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Unraveling Quaternary drainages in forested areas of northwestern Amazonia applying DEMs-SRTM

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Abstract. This work is based on the application of SRTM data for delineating past morphologic features under dense rainforest in an Amazonian lowland area. Application of this tool in southwestern Marajó Island revealed an abundance of paleochannels with exceptional precision under dense vegetation cover, which would be barely detected using other available remote sensing products. Integration with fieldwork revealed that these paleochannels are related to palimpsest drainage systems developed during the late Pleistocene to Holocene. In addition, a topographic survey provided measured altitudes, which attested that the areas related to paleochannels are higher with respect to adjacent floodplains. This fact has determined the successful application of SRTM data for mapping of paleochannels in this area. Integration of the data presented herein with geological information led to suggest that the paleochannels in southwestern Marajó Island were fed by flows derived from continental areas located to the south of the study area, when the island was still connected to mainland. With island detachment due to tectonic fault reactivations, this drainage became abandoned on the landscape, becoming completely covered by forests. The use of digital elevation models (DEM) based on SRTM has high potential for unraveling morphological features from many other similar Amazonian areas with low topography and dense forest cover.

Palavras-chave: Ilha do Marajó, paleochannels, SRTM, topography, northern Brazil

1.Introduction

Paleochannels are abundant in eastern Marajó Island, where they have been recently characterized integrating remote sensing techniques and geological fieldwork (e.g., Rossetti and Valeriano, 2007; Rossetti et al., 2007; Rossetti et al., 2008a,b). These morphological features represent important relicts of past drainage systems that are useful for reconstructing past changes in the physical environment in lowland areas of the Amazon River. The prevalence of grassland savanna-like vegetation, locally know as *campos do Marajó*, in eastern Marajó favored the prompt delineation of paleochannels using optical images (e.g., Landsat). The continuity of these features westward, where dense forest dominates, remains to be demonstrated (Figure 1A).

An increasing number of works has demonstrated that digital elevation models derived from the Shuttle Radar Topography Mission (DEMs-SRTM) are particularly useful to characterize physical environments in Amazonia (Rossetti et al. 2005, Almeida Filho and Miranda 2007, Rossetti and Valeriano 2007, Rossetti and Góes 2008, Rossetti et al. 2007, Rossetti et al. 2008a,b). However, there are several problems concerning to the use of free access SRTM data in Amazonian areas with dense vegetation cover (e.g., Kellndorfer et al. 2004), because only data collected in the C-band frequency were released for South America. Thus, digital elevation models (DEMs) derived from SRTM data records terrain morphology, but with influence of tree canopy (e.g., Brown 2003, Sun et al. 2003, Walker et al. 2007).

Exploring SRTM data for terrain characterization in Amazonia for mapping of morphological features requires previous tests taking into account true topographic data collected in the field. This is due to the overall low relief of this area and the canopy characteristics, marked by trees that might reach up to 50 m high, but with a non-uniform distribution, including the occurrence of savanna areas. Under such conditions, vegetation contrasts might be mistaken as terrain topographic gradients.

The present work integrates DEMs-SRTM and topographic information collected during fieldwork, as well as geological data available in the literature, in order to test the potential of SRTM data for detecting morphological features related to paleochannels in a forested area of southwestern Marajó Island, and use these features for paleogeographic purposes. The results of this approach are of great significance to evaluate the applicability of SRTM data in low-lying Amazonian areas, as well as to characterize drainage systems that were active previously to the establishment of the modern environment. Studies of this nature are important for helping reconstructing the geological history of the largest fluvial system in the world, so far poorly documented.

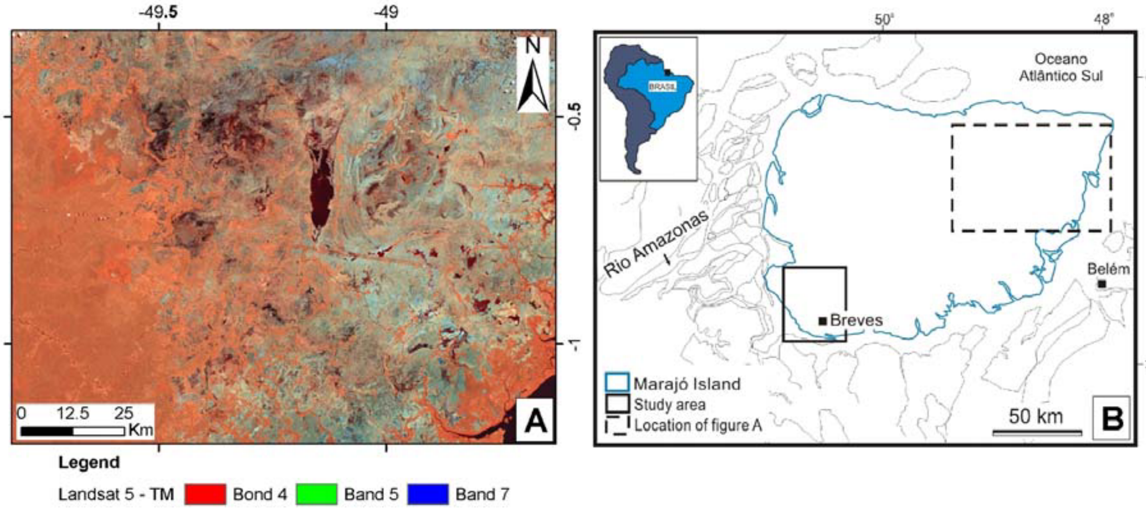

Figura 1 - A) Landsat 5-TM composition, illustrating the boundary between dense forest to the west (red color) and savanna to the east (greenish blue color). Note the numerous elongated and sinuous belts in the savanna dominated area, corresponding to paleochannels. Note also that these features are hardly distinghished in the forested side. B) Location map of the study area in southwestern Marajó Island, northern Brazil.

1.1 Study Area

Marajó Island, which encompasses nearly 50.000 km², locates in the northeast of the State of Pará (Figure 1B). This is a low-lying area with reliefs averaging 12.5 m. Climate is tropical, with mean annual temperature of 28°C and precipitation of 2,500 to 3,000 $mm.year^{-1}$. Vegetation consists of savanna, locally known as *campo*, and dense tropical *Ombrophyla* forest in the east and west side of the island, respectively (Bastos, 1984; Pires and Prance, 1985; Henderson et al., 1991; Maciel and Lisboa, 1993). Soils are dominated by poorly drained hydromorphic gleysol soils, with a few areas of podzols (Udult) (Radam 1974).

2. Material and Methods

This study was based on SRTM data acquired by the *National Aeronautics and Space Administration* (NASA) and *National Imagery and Mapping Agency* (NIMA), DLR (German Space Agency) and ASIA (Italian Space Agency) in February 2000 aboard of the spaceship *Endeavour.* The data used herein consist of original 90-m resolution (3 arc seconds) collected by synthetic aperture radar using C band (λ=6 cm). These data are unprojected, with geographic coordinates as reference units and WGS84 as reference ellipsoid and datum. Elevation is expressed in meters (integer).

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, as depicted below. This pre-processing is pointed as a key procedure to assure a better performance of the algorithms for morphometric analyses (Valeriano et al*.* 2006). The procedure followed a geostatistical approach, originally designed to construct DEM (Digital Elevation Models) from contour lines (Valeriano 2002). The method was adapted to SRTM-90m data structure through selection and detachment of squared sample areas (30x30 pixels) for geostatistical analyses. This procedure also includes a trend analysis to assure geo-stationarity of the data set submitted to the geostatistical analysis, by feeding variogram calculations with linear trend residues. The computational programs used for pre-processing were: ENVI (Research Systems Incorporation, 2002) for failure correction, sampling and ASCII data export; MINITAB® (MINITAB Incorporation, 2000) for trend analysis and calculation of residues; VarioWin (Pannatier 1996) for geostatistical analysis and Surfer (Golden Software 1995) for kriging interpolation.

The 30 m-resolution SRTM data derived from the above-described procedure were 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, though simple, revealed to be particularly useful for mapping networks of paleochannels under the dense forest cover of southwestern Marajó Island.

The topographic data were collected through combination of static and cinematic methods using high precision (i.e., few centimeters) Stratus L1-Sokkia and Topcon Hipe L1 and L2 GPS receptors, and one handheld receiver unit. One Sokkia unit was set as datum, while the other was used for mapping, which optimized data acquisition. Due to dense forest, data acquisition using high-precision GPS was only possible in areas where trees had been cut off. For this reason, the topographic survey was completed with classic topographic method based on topographic references previously established during the static-cinematic survey. A total of 88 topographic cotes were obtained for this study.

3.Results and Discussions

3.1 Paleochannel Characterization

The processing method of SRTM data used in this study revealed great efficacy for unraveling the morphological features that occur under the dense forest in southwestern Marajó Island, where other remote sensing products failed to do so (Figure 2A-B). Channel morphologies were promptly identified with basis on direct comparisons between the mapped features and the modern drainage systems. Likewise modern rivers, the features related to paleochannels that are preserved in southwestern Marajó Island consist of a network of elongated morphologies and related tributaries that are slightly sinuous and arranged into an anastomosing pattern (Figure 3A-B). The paleochannels, however, differ significantly in terms of dimension, morphology, and orientation, with respect to local modern channels. Hence, highly sinous, meandering paleochannels as long as 50 km and 1 to 3 km wide were recorded in the study area. Comparable large meandering channels are not present in the modern landscape of the study area (Figure 3C).

Additionally, the paleochannels are arranged into a complex network of superimposed channels, which indicate that, rather than representing a single drainage system, they record complex networks evolved in different times. While some channels are continuous, others are discontinuous, configuring a series of isolated segments, but which can be laterally correlatable within a channel belt.

An exceptionally well preserved drainage system consisting of main paleochannels with numerous smaller size tributaries occurs in the central part of the study area (Figure 4A). The main meander averages 2.6 km wide and 30 km long, and drains an area totalizing almost 80 km^2. This meander is relatively straighter southward, and after 15 km, it turns southeastward, continuing for more 18 km until to reach the southern margin of the island. Many tributaries are related to this paleochannel that is, in part, eroded by modern channels. In addition to the exceptional preservation, this paleomeander can be reached through an unpaved road, providing access to a northeast-southwest oriented trail into the forest, which was used for undertaking the topographic investigation planned in this study.

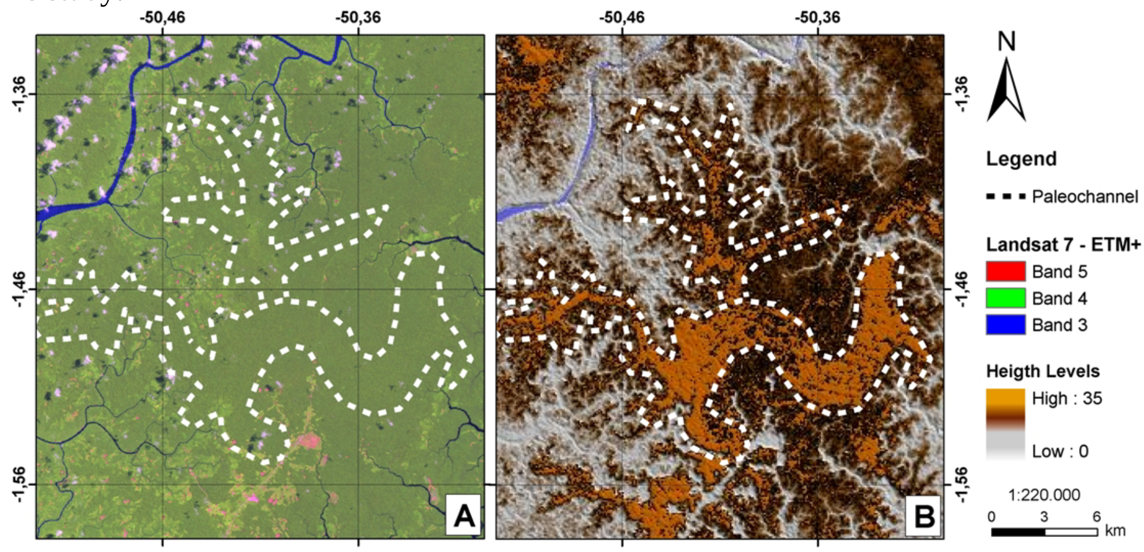

Figure 2. Comparison between Landsat composition (A) and SRTM data (B) from one location of the study area covered by dense vegetation, where an elongated morphological feature related to a paleochannel is present. Note that this feature cannot be seen in A (dotted lines indicate the paleochannel position), where the image displays a uniform green color due to vegetation cover. On the other hand, this paleochannel is promptly revealed in the DEM-SRTM data shown in B.

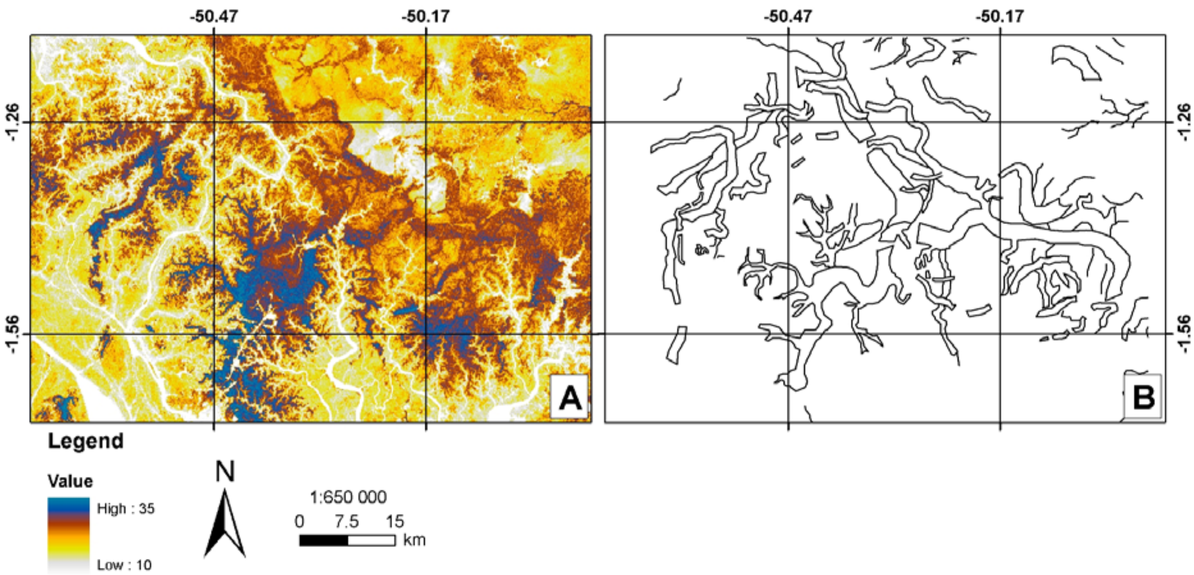

Figure 3. A) Properly processed SRTM data from the study area used to reveal and map the morphological features related to paleochannels. B) Paleochannel map derived from manual drawing over the SRTM data.

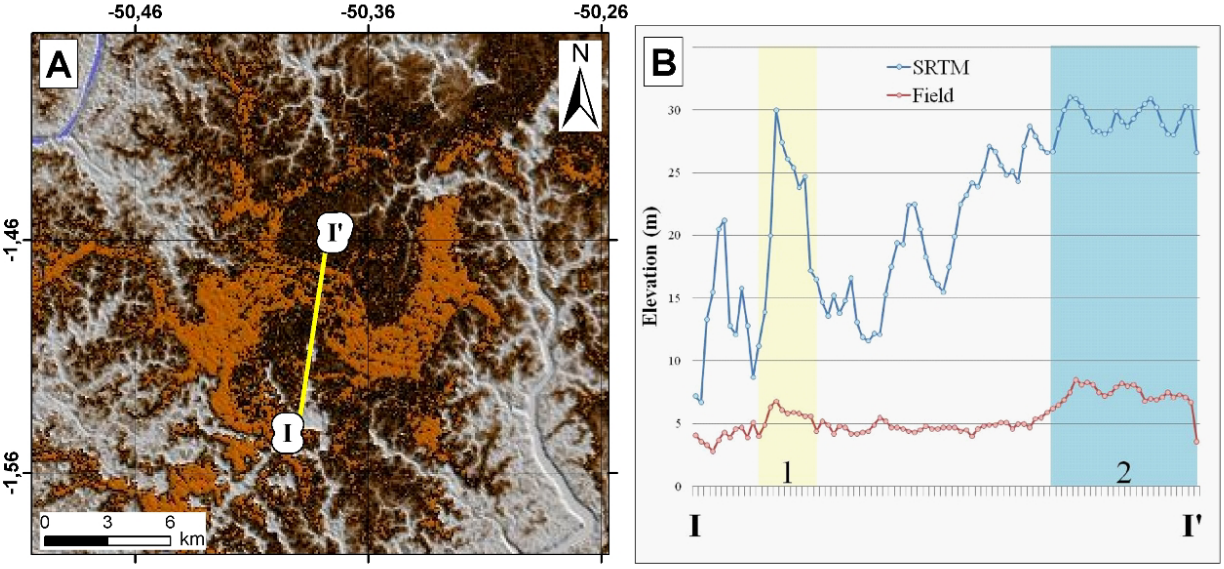

Figure 4. A) Detail of the large meandering paleochannel from the study area, with a well preserved network of tributaries (I-I' is the topographic transect shown in B). B) Comparison of the topographic profile derived from DEM-SRTM with the one resulting from direct field measurements, where 1=location of a tributary channel, and 2=location of the main channel.

3.2 Topography

DEMs derived from SRTM data suggest a topography that is systematically higher over paleochannel areas relatively to adjacent floodplains, with values ranging from 10-15 m to 25-30 m, respectively (Figure 4B). Topographic survey over a paleochannel area (Figure 4B) confirmed this pattern, though the relief revealed to be lower than the values indicated in the SRTM, as discussed in the following.

The degree of precision obtained with the applied topographic methods was of only 5 cm, which can be considered satisfactory for the present analysis. The data indicated altitudes of 2.7 to 8.0 m, characterizing a very low relief area, with absence of pronounced valleys or hills. Despite this overall low topography, there is a difference when floodplain and paleochannel areas are compared. Hence, the values are slightly lower over floodplains relative to paleochannels, with 2.7 to 6.8 m (average of 4.65 m), and 5.2 to 8.0 (average of 7.15 m), respectively. Although low, this topographic contrast was crucial for allowing defining the paleochannel morphology in the SRTM data, even considering the overlying dense forest.

The comparison between the profile obtained during the topographic survey with the one resulting from the SRTM data basis (Fig. 20) revealed considerable differences. The SRTM topographic values range from 6.2 to 30.0 m (average of 18.8 m) and from 26.6 to 31.0 m (average of 29.1 m) when floodplain and paleochannel areas are compared, respectively. Exceptions are localities corresponding to P12 and P27, which record large areas where vegetation has been extracted, thus the values obtained from topographic measurements are closer to those derived from SRTM data.

The topographic values indicated in the SRTM data are, in average, 16.7 m higher than the measured values. This corresponds to the average tree height in this study area. Hence, the topographic value derived from DEM-SRTM represents the sum of terrain height with canopy height. Despite canopy influence, both topographic profiles depicted in the figure 4B show similar patterns of topographic changes. Thus, DEMs-SRTM can be used to characterize paleochannel morphologies in this lowland Amazonian area.

3.3 Geomorphologic and Paleogeographic Implications

Likewise in the areas with savanna in eastern Marajó Island (Porsani 1981, Vital 1988, Rossetti and Valeriano 2007, Rossetti and Góes 2008, Rossetti et al. 2008 a,b), the data presented in this work revealed an abundance of paleochannels also in southwestern Marajó Island, dominated by dense forest. Integration of geomorphological mapping derived from DEMs-SRTM with geological information available in the literature provided the basis to further characterize these features, as well as discuss both channel dynamics and the possible factors related to their abandonment.

The positive relief recorded over paleochannel areas needs further explanation, as a channel consists primarily of a concave up depression that cuts down into floodplain areas. During abandonment, a channel fills up and ultimately bevels to surface. Sediment accumulation on levees might produce a positive relief around channels. This process, however, could not account for a concave up morphology across the entire paleochannel. Similar convex up paleochannels from eastern Marajó Island have been related to the less cohesive sandy nature of the channels deposits, relative to the more cohesive, muddy floodplain deposits (Porsani 1981, Rossetti 2008b). This typical concave up morphology was the major factor to have determined the recognition of the paleochannels in the forested southwestern side of Marajó Island.

The sinuous, and locally meandering, paleochannel morphology suggests moderately stable channels associated with muddy floodplains. In general, meandering forms in areas with mixed load channels with sand deposition along the channel bed and mud deposition from suspensions, which is consistent with our ongoing sedimentological studies that record deposits consisting of sands, but with mud interbeddings (Rossetti and Góes 2008).

The paleochannels vary in some aspects when compared to many modern channels in this study area. The fact that the channels became narrower from late Pleistocene to the Present could be related to a decrease in water table due to increased aridity, but this is not consistent with paleoclimatic reconstructions in Amazonia, which record an overall humidity increment during the Holocene (Baker et al. 2001, Sifeddine et al. 2001, Rossetti et al. 2004, 2005). Another possibility is that this change in channel dimension is due to water table oscillation related to an eustatic fall, a hypothesis also not supported by the overall rise in sea level proposed along the Pará coast during this period (Behling 2001, Behling and Costa 2000, Behling et al. 2001a,b, Vedel et al. 2006).

The decrease in channel dimension, on the other hand, seems to conform perfectly to a proposed tectonic origin for Marajó Island (Rossetti and Valeriano 2007, Rossetti et al. 2008a). According to models proposed by these authors, this island was detached from mainland due to fault reactivation, a process initiated in its eastern margin and continued to the south, with the establishment of the Tocantins and Pará rivers, respectively. This process might have reduced fluvial inflows into the island. The drainage was then reorganized, and a network of much narrower channels became established in southwestern Marajó, with many channels flowing from the island southward in the particular case of the study area.

4. Conclusion

This work demonstrates that MDEs-SRTM can be successfully applied for unraveling past morphologic features preserved under dense forested lowland areas of southwestern Marajó Island, which would be barely detected using other remote sensing techniques. Analysis of SRTM data from this area, integrated with geologic observations, led to relate the mapped features to paleochannels developed during the late Pleistocene and Holocene. As expected, altitudinal changes based on MDEs-SRTM in this area are greatly influenced by tree canopy. However, field topographic surveys revealed that the digital elevations reflect terrain variations in places where differences in tree heights are not significant.

Under this condition, MDEs-SRTM can be properly processed in order to highlight areas characterized by even small altitudinal contrasts, helping to delineate smooth morphological features related to past physical environments that were active before forest growth. Hence, the methodology applied herein revealed the features of interest with a high degree of precision, allowing mapping of complex paleochannel networks. Comparisons of past drainage with modern ones revealed differences that are of great significance for discussing channel dynamics through time.

Based on the results obtained from the study area, one can suggests that MDEs-SRTM might constitute a valuable tool for mapping and characterization of similar morphological features in other Amazonian lowland areas. This procedure might provide important information for reconstructing the history of fluvial dynamics of the Amazon drainage basin with a high degree of precision not yet approached using other techniques. Taking into account the large size, the difficult access imposed by the lack of roads and dense vegetation, as well as the high costs involved in undertaking fieldwork in this area, one should take advantage of the freely accessed MDEs-SRTM as a first approach for the recognition of morphological features that can be used for planning and optimizing future fieldwork aiming the reconstruction of Amazonian Quaternary landscapes.

Acknowledgements

This work was supported by FAPESP (Project# 004/15518-6). The Goeldi Museum helped with logistics during fieldwork.

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