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Cientific Paper

Identification and classification of the annual crop stages in the Parana state through the use of MODIS/NDVI temporal profiles

Rafael Aldighieri Moraes[1]

Abstract

The aim of this study was to identify and classify the stages cultivation of annual crops in the Parana state for the crop season 2009/2010, from the Modis NDVI temporal profiles analysis. It was considered a period of 11 months, beginning in August 2009 until June 2010, totaling 20 images of NDVI, VI Quality and Reliability, of the product MOD13Q1 (250 m). This period was selected in order to cover the entire cycle of summer crops, from the development, peak growth cycle and harvest. The methodology applied in this paper aims to identify and classify areas where the NDVI temporal profile behavior was similar to summer crops cultivation. Moreover, the transformations of these profiles in slope profiles allowed, through the characteristic slope curves, the determination of dates on each phase, being in the ascendant classified as growth, in the top as peak growth cycle and in the downward of the curve as harvest. The results were disposed in the map format and compared with municipal official data. The estimated harvested area presented accuracy (R^2) of 0.7701 and exactness coefficients (d) of 0.9201. The errors of area estimation occurred with maximum overestimation of 10.000 hectares (ha) and underestimation of 37.581 ha, with the exception of the Castro municipality, with 73.306 ha. The disposition of dates of the cultivation stages presented consistency with the official data, besides the spatial vision of the cultivation of annual crops in the Parana.

Key-words: temporal profile; Modis; mask.

Identificação e classificação de fases de cultivo de culturas anuais no estado do Paraná através do uso de perfis temporais MODIS/NDVI.

Resumo

O objetivo deste trabalho foi identificar e classificar as fases de cultivo de culturas anuais no estado do Paraná para a safra 2009/2010, a partir da análise da forma de perfis temporais de NDVI do sensor Modis. Foi considerado o período de 11 meses, iniciando-se em agosto de 2009 até junho de 2010, totalizando 20 imagens de NDVI, *VI Quality* e *Reliability* do produto MOD13Q1 (250m). Este período foi selecionado de modo a abranger todo o ciclo das culturas de verão, a partir do desenvolvimento, pico vegetativo e colheita. A metodologia aplicada neste trabalho se propõe a identificar e classificar áreas onde o comportamento do perfil temporal do NDVI fosse semelhante ao cultivo de cultura de verão. Além disso, as transformações destes perfis em perfis de coeficiente angular permitiram, através das inclinações características das curvas, a determinação das datas em cada fase, sendo na ascendente classificado como crescimento, no topo como pico vegetativo e na descendente da curva como colheita. Os resultados foram dispostos no formato de mapa e comparados com dados oficiais do IBGE para cada município. A área colhida estimada apresentou uma precisão (R^2) de 0,7701 e uma exatidão (*d*) de 0,9201. Os erros de estimativa de área ocorreram com superestimativa máxima de 10.000 hectares (ha) e subestimativa de 37.581 ha, com exceção do município de Castro com 73.306 ha. A disposição das datas das fases de cultivo apresentou coerência com dados oficiais, além da visão espacial da dinâmica do cultivo de culturas anuais no estado do Paraná.

Palavras-chave: perfil temporal; Modis; máscara.

Identificación y clasificación de las etapas de la producción de cultivos anuales en el Estado de Paraná a partir de la utilización de los perfiles temporales de NDVI/MODIS

El objetivo de este estudio fue identificar y clasificar las etapas de la producción de cultivos anuales en el Estado de Paraná para la zafra 2009/2010, a partir del análisis de la forma de los perfiles temporales de NDVI sensor Modis. Se consideró el período de 11 meses, a partir de agosto de 2009 hasta junio de 2010, con un total de 20 imágenes NDVI, VI Quality y Reliability del producto MOD13Q1 (250m). Este período fue seleccionado para cubrir todo el ciclo de los cultivos de verano, desde

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1 Universidade Estadual de Campinas – UNICAMP/FEAGRI, Avenida Candido Rondon, 501, CEP 13083-875, Campinas, SP. E-mail: rafagricola@yahoo.com.br. (Professor UNIESP/Policamp.)

el desarrollo, el máximo vegetativo y la cosecha. La metodología aplicada en este trabajo tiene como objetivo identificar y clasificar las zonas en las que el comportamiento del perfil temporal del NDVI fue similar al crecimiento de los cultivos de verano. Además, los cambios de estos perfiles en perfiles de coeficiente angular permitirán, por las pendientes características de las curvas, la determinación de las fechas en cada fase, siendo en el ascendente clasificado como crecimiento, en lo topo como máximo crecimiento vegetativo y en la descendente de la curva como cosecha. Los resultados fueron dispuestos en formato de mapa y se comparan con los datos oficiales del IBGE para cada municipio. La superficie cosechada presenta una precisión estimada (R^2) de 0.7701 y una exactitud (d) de 0,9201. Los errores de estimación de área se produjeron con la máxima sobreestimación de 10.000 hectáreas (ha) y con subestimación de 37.581 ha, con la excepción del municipio de Castro con 73 306 ha. La disposición de las fechas de las fases de cultivo mostró coherencia con los datos oficiales, además de la visión espacial de la dinámica de la producción de cultivos anuales en el Estado de Paraná.

Palabras clave: perfil temporal; la máscara; Modis

Introduction

In Brazil, the Parana state is one of the largest grain producers, responsible for approximately 24% of the maize and 20% of the soybean produced in 2010 (IBGE, 2012). Thus, has a strategic position, being important both for the internal supply as for exportation.

The monitoring of agricultural crops from the remote sensing has been proposed as an alternative for the subjectivity of the results presented by the governmental agencies. Both the identification as the division and visualization of the cultivation stages occurred during a season, allows a strategic visualization of the spatial and temporal dynamic of the entire process of crops cultivation, being this important information for governments and companies. To this end, sensors of medium spatial resolution and high temporal, allow monitoring agricultural areas.

The images of the sensor Moderate Resolution Imaging Spectroradiometer (Modis) are adequate to the monitoring of vegetal covers. This, of moderate spatial resolution (250 m) and high temporal resolution (1 to 2 days), are available free of charge, in composition of 16 days, having as one of its products images of vegetation indices (MODIS, 2010).

From the sequences of images of the NDVI of Modis sensor, that is, of multi-temporal, is possible to identify the crops dynamics, in large areas during the whole productive cycle. According to LABUS et al. (2002), temporal profiles can be obtained through subsequent observations of NDVI, made during the productive cycle of a crop, showing its progression, since the emergence, maturation and senescence, reflecting the performance of the crop. ESQUERDO et al. (2011) shows that the NDVI temporal profiles have potential for the soybean crop monitoring in Parana. Besides it, these profiles can explain the possible variations in yield.

Thus, the aim of this study was to indentify and classify the cultivation stages of annual crops in the Parana state for the season 2009/2010, from the NDVI temporal profiles analysis of the Modis sensor.

Material and Methods

The study was done in the Parana state, where were considered all the municipalities of the state. The period of 11 months was considered, initiating in August 2009 until June 2010. It was used 20 NDVI images, VI Quality and Reliability of the MOD13Q1 (250m) product, tile h13v11 in which the Parana state was cut. This period was selected in order to comprehend the entire cycle of the summer crops, from the development, peak growth cycle and harvest.

These images can be obtained through the NASA site (https://wist.echo.nasa.gov/api/), being originally in the sinusoidal projection and in the HDF format (*hierarchical data format*). The extraction of these was through the *MODIS Reprojection Tool* (https://lpdaac.usgs.gov/lpdaac/tools/modis_reprojection_tool) and was redesigned for the projection WGS-84 and format GeoTiff.

The methodology applied in this study proposes to identify and classify areas where the NDVI temporal profile behavior is similar to the summer crop cultivation. This methodology was also applied in the sugar cane crops according to MORAES (2012). All study stages were performed using the software ENVI 4.5 (*The Environment for Visualizing Images*) from the generation of routines in IDL (*Interactive Data Language*) version 7.0. For the maps generation was used the ESRI ArcMap 9.3.1. The study stages are presented in the flowchart (Figure 1).

The good pixels in the NDVI images were

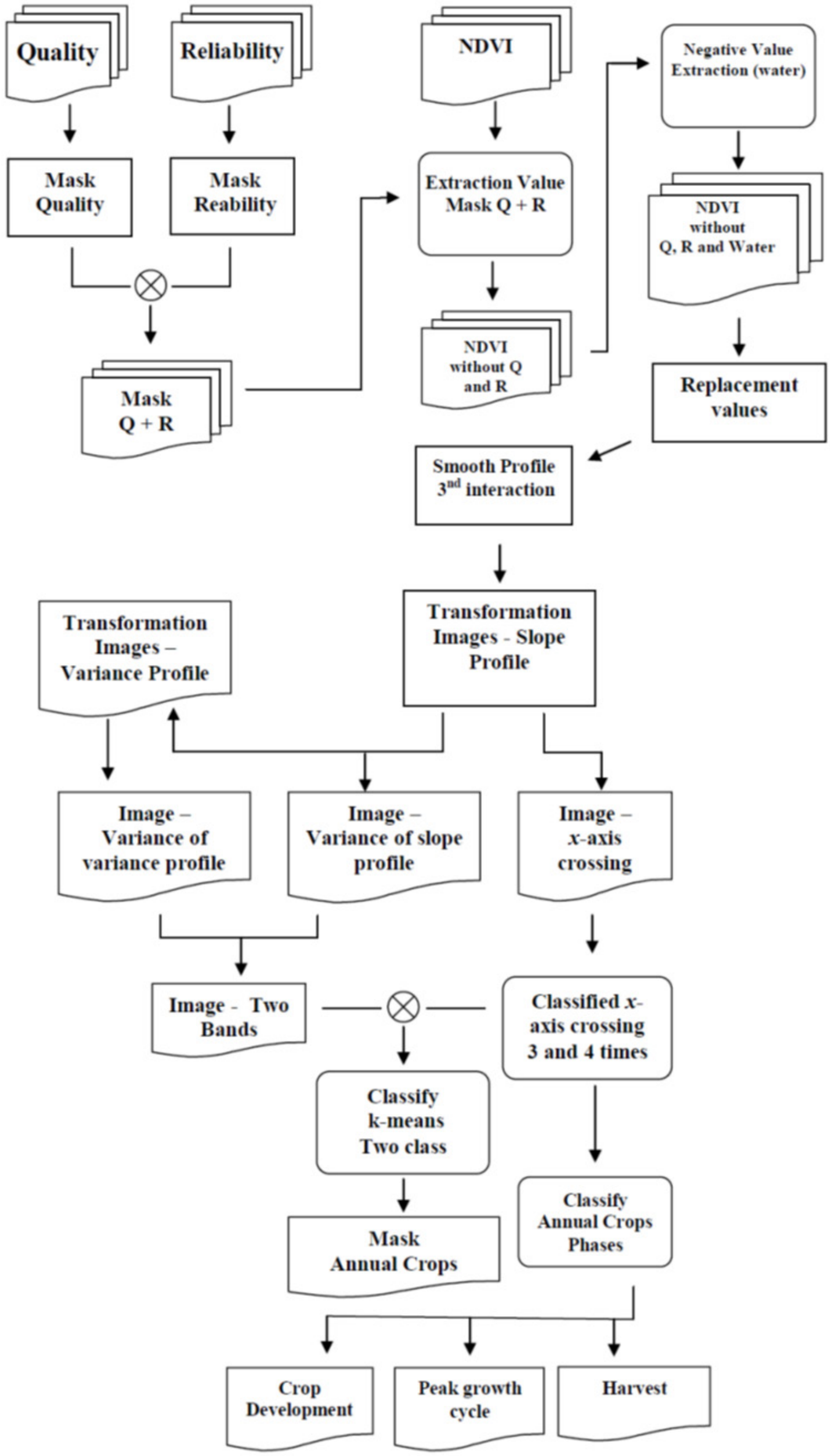

Figure 1. Flowchart of the study stages.

classified according to MORAES and ROCHA (2011), where were developed masks for each date of the Reliability and VI Quality images. After eliminating the dead pixels, we have in the considered profile, dead pixels equal to zero. With the intention of preserving the curve shape, were proposed simple rules of substitution of these pixels for up to three consecutive that were dead.

When there were four consecutive dead pixels, the profile was disregarded for the season period in study. To three consecutive dead pixels, it was considered that the first and the third were equal to the anterior and posterior respectively, after this process, the second was substituted by the average of new values. When two consecutive pixels were dead, they were substituted in a form that the first was equal to the anterior and the last equal to the posterior. Finally, for one dead pixel, the replacement was by the average of the anterior and posterior value. Therefore, after the substitution of the missing values, the profile shapes were preserved, mainly by the non alteration of the curve tendency, based in the near neighbors.

The smoothing of the NDVI temporal profile behavior is important because it eliminates small variations. The smoothing methodology used in this study had as objective to easy the pixel classification, highlighting the shape and tendency of the temporal profile curve, since that there is values without noises, because these were excluded in the anterior stage. For this, it was performed a smoothing based in the average, applied to the temporal profile, being carried out three times (3rd interaction). This smoothing uses a moving window of three points of NDVI profile with raw data, and generates a new profile from the central point. This process was repeated, traversing the entire profile until the last image. The first and last value of series in this process was repeated, being of equal value to the second and penultimate, respectively.

The NDVI profile, after being smoothed, presents determinant characteristics in relation to the curve shape, where stands out the growth, maturation and harvest stages. However, despite of the curve shape being similar in the pixels where there is summer crop, exists variation in the NDVI intensity, and in the planting and harvesting dates. Thus, aiming to analyze the curve shape and its intensity, was made the transformation of smoothed NDVI images in images of angular coefficient and of variance, respectively.

The images of angular coefficient or slope of linear regression line were generated through the interaction of three pixels in the profile where is calculated the slope of the straight line. From these three points was generated an angular coefficient value and this was plotted in a new temporal profile. This process was repeated, traversing the entire profile until the last image.

With the objective of highlighting even more the information present in the temporal profile, it was generated the variance temporal profile from the angular coefficient temporal profile. This was performed having as start point the three initial points of the angular coefficient profile and calculating the variance, being the result plotted in the central value; and the process repeated for the whole profile.

After the generation of new temporal profiles, of angular coefficient and of variance, for the images of each period, it were generated unique images, in which each pixel represented the variance value on each temporal profile, being one image of variance of the angular coefficient profile and the other of variance of the variance profile. The two generated images, for each period, were placed together in order that each one represented a band.

Thus, with the images together, it was made the unsupervised classification k-means, with a number of classes equal to two, threshold of 5% and maximum number of interaction equal to one. Moreover, the aim was to separate areas with great NDVI variation, in the period considered for areas with temporal profile with fixed or of low variation behavior. The intention of the image of temporal profile variance of angular coefficient was to assist in the separation of areas with great temporal variation and the image of variance of the temporal profile of variance of the angular coefficient profile was contribute in the separation of areas where the profile variation presented abrupt differences in determined points, indicating areas with agriculture in the harvest stage. Thus, these classified images were transformed in masks with values of zero and one, being one the pixels with greater variance.

The angular coefficient profile possesses positive and negative variations, where characterize the slope profile of the NDVI. This positive/ negative variation, that is, the crossing of the profile on the axis x occurs always after an alteration of direction of the NDVI profile, for example, of growth of a crop until the stage of senescence or the harvest, properly said.

The crossing of the axis x for the angular coefficient profile was counted on such form to separate pixels where the NDVI temporal profile presented a stage of negative inclination followed by a stage of positive inclination, and then again by a negative followed by another positive. This characteristic, for the considered period, would highlight pixels where the profiles were similar to the summer crop.

Thus, it was separated only the pixels whose angular coefficient temporal profile crossed the axis x three and four times and generated a mask with values for this equal to one, and zero for the values outside this consideration.

For the generation of the final mask, it was performed a multiplication of the generated mask from the classification of variance images, with the mask of crossing of the axis x. In this manner, it was obtained only the coincident pixels, i. e. equal to one and thus having characteristics of great variation in the temporal profile and the stages of annual crop cultivation.

Thus, from the images of angular coefficient the pixels classification of annual crop was made due to the characteristic form of the profile. Altogether, it could be identified, from the angular coefficient profile, the cultivation stages dates, that is, dates of growth/ development, of the peak growth cycle and of the harvest. These dates were determined from the maximum values, crossing of the axis x and minimum values, respectively. For the classification of the dates of crop growth were considered the maximum values in the images (number/ month) 225/ August until 017/ January. Now, for the classification of the peak growth cycle and harvest were considered the images between 305/ November and 097/ April. In Figure 2 is possible to identify the characteristics of the angular coefficient profile contrasting with the NDVI smoothed profile to a pure pixel of the annual crop.

Results and Discussion

Based on the methodology was generated a mask of annual crop for the Parana state in the period between 2009 and 2010, presented in Figure 3, along with the comparison of the area harvested in 2010, according to current data available at IBGE where it is added up the soybean area with the first maize crop of each producing municipality.

Thus, the mask underestimated the official values in up to 37.581 hectares, with exception of the Castro municipality, where the underestimation value was of 73,306. 2 hectares. Considering the state total area, the underestimation was of 2.114.983.8 thousand hectares, where the total area according to the IBGE in 2010 was of 5,377 ha and the mask of 3,262,165 ha. Even though, it presented a low systematic error of 7.194.9 ha.

In Figure 4 we have the dispersion graphic where the result of the estimated harvested area presented a precision (R^2) of 0.7701 and an accuracy (index d of Willmott) of 0.9201 In Figure 5 we have the differences comparison of data of municipalities in the Parana state, of estimated annual crop area in relation to the IBGE data, being that the municipalities were disposed in descending order in relation to the harvested area from the IBGE. From these results, it is verified that more errors occurred in

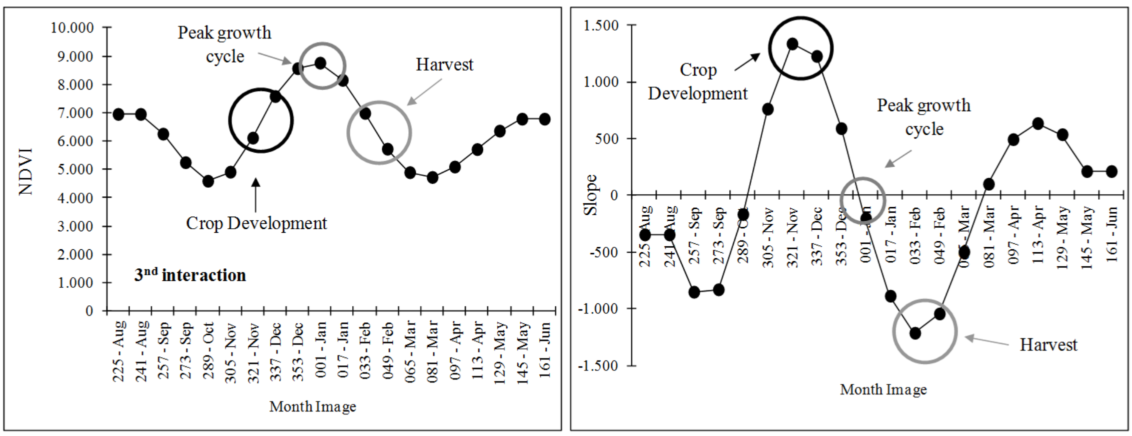

Figure 2. NDVI profile behavior for the smoothed annual crop and transformed in angular coefficient, highlighting NDVI temporal profile characteristics identified in the temporal profile of angular coefficient.

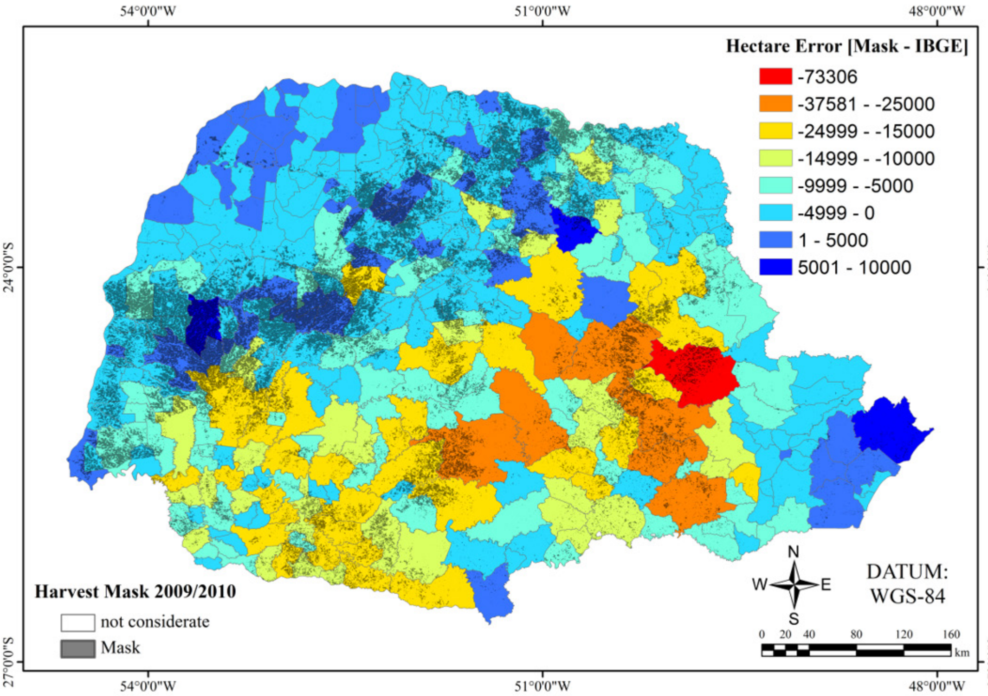

Figure 3. Mask of the annual crop presentation 2009/2010 after the methodology application, along with the map of mask error in relation to the harvested area data from IBGE (2010).

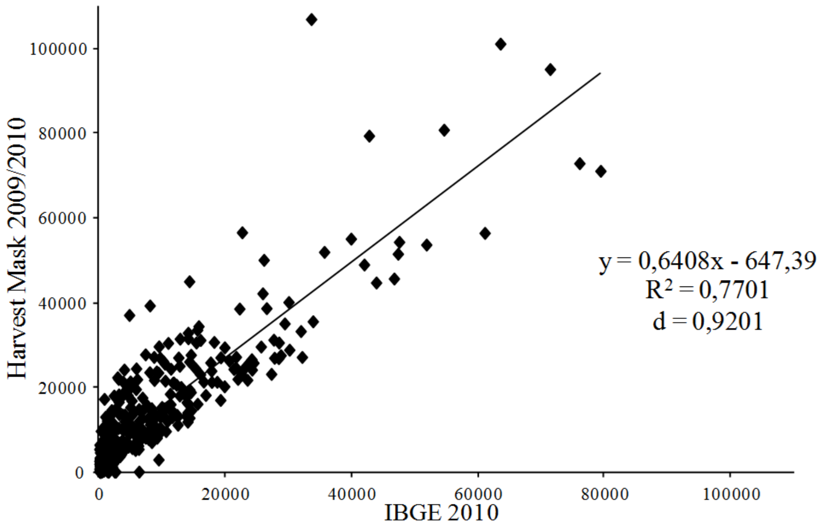

Figure 4. Comparison of the data of municipalities estimated annual crop area in the Parana state for 2009/2010 in relation to the IBGE data, together with the determination coefficient (R^2) and index d of Willmott.

the municipalities with larger harvested area (basing in the official data), being that for the municipalities with little annual crop, the methodology classified with less errors.

After the characteristic pixels identification of the annual crop, from the angular coefficient temporal profile, it was possible to identificate the annual crop cultivation stages, being these, the

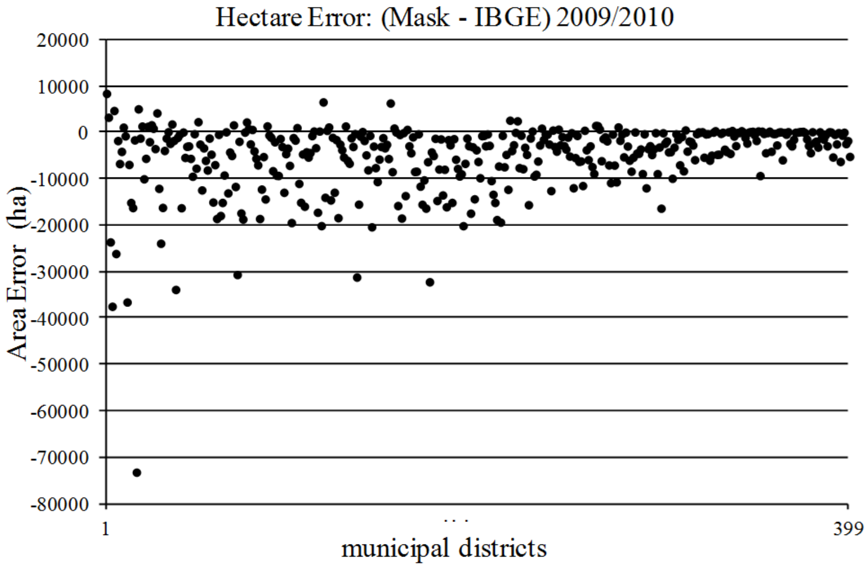

Figure 5. Difference of the municipality data in the Parana state of estimated annual crop area compared to the IBGE data, being the municipalities disposed in descending order in relation to the area given as reference.

period of development/ growth, peak growth cycle and harvest. According to ZHANG et al., (2003) it is possible to indicate the phenologic transition states from the changes in the curvature of the Modis sensor temporal profile.

The temporal classification of the development/ growth dates of the annual crop, for each pixel of the Modis sensor, is presented in Figure 6. It is verified that the beginning of this stage in the west part occurs during November, following north,

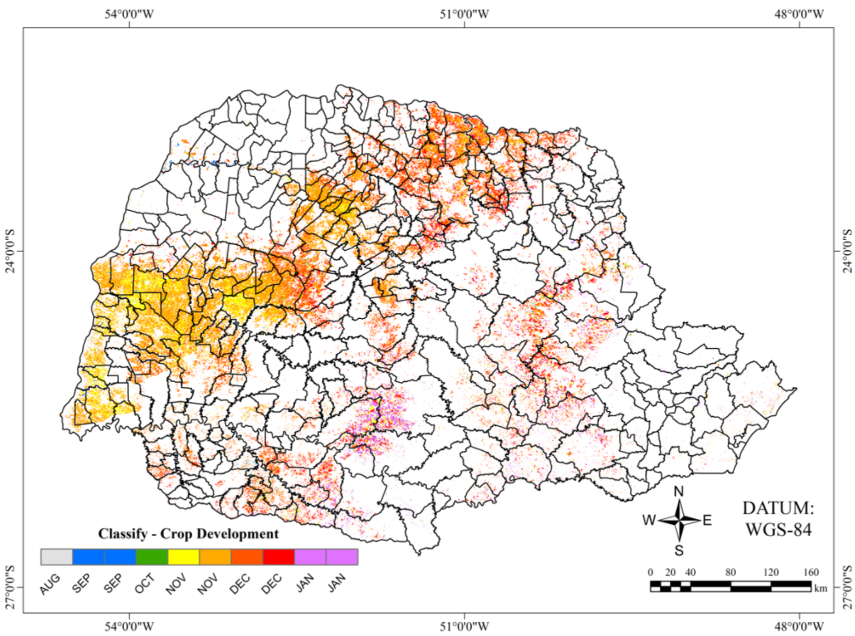

Figure 6. Temporal mask of the crop development cultivation stage, for the 2009/ 2010 season, obtained from the applied methodology.

it starts at December. In the rest of the state, south and east part, there is the predominance of the end of December and January. According the IAPAR (Parana Agronomic Institute, 2012) the soybean sowing dates occur for the different soil types with the tendency of being first in the north-east part and then in the rest of the state. As stated by the same institute, the maize sowing occurs in the months of August and September, however in a more heterogeneous form.

The temporal mapping of the peak growth cycle is presented in Figure 7, where clearly occurs at the months of December and January. These months presents high indexes of solar radiation, air temperature and rainfall, thus favoring the pods development and filling of soybean grains, and areas with maize. According to FARIAS et al. (2000), the water availability, the photoperiod and the air temperature are the factors which more affect the soybean development and yield.

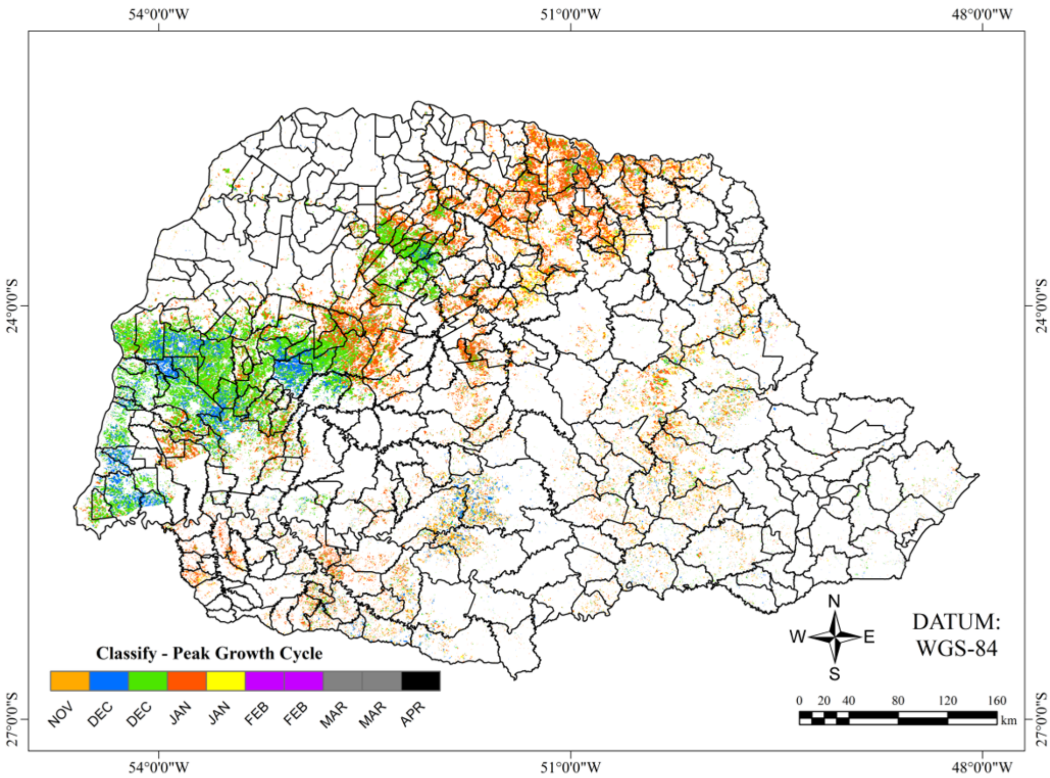

Figure 7. Temporal mask of the crop peak growth cycle stage, for the 2009/ 2010 season, obtained from the applied methodology.

The harvest dates for each pixel is presented in Figure 8, where we have some dated areas during January in the east part of the state. This harvest is anticipated for the sowing of maize in the off season, in order to take advantage of the rainy period. The rest of the state presents harvest between February and March.

The DERAL (Department of Rural Economy) of the Parana state, agency linked to the SEAB (State Secretariat of Agriculture and Supply) monitored the maize and soybean harvest in the state during the 2009/2010 season (PARANÁ, 2012). According with data presented by the DERAL, these present to be similar to those obtained in this study, with great part of the planting concluded between November and December and the harvest between the end of January and March.

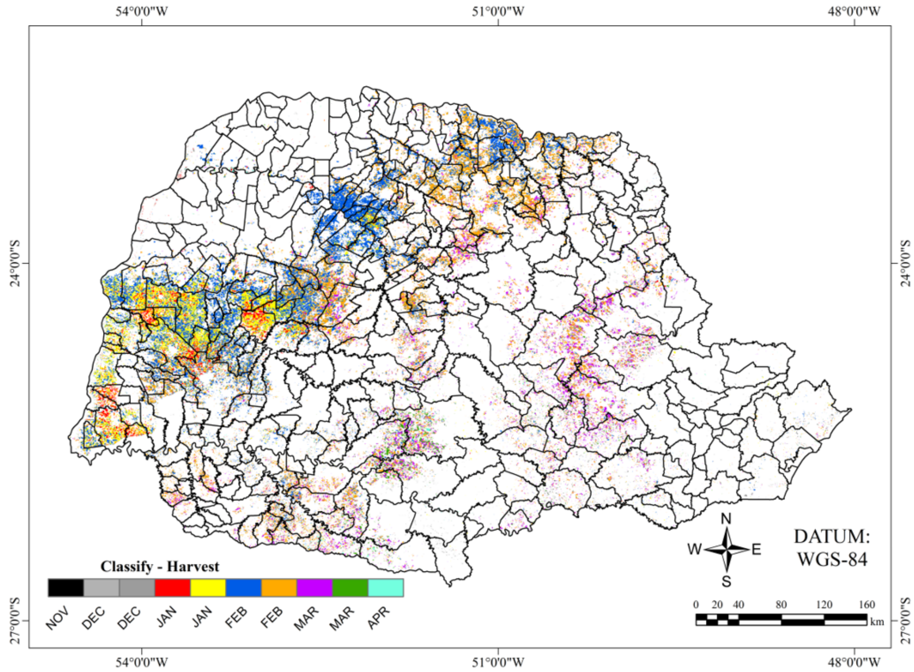

Figure 8. Temporal mask of the harvest stage, for the 2009/ 2010 season, obtained from the applied methodology.

Conclusion

The use of NDVI images from the Modis sensor allows the mapping and monitoring of the crops of summer, maize and soybean, in the Parana state.

The NDVI temporal profile analysis transformation in profile of angular coefficient and variance allow, from the methodology proposed, the identification of characteristic profiles in the summer crops.

The use of the proposed temporal profile of angular coefficient allows the definition of the cultivation stages dates present in the alteration of the vegetation index NDVI.

Due to the Modis spatial resolution, it is verified that any alteration in the cultivation dynamics of the annual crops, within the pixel, there is alteration in the form of NDVI temporal profile, impairing the identification.

The mapping considering all municipalities presented satisfactory results, with good precision and accuracy, indicating that the methodology is capable of annual crop identifying cultivations areas and distinguish them from another targets.

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