Evaluating remote sensing products to delineate paleodrainages in forested areas of southwestern Marajó Island

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Abstract. Morphological features related to paleochannels are abundant in Marajó Island, as in many other areas of the Brazilian Amazonia. Proper characterization of these features is useful for discussing the dynamic evolution of the rivers associated with the Amazonas basin, an issue still poorly emphasized by the scientific community. Previous studies undertaken in southwestern Marajó Island revealed that digital elevation data obtained during the Shuttle Radar Topography Mission (SRTM) were of great success for the recognition of paleochannels in areas characterized by dense forest, which are barely seem using other remote sensing products, mainly those acquired with optical sensors. However, the analysis of radar (JERS-1 90m and SAR/SIPAM-6m) and optical images (Landsat, ASTER) from a forested area of southern Marajó Island indicated a myriad of narrow paleochannels not previously detected using only SRTM data. Evaluation of these remote sensing products led to the conclusion that none of them were individually satisfactory to provide a complete view of the paleochannels, which are only mapped entirely using a combination of all these products. Combination of these data led to the recognition of a mainly northward-oriented paleodrainage that have a younger abandonment history with respect to the other paleochannels detected in southwestern Marajó Island with basis on SRTM data. These younger paleodrainage is northwestward-oriented, been contrary to the south/southeastern orientation of modern channels. The drastic drainage inversion through time suggests tilting of southern Marajó Island, a process that might be related to the final establishment of the Pará River.

Key-words: paleochannels, Quaternary, Marajó Island, SRTM, optical images, tectonics

1. Introduction

The landscape of Marajó Island is characterized by an abundance of morphological features related to paleochannels. These have been characterized in a number of publications (Porsani 1981, Vital 1988, Rossetti and Valeriano 2007, Rossetti et al. 2007, Rossetti et al. 2008a,b), given their significance for reconstructing the geological events that took place during the latest Quaternary in the lowest Amazon basin.

Landsat images have provided the basis for mapping of the paleochannels in eastern Marajó Island, where the morphological aspects of the terrain can be exceptionally observed due to its physiographic nature dominated by savanna-like vegetation (Rossetti et al. 2007, Rossetti et al. 2008b; **Figure 1**). Likewise, analysis of SRTM-digital elevation data was crucial for the recognition of paleochannels in the west part of this island, where dense forest prevails (Mantelli 2008).

Recent processing of other radar and optical images from the forested areas of southwestern Marajó Island revealed a myriad of narrow paleochannels that were either unrecognized or only suggested in previous analysis of SRTM data. Characterization of these paleochannels might help to provide new information concerning to the process that might have been involved in the southern detachment of the island. A model has proposed a slight subsidence of eastern Marajó Island due to tectonics related to its detachment from mainland (Rossetti and Valeriano 2007, Rossetti et al. 2007). The data available suggest a separation process starting to the east, with capture of the lower course of the Tocantins River by a NE-SW oriented fault. It was hypothesized that the southern fragmentation of the island took place after this process, but data to support this model remain to be collected. The present work has the main goal of testing different remote sensing products in order to characterize these paleochannels and potentially use them to better reconstruct the latest geological history of Marajó Island. In addition, contrasting the results from optical and radar data might help to decipher why these features could not be recognized with basis on SRTM data, while in other forested locations of western Marajó Island these data were successful for mapping of paleochannels in immediately adjacent areas.

2. Study area and methods

The study area is located in southwestern Marajó Island (**Figure 1**), which is a fluvio-marine setting that encompasses up to 50,000 km^2 at the mouth of the Amazon River. This area is characterized by wet tropical climate, with a mean annual temperature of 28^{o}C and precipitation of 2,500 to 3,000 mm.year^{-1}, 90% concentrated between January and July. The topography is low; though few measurements are available, digital elevation models indicate values <30 m for most of the area, with an overall mean height of 12.5 m (**Figure 1**). Vegetation consists mostly of dense ombrophyla forests including *terra firme* and seasonally flooded *varzea*.

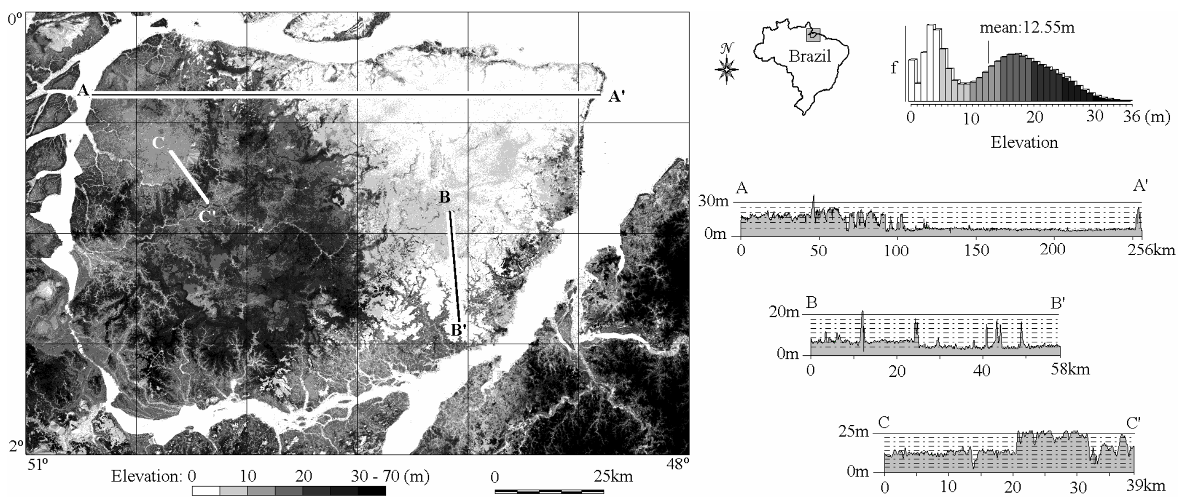

Figure 1 - Location of the study area (inside box) in southwestern Marajó Island and its digital elevation model-SRTM. Note the physiography of the island, characterized by dense vegetation (dark area) and savanna (white area) in the western and eastern margins, respectively. This vegetation contrast enhances the digital elevation in the western half side of the island (After Valeriano and Rossetti, in press).

This study was based on comparisons amongst several remote sensing products, consisting of radar (SRTM data, JERS-1, SAR-6m) and optical (ASTER and Landsat) images. The microwave sensors consist of synthetic aperture radar (SAR), which has the advantage of being less influenced by clouds than optical sensors, and also penetrate vegetation at some degree. The SRTM data consist of original 90-m resolution (3 arc seconds) InSar elevation data collected by the *National Aeronautics and Space Administration* (NASA), *National Imagery and Mapping Agency* (NIMA), German Space Agency (DLR) and Italian Space Agency (ASIA) in February 2000. The data was collected using the C and X bands, but only the C band products are freely available, thus they were used for this study. The C-band data, downloaded from the site http://edc.usgs.gov/srtm/data/obtainingdata.html, are unprojected, with geographic coordinates as reference units and WGS84 as reference ellipsoid and datum. The SRTM-90m data were pre-processed to improve information potential and to allow morphometric analyses. The applied modifications were pixel thinning (from 3” to 1”) after removal of data failures, with a slight smoothing directed to a reduction of artifacts and distribution of the spatial randomness according to procedures detailed by Valeriano *et al.* (2006). The resulting 30 m-resolution SRTM product was further processed using customized shading schemes and palettes in the software Global Mapper (Global Mapper Software LLC), in order to highlight the topographic and morphologic features of interest for this study. This procedure was applied in the study area because it was particularly useful for mapping networks of paleochannels in other similar forested areas of western Marajó Island, though, as discussed below, it failed to reveal the paleochannels in the present study.

The SAR images of the Japanese Earth Resource Satellite-1 (JERS-1) were collected in the L-band (1275 Mhz) frequency and HH polarization during the Global Rain Forest Mapping Project (GRFM) undertaken by the National Space of Development Agency of Japan (NSDAJ). The original dimension of 12.5 pixel spacing was modified to result a mosaic with pixel dimension of 3 arc seconds or 93 m resolution. These data were obtained during the dry (August-September 1995) and raining (May-August 1996) seasons, with the first been selected for this work. The JERS-1 data were processed only for adjustments in brightness, saturation and intensity.

The SAR-6m data were obtained by the *Sistema de Proteção da Amazônia* (SIPAM) aboard of an aircraft on October 2006. The radar images were collected using L-band with HH, HV, VH and VV polarization, and X-band using HH polarization. Only the latter were available for this study. As for the JERS-1 data, SAR-6 m images were processed only aiming to adjust brightness, saturation and intensity in order to help visualizing the paleochannel morphologies.

ASTER L1A images were purchased through the site http://edcimswww.cr.usgs.gov/pub/imswelcome/. The images with 15 m resolution were processed using automatic and manual linear adjustments, Gaussian curves and equalizations using the software ENVI. Several band compositions were attempted in order to highlight the features of interest for this study.

Landsat 5-TM and Landsat 7-ETM+ images (accessed from the electronic site <www.dgi.inpe.br>) were properly processed in the software SPRING testing several band compositions. Landsat images provided by Image Google were also used for comparisons of the results. These images were captured and their quality enhanced by properly processing applying automatic linear adjustments and equalization.

3. Results

While SRTM data were able to furnish a good view of the paleochannels that occur on forested terrains adjacent to the study area (**Figure 2A-C**), as documented on previous studies (Mantelli 2008, Rossetti and Góes 2008), they were totally ineffective to reveal these features in the study area (**Figure 2A-C**). However, this area shows an abundance of morphological features related to a paleodrainage system that can be recognized, with lesser or higher precision, using other microwave and optical products.

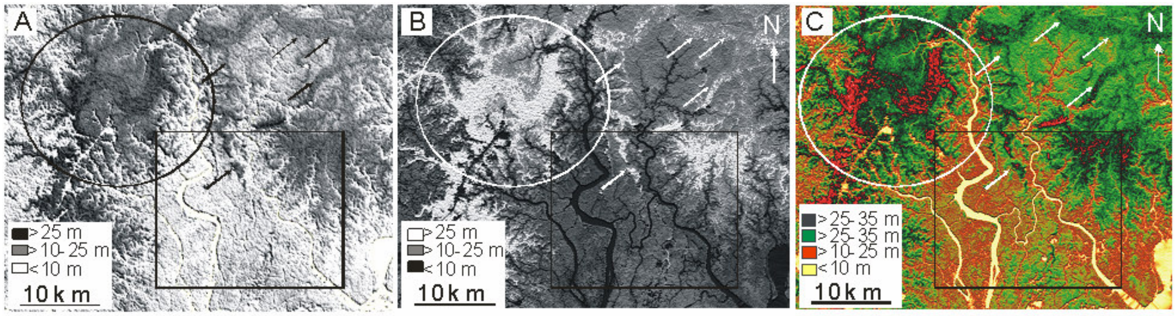

Figure 2 - SRTM data processing from forested areas in southwestern Marajó Island applying gray scales (A and B) and a color palette (C). This processing was of great success to highlight large paleochannel systems (circles and arrows), but failed to delineate the myriad of narrow paleochannels from the study area (inside box). Compare these results with following figures.

The JERS-1 90 m image did not detect the paleochannels mapped with basis on SRTM data, but it provided, in general, a good view of several other paleochannels in the study area (**Figure 3A-B**). However, the paleochannel contours were not entirely satisfactory to generate a precise map, and the tracing of many smaller size paleochannels was ambiguous. Likewise, the SAR/SIPAM-6m image failed to reveal all the paleochannels present in the study area, but where detected, the paleochannels could be delineate with great precision (**Figure 3C**). Despite the fact that some paleochannels could not be recognized in these SAR products, it is interesting to note that channel continuity was best achieved in those areas where these features could be seen (**Figure 3B,C**).

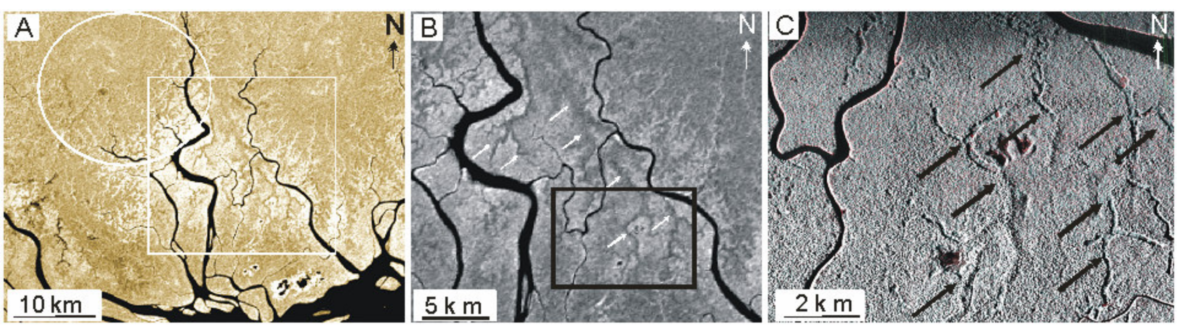

Figure 3 - A-B) JERS-1 90m of the study area and its adjacency. The circle indicates the position of the large meander shown in figure 2, which is entirely missing in this radar image. The inside box in A locates the study area, shown in more detail in figure B, were a paleodrainage can be delineated (arrows). C) A JERS-1 90 m resolution image of part of the study area (see inside box in B for location). Arrows locate the paleochannels.

The majority of the paleochannels in the study area was more promptly recognized using optical images. Hence, these features could be easily observed on Landsat images (**Figure 4A-C**), particularly using a R(3)G(4)B(5) and R(4)G(5)B(7). The image resulting from this procedure provided an excellent view of the paleochannels, which are highlighted in contrasting light colors with respect to the areas surrounding them. It is interesting to note that a Landsat image acquired from Digital Globe (**Figure 5A-C**) furnished comparable results, allowing a good visualization of the paleochannels. In the ASTER images (**Figure 6A**), the best results to reveal the paleochannels were obtained through linear adjustments of bands using the R(4)G(3)B(2) and R(4)G(5)B(6) compositions. The image achieved using this procedure was comparable to the ones obtained with Landsat images.

It is noteworthy that the paleochannels mapped using optical images show local interruptions loosing, either partly or completely, their continuity, which was not observed when the SAR products were analysed. Analysis of the paleochannels using QuickBird images (Image 2007, Digital Globe; **Figure 6B**) revealed that this is due to contrasts from savanna to forest. In general, the paleochannels display a distinctive brighter color due to the fact that they are mantled by savanna-like vegetation. In contrast, their surrounding flood plains display a forest cover. However, there are parts of the paleochannels where savanna has been replaced by forest (**Figure 6B**). In these instances, the paleochannels display the same color than their surrounding areas when analysed in optical images, which results in their apparent segmented nature.

The combined analysis of all remote sensing products evaluated herein led to the recognition of a northwestward oriented paleodrainage system consisting of narrow paleochannel (**Figure 5C**). These are commonly intercepted at several places by the modern channels, which are mostly southward/southeastward oriented (**Figure 5D**).

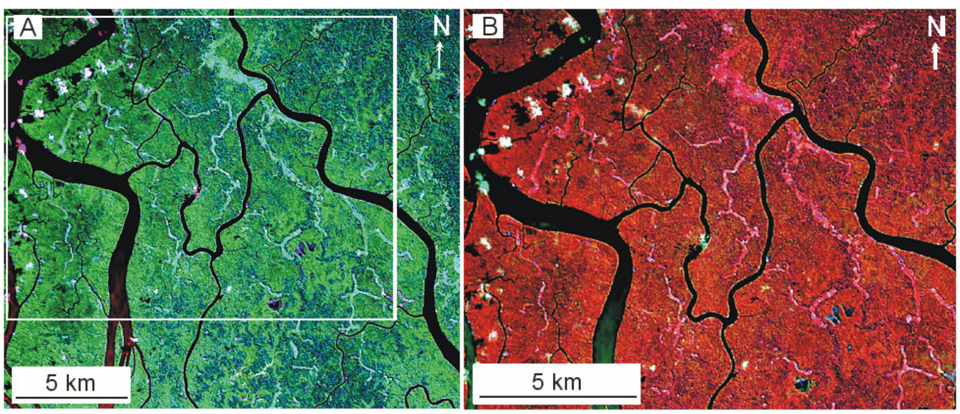

Figure 4 - A,B) Landsat R(3)G(4)B(5) and R(4)G(5)B(7) compositions, with paleochannels highlighted by brighter colors. The inside box in A locates **figure B**.

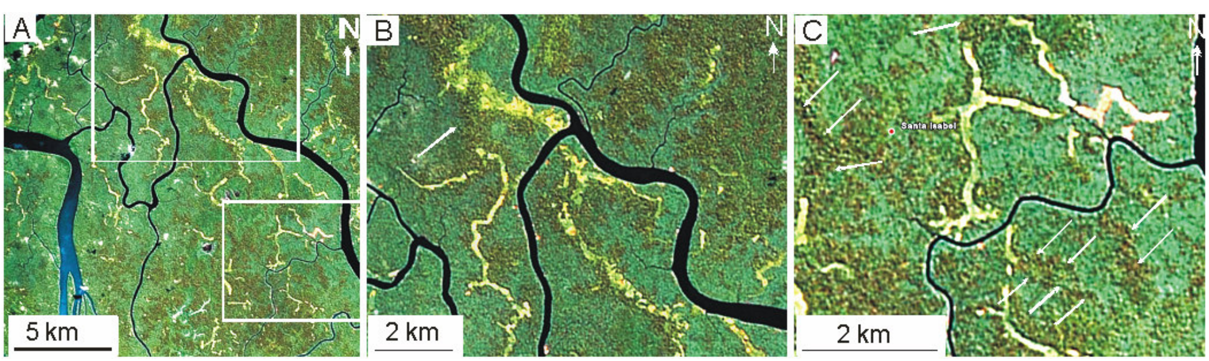

Figure 5 - A-C) Landsat images (Image 2007, Digital Globe) from the study area, showing most of the paleochannels in light yellowish green to white colors (arrows). A) A general view of the study area. B) A detail from the upper inside box. B) A detail from the lower inside box.

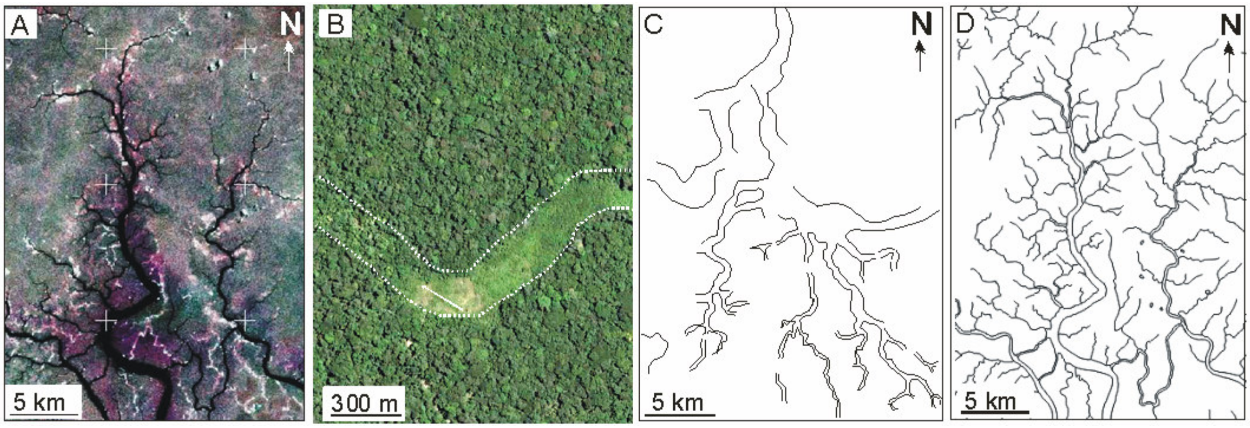

Figure 6 - A) ASTER image highlighting the paleodrainage composed of narrow paleochannels (white lines) in the study area (R(4)G(5)B6) composition). B) QuickBird (Image 2007, Digital Globe) image illustrating a paleochannel with a vegetation cover that grades from right to left from savanna to forest (arrow indicates the contact between these vegetation). Note that the areas surrounding the paleochannel are also dominated by dense forest. C) Map of the northwestward oriented paleodrainage in the area shown in A. D) Modern south/southeastward oriented drainage in the area shown in A.

4. Discussion and conclusion

Comparisons amongst several remote sensing products reveal that many paleochannels in forested areas of southwestern Marajó Island are missed if only SRTM products are taking into account. These are good only for mapping of paleochannels displaying digital elevations higher than surrounding areas due to a slight increase in terrain topography, as demonstrated in a previous work based on field surveys (Mantelli 2008). It has been proposed that many paleochannels in Marajó Island show a slightly convex up morphology due to differential compaction on contrasting sandy channel and muddy floodplain lithologies (Porsani 1981). Paleochannels that were abandoned more recently, did not have time to develop this positive relief due to the lack of burial compaction. Consequently, they are not recognized in digital elevation models.

Recently abandoned paleochannels present flatter surfaces relative to their ancient counterparts in the study area, having higher potential to be recognized using optical images or other SAR products. Based on the data presented herein, a model is proposed considering that as a channel is abandoned, it fills up with sediment that eventually reaches up to its top, becoming a site favorable to the growth of herbaceous vegetation. As the abandonment process proceeds, this vegetation is gradually replaced by forests.

The above proposed model leads to interpret that the paleochannels in the study area record a later phase of abandonment than those paleochannels from adjacent areas. The resulting vegetation contrast derived from this process was particularly useful to reveal these features on the remote sensing images analysed in this study.

Therefore, SRTM data must be combined with other radar and optical images in order to record precisely the several generations of paleochannels that occur in forested areas of Marajó Island. The drastic drainage inversion through time from a northwest to south/southeast orientation, is consistent with the tilting of southern Marajó Island, a process that might reflect the final establishment of the Pará River. Additional investigation including fieldwork must be undertaken in order to further characterize the paleochannels in the study area, and better analyse the evolutionary model suggested herein.

5. Acknowledgments

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