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Mapping the water cover of a protected area in the Amazon using Sentinel 1A data

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Abstract

A large diversity of terrestrial cover is observed in the Amazon rainforest, which includes large areas prone to floods. These areas are globally important as they are humid. This research analyses the potential of SAR Sentinel 1 images as identification tools for hydric cover in conservation areas of the Amazon Biome in the state of Maranhão during the rainy season in the Amazonian region. Via Google Earth Engine (GEE), a collection of scenes from the mission Sentinel 1A was collected, referring to the comprehended period, January and June 2024. These scenes were submitted to mathematical bands in a GEE processing tool, which extracted the smallest pixel value observed each month. Through identification work on-site, the reference areas and the sampled areas were inspected before validation. A cut-off limit was defined to what is classified as water and as non-water after comparing to the targeted references the statistical samples observed on-site, and, to conclude, the records of pluviometric precipitation were evaluated for the analyzed area. The results show that the average backscatter values indicative of water coverage is approximately between – 24dB and -21dB and are, therefore, compatible with the samples found in the Brazilian Amazon. The chosen cut-off was -20dB, which achieved hitting a rate of 76,6%, allowing us to observe that the months with the biggest recorded precipitation (March and April) also correspond to the months with the largest extension of hydric cover in the analyzed area.

1. Introduction

The Amazon presents a diversity of terrestrial coverages, which include extensive floodplain areas, areas seasonally flooded during the rainy season (Ab'Saber, 2002), known as alluvial plains. These regions, because of their environmental relevance as humid areas detaining a hydric retaining capacity, are considered global RAMSAR sites and sum up nine localities in the Amazon (MMA, 2021). In these scenarios, monitoring these environments becomes relevant to their environmental management and sustainable use.

An efficient manner of identification and monitoring hydric coverage is via remote orbital sensing. The remote optical sensors system presents natural physical limitations when detecting floods during periods of constant precipitation or high cloud coverage, frequent during the rainy season in the Amazon region. The use of sensing systems that operate in a microwave band (also named RADAR - Radio Detection and Ranging - or SAR - Synthetic Aperture Radar) has been historically utilized in humid tropical regions to diverse ends, an example from the Amazon, highlighting the program RADAM BRAZIL, in the 1970s (Azevedo, 1971; IBGE, 2018), the program "French Guyana through the clouds" (Rudant, 1994) in addition to the programs Globe-SAR (Wooding et al, 1994) and SAREX-92 (Brown et al, 1996).

Globally, multiple initiatives aiming to map water coverage, specifically when those result from floods and wetlands in tropical zones, relying on the SAR sensors of band C, have been noticed since the 1990s. In the last few years, a growing number of studies surrounding the subject, productions from Germany, China, Italy, and India stand out (Liz and Ribas, 2022).

Taking into account that the parameters of water coverage are of great relevance in humid areas and that, currently, orbital microwave data is public and different techniques to detect a target, this research aimed to evaluate the capacity of this mission sentinel 1A in identifying variations in hydric coverage, during the amazonian rainy season, in the conservation area - Sitio Ramsar-, in the extreme northeast of the Brazilian Amazon.

2. Study area and data

2.1 Study area

The present research was conducted on the Baixada Maranhense (APA Baixada) conservation area, integrally inserted in the Amazonian Biome, that is destined for the sustainable use of its natural resources (Decree 11900/1991) (figure 1). The area studied is part of a roll of 9 existent Ramsar sites in the Brazilian Amazon, and it was recognized as such in 2000.

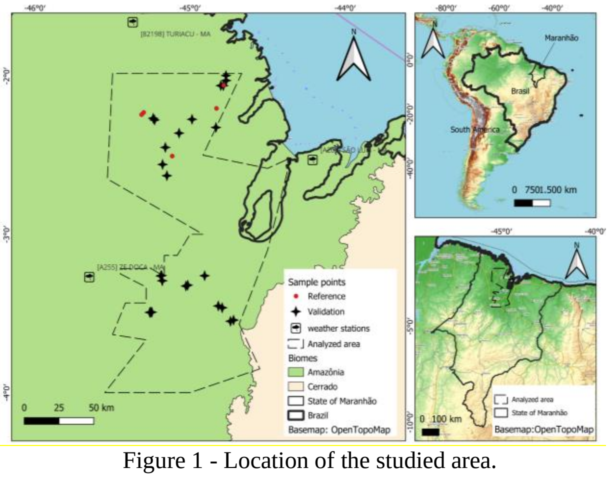

Figure 1 - Location of the studied area.

The studied area has an extensive flat relief, slightly corrugated, varying altimetrically between 20 and 55 meters (MARANHÃO, 2002). The lower areas are flooded during the rainy season, originating extensive lakes interconnected by a drainage system that connects channels to the lower river courses of the Mearim, Grajaú, Pindaré, and Pericumã rivers in addition to the influence of the tides (Feitosa, 2006).

The annual humidity average surpasses 80%, and the annual rainfall varies between 1700 and 1900mm (IBGE, 1998; EMBRAPA, 2013). The first eight months of the year concentrate the largest amounts of rain (Reschke et al, 2010).

2.2 Data and processings

As the main tool for acquisition and data processing, Google Earth Engine (GEE) was utilized as a source of orbital scenes from Sentinel 1A were selected, band C, polarization VH, interferometric wide (WI) level of acquisition, and the production type comprehending the period of January to June of 2024 (table 1). The use of polarizing VH, according to Magalhães et al (2022), in time series studies showed a greater coefficient of determination to the detection of hydric coverages in the Amazon. The Sentinel 1A was chosen due to its free data and temporal resolution. These scenes were distributed in a pre-processed collection (with noise removal, radiometric calibration, and terrain correction) made available in decibels (dB) concerning backscatter.

Table - 1 Scenes utilized in this research.

Date image (dd/mm/yyyy)	Orbit	Level
12/01/2024	Descending	GRD
24/01/2024	Descending	GRD
05/02/2024	Descending	GRD
17/02/2024	Descending	GRD
29/02/2024	Descending	GRD
12/03/2024	Descending	GRD
24/03/2024	Descending	GRD
05/04/2024	Descending	GRD
17/04/2024	Descending	GRD
29/04/2024	Descending	GRD
11/05/2024	Descending	GRD
23/05/2024	Descending	GRD
04/06/2024	Descending	GRD
16/06/2024	Descending	GRD

Several photographic records and aerial surveys were carried out in the field with RPA (Remotely Piloted Aircraft System) between March 25th and 30th, 2024. A total of 36 flooded areas (i.e, with water) were observed, that is, the presence of water cover (including floodable fields, dams, rivers, lakes, and others). Out of these 36 points, 6 locations were chosen as references, and another 30 were used for subsequent on-site validation. For the reference areas, the backscatter values for the selected orbital scenes on the different dates were evaluated, and the scene of 03/24/2024 was taken as the field reference scene.

The backscatter values were analyzed using basic statistics and in situ reference, where a separability threshold for the targets (water and non-water) was chosen. This technique has been widely used to detect water coverage through SAR images globally, with good results (Lis and Ribar, 2022). After applying the thresholding, a statistical cross-data validation was carried out, where the reference samples (used in the thresholding) were excluded, and the accuracy statistics were computed, considering:

$$Pa = 100 - \left(\frac{acc}{asc} * 100\right)$$

Pa: Success rate/ Percentage of success
Acc: Area with water coverage
Asc: Area without water coverage

The separability procedure between water and other targets was applied to scenes representing the months of the first half of 2024 in a GHG environment. The representative scenes corresponded to the ones resulting from minimum backscatter values for the VH polarization.

After obtaining the monthly water coverage, a comparison was made with the accumulated monthly rainfall records recorded by the conventional meteorological stations closest to the study area.

3. Results and discussions

For the date of the reference scene (24/03/2024), 6 points were observed, which presented a maximum coefficient of variation of 4.7% in their backscatter values. Average backscatter values varied between approximately -21 and approximately -24 dB. (table 2).

Table - 2. Backscatter values from different sampled locations.

Local	M (dB)	St	Var	CV
S. Helena (City/River)	-22,86	1,09	1,19	4,78
S.Helena (Wetland)	-21,21	0,43	0,19	2,05
Pinheiro (Wetland)	-24,00	0,81	0,66	3,38
Central do Maranhão (Wetland)	-23,00	1,02	1,04	4,44
Central do Maranhão (City/River)	-23,417	0,351	0,123	1,498
Mirinzal (City/River)	-21,924	0,596	0,356	2,720

Where M: Mean, St: Standard Deviation, Var: Variance, and CV: Coefficient of Variation.

When it comes to water coverage in the Amazon environment and with C-band sensors, the values obtained in Table 1 are close to other estimates in flooded areas in the VH polarization (Ferreira, 2018; Silva and Pestana, 2021; Magalhães et al 2022) for Sentinel 1A data. The multitemporal analysis also shows that throughout the semester, the locations present dynamics that allow inferring states of loss and gain of water coverage at the reference points (figure 2).

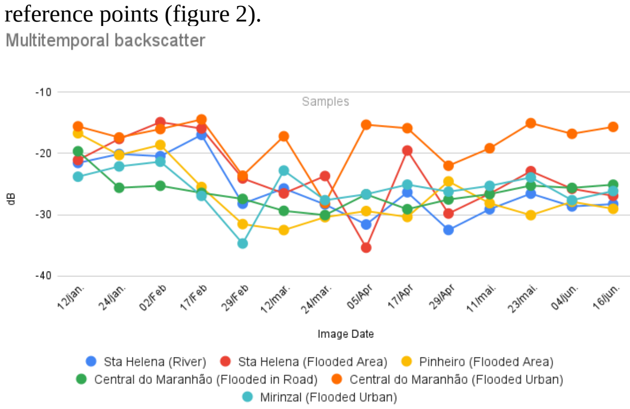

Figure 2 - Multitemporal backscatter for the sampled locations.

This change in the behavior of backscatter values is due to the dynamics of the local precipitation itself, which, when observing measurements from local surface meteorological stations, become more incident from February onwards (figure 3). This month, the dB values begin to show a decay pattern that suggests the presence of water and, in turn, greater backscattering of the SAR signal due to the peculiar characteristic of the water coverage (Bourgeau-Chavez et al, 2005; Jensen, 2009).

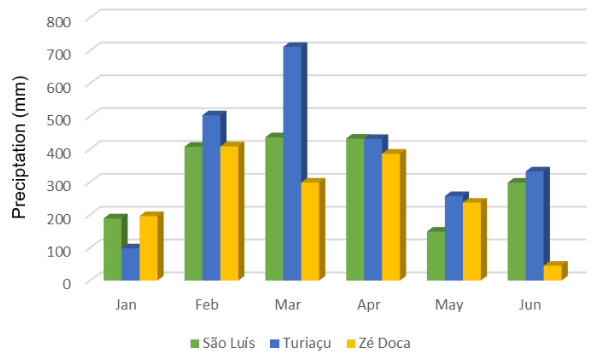

Figure 3 - Monthly accumulated rainfall (mm) in the study area was recorded at two reference stations.

Based on the behavior of the dB values (table 2), the value of -20dB was chosen as the cut-off threshold for separating water and non-water. The validation statistics for the presence of water in the reference scene showed an accuracy of 76.6% concerning the reference scene. Some of these areas could be inferred in situ, in the days following the passage of the reference scene (03/24/2024), highlighting the characteristic sign of the presence of water, that is, shades of black, gray, or close to black (figure 4).

Figure 4. Example of areas identified as having water coverage in the scene 03/24/2024 and confirmed on site.

For false-positive locations observed in the study area, that is, areas not previously identified as flooded but observed in the field as such, it is preliminarily important to highlight the behavior of precipitation observed in the days following the reference scene. Both meteorological stations in the study area show successive days with precipitations (figure 5).

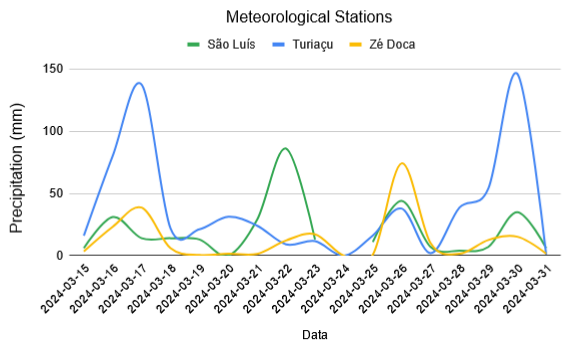

Figure 5. Distribution of daily precipitation on the days of the reference scene.

The -20 dB threshold allowed us to identify that the month with the greatest extent of water coverage was the month of April (~3,693 km²), followed by the month of March (~3,389 km²), as can be seen in Figure 6. Such months correspond to the ones with the highest rainfall incidence for the Turiaçu and Zé Doca stations.

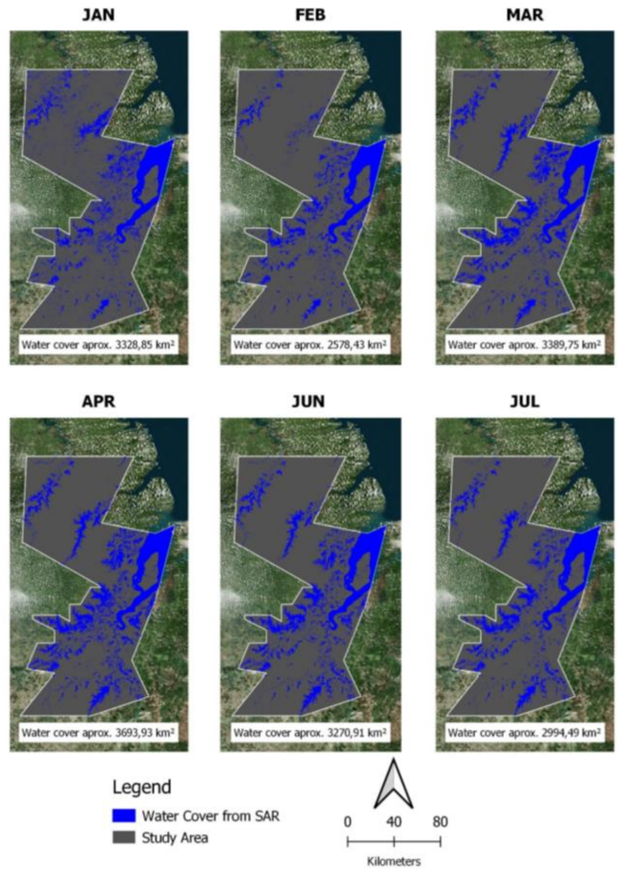

Figure 6. Monthly water coverage obtained for the study area.

Although January had the lowest rainfall recorded in both seasons, there was water coverage of the order of ~3328 km2. This scenario contrasts with the month of February, where the total precipitation recorded in the stations is higher than in January, but the extent of water coverage is lower than that recorded during the month of January

4. Conclusions

Through this research, it was possible to estimate the water coverage in a protected area of the Amazon during different periods of the rainy season in the region through the thresholding technique on scenes from the Sentinel 1A Sensor, obtaining, for the reference scene, a general accuracy of 76.6%.
The behavior of the backscatter values obtained in this research is close to other values obtained for water coverage in humid tropical zones and Amazonian environments when observed through C-band radar sensors.

In this research, the estimated extent of water coverage observed in January presents a discrepancy with the amounts of precipitation accumulated in the same month. For this situation, we suggest observing the precipitation from the previous month, namely December 2023, to verify whether there is evidence of the contribution of previously observed precipitations in a subsequent month. It is also important to evaluate whether and how dry periods affect backscatter values from water bodies.

It is also important to highlight that the absence of a greater number of surface meteorological stations and the lack of these within the studied area are limiting factors in the validation stages. For such validation, new alternatives must be considered.

The results found in this research corroborate the potential of data from SAR sensor systems as a means to obtain information from the earth's surface during periods of severe atmospheric conditions since the dB values are consistent with the literature and the relation between water coverage supply and precipitation in the months of February, March, April, May, and June appear to be coherent.

For future studies, it is important to compare such results with the ones found in other monitoring programs for global water coverage distribution.

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References

Ab’saber A. N. 2002. Base for studying ecosystems in the Brazilian Amazon. *Advanced studies* (16)45, 7-30. https://doi.org/10.1590/S0103-40142002000200002.

Azevedo, L. 1971. Radar in the Amazon. *Proceedings of the 7th International Symposium on Remote Sensing of Environment*, Center for Remote Sensing Information and Analysis, Ann Arbor, p.2303-2306.

Bourgeau-Chavez, L. L., Smith, K. B., Brunzell, S. M., Kasischke, E. S., Romanowicz, E. A.,Richardson, C. J. 2005. Remote sensing of regional inundation patterns and hydroperiod in the greater Everglades using synthetic aperture radar. *Wetlands* 25 176−191.

Brown, R.J., Brisco, B., D’iorio, M.A., Prevost, C., Ryerson, R.A., Singhoy, V. 1996. RADARSAT Applications: Review of GlobeSAR Program. *Canadian Journal of Remote Sensing*, 22 404-419. https://doi.org/10.1080/07038992.1996.10874664
complete satellite coverage.ESA Earth Observation Quarterly,

EMBRAPA – Brazilian Company of Farming Research. 2013. Final Report on the Ecological-Economic Macrozoning of the State of Maranhão. Embrapa Cocais, v.3, n2. 325f.
Feitosa, A. C. 1989. Morphogenetic evolution of the northern coast of Maranhão Island. *IOGCE/UNESP*: Master's thesis.

Ferreira, G. H. S. 2018. Identification of flood-prone areas in the southern portion of Roraima with the aid of Radar images. Master's Dissertation. University of Brasilia. Brasília.

Ferreira, N. S., Lima, A. M. M, Gomes, D. J. C. 2023. Vulnerability of wetlands and seasonal influence of rainfall in Eastern Amazon. *Geofronter*, (1) 9, 1-23. doi.org/10.61389/geofronter.v9i1.7366.

IBGE – Brazilian Institute of Geography and Statistics. 2018 . KNOW, MAP, EXPLORE: MEMORIES OF THE RADAM BRASIL PROJECT. *Library and Special Collections Management*.- Rio de Janeiro: IBGE, 2018. https://biblioteca.ibge.gov.br/index.php/biblioteca-catalogo?view=detalhes&id=2101614.

Jensen, J. R. 2009. *Remote Sensing of the Environment An Earth Resource Perspective*. São José dos Campos, São Paulo.

Liz, S. M. L. M., Ribas, P. R. 2022. Flood extent delineation using Sentinel-1 data as information source: systematic review of processing methods. *Brazilian Journal of Physical Geography*. (15)6, 3047-3076. doi.org/10.26848/rbgf.v15.6.p3047-3076.

Magalhães, I. A. L., Carvalho Junior, O. A. de., Guimarães, R. F., Gomes, R. A. T. 2022. Sentinel-1 time series analysis on Central Amazon floods. *Mercator (Fortaleza),* 21, 1-19 doi.org/10.4215/rm2022.e21019.

Maranhão. 1991. Estadual Decree 11900/1991 – Protected Area Baixada Maranhense. Available in: <https://documentacao.socioambiental.org/ato_normativo/UC/303_20100823_145738.pdf>. Acess from: 06 Jan. 2022.

MMA – Ministry of the Enviroment. Strategy for Conservation and Sustainable Use of Wetlands in Brazil. Brasília, 2018. < https://www.gov.br/mma/pt-br/assuntos/ecossistemas-/arquivos/estrategia_ramsar_final.pdf > Access from: 16 jun. 2024.

Rudant J.P. (1994) French Guyana through the clouds: first
Silva, F. S., Pestana, A. L. M. 2020. Mapping of the water cover of the micro-region of Baixada Maranhense with SAR Sentinel 1A sensor data. *Brazilian Journal of Remote Sensing*, 1(2), 58-71.

Wooding, M. G., Zmuda, A. D., Attema, E. 1994. An overview of SAREX-92 data acquisition and analysis of the tropical forest environment, In: Longdon, N. (Ed.). *Proceedings of the Second Euro-Latin American Space Days, European Space Agency*, Paris, ESA SP-363: 57-68.