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Mapping changes in the largest continuous Amazonian mangrove belt using object-based classification of multisensor satellite imagery

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A B S T R A C T

Mapping and monitoring mangrove ecosystems is a crucial objective for tropical countries, particularly where human disturbance occurs and because of uncertainties associated with sea level and climatic fluctuation. In many tropical regions, such efforts have focused largely on the use of optical data despite low capture rates because of persistent cloud cover. Recognizing the ability of Synthetic Aperture Radar (SAR) for providing cloud-free observations, this study investigated the use of JERS-1 SAR and ALOS PALSAR data, acquired in 1996 and 2008 respectively, for mapping the extent of mangroves along the Brazilian coastline, from east of the Amazon River mouth, Pará State, to the Bay of São José in Maranhão. For each year, an object-orientated classification of major land covers (mangrove, secondary vegetation, gallery and swamp forest, open water, intermittent lakes and bare areas) was performed with the resulting maps then compared to quantify change. Comparison with available ground truth data indicated a general accuracy in the 2008 image classification of all land covers of 96% (kappa = 90.6%, tau = 92.6%). Over the 12 year period, the area of mangrove increased by 718.6 km^2 from 6705 m^2 to 7423.60 km^2, with 1931.0 km^2 of expansion and 1213 km^2 of erosion noted; 5493 km^2 remained unchanged in extent. The general accuracy relating to changes in mangroves was 83.3% (Kappa 66.1%; tau 66.7%). The study confirmed that these mangroves constituted the largest continuous belt globally and were experiencing significant change because of the dynamic coastal environment and the influence of sedimentation from the Amazon River along the shoreline. The study recommends continued observations using combinations of SAR and optical data to establish trends in mangrove distributions and implications for provision of ecosystem services (e.g., fish/invertebrate nurseries, carbon storage and coastal protection).

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1. Introduction

Mangroves are a globally important coastal forest ecosystem that deliver numerous services for local people, store significant amounts of carbon (Donato et al., 2011), and act as habitat and nursery grounds for marine fauna, many of which are commercially important (Alongi, 2002, 2008; Glaser, 2003) and forest that mitigate coastal erosion (Kathiresan and Rajendran, 2005; UNEP-WCMC, 2006; Souza-Filho et al., 2006). To assess their status, several studies have generated maps of mangroves at regional to global levels (Saenger et al., 1983; FAO, 2005; Spalding et al., 2010; Giri et al., 2011), with these primarily utilizing aerial or optical remote sensing imagery (Green et al., 1998). However, the mapping has been compromised by the lack of consistency in the timing of observations, persistence of cloud cover and smoke haze in many coastal regions, and the complexity of the spectral response of mangroves arising from different species, growth stages, substrate types and tidal conditions (Souza-Filho et al., 2011). For similar reasons, the detection of change has remained a significant challenge. For these reasons, a number of studies have investigated the use of Synthetic Aperture Radar (SAR) for mapping and monitoring mangroves. The RADAM Brazil Project highlighted the potential of this technology for geomorphologic mapping, where GEMS 1000

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radar data were acquired over the Amazon region (Herz, 1991). Other studies (e.g., Proisy et al., 2000; Lucas et al., 2007) have also used SAR data for localized studies of mangroves, with these demonstrating additional potential for retrieving structural attributes and biomass.

For mapping mangroves, a number of techniques have been utilized including visual interpretation of airborne (Hertz, 1991) or satellite sensor data (e.g., Prost, 1997; Rebelo-Mochel, 1997; Souza-Filho and Paradella, 2003, 2005; and Souza-Filho et al., 2006), with most focussing on the use of optical data. Sub-metric and metric optical satellite images provided by recent satellite like Geoeye, Ikonos or Quickbird greatly improve thematic information on forest canopies as highlighted by Wang et al. (2004) and Proisy et al. (2007). But their use for regional or global mapping of coastal environments remains too much expensive and the archive is rather limited. Interestingly, the combination of optical and radar imagery often provides a good visual impression of the extent of mangroves as key elements (e.g., texture, form, size, color and patterning) can be recognized and interpreted for mapping (Souza Filho and Paradella, 2005; Rodrigues and Souza-Filho, 2011). However, the quality of interpretation depends on the experience and knowledge of the analyst (Lu et al., 2004) and the process is time consuming, particularly when mapping mangroves across large areas. Automated procedures (e.g., supervised classifications) provide a more quantitative and reproducible approach and, until recently, have largely been pixel-based. Green et al. (1998) compared different pixel-based approaches for mapping mangroves and conveyed that the main issue was the “granulated effect” observed in the derived maps, which was attributed to random variations in the intrinsic characteristics of the forest canopies and underlying surface (Lobo, 1997). Nevertheless, Souza-Filho (2005) successfully used a visual image interpretation of medium spatial resolution Landsat sensor data to generate the first regional map of mangroves in the Amazon-influenced coast of Brazil. Fromard et al. (2004) used a similar approach to detect major changes in mangroves in French Guiana from series of aerial and Spot images. It is to be noted that the first global map of mangroves computed using the same image analysis protocol was generated only recently i.e. 2011 through a pixel-based classification of approximately 1000 Landsat scenes (Giri et al., 2011).

Object-based approaches are a recent development, with these dividing the digital image homogeneous and spatially contiguous regions (Flanders et al., 2003; Walter, 2004). This reduces ‘granularity’ and facilitates better mapping and discrimination of classes (Lobo, 1997). These are particularly well suited to mapping mangroves, as these often form discrete units that are largely continuous in cover, relative homogeneous in terms of canopy properties, and often organized in zones that parallel the coastal margins. Object-based approaches also allow data from different sources (e.g., optical or SAR data or digital elevation models) to be integrated and can be used to compensate for gaps in times-series as a consequence of, for example, cloud cover. A limitation, however, is the definition of the Minimum Mapping Unit (MMU; Saura, 2002), which can be too large to allow inclusion of all areas of mangroves (i.e., isolated pixels or groups of pixels representing small areas or margins of mangroves may be omitted; Desclée et al., 2006).

This study aimed to utilize the benefits of both SAR data and object-based approaches for mapping and detecting changes in the extent of mangroves along the Brazilian coastline, with focus on an area southeast of the Amazon mouth, known locally as the Amazon Macrotidal Mangrove Coast (AMCC). For the study, Japanese Earth

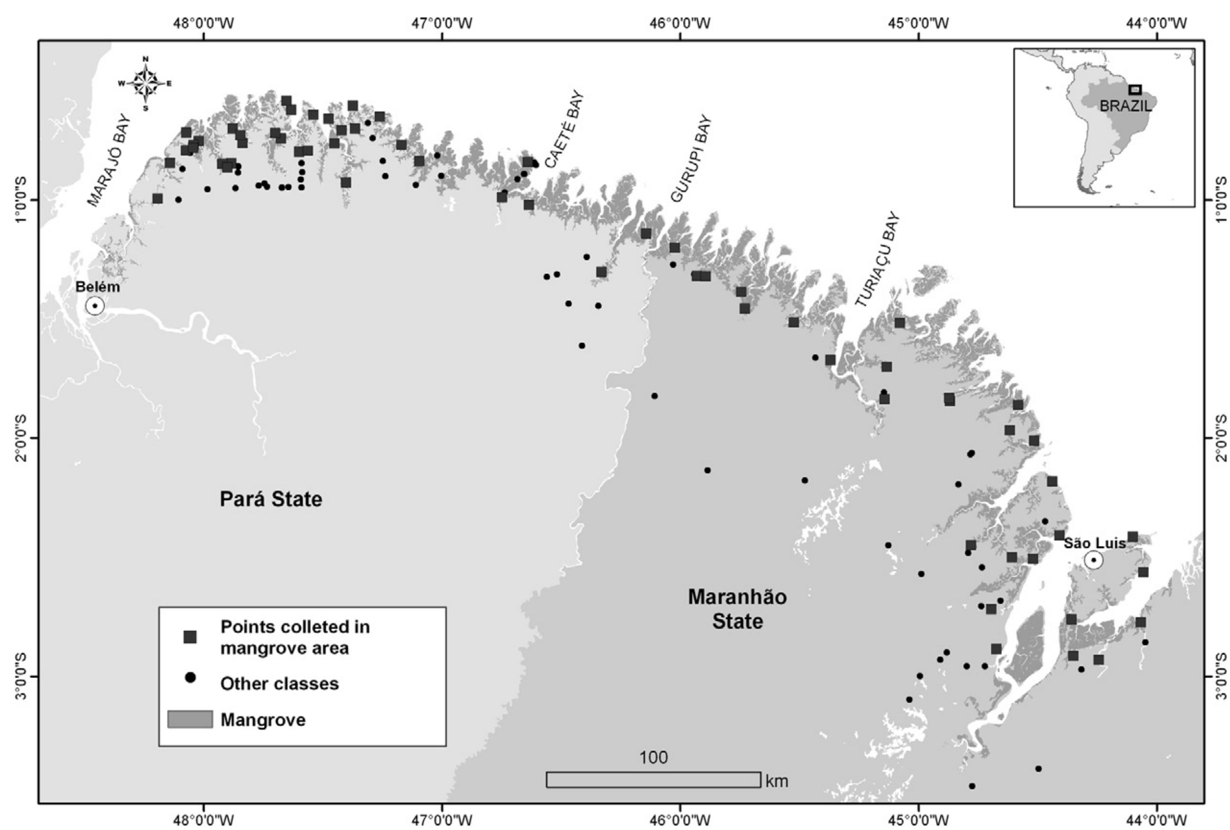

Fig. 1. Location map of the AMM coast between Marajó and São José Bay. See ground control points marked in the study area to validate mangrove classification and change detection.

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