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Assessment of Planet imagery use for wetland mapping in the Upper Paraguay Basin

Avaliação do uso de imagens Planet para o mapeamento de áreas úmidas na Bacia do Alto Paraguai

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Abstract

This study investigates the application of Planet/NICFI mosaics for the monthly mapping of surface water and other wetlands in the Upper Paraguay River Basin (BAP) from January 2021 to April 2024. Mapping was made using image classification techniques, based on machine learning and cloud computing processing. The study demonstrated the potential of these images to provide detailed information on the water surface in the BAP, especially in the plateau region, for the identification of new water bodies. Furthermore, the surface water mapping was satisfactory to monitor the monthly variation of the flood pulse in the floodplain. However, the study identified spectral limitations of the Planet sensor, with lower sensitivity for mapping wetlands beyond the water surface. The results indicate that the Planet/NICFI monthly mosaics are a promising tool for monitoring the water surface in the BAP, especially to add detail at the local scale when compared to existing mappings with other orbital images. The temporal analysis of the data also revealed that 2023 was the year with the highest volume of water in the period studied, while the first months of 2024 indicate a strong drought trend, showing the potential of the adopted processing flow as a tool for early detection of drought and flood trends.
Keywords:
Pantanal, Supervised classification, Google Earth Engine, NICFI mosaics, Flood pulse.

Resumo

Este estudo investiga a aplicação dos mosaicos mensais da Planet/NICFI para o mapeamento da superfície de água e demais áreas úmidas na Bacia Hidrográfica do Alto Paraguai (BAP) para o período de janeiro de 2021 a abril de 2024. O mapeamento foi realizado por meio de técnicas de classificação de imagens, baseada em aprendizado de máquina e processamento com computação em nuvem. O estudo demonstrou a capacidade dessas imagens em fornecer informações detalhadas sobre a superfície de água na BAP, especialmente na região de planalto, para a identificação de novos corpos d'água. Além disso, o mapeamento de superfície de água foi satisfatório para

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monitorar a variação mensal do pulso de inundação na planície. No entanto, o estudo identificou limitações espectrais do sensor Planet, resultando em menor sensibilidade para o mapeamento de áreas úmidas para além da superfície de água. Os resultados indicam que os mosaicos mensais da Planet/NICFI são uma ferramenta promissora para o monitoramento da superfície de água na BAP, especialmente como forma de adicionar detalhes em escala local quando comparados aos mapeamentos existentes com outras imagens orbitais. A análise temporal dos dados ainda revelou que 2023 foi o ano com maior volume de água no período estudado, enquanto os primeiros meses de 2024 indicam uma forte tendência de seca, mostrando o potencial do fluxo de processamento adotado como ferramenta para detecção precoce de tendências de seca e inundações.
Palavras-chave:
Pantanal, Classificação supervisionada, Google Earth Engine, Mosaicos NICFI, Pulso de inundação.

I. INTRODUCTION

The Paraguay Hydrographic Region (RH-Paraguay), or the Brazilian portion of the Upper Paraguay Basin (BAP), one of the twelve Brazilian hydrographic regions, is located in the States Mato Grosso and Mato Grosso do Sul, and occupying an area of approximately 362,000 km². BAP is divided in two main geomorphological units: the Plain area, which is equivalent to the Pantanal biome; and the Plateau area, composed in parts of the *Cerrado* (80%) and Amazon (20%) biomes (Figure 1A).

The Plain region is considered the largest continental wetland on the planet, recognized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) as a Natural Heritage of Humanity and Biosphere Reserve since 2000 (UNESCO, 2000). The Pantanal is a stronghold of biodiversity and is, proportionally, the most preserved Brazilian biome. Additionally, it is a biogeographic convergence zone between the domains of the Atlantic Forest, *Cerrado*, Amazon and *Chaco* (Junk et al., 2006). The Pantanal plain presents a unique dynamic of horizontal flood diffusion, called "flood pulse", in which the seasonal flooding can reach an area of up to 70% of the plain, resulting in a complex of unique landscapes that allow the coexistence of both aquatic and terrestrial fauna and flora (Alho; Sabino, 2012; Brasil, 1979; Resende, 2008).

The *Planalto* region, which makes up the BAP, currently has more than 60% of its area designated for agricultural use. According to data from MapBiomas Collection 8 (MAPBIOMAS, 2023), native vegetation has been reduced by approximately 40% since 1985 (Figure 1B), with a loss of over 5 million hectares. The remaining vegetation in this region is predominantly savannah, concentrated in areas of permanent preservation, legal reserves and more rugged terrain. Among the threats and drivers of degradation from the basin as a whole, one can mention the deterioration of springs, especially due to the lowering of the water table, because of excessive water use and the lack of riparian forests in the drainage headwaters (Oliveira; Calheiros; Hamilton, 2019; Roque

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et al., 2016). An additional problem was the installation of small hydroelectric power plants, drains and gold mining activities along the rivers (Cunha et al., 2023).

Although distinct, the two sub-regions are interdependent since all the rivers that flow into the Paraguay River along the Plain have its sources in the BAP Plateau. Therefore, to understand the flooding of the Pantanal, one must also consider the area of the springs on the Plateau, the origin of the water and sediment that arrives and remains in the Plain (Assine et al., 2015).

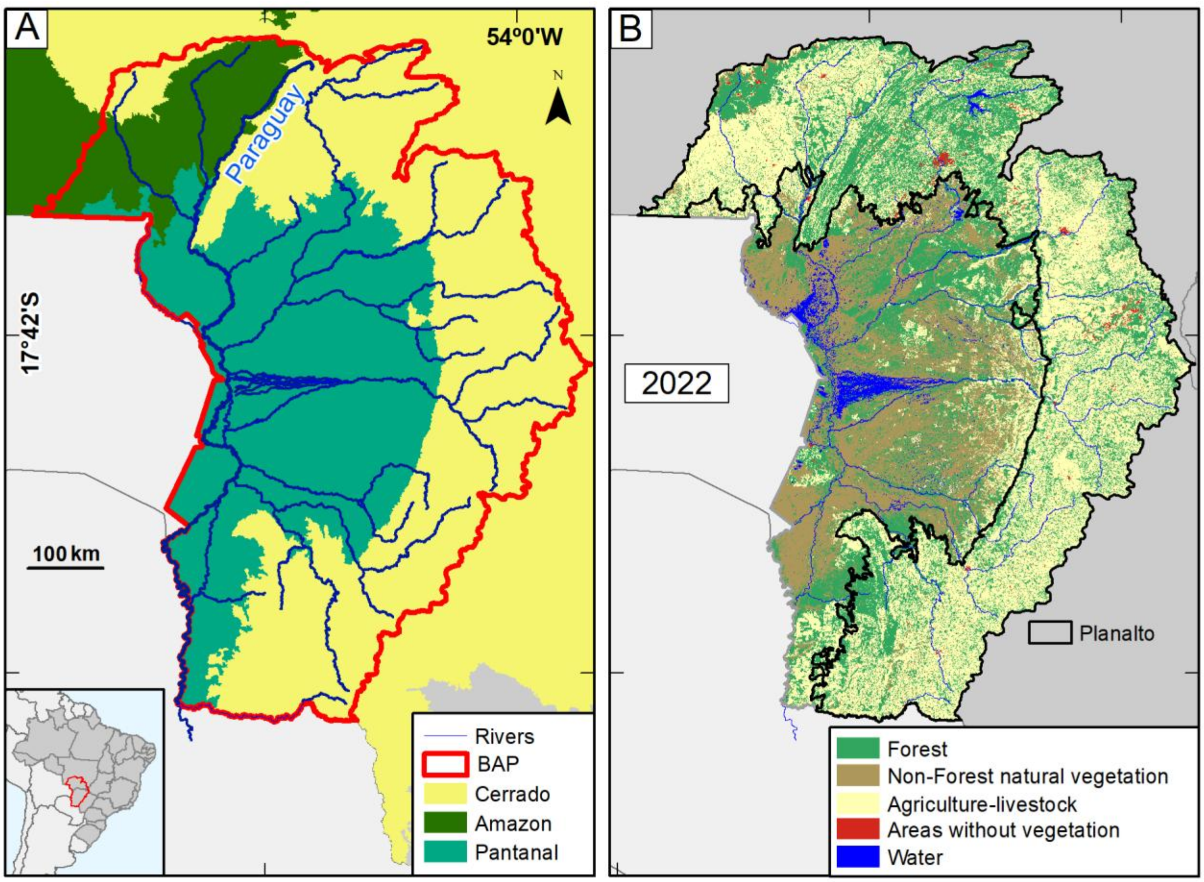

Figure 1– Location of the Upper Paraguay Basin (BAP); A) Distribution of brazilian rivers and biomes in the basin; B) subdivision of the plain and plateau regions; Land cover and use map for the year 2022 according to Mapbiomas (2023).

Earth observation sciences experienced significant advances with the new data sources and processing infrastructure. One example is the incorporation and use of nano-satellites in water studies and spatial analyses of time series, improved by automated data processing. These satellites, which are smaller in size and weight (1–10 kg) compared to traditional satellites, are designed to orbit in numerous constellations, with the aim to overcome temporal resolution gaps and offering a higher spatial resolution (Carvalho Júnior, 2018; INPE, 2011). The largest current nano-satellite constellation is that of Planet Labs, with more than 200 PlanetScope sensor

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systems in orbit (Strick et al., 2019). Despite documented limitations regarding spectral resolution and calibration between the constellation's sensors (Frazier; Hemingway, 2021), Planet images are meritorious to monitor seasonal events (Valman et al., 2024). Regarding the study and monitoring of water resources, Planet images have already been used in several research projects, such as the quantification of sediment load and flow (Strick et al., 2019), water level monitoring (Ehret et al., 2021; Karaman, 2022), bathymetric studies in shallow waters (Poursanidis et al., 2019), monitoring of lagoon flood dynamics (Cooley et al., 2019) and water quality (Mansaray et al., 2021).

To explore the spatiotemporal data from nano-satellites, alternatives such as image processing using cloud computing and machine learning are promising (Barbosa; Novo; Martins, 2019; Ramos et al., 2023). Cloud computing represents an innovation for geo-processing, especially in studies that require the manipulation of large data volumes or orbital images. This technology optimizes time and allows the application of different coverage scales and studies which have not yet been made (Barbosa; Novo; Martins, 2019; Carvalho Júnior, 2018; Gorelick et al., 2017).

The BAP is home to a diversity of wetlands distributed across the Plateau and Plain sub-regions. Considering the importance of mapping and monitoring these resources, the incorporation of new orbital data sources and processing flows represents a gain in spatial and temporal information for these areas (Ramos et al., 2023). Following this line of thought, the objective of this study is to map monthly time series of wetlands in the BAP with high temporal and spatial resolution images and cloud processing.

II. MATERIALS AND METHODS

The mapping and data processing method was guided by sub-regions, considering that in the Planalto there is a predominance of water occurrence in the form of perennial rivers, dams and reservoirs, while in the Plain there is a predominance of wider and intermittent rivers, in addition to seasonally flooded areas. Thus, the focus on the Plain was mapping those areas affected by the flood pulse, whether of the flooded vegetation or the water surface layer, while on the Plateau the mapping referred to the water surface of the rivers in the basin, for both periods from January 2021 to April 2024.

The processing involved supervised classification based on the Random Forests (RF) machine learning algorithm (Breiman, 2001) within the Google Earth Engine (GEE) cloud computing platform, as adapted from the methods used in Souza et al. (2020) and suggested by Ramos et al. (2023). The processing involves four main steps: sample collection and training; supervised classification of the algorithm; noise removal via application of

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data filters; and generation of frequency and total area statistics. Each sub-region followed a specific processing flow as illustrated in the flowcharts at Figure 2.

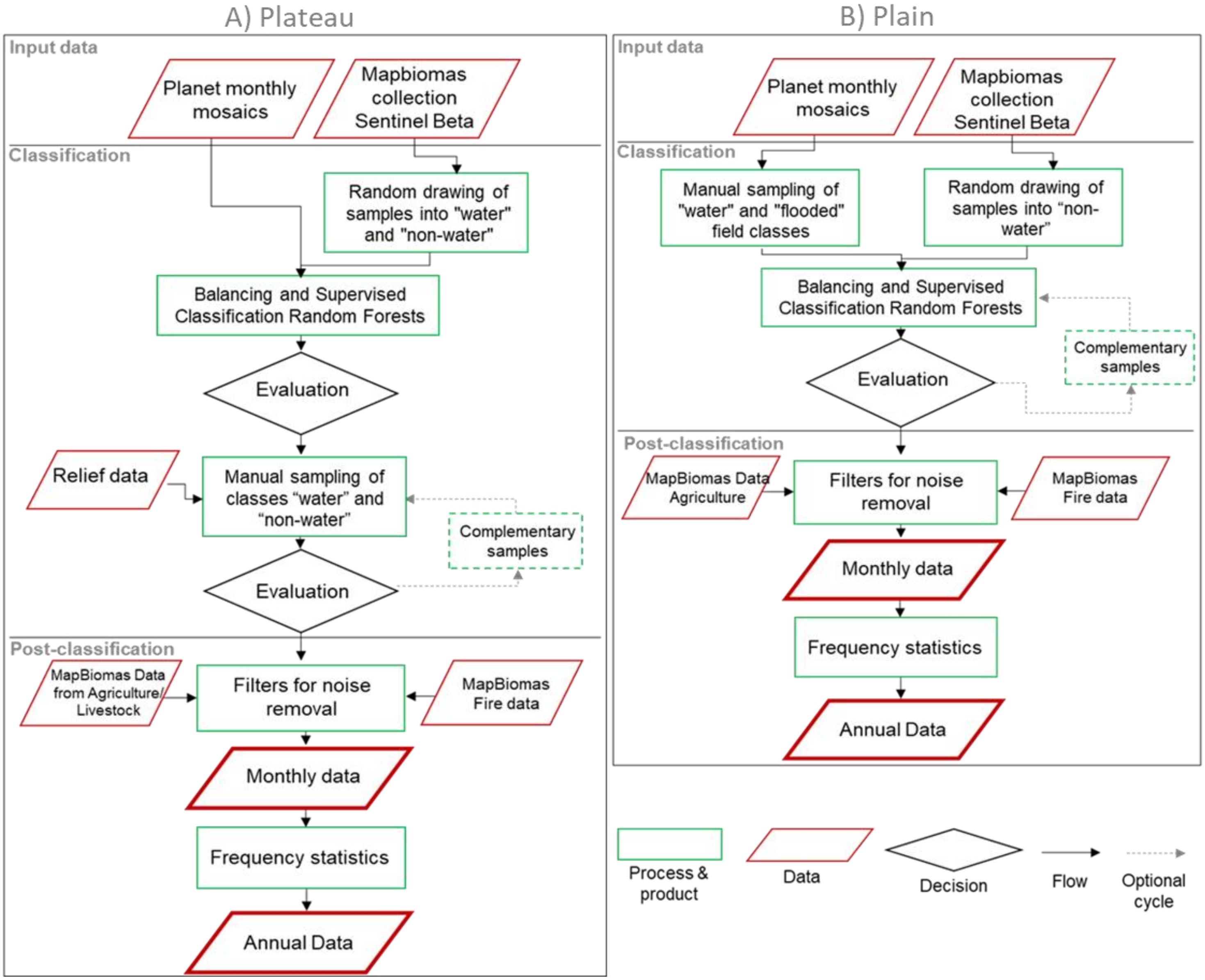

Figure 2 – Flowchart of materials and methods used within the GEE platform for the Upper Paraguay Basin (BAP); A) Flowchart applied to the Plateau region; B) Flowchart applied to the Plain region.

Input data

Through the Norway's International Climate and Forests Initiative - NICFI program (NICFI, 2025), monthly mosaics obtained with daily Planet images have been available for public access since January 2021. These mosaics guarantee cloud-free imaging of the entire tropical region, with a spatial resolution of 5 meters in the red, green, blue and near-infrared (NIR) bands (Planet Labs PBC, 2024). They can be accessed on the GEE platform and were used as the basis for mapping.

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Another input data for processing were the annual land use / land cover maps from the MapBiomas project from the Sentinel 2 satellite (Beta Collection), with a spatial resolution of 10 meters. Stable pixels,i.e., pixels that did not show class changes over the years mapped by MapBiomas, referring to the classes of 'water', 'flooded field' and other 'non-water' classes were selected and guided a sample draw for training the classifier.

Based on visual interpretation of the mosaics, manual samples were also collected from 'water', 'flooded field' and 'non-water' areas, especially in seasonally flooded areas. Manual sample collection was also performed within the complementary sample collection flow to generate new versions of mapping. The training samples consisted of 2000 randomly selected points for each class 'water', 'flooded field' and 'non-water'.

Classification

After collecting samples based on the Planet/NICFI mosaics, the RF classifier was trained. RF generates a series of decision trees built by regressions based on the spectral behavior of the samples (Breiman, 2001). The classifier was then applied to all monthly mosaics, qualitatively labeling each input pixel in relation to its respective class. As for the Plateau area, SRTM (Shuttle Radar Topography Mission) relief data were also inserted into the classifier's training feature space, and the pixel output classes were 'water' and 'non-water'. For the Plain, the output classes were 'non-flooded', 'water' and 'flooded field', the latter referring to flooded areas covered with herbaceous vegetation in the aquatic and terrestrial transition zones (Cunha et al., 2023).

After the first mapping result, data was evaluated through visual interpretation and, when necessary, entered a reinforcement learning cycle, which involves improving the quantity and quality of samples, that is, to increase with complementary samples of the different patterns of flooded and non-flooded areas, with the aim to improve a better discrimination of the targets and produce maps with lower commission and omission errors (Olofsson et al., 2014).

Post-classification

After the conclusion of the RF processing, some filters were applied to remove noise in the post-classification process. Initially the spatial mode filter was applied to reduce the salt and pepper effect of the classification, in addition to removal of isolated pixels. Afterwards, data from the MapBiomas project (2023) were used to reduce the commission of the classifier's gross product, with the fire scar data from the Fire Monitor (based on Sentinel 2) and the agricultural data from the land cover/land use maps of MapBiomas Collection 8 (2023). This step was necessary due to difficulties to discriminate some features from the spectral and radiometric limitations of the PlanetScope sensor images.

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Once the monthly maps were generated and the noise removed, statistics on the mapped area and flood frequency were calculated. The frequency data was essential to generate annual maps and data, i.e., maps that represent areas flooded for at least six months each year.

Mapping validation was performed by visual interpretation on screen of all mapped dates based on Planet/NICFI mosaics. For the Plateau region, visual validation considered additionally high spatial resolution images available in the Google Earth software database (Google LLC, 2023).

The maps and statistics generated were also analyzed in comparison with auxiliary public data covering the BAP region, produced by the MapBiomas project. The annual water surface data for the Plateau, made with Sentinel and Landsat images, were extracted directly from the project platform. The monthly water surface and flooded field data for the Plain, made with Landsat images, were available by MapBiomas (Collection 8) upon request after contact and requisition for the data. There is no monthly public data based on Sentinel images for the BAP. These auxiliary data were used to visually and quantitatively compare the results of the mapping made with Planet/NICFI mosaics.

III. RESULTS AND DISCUSSION

Processing of mosaics

Some regions presented systematic noise, especially due to confusion with areas of burn scars and exposed soil in the context of agricultural management. To mitigate this problem, data from areas mapped as burn scars and agriculture, made available by MapBiomas (2023), were used to remove the improper classifications of 'water surface' in the Plateau region. It was observed that the commission error occurred more frequently in certain areas than in others, corroborating studies as those by Valman et al. (2024), who pointed out a major difficulty of machine learning classifiers applied to Planet images in regions with high target diversity, such as urban and anthropic areas. Furthermore, variations in harmonization were identified across the pixels that make up the monthly mosaic, in line with the observations of Frazier & Hemingway (2021) who discuss the challenges of radiometric resolution and calibration among the satellites of the PlanetScope constellation, resulting in the lack of standardization of pixel values in large regions of interest. The Planet mosaics have the red, green, blue and near-infrared bands, while the Landsat 8 satellite can capture the spectral signal of the same Planet bands and seven additional wavelengths.

Despite these limitations, it is important to emphasize the importance of the production and accessibility from Planet/NICFI mosaics, including those associated with the high processing performance of cloud computing

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platforms, which generates the results discussed below. These are the first high spatial resolution water surface maps for the entire Brazilian limit of the BAP (Figure 3). Figure 3 illustrates areas for comparison between mapping performed with data from both the Planet and Landsat satellites, highlighting the information gain provided by spatial resolution. In section A, the mapping of a tributary from the *Rio Coité* River on the Plateau is presented, in addition to features of abandoned meanders. In section B, the map with Planet data improves details of the water surface in the low-water sections of the *Rio Taquari* megafan. In section C, abandoned water channels along *Rio Paraguay* are evident.

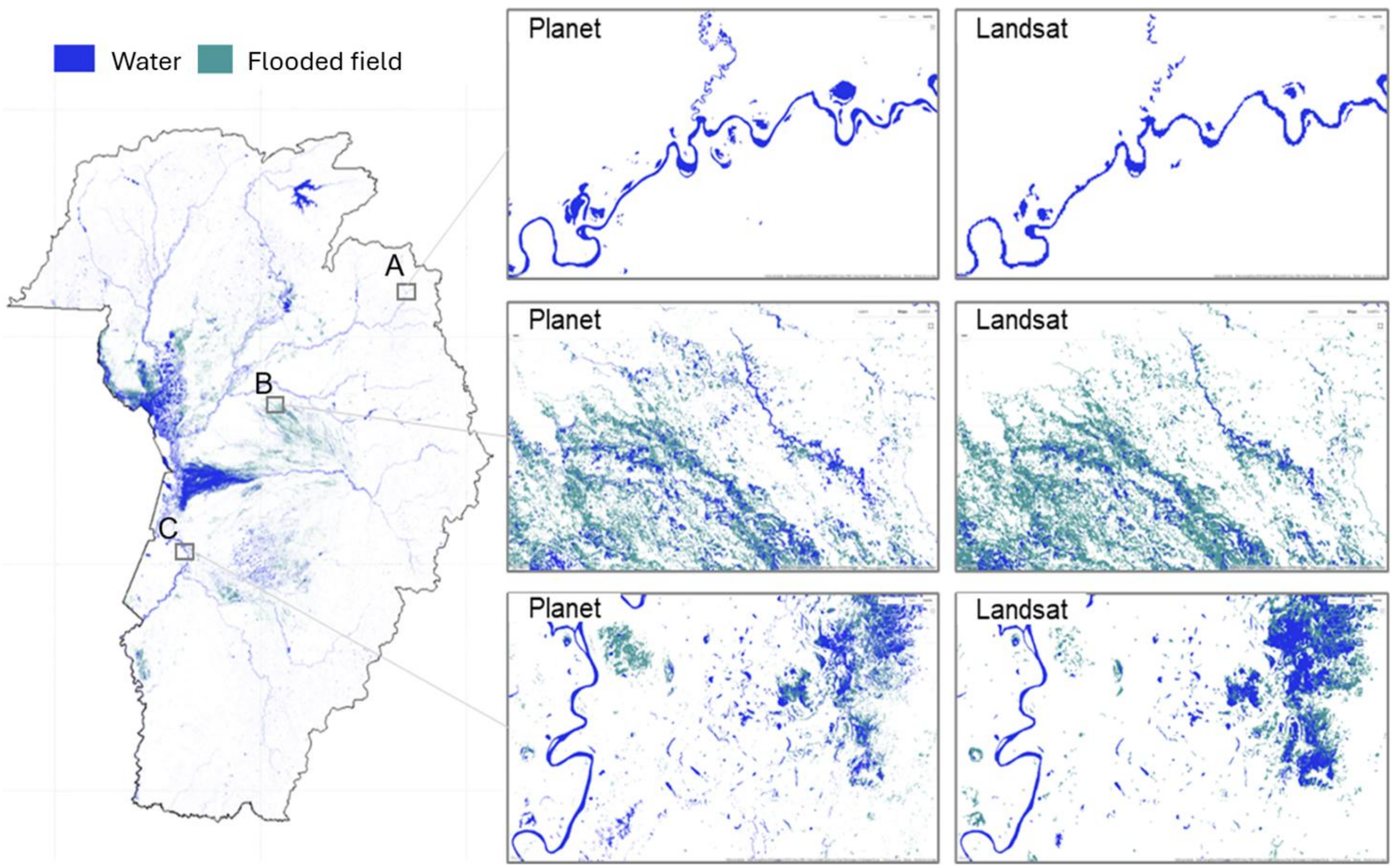

Figure 3 – Mapping result and comparison between Landsat (MapBiomas, 2023) and Planet products for the Upper Paraguay Basin (BAP). In blue is the Water, in light green the Flooded Field and in White non-mapped areas.

Mapping the Plain

In the Plain, monthly water and flooded field data are essential for mapping the flood pulse. A comparison between these two classes with the monthly MapBiomas data, generated with Landsat (30 meters of spatial resolution), a significant discrepancy is observed between the total mapped area, especially in the months of the first semester of each year analyzed, with a greater discrepancy in wetter years, such as 2023

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(Figure 4A). However, when the data is individualized by mapped class, one observes that the divergences are related to the flooded field class. Analyzing only the values of the 'water' class, a high correlation and alignment of the flood pulse mapped by both sources is noted, with an area increase on Planet images (Figure 4B).

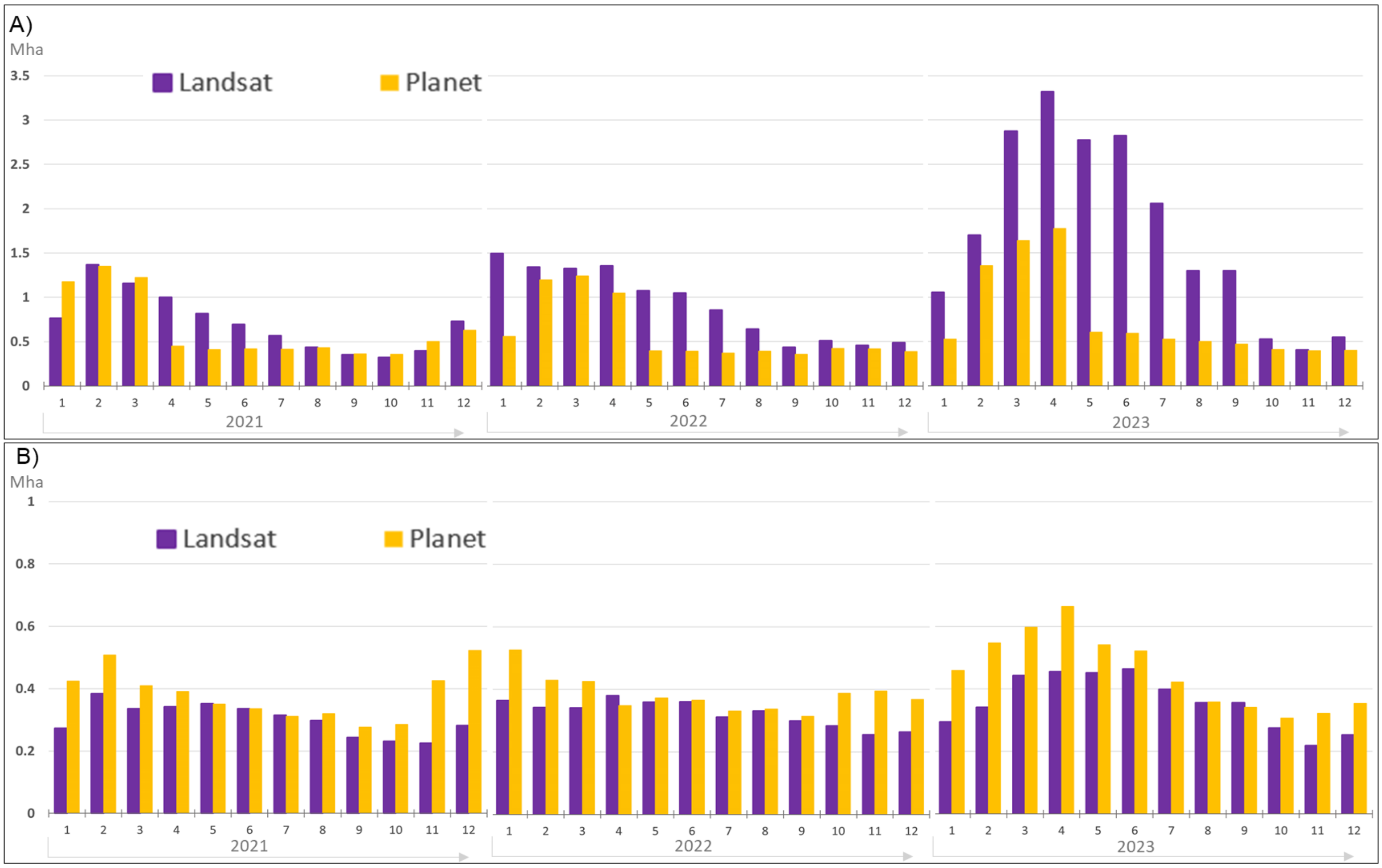

Figure 4 – Comparison of the area of the classes mapped with Landsat (MapBiomas, 2023) and Planet products for the Upper Paraguay Basin (BAP); A) Sum of the area considering the classes 'water' and 'flooded field'; B) Sum of the area considering only the 'water' class.

These mapping differences between the two sensors were mainly due to the spectral resolutions of both Planet and Landsat satellites. The water surface can be well mapped in Planet images, especially due to the difference in reflectance between the near-infrared and green bands. However, the moisture in the middle of the vegetation, in the area called 'Flooded field', does not show a consistent mapping, which is better discriminated in Landsat 8 images. This is probably due to the spectral limitation with the absence of shortwave infrared bands (SWIR 1: 1.57–1.65 µm and SWIR 2: 2.11–2.29 µm) in the Planet/NICFI mosaics, and present in Landsat. This allows an improved differentiation of areas with mixed targets, especially for the identification of flooded vegetation, allowing more assertive mapping (Gao, 1995; Xu, 2005; Chandrasekar et al., 2010).

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As a result, there is an inconsistency to mapping areas of flooded vegetation. During flood months, there are well-mapped regions and others with a commission of the flooded field class in areas of bare soil. Figure 5 shows the mapping result and comparison with Landsat map for a flood month, April 2023. The flooded field class (in green) presents a larger amount of mapped area than the water class (in blue) in the Planet map. However, much of the excessive flooded field map is commissioned with soil areas, while the water surface shows a good correlation with the satellite image.

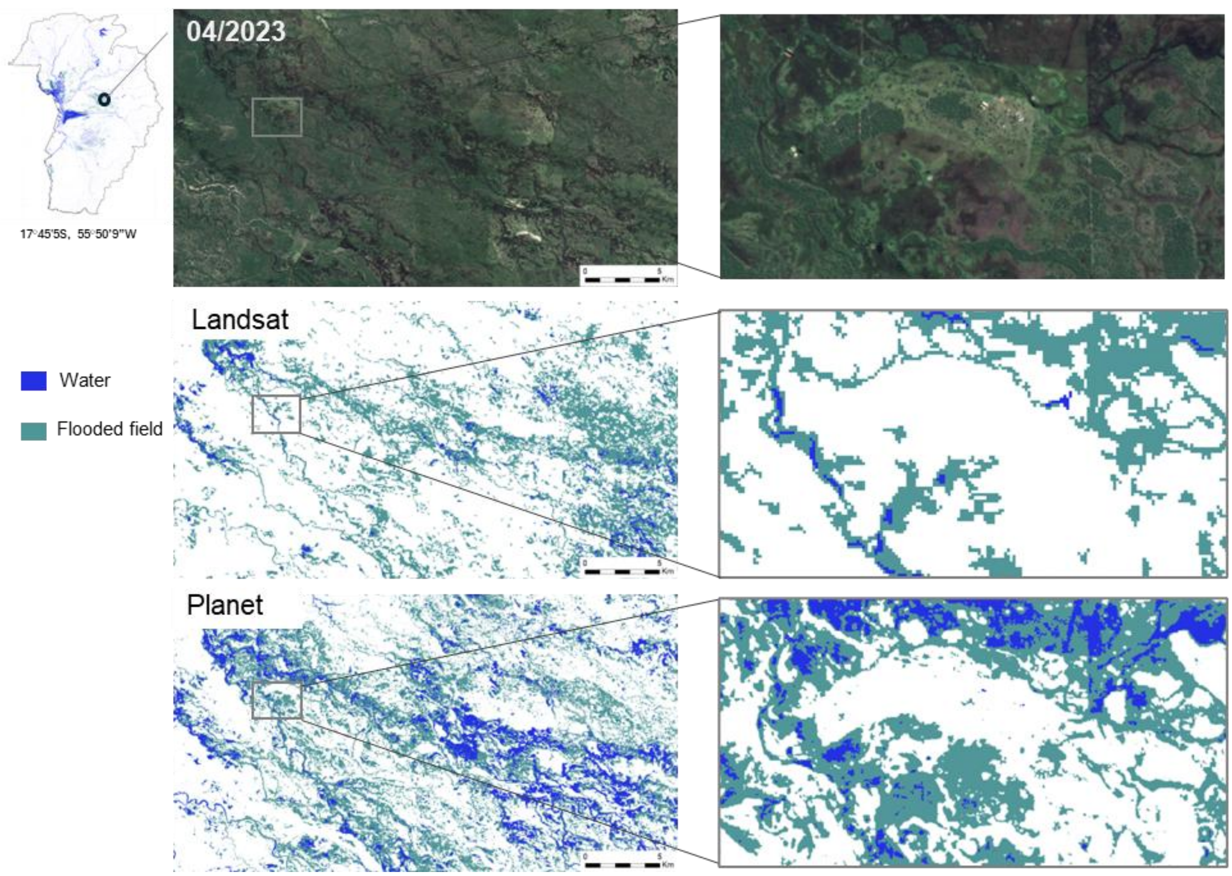

Figure 5 – Areal Comparison of classes mapped with Landsat (MapBiomas, 2023) and Planet products for BAP Plain in commission areas of the 'flooded field' class. In blue the Water classification, in light green the Flooded Field classification and in White are unmapped areas.

At the same time, sections with the greatest presence of permanently flooded vegetation, such as areas close to *Rio Paraguay*, are missing in the mapped 'Flooded field' class. Figure 6 exemplifies this relationship. When compared to the Landsat, the Planet classification highlights areas of water surface (in blue), but fails to map extensive areas of aquatic macrophytes (flooded field in green) in the area gion of the Pantanal Mato Grosso National Park. Therefore, the use of the monthly classification for the Pantanal Plain made with Planet images is recommended, referring only to the 'water surface' areas, as they presented an improvement in

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regard to the mapping with Landsat. Additionally, it presents a coherent spatial and temporal consistency in relation to the Pantanal flood pulse within the observed period.

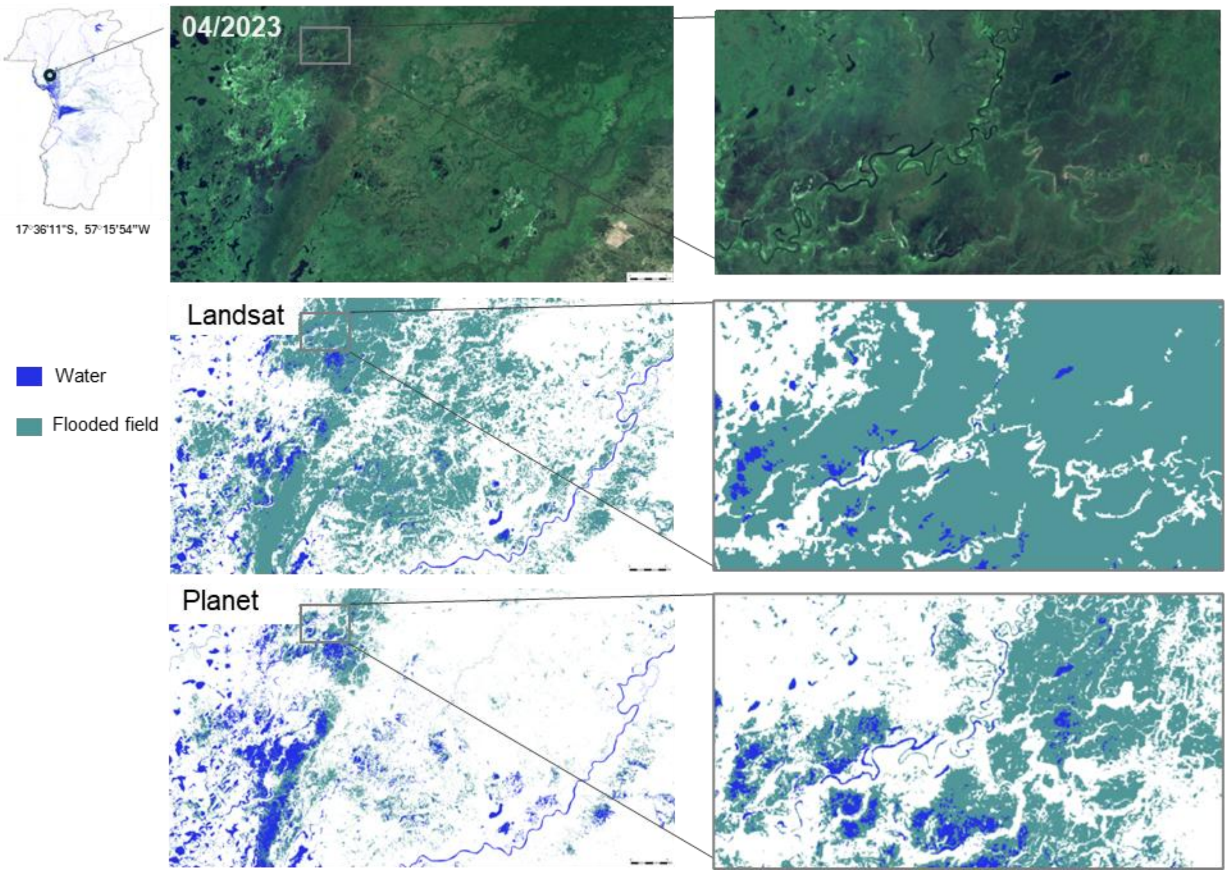

Figure 6 – Areal comparison of classes mapped with Landsat (MapBiomas, 2023) and Planet products for BAP Plain in sections where the 'flooded field' class is omitted. In blue the Water classification, in light green the Flooded Field classification and in White are non-mapped areas.

Analyzing the water surface data for the period from January 2021 to April 2024, one observe that the flood peaks and drought occurred between the months of October to April and May to September, respectively. The year 2023 had the highest observed flood, reaching its peak in April with more than 660 thousand ha of water surface mapped, while in April 2024 this figure was only 430 thousand ha of water (Figure 7), a reduction of 35% compared to the previous year.

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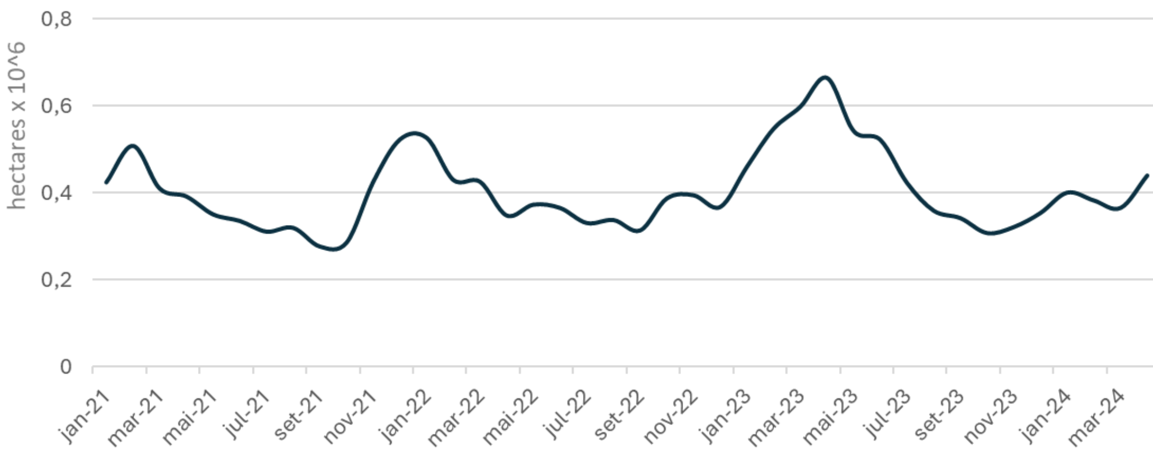

Figure 7 – Monthly water surface area mapped in the Upper Paraguay Basin Plain (BAP) with Planet/NICFI using monthly mosaics of Planet/NICFI for the period January 2021 to April 2024.

Despite its limitations to detect flooded fields, the mapping derived from Planet sensors has a great potential as a tool to monitor and consequently generate alerts about the flow of floods and droughts, considering the water surface. The release of water surface mapping data in the Pantanal (Dias et al., 2024) generated national and international repercussions, with warnings of extreme drought that the biome would face in 2024. Another evidence also reinforced the vulnerability of the Pantanal plain to changes in flood regimes in the BAP, such as the water level of *Rio Paraguay* in 2024, recorded by the Navy in Ladário (Mato Grosso do Sul): this river reached its lowest level ever measured since 1900, at the mark of 62 cm below the reference level (Jeronymo, 2024). This highlights the potential of mapping and disseminating products with more detailed temporal resolution to provide early warnings for extreme situations.

Mapping of the Plateau

Regarding the Plateau area, it is important to highlight that the monthly mapping presented excessive noise due to commission with areas of bare soil in rural areas. Therefore, considering the pattern of water bodies in this region: perennial and embedded rivers, dams and reservoirs, the annual data (with a monthly frequency equal to or greater than six months), with monthly mosaics of Planet/NICFI images was considered the best approach to map and analyze the water surface in this region. Figure 8 summarizes the construction of the annual data for the Plateau region, since the sum of the monthly data, which considers frequencies from 1 to 12, tends to include commission spots from the classification. When the frequency filter is greater than or equal to six (annual data), much of the noise is removed due to the temporal inconsistency of the commission areas, while the features of interest are highlighted.

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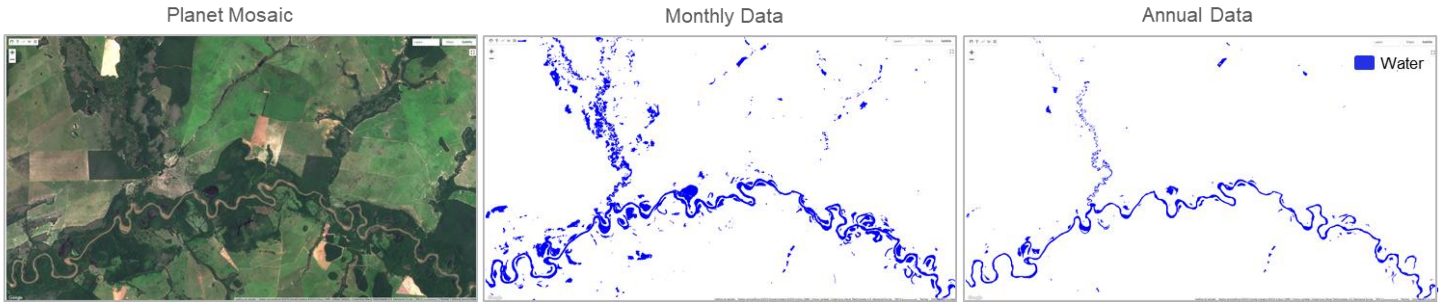

Figure 8 – Comparison of the sum from the monthly and annual classification for the Upper Paraguay Basin (BAP) Plateau region.

A gain of at least 3 thousand hectares of mapped water surface was observed when compared to other annual reference mappings made with Landsat and Sentinel 2 (both from the MapBiomas project) for the same area (Figure 9).

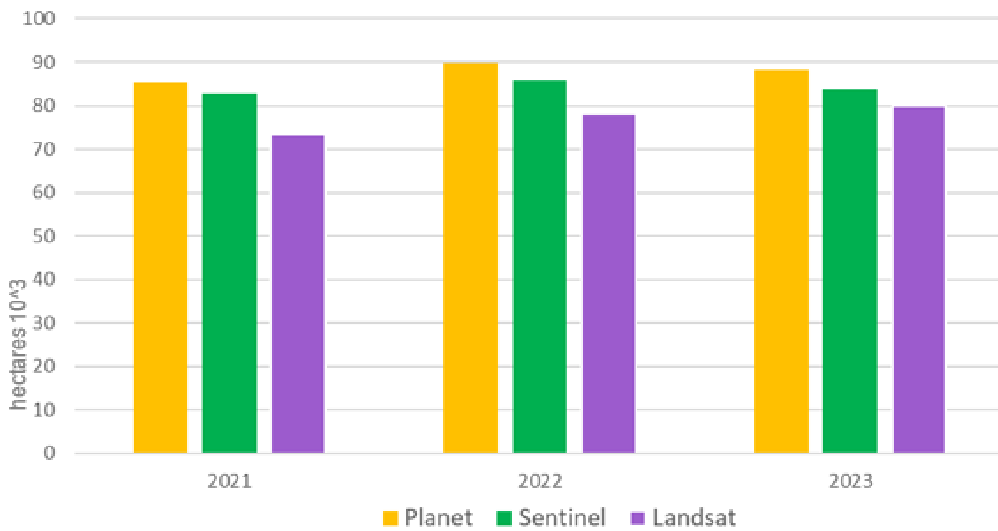

Figure 9 – Comparison of the annual water surface area mapped in the Upper Paraguay Basin (BAP) plateau with Planet, Sentinel and Landsat products.

The gains are mainly in the delimitation of riverbeds and in the delimitation of small dams, lakes and natural watering holes in pasture areas. This is due to the spatial resolution of the Planet data (5m) that allows the visualization and inclusion in the maps of these new water surface areas, and there is less generalization in the contours of rivers and water bodies. Figure 10 shows an example of information gain, when compared to the Landsat product, in the mapping of the Juba River and in detailing of the extension of a Small Hydroelectric Power Plant (PCH). Thus, considering the difference in the mapped area, it would be reasonable to say that, when using the Planet data in the Plateau, it is possible to map at least 3.1% more area than with other sources. This value is the result of the net balance between the gain in area due to the inclusion of new features and the loss due to the lower generalization of the pixels with such spatial resolution.

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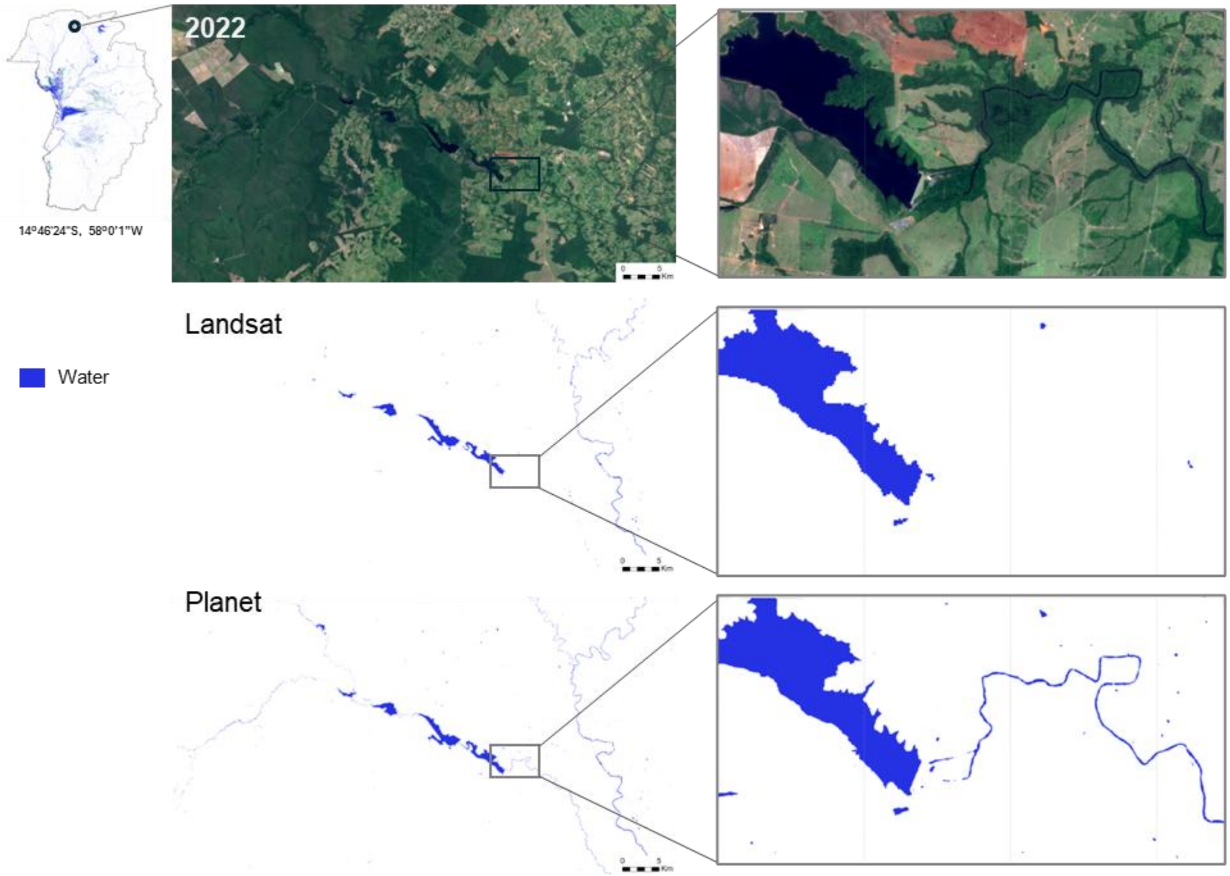

Figure 10 – Comparison of the area from classes mapped with Landsat (MapBiomas, 2023) and Planet products for the BAP Plateau, highlighting the new mapped features and less generalization of the water surface class.

IV. CONCLUSIONS AND SUGGESTIONS

The use of Planet images provides gains to map small bodies of water and monitoring rapid hydrological dynamics, while data from Landsat satellites maintain advantages in long-term multispectral analyses. The combination of both can optimize hydrology studies at multiple scales.

The free availability of Planet satellite images and high-performance tools, such as Google Earth Engine, is a significant advance for the free availability of remote sensing data. These characteristics allow greater accessibility to perform analyses and to understand the dynamic of environmental processes. The main challenge to use Planet/NICFI monthly mosaics, is its spectral resolution limitation, which makes it difficult to differentiate targets and apply spectral indices. Furthermore, the radiometric resolution requires the removal of classification noise, and there are difficulties to establish temporal consistency in the data from environments with large target diversity. Such factors could limit its use in very large regions, as they require an intensive manual validation and noise removal work. Therefore, the local approach stands out as the most recommended

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RA'EGA, Curitiba, PR, V.63, n.2, p. 98 – 115, 8/2025
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approach for the use of this data, as the manual effort of inspection and adjustment becomes viable, in addition to facilitate the development of a mapping validation protocol.

The mapping of the Plateau region indicated a great potential to identify water surface sections, especially for generating annual data that highlights the occurrence of water body features. However, it did not prove promising for a monthly analysis approach of the spatiotemporal behavior of these water surfaces. New areas were identified, mainly small water surfaces, in addition to improvement of detailed features already mapped with other data sources. For the BAP Plain, the monthly flood mapping stood out regarding the identification of water surface areas. However, for the 'flooded field' class, it did not perform well compared to existing Landsat-based products.

It is concluded that Planet/NICFI mosaics represent a valuable tool for monitoring small targets and highly seasonal events, thanks to its spatial resolution and monthly frequency. Its integration with cloud processing platforms enables large-scale analyses, although they are more effective when applied in localized contexts. This synergy between open data, accessible computational tools and machine learning methods can contribute to advances in Earth observation, providing subsidies for continuous flood monitoring and supporting actions adapting to climate change.

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