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NDVI Time Series for Mapping Phenological Variability of Forests Across the Cerrado Biome in Minas Gerais, Brazil

Thomaz Oliveira, Luis Carvalho, Luciano Oliveira,
Wilian Lacerda and Fausto Acerbi Junior
UFLA,
Brazil

1.Introduction

The constant threat that natural forests of the world have suffered over the years led to strategies that intend to prevent these from further losses in the near future. The tropical rain forest that exists in northern Brazil is the main concern of preservation, but other areas such as the "Mata Atlântica" have had losses over the years and almost 75 % of its remnants are under threat of deforestation. The main activities that lead to deforestation in the region are the expansion of agricultural frontiers, the extraction of coal and other minerals, timber exploitation, and other anthropogenic activities (Oliveira, 2004). Another area in Brazil that is under threat is the Cerrado Biome in Minas Gerais. The Cerrado biome of tropical South America covers about two million squared kilometres, representing almost 22% of the Brazilian territory. The biome was named due to its predominant vegetation type, a fairly dense woody savannah composed by shrubs and small trees. The term "cerrado" (Portuguese for closed or dense) was probably applied to this vegetation because of the difficulty of traversing it on horseback (Oliveira-Filho et al. 2002). The constant threat to the Brazilian Cerrado has led to the necessity of developing strategies and measures to promote the monitoring and mapping of this biome. The Cerrado has a rich biodiversity but its fragmentation throughout the years caused losses of a number of species from this biome (Oliveira 2004). The Cerrado has many types of phytophysiognomies, these include Semi-Deciduous Forests, Deciduous Forests, Cerradão (dense Savanna), Cerrado (Savanna), Floresta Ombrófila and other more specific types of vegetation. In order to prevent further deforestation of this biome, monitoring by means of remote sensing is regarded as an efficient tool. This technique can provide accurate mapping of the occurrence of each phytophysiognomy of the Cerrado Biome and promote efficient monitoring in order to detect changes so legal actions can be taken in due time.

Mapping land cover using remotely sensed 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, analyse and present all sorts of land cover information (Carvalho 2001).

The Statewide Vegetation Monitoring and Mapping of Minas Gerais was conducted by Carvalho (2007) with the use of multitemporal Landsat images. This project includes a dataset of images acquired in different seasons of a year so that the dry and wet seasons could be captured in order to characterize the phenological cycle of deciduous and semideciduous forests (Figure 1).

Fig. 1. Visual Difference of phytophysiognomies (a) Deciduous forest, (b) semi-deciduous forest Source Oliveira (2004). Semi-deciduous forests loose less leaves in the dry season.

Deciduous forests lose 70% of its leafs in the dry season, the semi-deciduous forests loose less of its leafs in this season, with less variation in greenness.

According to Jensen (2000), temporal signatures are very important when mapping different vegetation types or extracting vegetation biophysical information (e.g. biomass) from remotely sensed data. Multi-temporal imagery are currently of standard use when studying large areas at regional and global scales (Carrão et al. 2007).

However, errors occurred in the Official state map due to the characteristics of one specific phytophysiognmy within this biome - the Deciduous Forests. The deciduousness of these forests is determined by an alternating cycle of dry and wet seasons, where more than 70 % of the leaves are off (Figure 2) 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. The variation of greenness of the semi-deciduous forest – another phytophysiognomy of the Cerrado Biome – is not as intense as the deciduous counterpart, due to its occurrence in regions of intensified humidity (Oliveira 2004), like riparian areas.

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 behaviour (Carvalho et al. 2004). Phenological timing is an example of such features, which have the potential to reduce mapping errors.
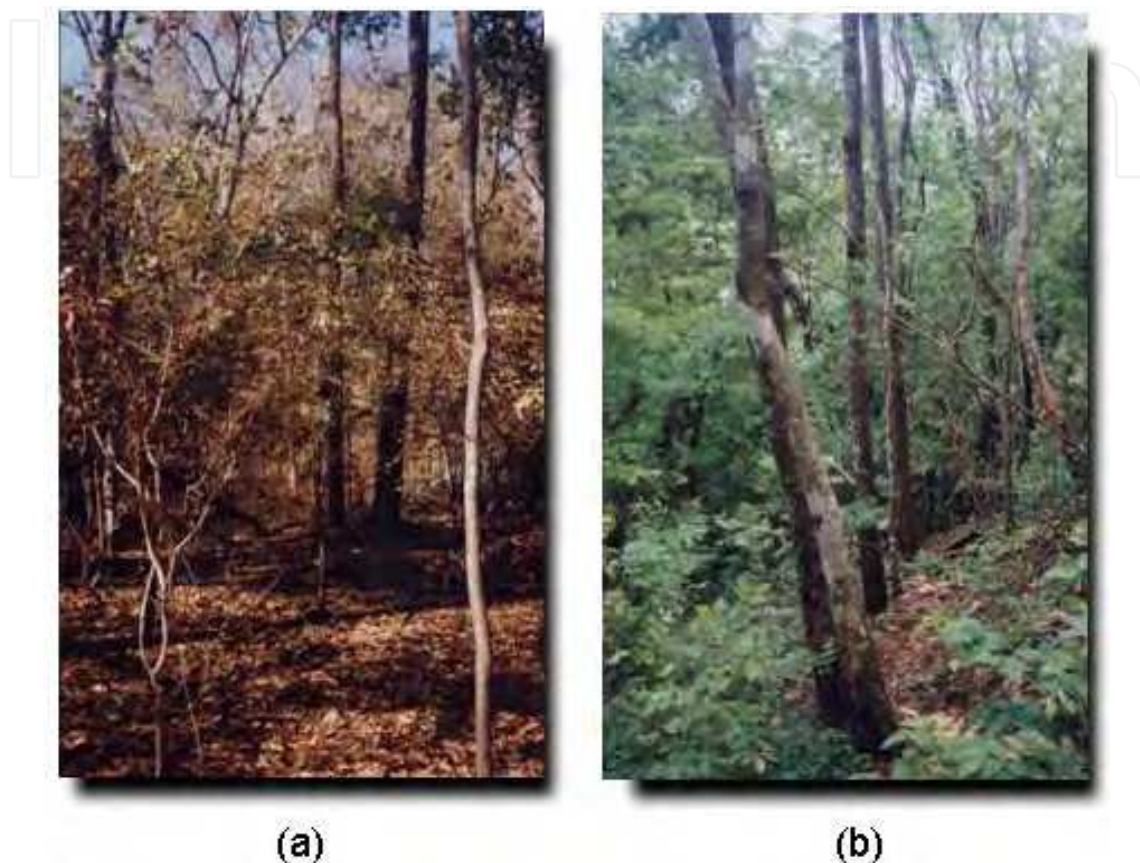

Fig. 2. Two picture of the same location of a Deciduous forrest of the Cerrado Biome, illustrating the difference of greenness: Wet season (a) and dry season (b). Oliveira-Filho (2011).

Considering the peculiarities of this vegetation type, there is a need to develop specific image processing approaches when mapping land cover in the Cerrado Biome due to this temporal variation in greenness. Since land cover features that have similar spectral reflectance are difficult to be differentiated when using single-date remote sensing imagery, the analysis of time series of images that capture vegetation seasonality may provide improved results. These include the quantification of the seasonal profile of Deciduous and Semi-deciduous forests. Errors among these classes were commonly found in the Official state map, which does not capture deciduous forests fragments present in the region of the Triângulo Mineiro, western Minas Gerais. Research however, suggests that remotely sensed time series data could possibly improve misclassification and the accuracy of mapping deciduous forests (Oliveira, 2004).

These errors may be associated with a time-shift in the phenological patterns of these forests that occur in different areas. One forest remnant in the eastern part of the state may have a

lag of time on its cycle that may lead to mapping errors. Thus, temporal images should be acquired in different dates in order to properly characterize leaf-on and leaf-off periods across the State.

Sano et al. (2008) have used NDVI time series for studying the Cerrado, in order to produce a semi detailed land cover mapping of the area considering the following classes: croplands, planted pasturelands, reforestations, urban settlements and mining areas. In another study conducted by Carvalho Júnior et al.(2006), the characterization of Deciduous Forests time profile was performed with the Minimum Noise Fraction (MNF) transformation in order to remove outliers from the time profile. This study was conducted in the states of Goiás and Tocantins, Brazil. The authors have also considered different vegetation classes when compared to the present study: deciduous forests, savannah, dense cerrado, and "Campo Sujo". Their methodology did not consider the discrimination between semi-deciduous and deciduous forests, nor timing of phonological cycles. In the work carried out by Silveira et al. (2008) in Minas Gerais, vegetation was classified using smoothed MODIS time series with excellent results. Nevertheless, the study did not consider different geographic locations within the State. No previous work was carried out to specifically characterize the deciduous forests of Minas Gerais with the use of Multi-temporal imagery and to quantify its phenological cycle.

The present work is concerned with the quantification of phenological time shifts among deciduous forests that are geographically distant. Preprocessing techniques were applied to the MODIS time series in in order reduce noise. The outcomes have the potential to provide less errors in future maps that could be benefited by the acquisition of images that take this time shift into account.

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

1. Do Geographically distant deciduous forests have different timing in their phenological cycle during the year, leading to an annual shift (figure 3) in their cycle?
2. Can MODIS filtered NDVI (Normalized Difference Vegetation Index) time series be used to generate better maps of deciduous forests in different regions?
3. Which of two filtering techniques, viz. HANTS Fourier Analysis and Wavelet Filtering, produces the best smoothed time series for mapping this phytophysiognomy.
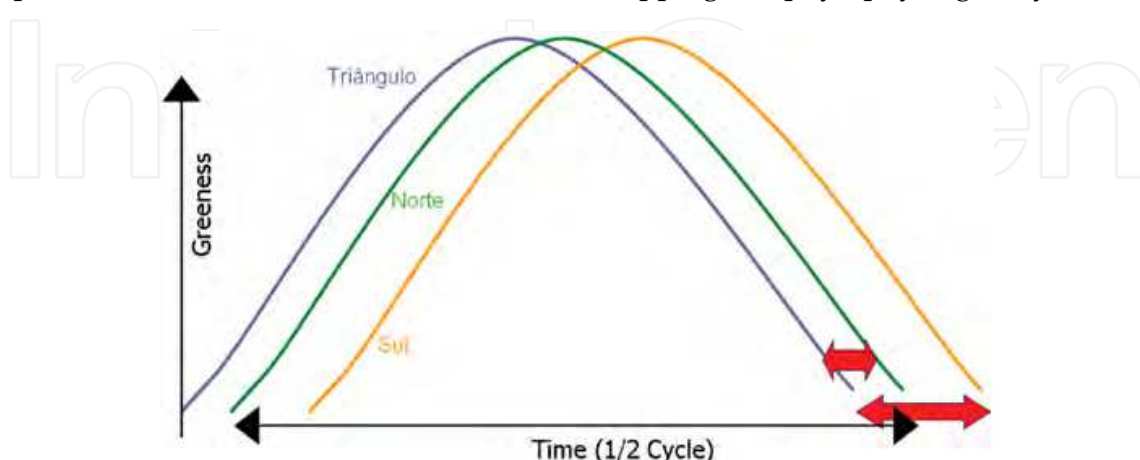

Fig. 3. Time shift analysis of phenology. The arrows indicate the time delay that was calculated later in this work. The plot indicates the variation of greenness in time in different regions of deciduous forests of the Cerrado for ½ year period.

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 modelled 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 use. 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 et al., 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 (Coldiz et al., 2007; Jensen, 2000)
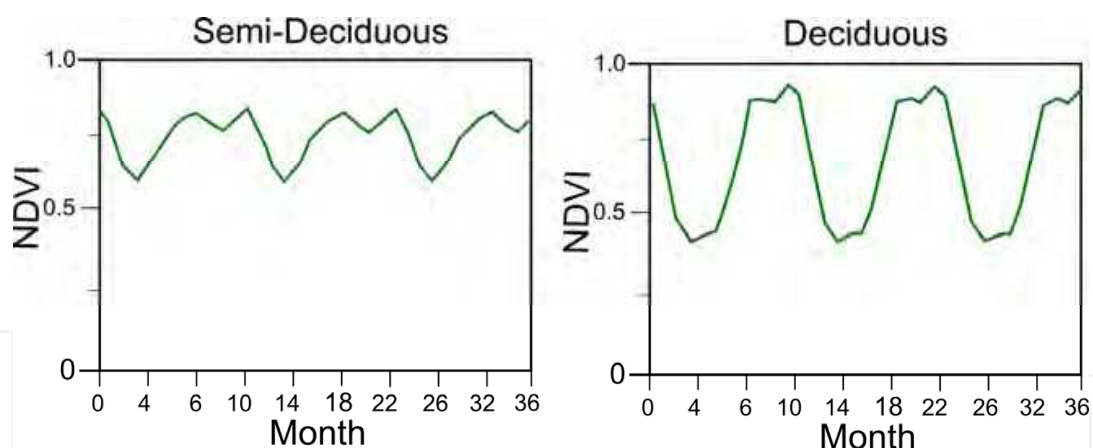

Fig. 4. Denoised MODIS NDVI time series for Deciduos and Semi-deciduous Forests. The difference in amplitude is noticeable in this plot for these two phytophysiognomies, indicating the different time signature among them.

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 4. In most cases, different types of vegetation have different phenolgical patterns. For example, evergreen plants will have a more steady temporal dynamics throughout the year when compared to tropical plants that lose their leaves (Bruce et al., 2006).

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 MODIS NDVI time series

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).

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).

2.3 Dataset and study site

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 5), and the Official State Map by Carvalho (2007). 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 by visual interpretation.

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

The original images were pre-processed using the MODIS Reprojection Tool (MRT). The data set was sampled to 23 values per year, approximately two images per month. This dataset included the years of 2007, 2008, and 2009. The representation of this time series is pictured in figure 6.

2.4 MODIS compositing methods

Several factors 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).
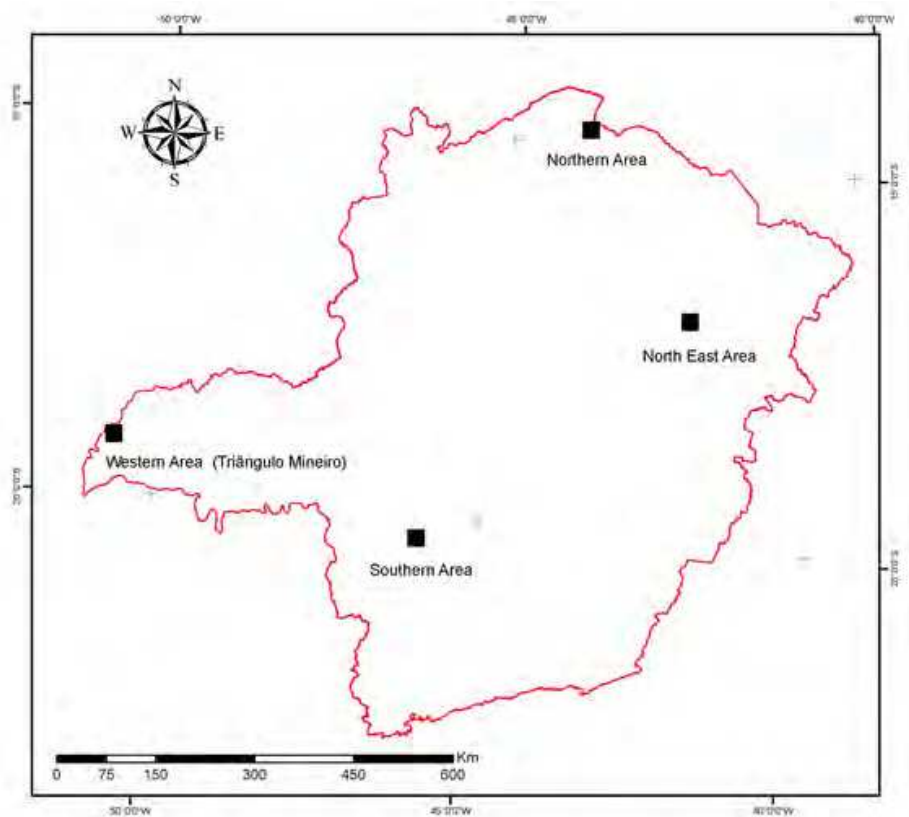
Fig. 5. Locations of Deciduous Forests of four different geographical areas chosen to calculate the timing difference among each location. Each area was chosen accordingly to the occurrence of Deciduous Forests from the TreeAtlan database and the Official State Map.
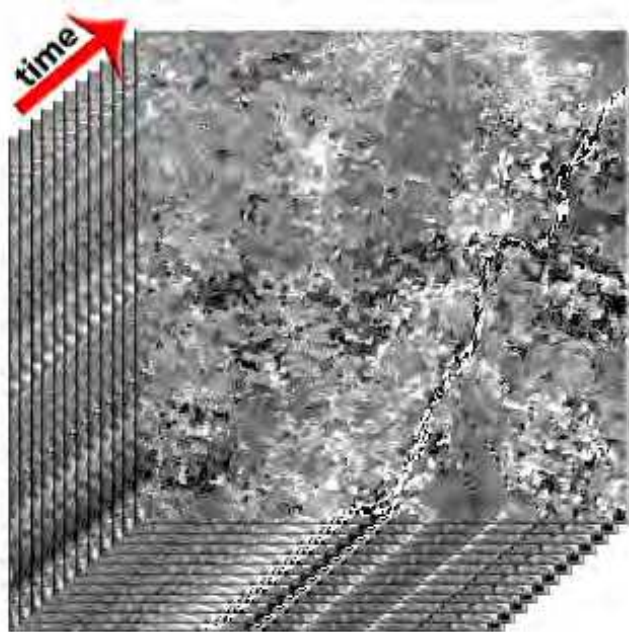

Fig. 6. MODIS NDVI time series dataset. The multi-temporal remote sensing MOD13 data is layered as described in this figure in order to acquire a time series for each pixel.

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 days 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 global scales, variations in community composition, micro and regional climate, soils, and land management result in complex spatio-temporal variation in phenology. Furthermore, 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).
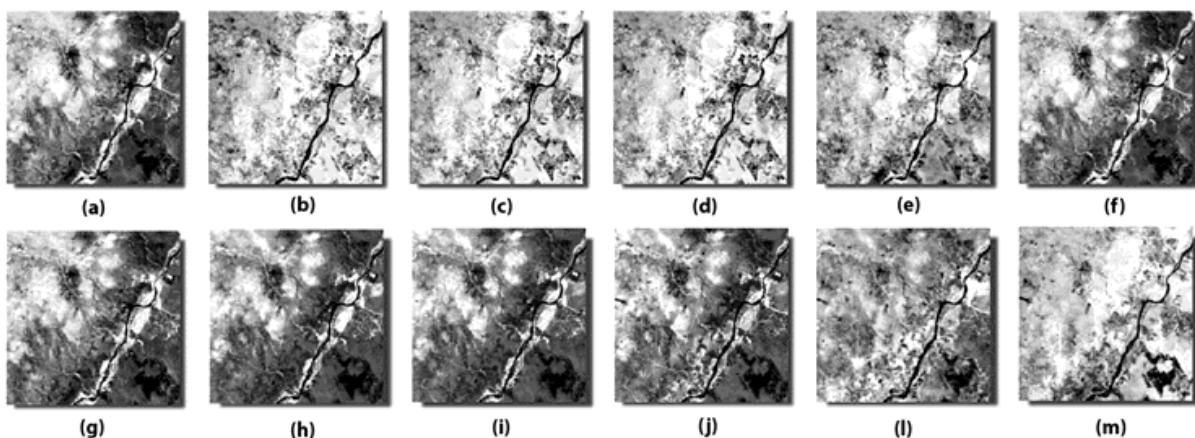
Fig. 7. Original MODIS MOD13 NDVI time series with compositing procedures. From (a) to (m) this time series corresponds to one full year cycle of the northern studied area

Figure 7 exhibits 1 full year of the NDVI original time series before the noise reduction algorithms.

2.5 Signal denoising

In order to extract pertinent features from time signatures for potential target applications, the signals must first be denoised. The main noise from remote sensing time series comes from pixels that were cloud contaminated, these appear as low NDVI values in the time signatures, as observed in figure 9, in the datasets prior to denoising procedures. 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 (Zahng et al. 2003). Other methods for phenology curve fitting and noise reduction are included in the Timesat software (Jönsson & Lars 2004) and its enhanced version by Tan et al. (2010) which uses traditional least square fit for polynomial, Gaussian and Sigmoidal functions, they are also useful for computing derivates which correspond to annual senescence and growth and other important phonological metrics.

A study by Couto-Júnior (2011) concluded that MODIS is an adequate tool for monitoring and extracting metrics for the Cerrado biome due to its high temporal resolution and availability. Although one of its drawbacks is its high signal-to-noise ratio leading to the use of advanced signal processing methods.

2.6 Fourier transform

The Fourier Transform has been traditionally used to solve differential and partial 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 behaviour under a change in time scale (Bloomfield, 1976).

Fourier analysis have been used for denoising and curve fitting in MODIS vegetation index data sets (Colditz et al., 2007; Bruce et al., 2006; Yu et al., 2004; Wang et al., 2004). 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], has N samples. Two vectors containing N/2 values 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.

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 thorough compositing, the pixels have different acquiring dates that lead unequal time spacing.

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

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

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

Equations 1, 2 and 3 – Fourrier analysis equation in discrete time, Equation (5) sysnthesis equation in frequency domain – Source Smith (1998)

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 et al., 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).
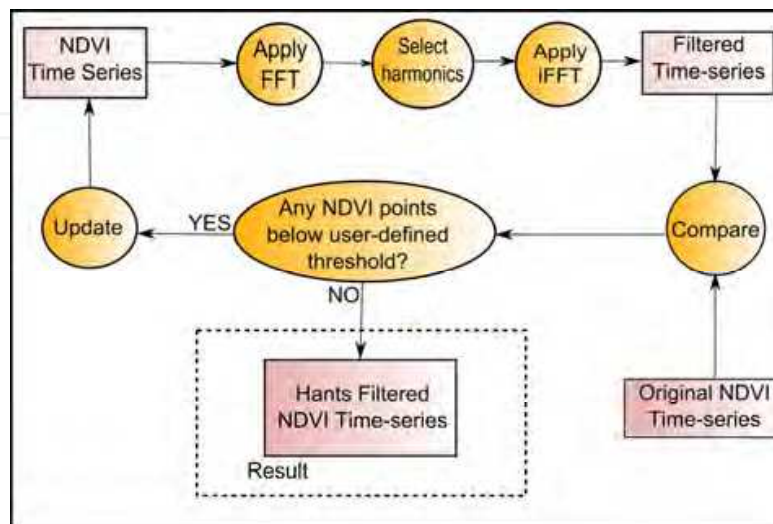
Fig. 8. Flowchart of the FFT based HANTS algorithm, it is a cyclic algorithm that removes the pixels that are below a user chosen threshold - Source (De Wit, 2005)

The algorithm starts in the upper left block with the raw NDVI time series. These are used as input in the FFT and the relevant frequencies (usually mean, annual and half-year signal) are selected from the Fourier spectrum. The inverse FFT (iFFT) then transforms the spectrum back into a filtered NDVI time-series. Next, a comparison is made between the filtered NDVI time-series and the original NDVI time-series (Figure 8). The difference is calculated between the filtered and the original NDVI time-series. Any point in the original NDVI time-series that are below a user-defined threshold are considered 'cloudy' and are replaced with the value of the filtered NDVI time-series. However, by replacing values in the NDVI time-series, the average of the entire profile becomes larger. Therefore, a next iteration is needed and 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.

Among the resulting files, the algorithm outputs a FFT file which has a complex number pair, this pair 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 serves well 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, 2006). 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 and5) 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 (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.

$$Cj = \sqrt{Aj^2 + Bj^2} \qquad (4)$$

$$\phi = \tan^{-1} \frac{B_j}{A_j} \qquad (5)$$

Equations 4 and 5 - 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

The exact location of the deciduous forests for this study was determined by the use of the official state map by Carvalho (2007) , auxiliary Landsat images, and using information from Oliveira-Filho and Ratter (2002) which describes deciduous forest fragments which were not captured in the official state map. With this information, it was possible to calculate the amplitude-phase statics of each forest fragment within the four chosen areas.

After the calculation of amplitude and phase of each harmonic of the original NDVI images of different locations, a subset of the original images was generated. This subset contains only the pixels corresponding to the occurrences of Deciduous Forests. Statistics were computed to the phase of the first harmonic so that annual shifts of deciduous forests of different geographic locations could 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.

2.9 Wavelet transform

Fourier series are ideal for analysing 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
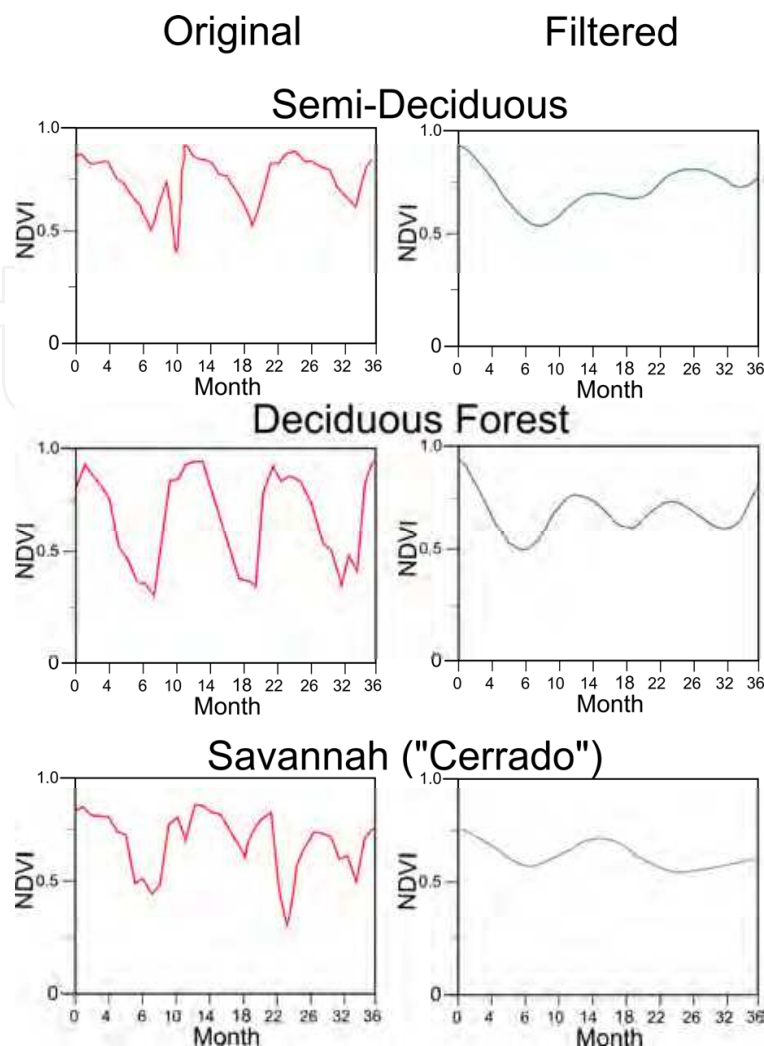
Fig. 9. Denoised phenology time series by wavelet transform. It is clear that before denoising, the data set has many outliers most of them being cloud contaminated pixels. Denoising procedures remove these pixels smoothing the time signatures.

substitutes are the windowed Fourier transform (WFT) and the wavelet transform. The windowed Fourier transform can, however, be an inefficient tool to analyse regular time behaviour that is either very rapid or very slow relative to the size of the analysing window. The Wavelet transform solves both of these 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; Galford et al., 2007; Bruce et al., 2006).

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 similarly 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 aj. The input signal was decomposed using one scale, two scales and three scales. Figure 9 shows smoothed time series of NDVI data by denoising via wavelet transform. The resulting different data sets were used as inputs for image classification, described as followed.

2.10 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.

2.11 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. The samples were separated in 3 datasets. These contained samples of each phytophysiognomy of the four different locations. Each location was processed separately, with 2 different datasets. One dataset was used for training the network, and the other for validation. These datasets 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 networks to remote sensing image classification.

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 analysed forest fragments are not mixed with other vegetation that have higher mean NDVI value such as the semi-deciduous forests.

This explains the errors occurred in the Official state map in the Triângulo Mineiro region. This indicates that this time lag should be taken into account when mapping Deciduous Forests of this region.

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

Table 1. Statistics of harmonic analysis of the four different study areas.

Previous work from Sakamoto (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 behaviour, our FFT approach is most suitable.

The proximity in results regarding mean value of the phase in the North and the North West 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.

3.1 Classification results

Classification results as shown in table 2 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, 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.

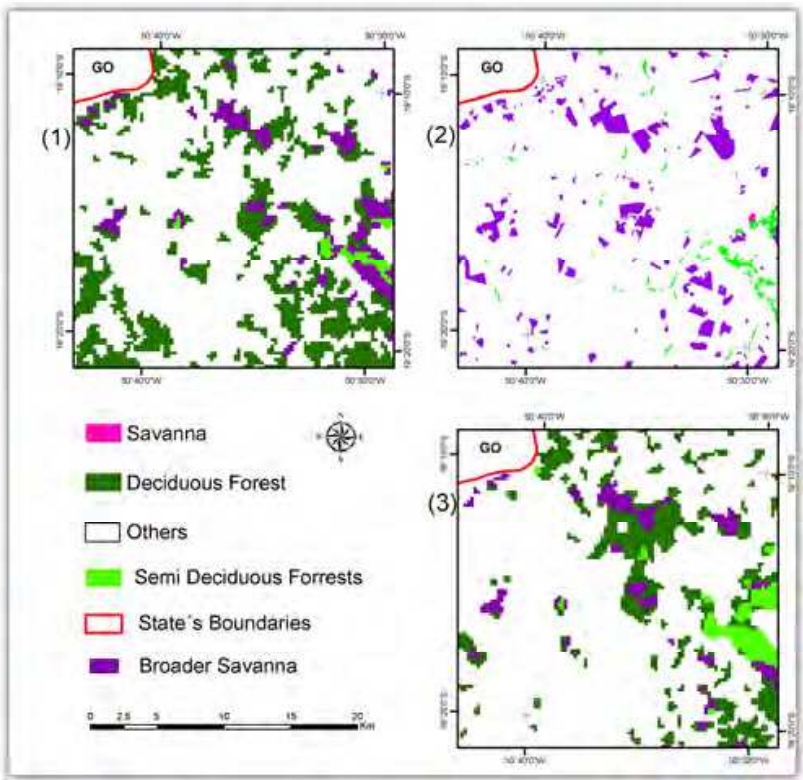| Region	Kappa Coefficient (wavelet filtering)	Kappa Coefficient (HANTS filtering)
North East	0.9480	0.8257
North	0.8476	0.8333
South	0.6355	0.7412
West region (Triângulo Mineiro)	0.8729	0.9051

Table 2. Classification results.

Fig. 10. Triangulo Mineiro Region Classification Results with Neural Networks: (1) Wavelet transform filtered time series, (2) Official State Map, (3) HANTS filtered time series.
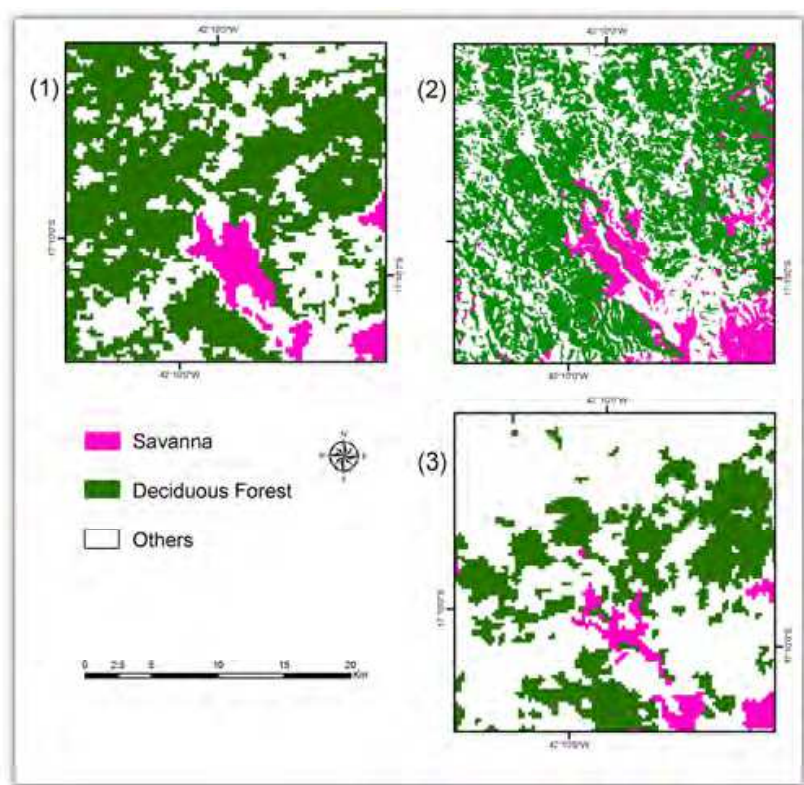
Fig. 11. NothEast Area Classification Results with Neural Networks: (1) Wavelet transform filtered time series, (2) Official State Map, (3) HANTS filtered time series.
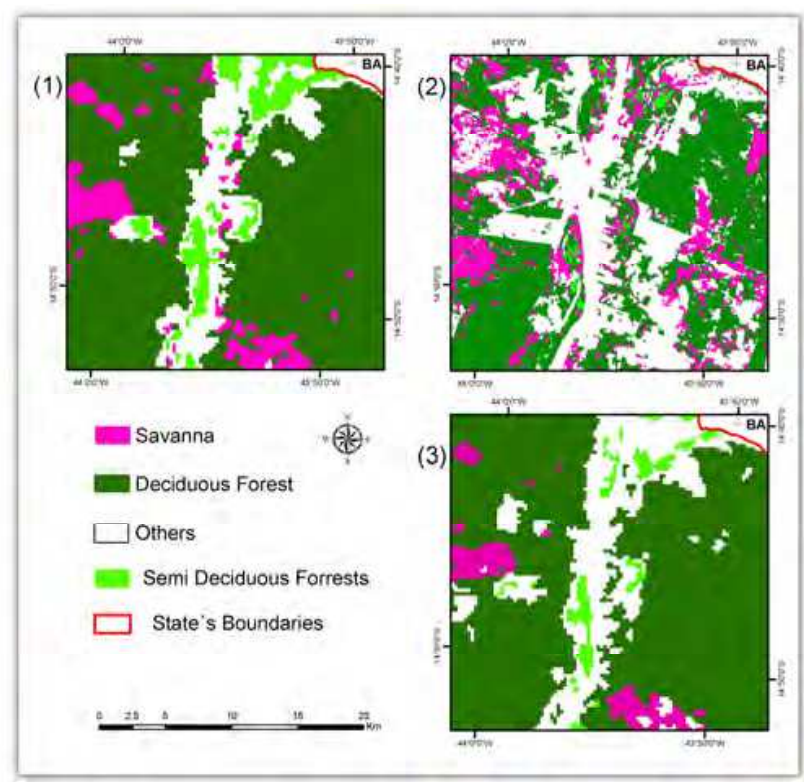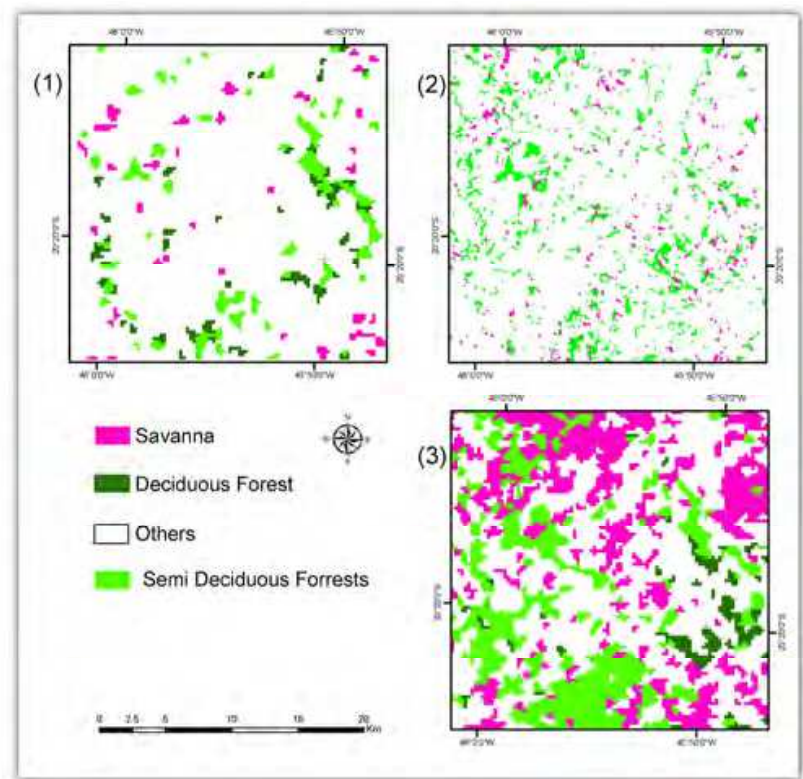

Fig. 12. Northern Area Classification Results with Neural Networks: (1) Wavelet transform filtered time series, (2) Official State Map, (3) HANTS filtered time series.

Fig. 13. Southern Area Classification Results with Neural Networks: (1) Wavelet transform filtered time series, (2) Official State Map, (3) HANTS filtered time series.

The rows of figures 10 to 13 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 (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.

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. However this work could be further improved by investigating how large the impact of the time delay of the Deciduous Forests is on mapping.

This work developed an efficient methodology to map the deciduous forests present in the Cerrado Biome by using MODIS temporal attributes and artificial intelligence neural networks algorithm for classification. It is concluded that MODIS filtered NDVI (Normalized Difference Vegetation Index) time series might generate accurate mapping of deciduous forests in different regions.

- The maps generated from both HANTS and wavelet transformation curve smoothing procedures showed very similar and 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 of forest did not.

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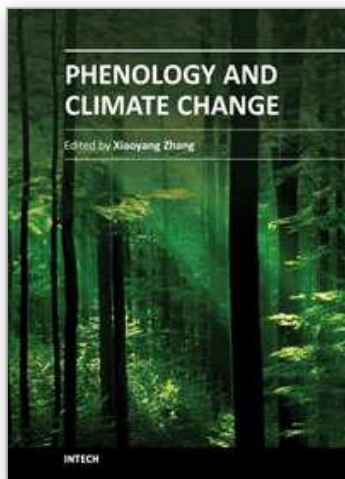
Phenology and Climate Change

Edited by Dr. Xiaoyang Zhang

Phenology, a study of animal and plant life cycle, is one of the most obvious and direct phenomena on our planet. The timing of phenological events provides vital information for climate change investigation, natural resource management, carbon sequence analysis, and crop and forest growth monitoring. This book summarizes recent progresses in the understanding of seasonal variation in animals and plants and its correlations to climate variables. With the contributions of phenological scientists worldwide, this book is subdivided into sixteen chapters and sorted in four parts: animal life cycle, plant seasonality, phenology in fruit plants, and remote sensing phenology. The chapters of this book offer a broad overview of phenology observations and climate impacts. Hopefully this book will stimulate further developments in relation to phenology monitoring, modeling and predicting.

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