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Classification of Rios Solimões-Amazonas Wetlands through Application of Spectral Mixture Analysis to Landsat Thematic Mapper Data

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Abstract. This paper describes a methodology proposed for producing a digital mosaic of Solimões-Amazonas Wetlands through the application of spectral mixture analysis to Landsat Thematic Mapper Data. The proposed methodology includes the following steps: georeferencing, calibration to surface reflectance, spectral mixture analysis, classification of fraction data, quality control through digital and visual review, accuracy assessment using visually interpreted and ground data, and addition to the mosaic.

Keywords: Solimões, mixture, Landsat.

1.Introduction

Junk et al. (1989) described the "flood-pulse" as a moving littoral zone of ever-increasing inundation of a river's floodplain. This description only partially characterizes the patterns and rates of water transfer to and from the Amazon River floodplain due to the variety of pathways for water to enter the floodplain. Flooding is the product of the hydrology of different water types as they enter the floodplain, either directly from rainfall, over land off surrounding slopes, flooding of local tributaries, groundwater, or exchange with the river channel. The spatial and temporal patterns of the inundation hydrology are in turn influenced by the topography, soils, and vegetation of the floodplain. Therefore, variation in spatial heterogeneity of the landscape is expected on geomorphically and hydrologically distinct floodplains.

Considering these factors, Mertes et al. (1995) reported on the variation in landscape and water patterns for three geomorphically and hydrologically distinct reaches (Mertes et al. in press) of the Amazon River floodplain based on application of spectral mixture analysis to Landsat Thematic Mapper (TM) images. The results showed that the hydrology of inundation of the Amazon River varies from reach to reach. Upstream reaches are characterized by flooding river water channelized into floodplain channels, and limited mixing of river water with locally derived water during flooding. Middle reaches are characterized by greater mixing of water types, because river water inundates the floodplain as diffuse, non-channelized overbank flows. During the high-water period in the downstream reaches, large lakes have sufficient hydraulic head to prevent river water from entering large sections of the floodplain. Unexpectedly, semi-variance statistics showed that the middle reach has the greatest spatial heterogeneity compared to upstream or downstream reaches. The greater spatial heterogeneity in the middle reach was concluded to be the product of the greater diversity of water types and landforms due to the large amount of mixing of river water with locally derived floodplain water.

Additionally, Novo et al. (1995) reported on the spatial variation in landscape units of the Amazon River floodplain from the confluence of the Rio Madeira to the confluence of the Rio Tapajos through visual interpretation of TM data.Their results showed that the floodplain was covered by 3.9 % macrophytes, 1.7 % forest, 49.5 % open water, and 45.5 % of non-flooded forest. In a more recent study Novo and Shimabukuro (1995) have used a method suggested by Hall et al. (1991) to rectify the images before applying the mixing model.

The results from Mertes et al. (1995) , Novo et al. (1995) and Novo and Shimabukuro (1995) have motivated a project to develop a mosaic of the entire Amazon River wetlands based on application of spectral mixture analysis to TM images recorded during high water conditions. In particular, optical data were selected for this project because of our ability to extract both vegetal and water quality characteristics. The goal of this project will be to produce for digital review a fully classified layer of approximately 1 Gigabyte, that shows minimally 2 classes of flooded forest, 3 classes of macrophyte, surface suspended sediment concentration in milligrams per litre, and farmland. We describe here our methodology for developing the mosaic and preliminary results from the section of the river between the confluences of the Rios Negro and Tapajós.

2. Study Area

Wetlands on the alluvial floodplains of the Amazon River and tributaries in Brazil are believed to cover over 300,000 km^2 (Klinge et al. 1990). The alluvial deposits along the mainstem Rios Solimões-Amazonas in Brazil (Figure 1) cover approximately 92,000 km^2 (Sippel et al., 1992). The floodplain can be divided into the varzea, which is flooded by sediment- and nutrient-rich water (white water), and igapó, which is flooded by sediment- and nutrient-poor water (black water) (Sioli 1968). The floodplain vegetation generally consists of forest, grassland, and "floating meadow" (Junk 1970, 1984; Sternberg 1975) whose spatial distribution, until recently, was described based primarily on detailed field studies at a few locations. Corves and Place (1994) and Melack et al. (1994) described the distribution of general categories of wetland vegetation based on classification of Landsat data and field data for areas in the central Amazon. Recent work with microwave data has also produced classification of similar categories for the central Amazon (Hess et al. 1995).

The Amazon River and floodplain in Brazil show an upstream to downstream trend in channel behavior and geomorphology (Mertes et al. in press). The upstream reaches are characterized by sediment erosion in the main channel and deposition in floodplain channels that are an order of magnitude smaller in discharge than the main channel. Sediment deposition in and migration of the floodplain channels erases oxbow lakes of the main channel and yields an intricate scroll-bar topography that forms the boundaries of hundreds of long, narrow lakes. Middle reaches are characterized by both long, narrow lakes and more equant lakes, with an immobile and straight channel apparently confined due to the presence of structural features. Downstream reaches are characterized by channels restricted by stabilizing, long-term, levee building and floodplain construction dominated by overbank deposition. Overbank deposition buries the scroll-bar topography which results in a flat floodplain covered by a patchwork of large, more equant, shallow lakes. Based on estimated rates of recycling of floodplain sediments, the modern floodplain of the Brazilian Amazon could have been recycled in less than 5000 years, and is recycled more rapidly in the upstream than the downstream reaches.

3. Data and Methods

For mapping the entire floodplain twenty-five scenes are required to complete the mosaic, although several of the scenes cover only a small portion of the floodplain. Scenes were selected through INPE to insure that each image was the best high-water, cloud-free image available. Figure 1 shows the spatial distribution of the images to be used in this study.

The methodology for analysis of each image includes the following steps: georeferencing, calibration to surface reflectance, spectral mixture analysis, classification of fraction data, quality control through digital and visual review, accuracy assessment using visually interpreted and ground data, and addition to the mosaic.

Georeferencing of the images will involve use of the satellite-reported location characteristics for each image and registration to ground-control-points taken from 1:250 000 topographic maps for each region. The Calibration to surface reflectance is a requirement for two reasons. First, in order to effectively track the incursion of river water into the floodplain, it is critical to have estimates of suspended sediment concentrations in milligrams per litre. The method developed by Mertes et al. (1993) for this calculation requires the image data to be in surface reflectance units in order to use reference (laboratory) endmembers for water types. The second reason for surface reflectance units, is that these are reliable units to account for seasonal differences in sun angle and atmospheric conditions. Tests of classified images without surface reflectance calibration, showed significant differences in overlap areas of the mosaic. These differences were substantially reduced after surface reflectance calibration was performed. Surface reflectance calibration involves coordinating image and laboratory endmembers of invariant surfaces such as clear water and dense forest canopy (Smith et al. 1990; Mertes et al. 1993; Adams et al. 1995). Through optimization statistics, the endmembers are fit to a line, for which the slope and offset are the gain and offset to convert raw radiance units to surface reflectance for each band.

Another method for radiometric rectification proposed by Hall et al. (1991) is also being tested (Novo and Shimabukuro, 1995).

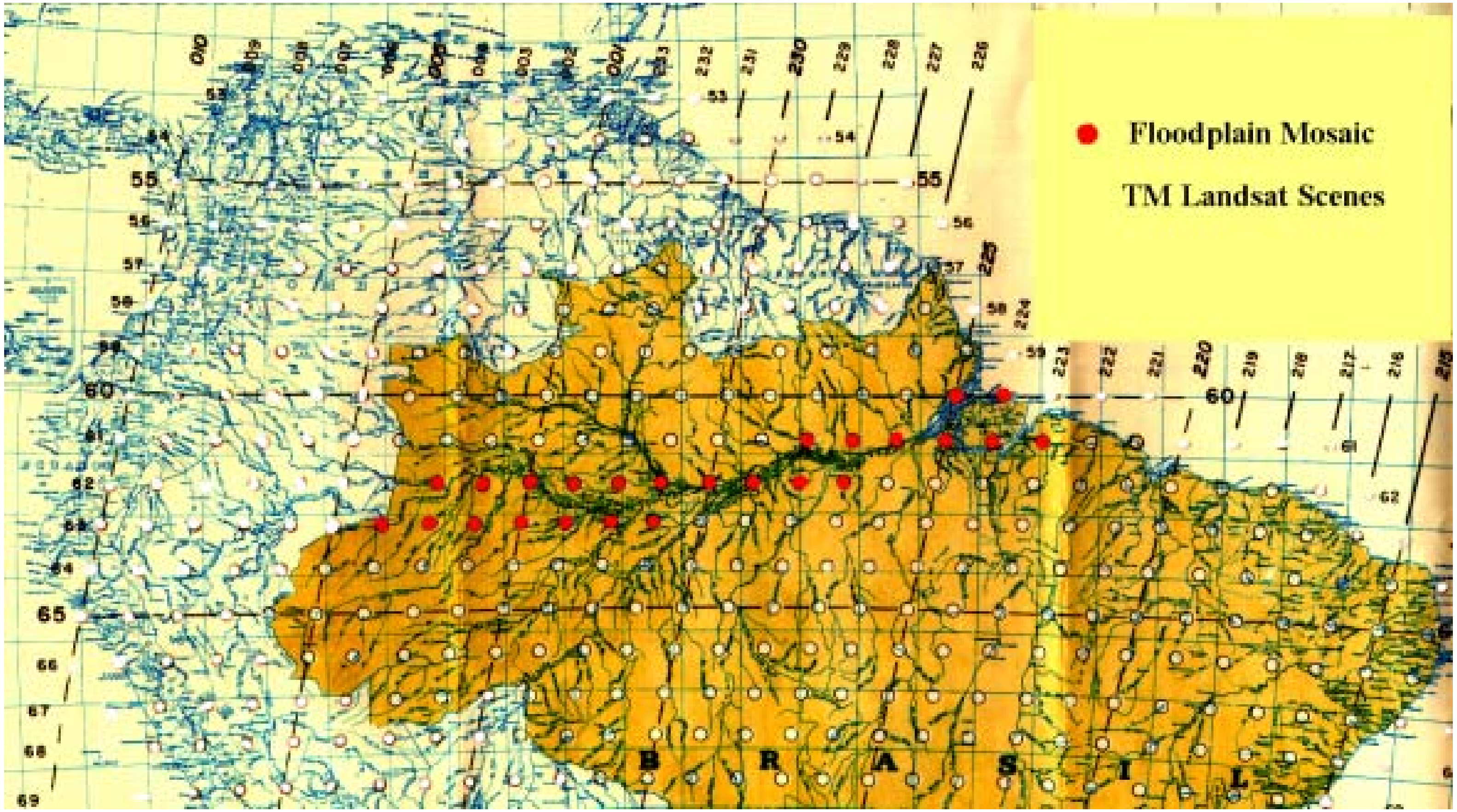

Figure 1 - Landsat scenes to be used to build the floodplain mosaic.

Figure 2 shows a subscene of two adjacent TM images after the radiometric rectification. It can be observed that there are only small differences between the scenes and they can be connected to environmental changes.

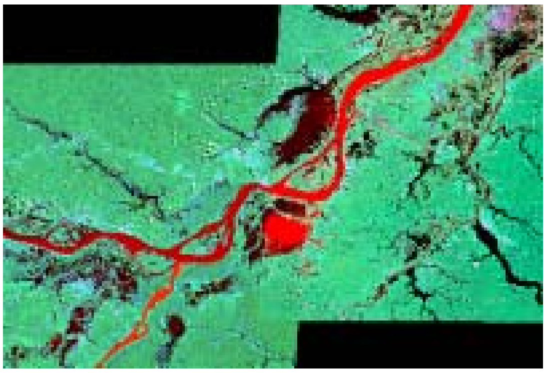

Figure 2 - Subscene of the rectified mosaic using the radiometric rectification algorithm developed by Hall et al. (1991)

Spectral mixture analysis of the surface reflectance data will follow both a modified method of a least-squares mixing model (Shimabukuro and Smith 1991) and a modified Gram-Schmidt method of decomposing the gradients (Smith et al. 1990). Results from each method are comparable in producing fraction images for each endmember. Given surface reflectance units it will be possible to use the same reference endmembers from spectral libraries for vegetation and soil for images that are close to one another. For all of the images the endmembers for clear water and sediment-laden water of known concentration will be based on laboratory data reported by Witte et al. (1981). These surface reflectance data were collected over water with varying sediment concentration and have been convolved to TM filter specifications and tested for use in Amazon waters (Mertes et al. 1993).

After fraction data are produced for each image, the data are passed through a parallelepiped classifier with thresholds that separate vegetation groups, sediment concentration groups, and soil groups (Mertes et al. 1995). This separation produces minimally the following categories: high- and low-density flooded forest, senesced and high- and low-density macrophyte, river and floodplain water of different concentrations, and farmland. We consider these categories sufficient to adequately survey the regional patterns in spatial heterogeneity of the landscape of the Solimões-Amazonas wetlands. Figure 3 shows the results of the classification (not including a calibration to surface reflectance) for Path 229, Row 62.

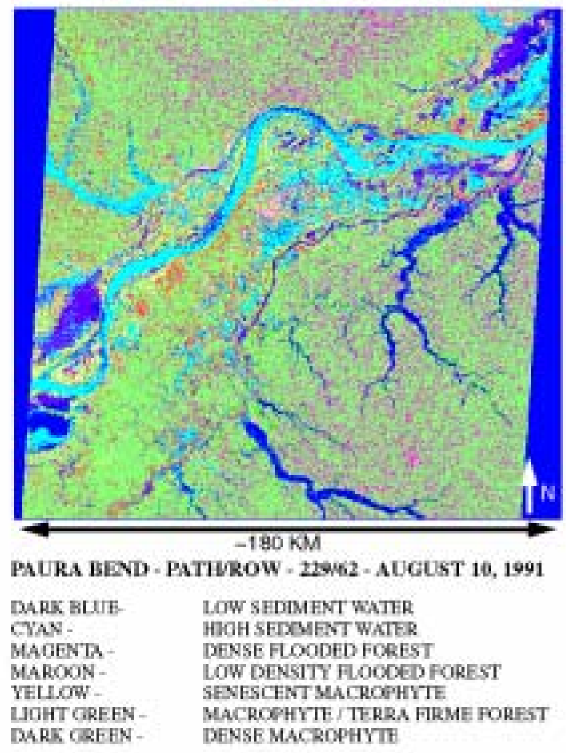

Figure 3 - Result of classification using the fraction images as input.

Currently accuracy assessment of the image products involves matching to ground information in the form of aerial photography and field surveys. We plan to use the georeferenced, visually interpreted data (Novo et al. 1995) to perform a random-sample accuracy assessment (Jensen 1986) of the digital data.. Additionally, video, photographic, and microwave data collected in conjunction with microwave projects (JERS-1, ERS-2, Radarsat, SIR-C) will be available for many river reaches. These data will help particularly with assessment of the accuracy of the vegetation classification.

The mosaic will be produced in sections and before final publication will be available for digital review through world-wide-web sites at the University of California, Santa Barbara, and INPE. We will request that researchers around the world who have expertise in wetlands in general or in the Amazon basin will download portions of the mosaic and contribute review comments regarding the accuracy of the mosaic. In addition, the initial mosaic will be built at the spatial resolution of the TM data (approximately 30-m pixels). Given the size of a single layer (more than 1 Gigabyte) we will resample the images to more accessible sizes as specified by the community of users during this digital review process.

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