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Comparison of Linear Spectral Mixture Models and Vegetation Indices in Two Land Cover Sample Zones in Brazil by Using MODIS and ETM+ Data Products

John Mauricio Arenas Toledo[1]
Yosio Edemir Shimabukuro[1]
[1] Instituto Nacional de Pesquisas Espaciais - INPE
Caixa Postal 515 - 12201-970 - São José dos Campos - SP, Brasil
{john, yosio}@ltid.inpe.br

Abstract. The objective of this work was to compare and to test the linear spectral mixture model and vegetation indices (NDVI & EVI) for discriminating the principal earth-surface features using moderate (MODIS) and high (ETM+) spatial resolution data. The fraction images (vegetation, soil and shade/water) and vegetation indices images were derived from both sensors for two different landscape areas in Brazil (Amazonian Forest and Southern mountainous system). Several comparative plots and correlation equations were made between MODIS and ETM+ data. The digital geoprocessing was performed using SPRING software developed by INPE. The results showed important information about a comparative and validating reference of a larger spatial scale of MODIS data to use in landcover / landuse approaches.

Keywords: linear spectral mixture model, vegetation index, random points, comparison plots, linear correlation, modelo linear de mistura espectral, índice de vegetação, amostras aleatórias, comparação de gráficos, correlação linear.

1. Introduction

The current necessity of finding new alternatives of assessing the natural resources specially landcover units which involve strategic ecosystems, critical areas with degradation, intensive agricultural plot sites, etc., creates the space for the application of new remote sensing products to monitor the dynamical changes of the earth resources.

Among those sensors for global-monitoring, the Moderate Resolution Imaging Spectroradiometer (MODIS), on EOS's Terra satellite, is an instrument which acquires data in several spectral ranges at different spatial resolutions (250m, 500m and 1Km) and have different data products which allow to improve the information for natural resources assessment.

The MODIS vegetation index products (MOD13) provide a consistent spatial and temporal data for comparison of regional vegetation conditions. The algorithms of the two vegetation indices (NDVI and EVI) bring either continuity or enhancement over the vegetation sensitivity and minimal variations associated with external influences and inherent non-vegetation influences in the surface itself (Huete,Justice & Leeuwen 1999).

This work has as principal objectives to test by numerical data the product data from two different resolution sensors over two site areas in Brazil. For this, (1) the linear spectral mixture model for a large resolution sensor (MODIS) is compared with a medium resolution known sensor (ETM+); and (2) the task to validate and correlate the indices vegetation data and their behavior using the two different products are performed.

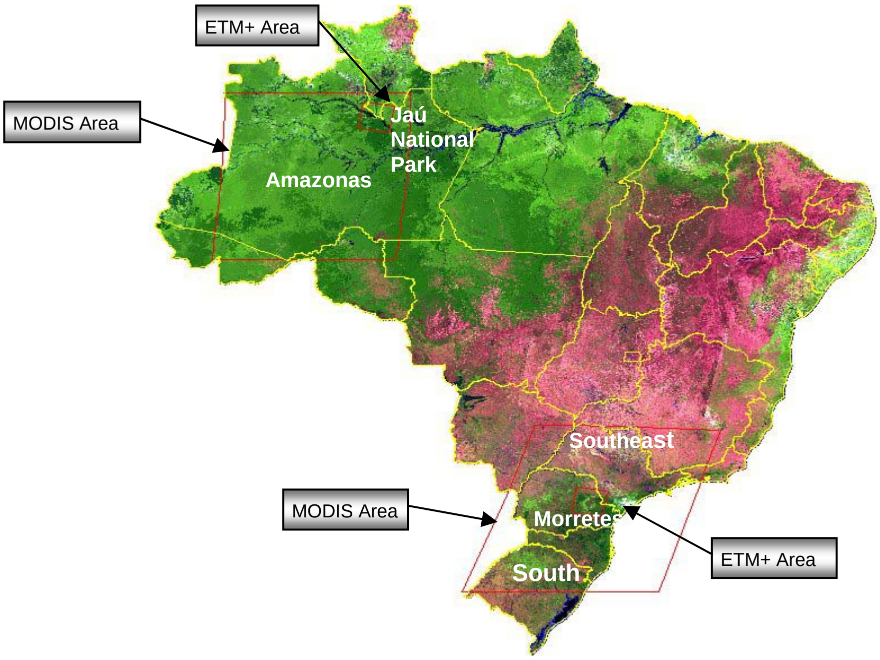
2. Materials and Methods

2.1 Study Area

The two sample areas used to develop the study take place on two different landscape areas of Brazil (Amazonian Forest and Southern mountainous system). The area of the Amazonian forest correspond to a larger area in the Amazonas state, and some part of the states of Roraima, Acre, Rondonia and Mato Grosso, approximately 5490 km2 (a MODIS scene – V09H11), covering the whole area of National Park of Jaú, and the Landsat scene sample area (P232R61) chosen, is included on it. The National park of Jaú is located in the regions (municipalities) of Novo Airão and Barcelos. It is a large national park of Brazil (2.272.000 Ha), in addition it is the great protected area of forest around the world (IBAMA, 1998).

The second study area corresponds to an area covered by the MODIS imagery (V11H13), comprising the whole states of Santa Catarina, Paraná, São Paulo and part of the states of Rio de Janeiro, Minas Gerais and Rio Grande do Sul. The Landsat sample area (path 221/row 77) takes place on Morretes, in the Paraná state; situated in physiographical zone of the Paranaense coast, extended itself of the hillside of 'Serra do Mar' in the east (**figure 1**).

Figure 1. Study site areas of the project. (source: Modified of data base of Atlas Brazil)



The landcover characteristics of the North area, corresponding to a homogeneous humid tropical primary forest in the Brazilian Amazonian, large protected areas with just some clear-cuts in the Rondonia state, with a relative flat territory and small variations in landcover units.

The landcover characteristics of the South area, corresponding to a heterogeneous landcover site with different terrain scale covers: cropland, stand forest, grasslands, savannas, bare soils, etc., in a variable relief.

For this project, several images of MODIS & ETM+ sensors were analyzed according to minimal cloud cover percentage on images and coincidence of data for the two landscape areas, completing a minimum set of four images (**table 1**).

Table 1. Images used in the project

Sensor	Data ID	Data Acquisition	Cloud cover
MODIS	SC: MOD13Q1.004:2013940294 MOD13Q1.A2001273.h11v09.004.2003161035043.hdf	2001/9/30 – 2001/10/15	1 %
MODIS	SC: MOD13Q1.004:2013970364 MOD13Q1.A2001273.h13v11.004.2003162054707.hdf	2001/9/30 – 2001/10/15	0 %
ETM+	P221R77	2001/10/5	23 %
ETM+	P232R61	2001/10/5	0 %

For ETM+ images it was necessary to correct the atmospheric effects and the radiometric conversion of de digital values (DN) to reflectance ones. For this purpose it was used the 6S (second simulation of the satellite signal in the solar spectrum) modeling approach.

2.2 The Linear Spectral Mixture Modelling

Assuming that the mixture components are the major source of spectral variation in the scene (Shimabukuro, 1987), then the endmembers or 'pure pixels' for each image were selected by visual interpretation of the images according to the spectral behaviors expected in the imagery for the three mixture components chosen (Soil, Vegetation and Water/shade).

Like the components are highly separable spectrally (few expected ambiguity between them), the error estimated for the four image set was small (mean error 2.3); it was generated plots of the spectral response of the endmembers, and several pixels 'candidates' were tested, before saving each endmember into the model.

Once the fraction images were obtained the results were checked by visual interpretation, comparing the gray levels according to each mixture component, in addition of checking the error images.

The water/shade component involves more than just water spectral response, the shade present in the image it is also modeled. The shade represents shading (variation in lightness due to local incident angle) and shadow of all spatial scales (Smith, 1990). Therefore, the water component it is a water-shade component.

2.3 The Vegetation indices (NDVI & EVI)

Like the MODIS data product MOD13 include the vegetation indices NDVI and EVI in 250m resolution, the same indices were made for the ETM+ data in a 30m spatial resolution, using for this purpose the LEGAL (Linguagem Espacial para Geoprocessamento Algébrico) programming language, -include it in SPRING software. Like the SPRING by now, just work with 8 bit imagery, it was necessary to generate a numerical plane, taking the minimal-maximum information to generate an image with the precise gain and offset to be represented in an 8 bits histogram. The EVI was generated previous conversion of the 255 imagery values into reflectance values, because the equation coefficients do not have sense without this conversion.

2.4 Plots Comparisons and Correlations

Once the fraction images and the vegetation indices were finished for ETM+ data for the two study areas, different sample random pixel data were read over all the image products of each sensor. The comparisons were made between the vegetation indices (NDVI & EVI) and each fraction image (soil, vegetation and water) in the Amazonian forest (North) and the mountainous landscape (South). After this, a data comparison for Jaú and Morretes of the two sensors for the same coincident sample areas were made.

The reading of the digital data in the pixels was achieved by a random sample of points (300 to 400), then it was generated a dispersion crossplot of the percentage images and the vegetation indices extracted from the random points.

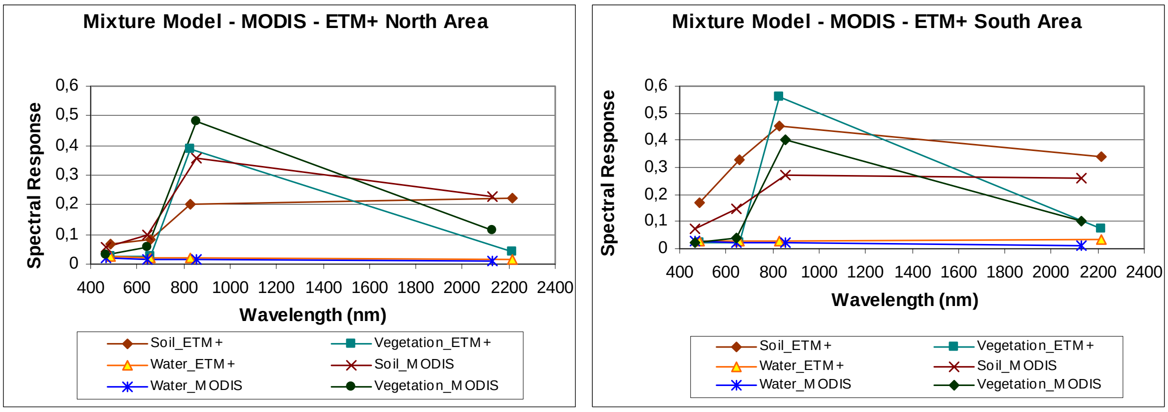
3. Results and Discussion

3.1 linear Spectral Mixture Models

The spectral mixture model applied to each sensor image, showed a higher spectral response for the MODIS vegetation and soil endmembers for the North area, and very similar for the water component; this can be explained because the spectral variability was greater for the MODIS scene than the ETM+, some part of the lower values pixels in image took place in Rondônia and Acre states, where exist a clear-cutting. There, a soil spectral response is ‘purer’ than the existent pixels for the Landsat area in the Jaú National Park (without clear-cutting), the chosen pixel there, was the sand-banks over the river buffer with high moisture.

In the South site area the results were the opposite thing, the Landsat’s endmember responses were higher than MODIS, which could indicate that the small bare soil land areas and crop plots identifiable on ETM+ image, were well defined a ‘purer’ than the larger pixels with mixture, chosen in the MODIS image. The Spatial heterogeneity in the scene defines another spectral behavior and mixture combination of the fraction components comparing these results with the first sites (**figure 2**).

Figure 2. Comparison of spectral responses of the endmembers for MODIS and ETM+ for North and South Area



3.2 Vegetation Indices

The vegetation indices applied for the ETM+ imagery set, and including MODIS data product MOD13, were made to allow a comparison with the fraction images derived by the linear spectral models. It is important to mention that the ETM+ imagery used here involved corrected nadir-view vegetation indices and did not consider bidirectional reflectance factor (BRDF) like the MODIS indices (Huete et al., 1994; Huete et al., 1997).

The NDVI for Jaú site area shows a high concentration of vegetated cover area, most of the pixel concentration are in the range of 0.66 to 0.91; some pixels are about the 0.1 value, corresponding to those pixels in areas of sandbank and mud planes along the rivers’ borders. The NDVI values after this range, fails down, because of the saturation for high biomass content - high sensitivity in Red responses- (Huete et al., 1997). For the Morretes area, instead of the last site behavior, the NDVI range of values between 0.08 to 0.90; indicating the great heterogeneity on landcover classes for that site, showing not absolute dominance for a particular landcover class. The EVI has a more regular behavior for both study sites, they did not have an abrupt decrease at the higher extreme of the plot, indicating better performance with dense canopy contents, specially for the Jaú case.

3.3 Comparison Plots

Comparing the NDVI with the fraction images derived by the linear spectral mixture model, in a set of 300 random points in the MODIS scene, it shows the highest correlation for those points for the soil and vegetation fraction images with R^2 values of 0.4708 and 0.5537, respectively, water component did not show an important correlation (0.2548) with the NDVI, soil correlation was probably for the background influence in the NDVI (soil noise effect) (Huete, 1988). The comparison NDVI vs EVI for the North site area shows a R^2 of 0.537, behavior expected for higher dominance of forest cover, that is the case of the North scene with the random points generated. The EVI comparison with the spectral mixture components shows a low correlation with soil (0.2562) and high correlation with vegetation (**figure 4**) and water components (0.9282; 0.8691). These results match with EVI's characteristic of sensitivity in high biomass regions, it did not saturate like the NDVI and the Soil background effect (canopy background noise) is removed, because of the low correlation with the soil mixture component. The water component which is also associated with the shade, presents in a primary forest; it shows a good relationship between this component with the Enhance Vegetation Index, at this site landcover characteristics.

For the second area (South), the correlation coefficients vary specially in the soil and water components, soil component-NDVI relationship increase at 0.8002, low soil percentage component value corresponds to high NDVI values. To increasing the soil component, NDVI values get down. For the Vegetation component the correlation had a R^2 equal to 0.6119, in this case there was not saturation of the NDVI. The water component vs NDVI shows low correlation, this is because there is not exist large zones of primary forested areas and probably the topographical shadowing at different landcover background, could 'disperse' the values. In the EVI-fraction image correlations shows low correlation for soil component (0.3646) expected for EVI, the vegetation component (**figure 4**) conserves a high correlation (0.8423), little lower comparing with the homogeneous canopy cover landscape of North site area. At this case water component correlation was too low (0.096), probably because there was no associated the shadows of the large natural forest and the shading of the topography variability generated a wide dispersion for the percentage data. The linear relationship between EVI & NDVI from MODIS was 0.646, higher than the North area due to the NDVI values were not saturated for the vegetation class units, the difference between the two vegetation indices seems to be related to their particular sensitivities to the red – NIR reflectances (Huete et al., 1997).

For ETM+ data the NDVI calculated shows a summary correlation value very low (0.0002). The Vegetation component displays a higher linear correlation with NDVI (0.8455); the remaining component (water) gives a correlation of 0.7776 in the comparison with NDVI.

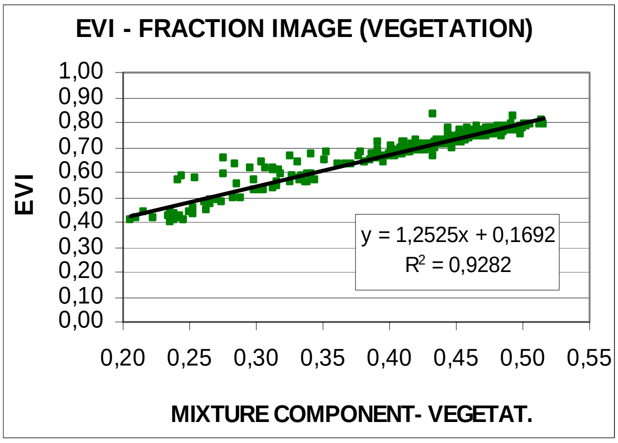
For the EVI set comparisons, Soil fraction component shows the expected no linear correlation with soil presenting a R^2 of 0.0088. Vegetation component has a high correlation with EVI (0.9679) coincident with the MODIS correlation but for a larger area. Analog behavior to the MODIS' shows the water component, high correlation value (0.9426) relating to the pixels that took place on water bodies and the shade proportion of the forested areas. NDVI – EVI comparison shows a high linear correlation with a R^2 equal to 0.8406, greater than the MODIS VIs correlation (0.537); the reason for that difference could be attributable to the scene target characteristics (MODIS scene is larger, therefore more land-classes) in addition to the reflectance-geometry characteristics of each sensor at this area.

The ETM+ data comparison for the South site (Morretes) shows for the NDVI vs Soil fraction image a relatively good correlation (R^2 = 0.6918). The vegetation component had a linear correlation of 0.7799 while the water component has a low correlation (0.1454), similar for the MODIS´ (0.0802). Ratifying the low correlation of the NDVI with water component for non-forested dominant-scene and heterogeneous topography altitude.

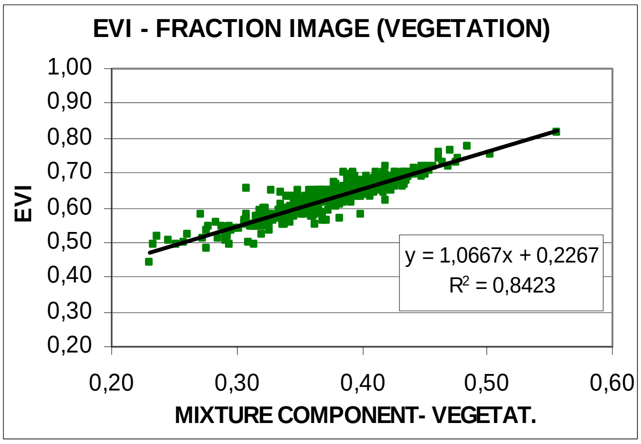
The EVI's comparison with mixture components shows low correlation in the Soil component (0.1340), Vegetation component has a linear correlation of 0.803 and the water component did not show any linear correlation with EVI (0.0589).

The EVI-NDVI comparison for Morretes site has a medium correlation (0.5263), similar to this case with MODIS (0.646), that behavior more similar between de two sensor products is due to that the scenes have an proportional class heterogeneity and none of the VIs get saturated for the landcover conditions for the South scenes (**table 2**).

Figure 4. Crossplot of EVI vs Vegetation component for MODIS in both landcape sites North (A) – South (B)



(A)



(B)

3.3 Comparison of MODIS Data Products vs ETM+

The comparison for a data set of 300 random points for the coincident area by both sensors (MODIS & ETM+) shows the next relationship and linear correlations (see also **table 2**):

The NDVI comparison for the Jaú site shows a correlation of 0.4354, the higher NDVI values seem to have a better correlation, those values are for forested random points, besides this behavior it is 'contaminated' for the saturation of the Index.

EVI's crossplot has a high linear correlation (0.8029) for the Jaú site area; the EVI relationship was optimal (in the correlation for both sensors).

The Soil fraction image for both sensors shows a very low correlation (0.2481), that is explained because the endmember chosen for MODIS has a different spectral response and has less moisture content that the chosen for ETM+.

The Vegetation component for the two sensors displays a high correlation (R^2 = 0.7833). The Water fraction image plot displays a value of 0.693 for the linear correlation in the two sensors product data. The relationship in this mixture component exists because the forest landcover unit, that dominates the both scenes.

The sensors comparisons for the Morretes site shows different results from Jaú's case. The NDVI comparison had a very low correlation value (0.0774). There is not an 'accumulation' of points in any particular value, showing the heterogeneous values of the random points that represent different class-cover values.

For the EVI, the correlation was too small, just 0.1213 for the data product for both sensors showing that for small parcels and detail scale of the landcover classes the mixture problem was a landscape difficult to modeling at that pixel resolution.

Linear spectral mixture components showed lower correlation values for three components (Soil, Vegetation and Water, 0.038; 0.0951 and 0.0198, respectively), indicating that the landscape characteristics of the site could be sensible for the sensor spatial resolution (Price, 2003).

Table 2. Summary values of the Coefficients of determination (R^2) for the linear correlation of product data imagery

COMPARISONS VIs vs. Components	MODIS		ETM+	
	NORTH	SOUTH	NORTH	SOUTH
EVI - Soil Component	0,2562	0,3646	0,0088	0,1340
EVI - Vegetation Comp.	0,9282	0,8423	0,9769	0,8030
EVI - Water Component	0,8691	0,0960	0,9426	0,0589
NDV I - Soil Component	0,4708	0,8002	0,0002	0,6918
NDVI - Vegetation Comp.	0,5537	0,6119	0,8510	0,7799
NDVI - Water Component.	0,2548	0,0802	0,7776	0,1454
EVI - NDVI	0,5370	0,6460	0,8406	0,5263

BOTH SENSOR COMPARISON FOR SAME COINCIDENT AREA

JAU	NDVI	EVI	Soil Comp.	Vegetat Comp.	Water Comp.
	0,4354	0,8029	0,2480	0,7833	0,6930
MORRETES	NDVI	EVI	Soil Comp.	Veget.at. Comp.	Water Comp.
	0,0774	0,1213	0,0380	0,0951	0,0198

4. Conclusions

Using linear spectral mixture model on MODIS imagery showed optimal results for a primary forest landscape as the case of the North site area (Amazonian tropical forest). The MODIS product data represents an important input on the land monitoring temporal-spatial research in despite of the spatial resolution evaluated (250 m) compared with the information from a well known sensor like ETM+. Several high linear correlation obtained allows to affirm the potentialities of this 'new' satellite sensor.

Fraction images show to be suitable in the visual discrimination of different primitive classes in which the conventional transformation procedures need to be usually more complex approach and demanding more time compared to the linear mixture modeling procedure. The soil component shows great aptitude of recognizing and highlighting bare-soils and water sediments on both regional areas of Brazil; the vegetation component did not show great separation of canopy-closure variations for North area, but in the South site area have a better performance. However depending on the non-vegetated landcover characteristics of the surrounding area, this approach did not isolate the border of the green-coverage units at this landcover site. Finally, the third component (water/shade), besides of stood out clear water-bodies for the four set imagery, the component was sensitive for forested areas (North sites) coinciding with results cited by Shimabukuro (1987) and others.

The Enhanced Vegetation Index (EVI) results represent an interesting and validating perspective of MODIS product data characteristics for future monitoring and evaluation of landcover changes according to the procedures applied. EVI did not correlate with soil mixture component at all, for any study site; for the South area the correlations were just above of the North sites; those results just corroborate the removing canopy background characteristics of the Enhanced Vegetation Index adjusted to the case for ETM+ imagery. At forest landcover conditions on imagery, the EVI shows a high correlation with water/shade component, but this affirmation only stand of high canopy-closure vegetation for a dominating image scene (primary forest cover).

The NDVI index in the comparison with the vegetation mixture component displayed similar correlation with the same sensor in both cases, but a something different for North and South areas. This is explainable because the correlations were calculated using the random sample points in different coverage-area (larger on MODIS), then finding the higher correlation values for the better pixel resolution sensor (ETM+) data. NDVI presented good correlations (0.8002 in MODIS; 0.6918 in ETM+) with the soil component for the heterogeneous landcover site (South area) showing the background noise effect on green-response in a small scale landcover variability scene.

There was no prove undoubtedly that the variation of slopes (topography elevations) influence the water/shade component and in general the mixture components, that is because just this condition was not the only present at this site conditions, comparing with the first site area (North zone, Amazonian).

In the both sensors comparisons for a same coincident area show quasi antagonistic result in the linear correlation for the different landscape zone. High correlations for Jaú area were obtained for EVI, Vegetation and Water; while soil correlation was low and NDVI linear correlation was medium.

In Morretes site area, the comparisons of the product data were too low indicating that for the landcover conditions the spatial resolution sensor are critical for discriminating and recognizing mixed landcover class units.

The EVI appears suitable for medium resolution atmospheric corrected data (ETM+) with cloud masking and it could be applied to other sensor data studies.

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