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# EXPLORATORY COMPARISON BETWEEN MAXIMUM LIKELIHOOD AND SPATIAL-SPECTRAL CLASSIFIERS USING LANDSAT TM BANDS AND PRINCIPAL COMPONENT ANALYSIS FOR SELECTED AREAS IN TOMÉ AÇU BRAZILIAN AMAZON

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## RESUMO

Desflorestamento e sucessão secundária na Amazônia são processos relevantes de alteração no uso e cobertura do solo. Para abordar esses fenômenos, o uso do sensoriamento remoto é uma importante ferramenta, se a exatidão das classificações for suficiente para permitir a distinção entre diferentes feições vegetais. Este trabalho é uma comparação exploratória entre classificadores por máxima verossimilhança e espaço-espectrais, utilizando bandas Landsat TM e análise de componentes principais (PC). A área de estudo é parte do Município de Tomé Açu, Estado do Pará. Dados de campo foram utilizados para orientar as classificações. Bandas PC foram geradas pela reformatação da imagem TM. Dez classes foram definida Os resultados revelaram que as bandas PC não aumentaram a exatidão da classificação de forma significativa. Por outro lado, o classificador espaço-espectral mostrou um desempenho bem melhor, levand em conta a distribuição espacial da vegetação na paisagem e não só sua assinatura espectral. Estas técnicas podem permitir uma abordagem mais adequada dos processos de conversão da terra em Tomé Açu, podendo também ser aplicadas a outras áreas da Amazônia.

## ABSTRACT

Deforestation and secondary succession in the Brazilian Amazon are relevant processes of land-use/land cover change. To monitor these trends, the use of remote sensing techniques is an important tool, if classification accuracy is sufficient to distinguish different vegetative features. This paper is an exploratory comparison between maximum likelihood and spatial-spectral classifiers using Landsat TM bands and principal component (PC) analysis. The study area is part of Tomé Açu County, Pará State, being located approximately on 2o40' S and 48o20' W. A subset of the Landsat TM scene was selected to test the algorithms. Training samples were created using field data. PC bands were generated reformatting the input image (TM bands) through the use of eigenvectors statistics. Land-use/land cover classification defined ten main classes. Results showed that the use of PC bands did not bring a significant improvement in classification accuracy for the focused features. Otherwise, the spatial-spectral classifier increased the accuracy significantly, taking advantage of the spatial distribution of vegetation features in the landscape an not just their spectral signatures. These techniques may provide a way to better understand processes of lan conversion in Tomé Açu and probably in other portions of the Amazon as well.

## I. INTRODUCTION

In recent years, land-use/land cover change has been interpreted as a relevant process occurring in many ecological systems. Phenomena as deforestation and secondary succession in the Brazilian Amazon are examples of this dynamics. Facing the challenges of living there, many communities have used different strategies to cope with the needs of production and subsistence.

One of the best examples of relative economic success of colonization in the Amazon occurred in Tomé Aç State of Pará. The process began over 60 years ago, when a group of Japanese immigrated to an area located approximately 115 km south of Belém, the capital city. They have tried many production systems, dealing with difficulties, such as forest cleaning, lack of knowledge on tropical agriculture, the consequences of Second World War, transportation, diseases, and so on. The dedication of these people to work, their availability to try alternatives, and their household structure based on the nuclear family were central to establish the settlement.

However, the older settlers always worried about the possibility of the younger generation to leave the land i search of more attractive economic activities. Today, this is happening in a certain way, as many Japanese descendants are working in Japan. Together with the decline on agricultural activities in terms of cost/benefi that fact seems to contribute to pasture and cropland conversion as a way to still keep the land, but with less labor. To monitor these trends, the use of remote sensing techniques appears as an important tool if the classification accuracy is sufficient to distinguish different land-use and land cover categories.

One of the problems of this approach is that different features may present similar spectral signatures and similar features may present different spectral signatures. Thus, there is an urgent need to test procedures that will allow those distinctions in order to achieve a more efficient way of dealing with vegetation heterogeneity in those areas.

This paper is an exploratory comparison between two classification algorithms using Landsat TM bands and principal component analysis. Testing the capabilities of these techniques may produce a way to better understand the processes of land conversion in Tomé Açu and probably in other portions of the Amazon as well.

## II. BRIEF BACKGROUND

Processes of colonization in the Amazon Basin have attracted a great deal of attention. Research has focused on the amount and rate of deforestation (INPE, 1996; FAO, 1993; Skole, 1993) and related social, economic, and ecological processes involved (Gerber, 1997; McCracken et al., 1998; Brondizio et al., 1994; Moran, 1994; Goodland et al., 1993; Turner II et al., 1993; Conant et al., 1983).

To study these issues, there has been a growing use of remote sensing to monitor land cover (Moran and Brondizio, 1998; Wood and Skole, 1998; Quattrochi and Pelletier, 1991; Skezielda, 1988). The extent to which TM data can be used to discriminate between different classes of vegetation in the complex rain fores ecosystems has been explored (Mausel et al., 1993; Sader and Joyce, 1985; Johannsen and Sanders, 1982 Spectral data has also been closely linked with structural and floristic surveys of plant cover and historical/ethnographic studies of land-use, for several Amazonian sites (Brondizio et al., 1996; Myers et al., 1989).

It has been demonstrated that remotely sensed digital data can be geocoded in geographic information systems to track past deforestation, but also to model future trends of new agro-ecological processes (Lillesand and Kiefer, 1996; Mladenoff and Host, 1994; Domon et al., 1989; Marble et al., 1983).

Several questions have arisen: when, where, and why is deforestation taking place in Brazil and what are its consequences? When and where is deforestation likely to be detected by using remotely sensed digital data In the other hand, Landsat TM scenes with a spatial resolution of 30m have been very useful for locating secondary growth. Questions may be informed by agro-ecological and social-economic data collected from ground surveys (Moran et al., 1994).

Recent development of GIS and satellite imagery tools has facilitated analysis and production of results with significant accuracy, based on objective procedures (Goodchild, 1992; Star and Estes, 1990; Aronoff, 1989; Burrough, 1986). The application of these techniques has allowed for assessment of the spatial organization of agro-ecosystems and natural resources in the Amazon, defining potentials for preservation and development. As a result of complex interactions between the agro-ecological determinants of a territory an the socio-economic components that command its development, this spatial zoning is of fundamental importance (Coulson et al., 1991; Jurdant et al., 1977).

The example of Tomé Açu shows specific agro-ecological dynamics following deforestation in the Brazilian Amazon. The migrants have cleared significant areas of forest and established polycultural production systems. The spatial patterns in that landscape suggest several ecological and socio-economic processes, such as secondary succession, land-use changes, and alterations in social organization.

The first migration trip occurred in 1929, when forty-three Japanese families arrived in Tomé Açu. Other trip brought new families to try a new life in the Brazilian Amazon. Right after clearing the forest, they started growing cocoa and rice without immediate success (Tsunoda, 1988). In 1931, they founded a Cooperative with the intention of stimulating agricultural activities and organizing the production of the settlement. The disappointment was clear during the first ten years. Several people left the community due to economic failure or diseases (CAMTA, 1967).

In 1947, the Cooperative had the first indication of success, based on the production of black pepper. The next years were a period of prosperity, as Tomé Açu became one of the largest pepper-producing communities in the world (Uhl and Subler, 1988). The increase in production and the cooperative system were followed by improvements in infrastructure, investments in health and education, and expansion of black pepper culture to adjacent lands (CAMTA, 1975).

During the late 60's and early 70's, fungal disease and international market oscillations pushed the community to try other agricultural products, such as cocoa, rubber, passion fruit, and Papaya (Yared and Veiga, 1985). Recently, polycultures characterized by overlapping crops are the dominant farming system in Tomé Açu, but pasture and cropland conversion seems to be a new trend in the area. These changes represent an incentive to develop new techniques of image classification in order to produce a more accurat picture about the area in terms of land-use and land cover.

## III. OBJECTIVES

The main objective of this project is to compare the accuracy of maximum likelihood and spatial-spectral classifiers using Landsat TM bands and principal component bands for selected areas in Tomé Açu, Brazilia Amazon. Multiple image processing techniques were used for achieving this objective.

Specific questions included:

- Based on the satellite imagery, what land-use patterns are evident in the study area?
- How many land-use categories can be identified by their distinct spectral characteristics?
- What are the advantages of integrating principal component analysis to achieve a better land cover classification in Tomé Açu, specially to distinguish secondary succession stages?
- Do spatial-spectral classifiers improve the classification accuracy for the study area?

## IV. STUDY AREA

The study area is part of the Tomé Açu County, Pará State, in the eastern Brazilian Amazon. It is currently connected by partially paved highways in the north and the Belém-Brasília Highway in the south. The origina settlement is located along the left margin of River Acará, approximately on 2o40' S and 48o20' W.

In terms of geological substrate, the Formations Boa Vista and Pará, belonging to the Holocene, constitute the parent material of the soils (DNPM, 1960; Oliveira and Leonardo, 1943; and Museu Paraense, 1953 cite in Falesi et al., 1964). The land is primarily upland, with highly weathered acid Oxisols characterized by low nutrient supply and retention capabilities (Falesi et al., 1964; Sanchez, 1976). Topography is generally flat, with Red Yellow Concretionary Latosol in more ondulating areas.

The climate corresponds to the type Af, according to Koppen classification (Koppen, 1948). It is hot and humid, with the annual average temperature around 27.9oC. The area receives an annual average of 2,600 mm of rain, with irregular distribution characterizing a drier season between July and October (Bastos, 1972)

Falesi et al. (1964) found five main soil types and associations, generally showing good drainage potential: Yellow Latosol of heavy clay content, ranging from 50 to 70% at the B horizon; Yellow Podzolic Latosol of rather heavy texture, clay content from 35 to 50% at the B horizon; Yellow Latosol of medium texture, clay content from 15 to 35%; Red Yellow Concretionary Latosol; and Tomé Açu Association, meaning occurrence of all kinds above.

Land-use/land cover characteristics are defined by different stages of land occupation and secondary succession. Vegetation is primarily moist forest, including several species with a high timber value (Rodrigue and Baena, 1974). According to Flohrschutz (1983), there are two main types of rural properties in Tomé Aç Small areas cultivated with manioc or rice, generally owned by Brazilian small holders, characterize the first one. The other type is predominantly used for perennial agriculture and owned by Japanese descendants. Besides social origin and organization, size of cultivated area, invested capital, fertilization, production, and productivity also differentiate these properties.

Major land-use/land cover changes in Tomé Açu took place after the establishment of agriculture settlement by Japanese immigrants beginning in 1929. The population oscillated during the next fifty years, depending on the periods of success achieved by the community. In 1991, there were approximately 280 Japanese families living there, with a local population of about 3,000 people (Yamada, 1998). This area is economicall diverse, but dependent upon agricultural and forestry activities as a primary source of income. The populatic of Tomé Açu engages in numerous agricultural pursuits, including the growing of black pepper, cocoa, passion fruit, rubber, African oil palm, citrus, other fruit trees, and economically valuable tree species (Suble and Uhl, 1990).

## V. METHODS

Multiple methodological techniques were used for achieving the goals of this paper, including image processing and geographic data integration. Data was provided by the Anthropological Center for Training and Research on Global Environmental Change (ACT) at Indiana University, including:

- Landsat TM scene, dated June, 1991, path 223 and row 061;
- 1: 100,000 scale topographic maps (BRASIL, 1983; 1983a).
- 1:50,000 scale property boundaries map (COERTA, s.d.).
- Numeric socio-economic and agro-ecological field data with variables about characteristics of the trainin fields;
- Other ancillary information.

Land-use/land cover classifications were derived by manipulation of Landsat TM image acquired in 1991, ar read as binary files. Cursory visual analysis was done to achieve a general concept of the study area, including vegetation, land-use patterns, and possible data limitations, such as cloud cover and noise. Some image enhancement techniques such as contrast stretching were applied to improve the visual interpretabilit by increasing the varied apparent distinction between features. The image was striped, requiring pre-processing techniques to improve the quality of data, including destriping, noise removal, and Fourier analysis. Geometric correction using Ground Control Points (GCP's) was done to register the image using UTM coordinates (Lillesand and Kiefer, 1996; Richards, 1986). All these pre-processing techniques were done in Erdas Imagine (Erdas Inc., 1997). The file was then exported to .lan format to be manipulated in MultiSpec, a public domain image processing system developed at Purdue University (http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/).

Due to the variability of land-use and land cover observed in the scene, a subset including the older part of the Japanese settlement was selected. This area of 33,634 ha is a rectangle of 22.5 km by 15 km, representing the majority of vegetative features present in the landscape.

In MultiSpec, training samples were created using data collected in the field. Then, statistics such as mean, standard deviation, correlation matrix, and covariance matrix were calculated in order to generate eigenvectors for the standardized and unstandardized principal components (PC). PC bands were created reformatting the input image through the use of eigenvectors statistics (Landgrebe and Biehl, 1995). These PC bands were stacked into the previous image, generating a file with 18 bands (6 TM bands, 6 standardize PC bands, and 6 unstandardized PC bands), allowing the manipulation of all these layers during the classification procedure.

The supervised classification was based on training samples collected in 94, during fieldwork. The best samples were selected by their spectral characteristics for each land-use/land cover class using separability analyses (Jensen, 1996). Two classification algorithms were tested for the TM bands and the PC bands: maximum likelihood and ECHO, a spatial-spectral algorithm (Landgrebe and Biehl, 1995). Overall accuracy and Kappa statistics were calculated based on the classification of training fields.

## VI. RESULTS AND DISCUSSION

This study incorporated remotely sensed imagery and ancillary data to present an analytical approach to land-use/land cover in Tomé Açu, Brazilian Amazon. Bands 1 (0.45-0.52µm), 2 (0.52-0.60µm), and 3 (0.63-0.69µm) are in the visible portion of the spectrum (blue, green, and red, respectively). Band 4 is near-infrare (0.76-0.90µm), band 5 is mid infra-red (1.55-1.75ìm), and band 6 is also mid-infrared (2.08-2.35ìm), actually the seventh band of the TM sensor (Lillesand and Kiefer, 1996).

Using the statistics in covariance matrix form, the unstandardized eigenvectors data were developed, as listed in Table 1. Table 2 shows the results for the standardized eigenvector data, derived from the correlatic matrix. The unstandardized eigenvectors data show that 94.4% of the information is restricted to the first twc components. Standardized PCs have more information also being expressed by the other components (Tables 1 and 2).

*Table 1 – Unstandardized principal component analysis for the study area in Tomé Açu, Brazilian Amazon.*

| Component | Eigenvalue | Percent | Cumulative Percent | | | |
|---|---|---|---|---|---|---|
| 1 | 431.5807 | 70.3536 | 70.3536 | | | |
| 2 | 147.3414 | 24.0187 | 94.3723 | | | |
| 3 | 24.4401 | 3.9841 | 98.3564 | | | |
| 4 | 5.0669 | 0.8260 | 99.1824 | | | |
| 5 | 3.8879 | 0.6338 | 99.1862 | | | |
| 6 | 1.1278 | 0.1838 | 100.0000 | | | |
| | | | | | | |
| Eigenvectors Components: | Channels | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 0.19749 | 0.17830 | 0.26111 | 0.42384 | 0.77368 | 0.28778 |
| 2 | 0.16426 | 0.09563 | 0.26870 | -0.87961 | 0.23355 | 0.25182 |
| 3 | 0.58773 | 0.35119 | 0.49753 | 0.17340 | -0.50302 | 0.02459 |
| 4 | 0.45451 | 0.01076 | -0.15903 | -0.11569 | 0.30157 | -0.81467 |
| 5 | -0.60437 | 0.24543 | 0.61912 | -0.00694 | 0.05394 | -0.43385 |
| 6 | -0.12934 | 0.88056 | -0.45110 | -0.05610 | -0.00012 | 0.03545 |

The loadings for the standardized eigenvectors components show the first component as the overall brightness, with all channels being similarly important. The second component reveals the 'greenness' of the image, as the most significant values are related to near Infrared (channel 4). The third component might be called the 'wetness band', also expressing soil moisture. The fourth component (1.9% of the information) shows a high response on the visible portion of the spectrum and the fifth one on the mid-infrared portion. Visual results of the principal components' data were also analized. The unstandardized version separates much more noise after the third PC than the version using the correlation matrix.

Land-use/land cover classification for the Tomé Açu subset defined ten main classes: forest, advanced secondary succession, intermediate secondary succession, initial secondary succession, pasture, bare soil (agriculture), bare soil (urban), water, clouds, and shadows.

Overall accuracy and Kappa statistics are shown in Table 3. Overall accuracy using the maximum likelihood algorithm was 74.3%, 73.1%, and 73.5% for the six TM bands, standardized PC bands and unstandardized PC bands, respectively. Using the ECHO classifier, the accuracy increased to 90.9%, 88.5%, and 91.2% for the same set of layers. Results showed that the use of principal components bands did not bring a significan improvement in classification accuracy for the focused features. Otherwise, the spatial-spectral classifier increased the accuracy significantly, taking advantage of the spatial distribution of vegetation features in the landscape and not just their spectral signatures.

*Table 2 – Standardized principal component analysis for the study area in Tomé Açu, Brazilian Amazon.*

| Component | Eigenvalue | Percent | Cumulative Percent |
|---|---|---|---|
| 1 | 4.4555 | 74.2589 | 74.2589 |
| 2 | 0.9758 | 16.2627 | 90.5217 |
| 3 | 0.3502 | 5.8359 | 96.3576 |
| 4 | 0.1130 | 1.8841 | 98.2417 |
| 5 | 0.0639 | 1.0645 | 99.3062 |
| 6 | 0.0416 | 0.6938 | 100.0000 |
| | | | |

| Eigenvectors Components: | Channels | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | 0.42547 | 0.45495 | 0.44778 | 0.18058 | 0.43226 | 0.43821 |
| 2 | -0.17357 | -0.02694 | -0.23775 | 0.92738 | 0.18929 | -0.12944 |
| 3 | -0.56292 | -0.29609 | -0.11179 | - 0.17945 | 0.53334 | 0.51604 |
| 4 | 0.68357 | -0.48809 | -0.48328 | - 0.02094 | 0.17269 | 0.17516 |
| 5 | 0.04782 | 0.04609 | 0.02132 | - 0.22016 | 0.67989 | -0.69600 |
| 6 | -0.04913 | 0.68137 | -0.70460 | - 0.16199 | 0.02834 | 0.09909 |

The accuracy achieved for each land-use/land class using with maximum likelihood and ECHO algorithms is described in Table 4. In general, the spatial-spectral classifier (ECHO) improved the accuracy significantly in relation with the maximum likelihood algorithm. The use of standardized PC bands increased the accuracy t classify intermediate secondary succession with the maximum likelihood algorithm. Accuracy decreased when these same bands were classified by ECHO to map advanced secondary succession (Table 4).

*Table 3 – Overall accuracy and Kappa statistics for maximum likelihood and ECHO classifiers using Landsa TM bands, standardized, and unstandardized PC bands for the study area in Tomé Açu, Brazilian Amazon.*

| | Bands | Overall Accuracy (%) | Kappa Statistics (%) |
|---|---|---|---|
| Maximum Likelihood | TM Bands | 74.3 | 70.7 |
| | Standardized PC bands | 73.1 | 69.4 |
| | Unstandardized PC Bands | 73.5 | 69.9 |
| ECHO | TM Bands | 90.9 | 89.6 |
| | Standardized PC Bands | 88.5 | 86.8 |
| | Unstandardized PC Bands | 91.2 | 90.0 |

*Table 4 – Accuracy for each land-use/land cover class using maximum likelihood and ECHO algorithms for Landsat TM bands, standardized, and unstandardized PC bands for the study area in Tomé Açu, Brazilian Amazon.*

| | Maximum Likelihood | | | ECHO | | |
|---|---|---|---|---|---|---|
| Land-use/land cover classes | TM Bands | Standardized PC Bands | Unstandardized PC Bands | TM Bands | Standardized PC Bands | Unstandardized PC Bands |
| Forest | 79.9 | 75.6 | 77.5 | 95.2 | 94.7 | 95.2 |
| Advanced Secondary Succession | 54.1 | 49.5 | 52.3 | 88.3 | 67.6 | 91.0 |
| Intermediate Secondary Succession | 51.4 | 58.3 | 52.8 | 95.8 | 97.2 | 95.8 |
| Initial Secondary Succession | 47.1 | 44.7 | 46.6 | 78.2 | 76.7 | 79.1 |
| Pasture | 78.7 | 78.7 | 79.4 | 83.9 | 82.6 | 83.9 |
| Bare (Agriculture) | 81.4 | 84.3 | 80.0 | 94.3 | 94.3 | 94.3 |
| Bare (Urban) | 92.0 | 90.7 | 90.7 | 97.5 | 97.5 | 96.9 |
| Water | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Clouds | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Shadows | 99.0 | 99.0 | 99.0 | 99.0 | 99.0 | 99.0 |

## VII. CONCLUSIONS

The diversity in local cropping patterns contributes significantly to the landscape heterogeneity in Tomé Açu

Farmers clear forest or secondary successional vegetation and combine short-lived perennials with annual grain or vegetable crops. Intermediate perennials or forest tree species are also planted at the same time or soon after. This combination of trees and crops varies output over time and space.

This paper focused on a particular subset within the Tomé Açu settlement, using remote sensing as a tool to assess land-use/land cover through two different classification algorithms. Principal components analysis wa also used. Satellite image was useful to identify vegetative features in the study area. Due to their spectral characteristics, Landsat TM images allowed the distinction of ten thematic classes. The procedure is interactive and still may be improved using additional techniques and field data.

The use of PC bands did not increase the accuracy of classifications significantly. Otherwise, the spatial-spectral classifier (ECHO) provided very good results compared with the maximum likelihood algorithm. Further research in the area will be done integrating previous experiences on spectral identification and spatial analysis of land-use/land cover in the Amazon (Moran et al., 1994; Moran et al., 1994a; Mausel et al. 1993).

This is part of an ongoing research project carried out by Indiana University/ACT and funded by NASA/LBA. The goals for this project include acquisition of other satellite images, integration of property grids in Geographic Information Systems, generation of numeric databases about farming systems, and test of other procedures, such as ratios, different parameters for digital classifications, and accuracy assessment based c ground truth.

Following trends of integration between tools and techniques provided by Geographic Information Systems, Image Processing Systems, and relational databases, further research in Tomé Açu will allow a better understand about the ecological resultant, in terms of spatial organization of production systems and use of natural resources. The procedure may also be extended for adjacent landscapes to compare different strategies of production practiced by the community and the Brazilian small holders also present in the area.

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