Yu et al., 2004).

MODIS Vegetation Indices (VI) products are appropriate for vegetation dynamics studies and characterization. MODIS-VI are found to be sensitive to multi-temporal (seasonal) vegetation variations and to be correlated with LAI across a range of canopy structure types, species and life forms, land cover variations. The MODIS NVDI demonstrates an appropiate dynamic range and sensitivity for monitoring and assessing spatial and temporal variations in vegetation amount and condition. The seasonal profiles outperform in sensitivity and fidelity the equivalent AVHRR-NDVI profiles, particularly in atmosphere with water vapor contents. (Huete et al., 2002)

2.3 Study site

The widespread occurrence of deciduous forests in the state of Minas Gerais has led to the choice of four different study areas (Figure 1) according to the locations of deciduous forest fragments extracted from the Treeatlan data base. (Oliveira-Filho, 2009)

2.4 Data acquisition

The NDVI time series was derived from the MOD13 product, which has a spatial resolution of 250m, and has a 16-day compositing period. This product is freely available for download from the MODIS website via FTP protocol. The original data was reprojected using MRT(MODIS Reproduction Tool). A set of temporal images from the Landsat TM sensor were also used as auxiliary data. These images were collected from summer and winter dates to each area and were used so that the exact locations of the deciduous forests fragments and other types of vegetation were known in advance. The data set has 23 images per year and included the years of 2003, 2004 and 2005.

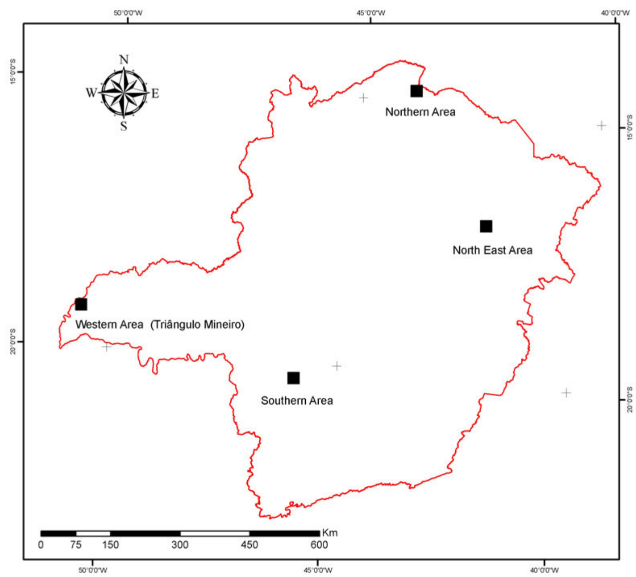

FIGURE 1 The four different data subsets

2.5 Signal denoising

In order to extract pertinent features from time signatures for potential target applications, the signals must first be denoised. Authors have investigated automated methods for denoising, including straightforward methods such as median filters and moving-average filtering, as well as more advanced methods such as wavelet denoising (Bruce et al., 2006). Curve fitting parameterization using logistic functions have also succeeded in generating time signatures of MODIS VI (Zahng et al., 2003).

2.6 Fourier Analysis HANTS

The Fourier Analyses or Harmonic analyses have been used traditionally to solve differential and partial equations in the fields of mathematics and physics. Its main objective is to approximate a function in the time domain by a linear combination of harmonics (sinusoids) (Morettin & Toloi, 2006).

The most basic property of the sinusoids that makes them suitable for the analysis of time series is their simple behavior under a change in time scale (Bloomfield, 1976).

Fourier analysis have been traditionally used for denoising and curve fitting in MODIS VI data sets (Wang et al., 2004; Yu et al., 2004; Bruce et al., 2006; Colditz et al., 2007). If the original data is discrete rather than continuous, the discrete Fourier transform (DFT), which requires regular spacing on samples within the temporal domains, should be applied (Wang et al., 2004).

There is a drawback in this approach, since the NDVI images are composite images of different dates. The pixels have different acquiring dates that lead unequal time spacing. However, the HANTS (Harmonic Analysis of Time Series) algorithm was developed to deal with time series of irregularly spaced observations and to identify and remove cloud contaminated observations (Verhuef, 1996; Roerink et al., 2000).

The HANTS algorithm considers only the most significantcant frequencies expected to be present in the time profiles (determined, for instance, from a preceding FFT analysis), and applies a least squares curve fitting procedure based on harmonic components (sines and cosines) (Verhoef, 1996; Roerink et al., 2000). For each frequency the amplitude and phase of the cosine function is determined during an iterative procedure. Input data points that have a large positive or negative deviation from the current curve are removed by assigning a weight of zero to them. After recalculation of the coefficients on the basis of the remaining points, the procedure is repeated until the maximum error is acceptable or the number of remaining points has become too small. (Roerink et al., 2000).

Many different phenological indicators have been defined in various satellite-based studies. The advantage of the HANTS algorithm is that the output consists of a completely smoothed NDVI profile which is convenient for calculating derivatives. (De Wit & Su, 2005) The calculations of derivates are very important for the estimation the start of growing season and senescence dates (Sakamoto et al., 2005).

The version of HANTS used was implemented in IDL by (DE WIT, 2005) and is under the GNU General Public License.

The data set of temporal NDVI images, which contained a series of 23 samples per year was input to the HANTS algorithm. The output is a similar time series but smoothed and containing only the annual, 6 months and 3 months frequencies of the signal. The resulting different data sets were used as input data sets for image classification.

2.7 Wavelet transform

Fourier series are ideal for analyzing periodic signals, since harmonics modes used in the expansions are themselves periodic. In contrast, the Fourier integral transform is a far less natural tool because it uses periodic functions to expand nonperiodic signals. Two possible substitutes are the windowed Fourier transform (WFT) and the wavelet transform. The windowed Fourier transform can, however, be an inefficient tool to analyze regular time behavior that is either very rapid or very slow relative to the size of the analyzing window. The Wavelet transform solves both problems by replacing modulation with scaling to achieve frequency localization. The WFT might also be an inefficient tool when very short time intervals are of interest. On the other hand, a similar situation occurs when very long and smooth features of the signal are to be reproduced by the WFT. (Kaiser, 1994).

Different from the infinite sinusoidal waves of the Fourier transform, a wavelet is a small wave localized in time or space. Since a wavelet has compact support, which means that its value becomes 0 outside a certain interval of time, the time components of time-series can be maintained during the wavelet transformation. (Sakamoto et al., 2005)

Previous work reveal that the wavelet transform is a powerful tool for denoising data sets and for curve fitting procedures in NDVI time series (Sakamoto et al., 2005; Bruce et al., 2006; Galford et al., 2007).

For the present work, we used the methodology proposed by (Carvalho, 2001). In remote sensing outliers caused by clouds and shadows (noise) appear as peaks with narrow bandwidth in the temporal spectrum. They appear similar in the spatial domain, but with variable bandwidth. If we consider the presence of clouds and shadows as signal response against a "noisy" background, a framework for their detection can be based on noise modeling in transformed space. The discrete wavelet transform was implemented with the 'à trous' algorithm with a linear spline as the wavelet prototype. It produces a vector of wavelet coefficients d at each scale j, with j=0,…,J. The original function $f(t)$ was then expressed as the sum of all wavelets scales and the smoothed version a_j. The input signal was decomposed using one scale, two scales and three scales. The resulting different data sets were used as inputs for image classification, described in the following section.

2.8 Image Classification

The main objective of this work is to compare different filtering techniques and their output vegetation signature for time series of NDVI. One way to accomplish this is to use smoothed time series as input vectors to automated image classification.

For Moreira (2003) automatic image identification and classification can be understood as the analyses and the manipulation of images through computational techniques, with the goal of extracting information regarding an object of the real world.

2.9 Artificial Neural Networks

Humans and other animals process information with neural networks.

These are formed from trillions of neurons (nerve cells) exchanging brief electrical pulses called action potentials. Computer algorithms that mimic these biological structures are formally called artificial neural networks to distinguish them from the squishy things inside of animals (Smith, 1998). These biological inspired models are extremely efficient when the pattern of classification is not a simple and trivial one. Theses networks have shown to be helpful in the resolution of problems of practical scope. Problems such as voice recognition, optical character recognition, medical diagnosis and other practical scope problems are by no means complex problems to the human brain and sensor as they are for a computer to resolve.

Even though, some researchers do not recognize the artificial neural networks as being the general natural solution surrounding the problems of recognizing patterns on processed signals, it can be noticed that a well trained network is capable of classifying highly complex data. The use of artificial neural networks in pattern recognition and classification has grown in the last years in the field of remote sensing (Kanellopolous, 1997).

This work proceeded with 2 filtered data sets per region, these data sets included one HANTS filtered time series and one Wavelets filtered time series. These data sets were input into a neural network with the following characteristics: sigmoidal activation function, 0.01 learning rate, momentum factor of 0.5, sigmoid constant of 1.0, 14 hidden layers, with 69 neurons per layer. For training the network, 10000 iterations were used, with RMS error of 0.0001. These parameters were extracted from literature based on standard applications of neural to remote sensing image classification.

3 RESULTS AND DISCUSSION

Classification results as shown in table 1 confirm that no time series filtering technique necessarily produces a more accurate classified map. In some cases the classified maps produced from HANTS filtered time series generated more accurate results. In others cases it produced less accurate results. The kappa coefficient for the classification results can be either classified as substantial or almost perfect (Landis & Kock, 1977). Different from our findings, previous work carried out by Burce et al. (2006), which have also used filtered time series from Wavelet and Fourier transforms for image classification, showed that the former produced more accurate results. This can be partly explained by the fact that the HANTS algorithm have some enhancements over traditional Fourier based algorithms which was present in the cited work.

Region	Kappa Coefficient (wavelet filtering)	Kappa Coefficient (HANTS filtering)
North East	0.9480	0.8257
North	0.8476	0.8333
South	0.6355	0.7412
West region (Triângulo Mineiro)	0.8729	0.9051

TABLE 1 – classification results

The rows of figure 2 show the classification results in the four study areas. The results of Wavelet filtering time series, used as input for classification are in the right hand column. In the left hand column, the HANTS filtered time series as input to the neural network are illustrated. In the middle column we have the official forest map of Minas Gerais, carried out by Carvalho & Scolforo (2008), with a 30m spatial resolution. The proposed methods captured the general characteristics of vegetation of each area. In some cases such as the North East area, the classification results resemble the general "shape" of forest fragments. Both Northern area data sets have similar patterns when compared to the official state map. The other areas, however, do not show these similarities with the general shape of forest fragments from the official map. Note that the spatial resolution has important implications in the map comparisons. The Northern areas have a more accurate "shaping" of vegetation classification.

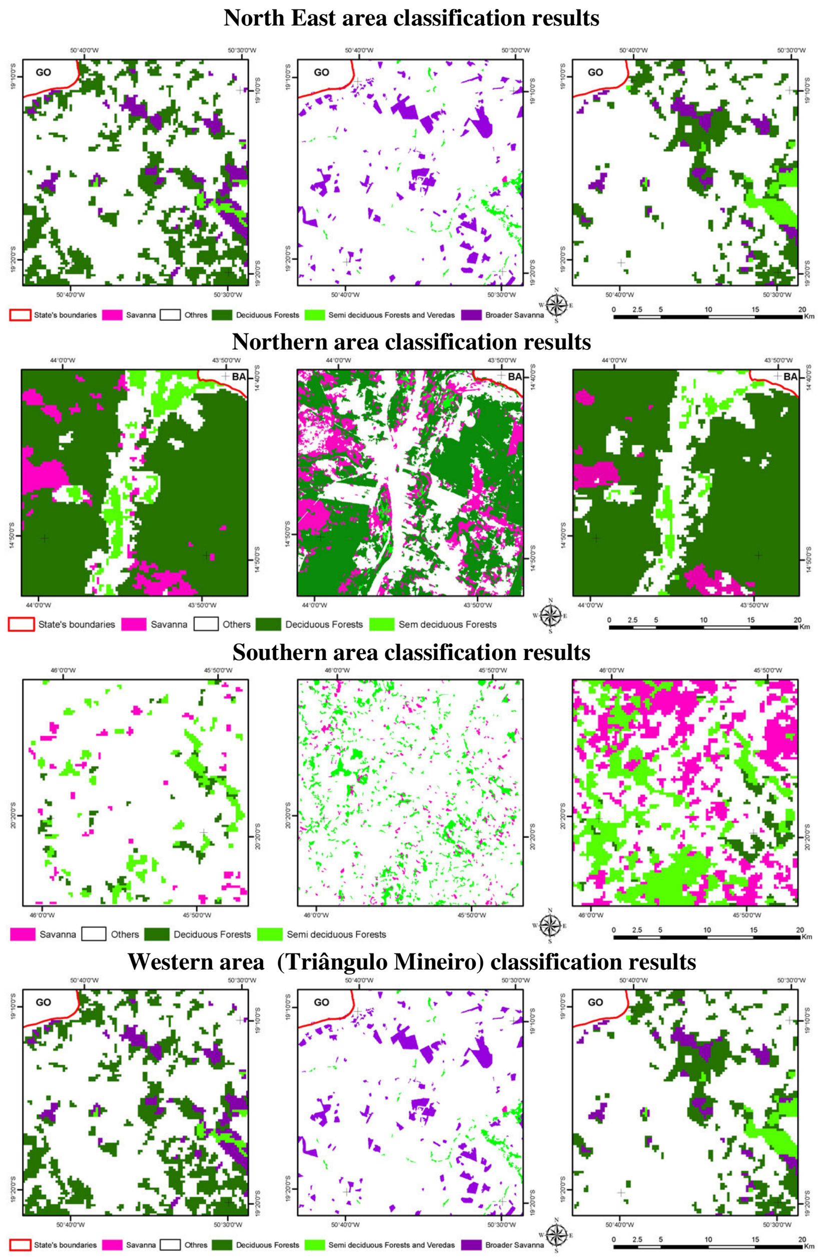

FIGURE 2 classification results

This work developed an efficient methodology to map the deciduous forests present in the Cerrado biome using MODIS temporal attributes and artificial neural networks algorithm. This study concluded that MODIS filtered

NDVI (Normalized Difference Vegetation Index) time series can generate accurate maps of deciduous forests in different regions.

- The maps generated from both HANTS and wavelet transformation curve smoothing procedures showed very similar high accuracy, indicating that any of these procedures can be used to denoise similar data sets.
- In the Northern areas, the maps generated from temporal features resemble the general "shape" of forest fragments, having similar patterns when compared to the official state map
- This methodology was capable of detecting fragments of deciduous forests in the Triângulo Mineiro region where the official state map did not.

Future research on this topic could be enhanced by the use of soft classifiers, such as Fuzzy logic which considers the possibility of one location belonging to various classes of vegetation. Oliveira-Filho (2009) criticizes the "rigidness" of the forest classification systems and is also concerned about the authenticity of trueness regarding these assessments. His work presents a 'new' and 'flexible' method which could be coupled with the fuzzy logic in the future. There is, however, the possibility of a chaos injection as predicted by the author, as the necessity of naming complex structures is ever present and useful.

5 BIBLIOGRAPHICAL REFERENCES

BLOOMFIELD, P. **Fourier analysis of time series**. New York: J.Wiley, 1976. 257p.

BRUCE, L.M.; MATHUR, M.; BYRD JUNIOR, J.D. Denoising and wavelet-based feature extraction of MODIS multi-temporal vegetation signatures. **GIScience & Remote Sensing**, v.43, p.170-180, 2006.

CARVALHO, L.M.T. **Mapping and monitoring forest remnants**: a multi-scale analysis of spatio-temporal data. 2001. 140p. Thesis (Doctor in Resources Conservation and Production Ecology)-Wageningen University, Wageningen.

CARVALHO, L.M.T. de; CLEVERS, J.G.P.W.; SKIDMORE, A.K.; JONG, S.M. de. Selection of imagery data and classifiers for mapping Brazilian semideciduous Atlantic forests. **Internacional Journal of Applied Earth Observation and Geoinformation**, Enschede, v.5, p.173-186, 2004.

CARVALHO, L.M.T.; SCOLFORO, J.R. **Inventário florestal de Minas Gerais**: monitoramento da flora nativa 2005-2007. Lavras: UFLA, 2008. 312p.

COLDITZ, R.R.; GESSNER, U.; CONRAD, C.; ZYL, D. van; MALHERBE, J.; NEWBY, T.; LANDMANN, T.; SCHMIDT, M.; DECH, S. Dynamics of MODIS time series for ecological applications in southern África. In: INTERNATIONAL WORKSHOP ON THE ANALYSIS OF MULTITEMPORAL REMOTE SENSING IMAGES, 14., 2007, Leuven, Belgium. **Proceedings**... Leuven: Multitemp, 2007. p.18-20.

GALFORD, G.L.; MUSTARD, J.F.; MELILLO, J.; GENDRIN, A.; CERRI, C.C.; CERRI, C.E.P. Wavelet analysis of MODIS time series to detect expansion and intensification of row-crop agriculture in Brazil. **Remote Sensing of the Environment**, New York, v.112, n.2, p.576-587, 2007.

HUETE, A.; DIDAN, K.; MIURA, T.; RODRIGUEZ, E.P.; GAO, X.; FERREIRA, L.G. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. **Remote Sensing of Environment**, New York, v.83, n.1, p.195-213, Nov. 2002.

JENSEN, J.R. **Remote sensing of the enviroment**: an earth resource perspective, retune hall series in geographic information science. New Jersey: Upper SaddleRiver, 2000. 544p.

KAISER, G. **A friendly guide to wavelets**. Boston: Springer-Verlag, 1994. 175p.

KANELLOPOULOS, G.G.; WILKINSON, F.; ROLI, J. **Neuro-computation in remote sensing data analysis**. [S.l.]: Springer, 1997. 284p.

LANDIS, J.R.; KOCH, G.G. The measurement of observer agreement for categorical data. **Biometrics**, Washington, v.33, p.159-174, 1977.

MOREIRA, M.A. **Fundamentos de sensoriamento remoto e metodologias de aplicação**. 2.ed. rev. e ampl. Viçosa, MG: UFV, 2003. 295p.

MORETTIN, P.A.; TOLOI, C.M. **Análise de séries temporais**. 2.ed. São Paulo: E.Blucher, 2006. 433p.

OLIVEIRA-FILHO, A.T. Classificação das fitofisionomias da América do Sul cisandina tropical e subtropical: proposta de um novo sistema - prático e flexível - ou uma injeção a mais de caos? **Revista Rodriguésia**, 2009. No prelo.

OLIVEIRA-FILHO, A.T. **TreeAtlan 1.0**: flora arbórea da Mata Atlântica e domínios adjacentes: um banco de dados envolvendo geografia diversidade e conservação. Available at: <http://www. treeatlan.dcf.ufla.br/>. Access in: 10 Jan. 2009.

OLIVEIRA-FILHO, A.T.; CURI, N.; VILELA, E.A.; CARVALHO, D.A. Effects of canopy gaps, topography and soils on the distribution of woody species in a central Brazilian deciduous dry forest. **Biotropica**, Washington, v.30, n.3, p.362-375, 1998.

OLIVEIRA, L.T. **Fusão de imagens de sensoriamento remoto e mineração de dados geográficos para mapear as fitofisionomias do bioma Cerrado**. 2004. 131p. Dissertação (Mestrado em Manejo Ambiental)-Universidade Federal de Lavras, Lavras.

ROERINK, G.J.; MENENTI, M.; VERHOEF, W. Reconstructing Cloudfree NDVI composites using Fourier analysis of time series. **International Journal of Remote Sensing**, Basingstoke, v.21, n.9, p.1911-1917, 2000.

SAKAMOTO, T.; YOKOZAWA, M.; TORITANI, H.; SHIBAYAMA, M.; ISHITSUKA, N.; OHNO, H. A crop phenology detection method using time-series modis data. **Remote Sensing of Environment**, New York, v.96, p.366-374, 2005.

SMITH, S.W. **The scientist and engineer's guide to digital signal processing**. San Diego: California Technical, 1998. 626p.

SOARES, J.V.; BATISTA, G.T.; SHIMABUKURO, Y.E. Histórico e descrição. In: RUDORFF, B.F.T.; SHIMABUKURO, Y.E.; CEBALLOS, J.C. (Org.). **O sensor MODIS e suas aplicações no Brasil**. São José dos Campos: Parêntese, 2007. cap.1, p.2-22.

VERHOEF, W. Application of harmonic analysis of NDVI time series (HANTS). In: AZZALI, S.; MENENTI, M. (Ed.). **Fourier analysis of temporal**

NDVI in the Southern African and American continents. Wageningen: DLO Winand Staring Centre, 1996. p.19-24. (Report 108).

WANG, Q.; TENHUNEM, J.; DINH, N.Q.; REICHSTEIN, M.; VESALA, T.; KERONEN, P. Similarities in ground and satellite-based NDVI time series and their relationship to physiological activity of a Scots pine forest in Finland. **Remote Sensing of Environment**, New York, v.93, n.2, p.225-237, 2004.

WIT, A. de; SU, B. **Deriving phenological indicators from spot-vgt data using the *Hants* algorithm**. Wageningen: Centre for Geo-Information, 2005. Available at: <http://www.vgt.vito.be/vgtapen/pages/fullpapers/Dewit_full.pdf>. Access in: 8 Feb. 2009.

YU, X.; ZHUANG, D.; CHEN, H.; HOU, X. Forest classification based on MODIS time series and vegetation phenology. In **International Geoscience and Remote Sensing Symposium**, 4., 2004, Toulouse. Annual publications of… Toulouse, 2004. p. 2369-2372.

ZHANG, X.; FRIEDL, M.A.; SCHAAF, C.B. Monitoring vegetation phenology using modis. **Remote Sensing of Environment**, New York, v.84, p.471-475, 2003.

General Conclusions

This study's objective concluded that time series data could provide helpful information to map deciduous forests. It was successful in answering the following questions:

1) Do geographically distant deciduous forests have annual shifts in their phenological cycles during the year?

In chapter 01, a time shift was found in some of the study areas compared to others, the largest time shift was of about half a month in the annual phenological frequency.

2) Can MODIS filtered NDVI (Normalized Difference Vegetation Index) time series generate precise mapping to deciduous forests in different regions?

In chapter 02 it was concluded that MODIS filtered NDVI (Normalized Difference Vegetation Index) time series can generate accurate mapping to deciduous forests in different regions.

3) Which of two filtering techniques (HANTS Fourier Analysis), Wavelet Filtering produces the best filtered time series for mapping this phytophysiognomy.

In chapter 02, the maps generated from both HANTS and wavelet transformation curve smoothing procedures showed very similar results and high accuracy indicating that any of these procedures can be used to denoise similar data sets.