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# ASSESSMENT OF THE MULTIPLE ENDMEMBER SPECTRAL MIXTURE ANALYSIS (MESMA) MODEL APPLIED TO THE HYPERION/EO-1 HYPERSPECTRAL DATA OF THE COASTAL PLAIN OF RIO GRANDE DO SUL, BRAZIL

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**KEY WORDS:** Land Cover, Radiometry, Classification, Processing, Pattern, Hyper spectral

**ABSTRACT:**

The objective of this work was to evaluate the potential use of the Multiple Endmember Spectral Mixture Analysis (MESMA) when applied to EO-1 Hyperion hyperspectral data to discriminate land covers in the southern state of Rio Grande do Sul, Brazil. The methodology involved: (a) pre-processing and atmospheric correction of Hyperion data; (b) sequential use of the Minimum Noise Fraction (MNF), Pixel Purity Index (PPI) and n-Dimensional Visualizer techniques in the 454-2334 nm range for the initial selection of a general group of endmember candidates (first spectral library) and of another group of pixels to be used for model validation; (c) use of the Visualization and Image Processing for Environmental Research Tools (VIPER Tools) to perform the final selection of endmembers based on the first spectral library and to obtain MESMA models; and (d) evaluation of resultant fraction images and root mean square error (RMSE) values to determine the optimal number of components of the MESMA model. Results showed that a four-endmember MESMA model (soil = dunes and dry fields; green vegetation = pinus, eucalyptus and grasslands; water = without sediments, with sediments, and with chlorophyll; and shade) adequately described the diversity of the scene components, including that of materials within the same class (e.g., pinus and eucalyptus) and produced the largest fractions and the lowest RMSE values on a per-pixel basis. Results demonstrated the potential use of the MESMA with EO-1 Hyperion hyperspectral data to discriminate land covers in the coastal plains of Rio Grande do Sul, even considering the low signal-to-noise ratio of the instrument, especially in the shortwave infrared range.

## 1. INTRODUCTION

Numerous techniques for the classification of orbital images have been used in the extraction of land surface data (land covers and land use, for instance). Multispectral sensors such as the Enhanced Thematic Mapper (ETM+, Landsat 7) with 8 spectral bands are generally used in such studies. However, these sensors do not allow for a more detailed study of the spectral behavior of the targets.

On November 21st, 2000, the Hyperion sensor was launched aboard the National Aeronautics and Space Administration's (NASA) Earth Observing-1 satellite (EO-1), becoming the first hyperspectral sensor to operate from the Earth's orbit. With 242 spectral bands laid out between 0.4 and 2.5 µm, the sensor enables the extraction of a practically seamless detailed reflectance spectrum for each scene element (pixel) in the image (Goodenough et al., 2002; Galvão et al., 2005).

On the other hand, the spectral response of a pixel is, in fact, the integrated sum of the spectral response of the scene components as registered in the field of view of the sensor (Instantaneous Field of View - IFOV) such as those of the soil, vegetation, water and of the shade projected on the land, as well as atmospheric contributions (Shimabukuro and Smith, 1991).

In order to identify the ratio of the different materials that comprise a pixel, one can use models which decompose the pixel into its pure components or endmembers. The Spectral

Mixture Analysis (SMA) (Smith et al., 1985) is a digital image-processing tool that can separate the relative ratio of each material within a pixel by using a set of pure components of the image (Pereira et al., 1998). Nevertheless, the SMA fails in that it considers all pixels to be a mixture of a single initial set of endmembers, thereby possibly allowing a pixel to be modeled by endmembers which might not actually be present therein.

In order to correct such error, the Multiple Endmember Spectral Mixture Analysis model (MESMA) (Roberts et al. 1998a) was proposed as it allows the number and type of endmembers, as well as their prevalence, to vary from pixel to pixel and establishes the best-fit mixture model for each pixel individually.

In this context, the objective of this research was to assess the potential of the data deriving from the Hyperion orbital sensor and from the MESMA model for the discrimination of land cover classes in the Coastal Plains of Rio Grande do Sul.

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In: Wagner W., Székely, B. (eds.): ISPRS TC VII Symposium – 100 Years ISPRS, Vienna, Austria, July 5–7, 2010, IAPRS, Vol. XXXVIII, Part 7A

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## 2. MATERIAL AND METHODS

This study used an EO-1 Hyperion stock image, level L1R (USGS), which was acquired on May 2nd, 2004 and depicts the northern area of the Coastal Plains of Rio Grande do Sul (Figure 1).
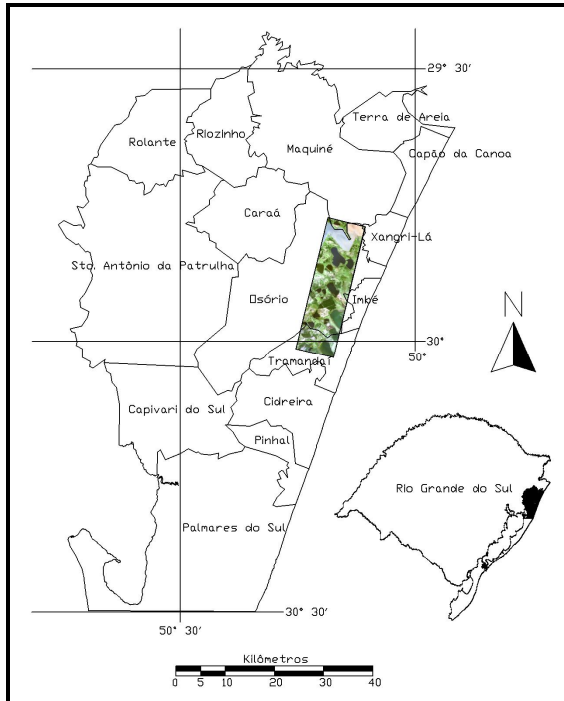


Figure 1. Location of the study area

In order to identify the type of materials present in the scene and characterize land cover classes and subclasses, two two ground truth measurements took place in 2007.

The stages of the preprocessing of Hyperion data involved: correction of anomalous pixels (stripes) by interpolation; exclusion of the bands which had no data of the L1R product and which were positioned around the atmospheric absorption bands (1,400 nm and 1,900 nm); conversion of data into surface reflectance values through the use of a radiative transfer model based on the MODTRAN-4; and image georeferral using a GeoCover image of the study area as the reference.

The Minimum Noise Fraction (MNF), the Pixel Purity Index (PPI) and the n-Dimensional viewer processing sequence was applied over the 143 bands selected from the 454 to 2334 nm interval in order to compose the first spectral library and generate a group of samples for the validation of the results obtained by MESMA.

For the selection of the most representative spectra of the first spectral library, the following metrics were used: EAR (Endmember Average RMSE), MASA (Minimum Average Spectral Angle) and CoB (Count Based Endmember Selection), all included in the VIPER (Visualization and Image Processing for Environmental Research) Tools program (Roberts et al., 2007). The spectra that had the best performance in each metric were selected to generate the second spectral library.

From this second spectral library, the two, three and four endmember MESMA models were applied to the Hyperion data

using the "Run SMA/MESMA" module of VIPER Tools. Restriction parameters required by the program regarding the type of shade (photometric or non-photometric), minimum and maximum fractions of the non-shade component, maximum shade fraction, and maximum RMSE allowed are all shown on Table 2.

| Shade | Photometric |
|---|---|
| Minimum Allowable Fraction | -6% |
| Maximum Allowable Fraction | 106% |
| Maximum Allowable Shade Fraction | 80% |
| Maximum Allowable RMSE | 0,025 |
| Residual Threshold | 0,025 |
| Number of Contiguous Bands | 7 |

Table 2. Parameters used in the "*Run* SMA/MESMA" module of the VIPER Tools for the application of the MESMA models.

In order to generate the fraction image for each subclass represented in this study as well as a classified image, a MatLab routine was developed, in which the subclass with the greatest ratio was attributed to the pixel.

The accuracy assessment was obtained in relation to the "pure" pixel demixing (Validation Sample) resulting from the PPI process. Thus, the fractions produced by each model for each subclass were compared in relation to the RMSE produced so as to assess the performance of the MESMA mixing models.

## 3. RESULTS AND DISCUSSION

### 3.1. Components of the Scene

Lacustrine wetlands are the most present elements in the study area (Figure 3), accounting for approximately 50% of it. Basically, three distinct shades of water were identified and labeled in this study as follows: water with sediments, water without sediments and water with chlorophyll. Current land use is dominated by rice crops and pinus and eucalyptus plantations in small and mid-sized properties. The open field areas are composed of low vegetation, namely grasslands, identified by the bright green shades located among the lacustrine wetlands spread across the image. The dry field areas are characterized by disperse dry vegetation made up of dry pinus branches and rice straw. Finally, a small lot of the urban area of Tramandaí can be seen between the Lagoa das Custódias and Lagoa do Armazém.

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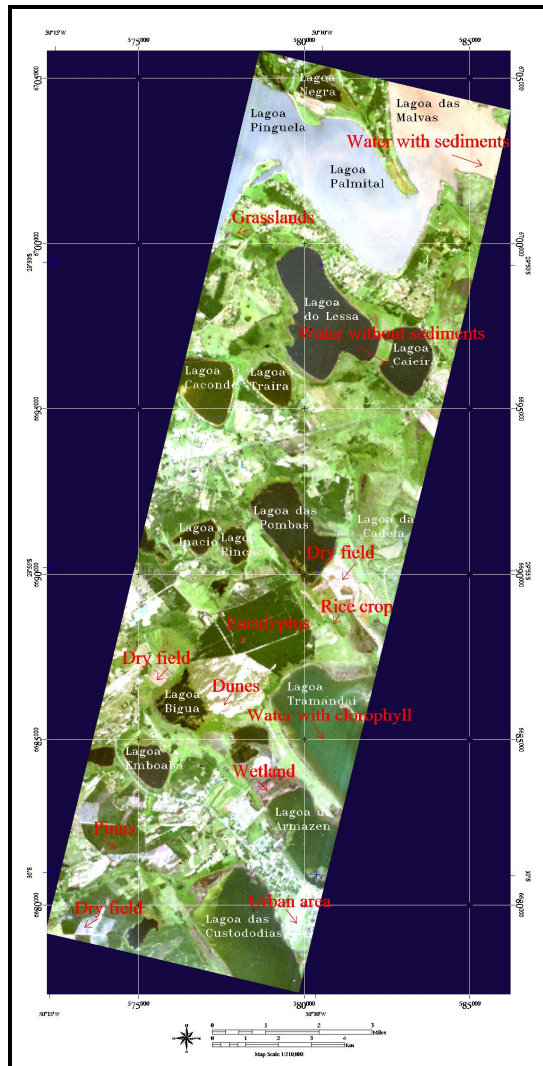Contents          Author Index          Keyword Index

Figure 3. Normal color composition with bands positioned at 638 nm (red), 546 nm (green) and 465 nm (blue). Main components of the scene are highlighted

### 3.2. First Spectral Library and Validation Sample

In total, 14,101 pixels were selected as endmember candidates by the PPI technique (6.12 % of the imaged area), applied over the 9 first MNF components. Those pixels occurred especially in portions of the scene of 8 subclasses related to three main classes (water, vegetation and soil): water with sediments, water without sediments and water with chlorophyll (water); pinus, eucalyptus and grasslands (vegetation); and dunes and dry fields (soil).

The number of "pure" pixels selected manually from the Hyperion image, with the aid of the n-Dimensional viewer to compose the first spectral library and the validation sample is shown on Table 4.

| Classes | Subclasses | Number of pixels (1st Spectral Library) | Number of pixels (Validation Sample) |
|---|---|---|---|
| Water | water with sediments | 105 | 80 |
| | water without sediments | 105 | 80 |
| | water with clorophyll | 105 | 80 |
| Vegetation | pinus | 105 | 80 |
| | eucalyptus | 105 | 80 |
| | grasslands | 105 | 80 |
| Soil | dunes | 105 | 80 |
| | dry fields | 20 | 80 |
| Total of pixels | | 755 | 640 |

Table 4. Classes, subclasses and number of pixels selected to compose the First Spectral Library and the Validation Sample, resulting from the sequential application of MNF, PPI and n-Dimensional viewer techniques

### 3.3. Second Spectral Library

Using the EAR, MASA and CoB metrics, 23 spectra were selected from the first spectral library. Those endmembers corresponded to the most representative spectra of each subclass, that is, those which presented the lowest RMSE (EAR) and spectral angle and the highest CoB index when modeling the same subclass.

The spectra which presented the best performance in each metric (EAR, MASA and CoB) were selected for each subclass. Therefore, each subclass received three representing spectra (endmembers), except the dune subclass, which, due to the low CoB index produced, had its spectrum selected by the EAR and MASA techniques only.

### 3.4. MESMA spectral mixture models

The performance result of the 2, 3 and 4 endmember models generated from the second spectral library (Table 5) can be observed in Figure 6. The 4 endmember models obtained the lowest RMSE and the largest fraction when modeling "pure" pixels in the validation sample.

| Number of endmembers | 1st endmember | 2nd endmember | 3rd endmember | 4th endmember | Number of models |
|---|---|---|---|---|---|
| 2 | water/vegetation/soil | shade | | | 23 |
| 3 | water/soil | vegetation | shade | | 126 |
| 4 | soil | vegetation | water | shade | 405 |

Table 5. Number of MESMA models generated from the 2$^{nd}$ spectral library for performance assessment.

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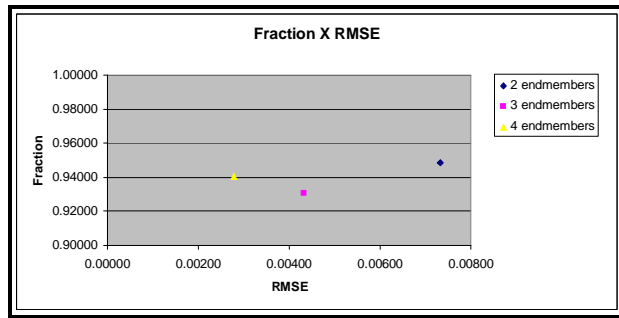Contents        Author Index        Keyword Index



Figure 6. Result obtained by the 2, 3 and 4 endmember MESMA models on the validation sample

Approximately 85% of the Hyperion image was modeled by the 4 endmember MESMA, which corresponds to 195,725 pixels (a total of 230,400 pixels). Most pixels of the water, dry field, pinus, grasslands and eucalyptus subclasses were properly modeled and classified. The dune subclass only had 46.25 % of its sample modeled (Table 7).

| Classes | Subclasses | % modeled |
|---|---|---|
| Water | Water with Sediments | 100,00% |
| | Water without Sediments | 100,00% |
| | Water with Clorophyll | 100,00% |
| Vegetation | Pinus | 100,00% |
| | Eucalyptus | 100,00% |
| | Grasslands | 97,50% |
| Soil | Dry Fields | 100,00% |
| | Dunes | 46,25% |

Table 7. Result obtained by the 4 endmember MESMA model on the validation sample

The RMSE image indicated that the most significant mistakes were produced by MESMA when modeling grasslands and dunes due to the high spectral variation of those targets. With the aid of histograms of the fraction images of each subclass, it was found that most of the pixels of the Water Body Class were modeled with fractions superior to 90%. In the Vegetation Class, the average fractions produced varied between 60% (grasslands) and 90% (pinus and eucalyptus). The Soil Class presented the smallest fraction values, with approximately 50% for the dry field subclass. The dune subclass had a practically linear distribution, with intervals between 20% and 104%.

The final classification (Figure 8) obtained from the land vegetation and water fraction images depicts the spatial distribution of the eight subclasses presented in this study. It was observed that some areas that actually corresponded to the cultivation of eucalyptus were erroneously classified as pinus, yet the opposite did not occur. For the water classification, the result seems to be consistent with the normal color image in Figure 3. Nevertheless, in shallow waters (margins), there was a slight confusion between the subclasses Water with Sediments and Water with Chlorophyll, mainly due to the background effect. Similarly to what happened in the validation samples, dune-covered areas were mostly not modeled. The urban area, which was not represented in the mixing models, was partially modeled as dry field (soil).
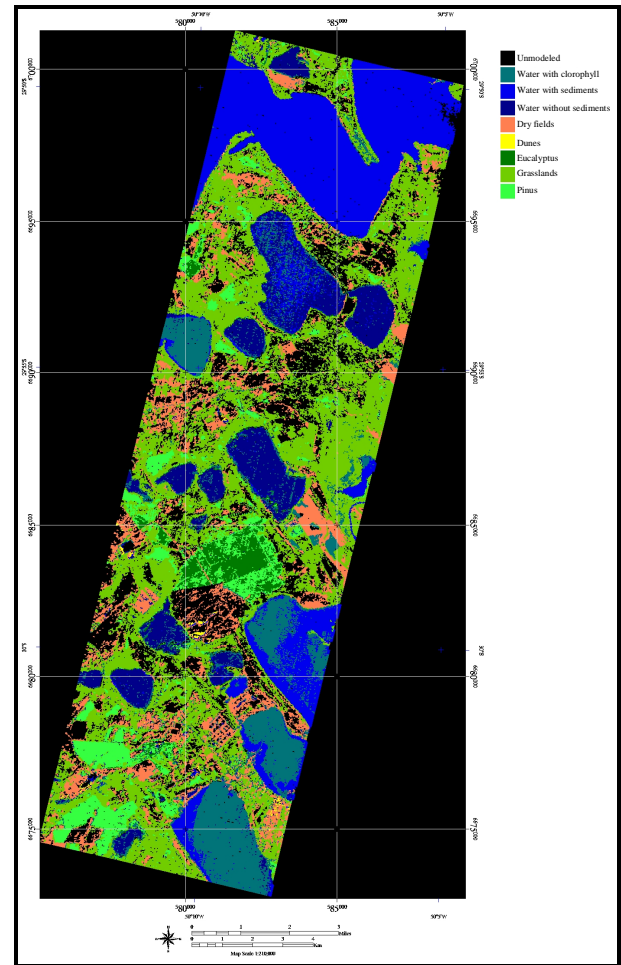


Figure 8. Result obtained by the 4 endmember MESMA model. Image classified from the component with the highest fraction

## 4. CONCLUSIONS

When applied over a Hyperion image and over the validation sample, the 4 endmember MESMA model (soil = dunes and dry field; green vegetation = pinus, eucalyptus and grasslands; water = with sediments, without sediments and with chlorophyll; shade) properly described the diversity of the scene components, including that of materials within the same class (e.g.: pinus and eucalyptus).

The Fractions produced by the MESMA models when modeling "pure" pixels corresponded to the expected values, mostly reaching fractions above 90% with low RMSE.

The results, as a whole, demonstrate the potential of the application of the MESMA model with EO-1 Hyperion sensor hyperspectral data, even considering the low signal-to-noise relationship of the instrument, especially in the SWIR.

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