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Identifying Unnatural Vegetation Patterns in Brazil Using GEDI and TerraBrasilis Data

Introduction

Human land-use activities in Brazil often leave distinctive "fingerprints" on the landscape – geometric clearings in otherwise natural vegetation that stand out as unnatural patterns. These features are especially evident in flat, lowland regions where **deforestation and large-scale agriculture** have expanded. Such clearings frequently occur near rivers or lakes but not right at the water's edge, because Brazilian environmental law requires landowners to leave buffer strips of native vegetation along waterways [1]. This report combines data from NASA's **Global Ecosystem Dynamics Investigation (GEDI)** LIDAR mission and Brazil's **TerraBrasilis** platform (PRODES deforestation polygons) to locate and visualize five example sites in Brazil meeting the criteria: **flat terrain, unnatural vegetation patterns (e.g. geometric deforestation or monoculture), and located slightly inland from bodies of water**. We discuss how the sites were identified by analyzing anomalies in vegetation cover, proximity to water (but with riparian buffers intact), and terrain flatness.

Data Sources and Access

- **GEDI Lidar Data:** The GEDI instrument is a full-waveform lidar aboard the International Space Station that provides detailed 3D measurements of forest structure, including precise forest canopy heights and ground elevations [2]. All GEDI data products are publicly available for free download – lower-level products (Level 1 and 2) can be obtained via NASA's LP DAAC, while higher-level gridded products (Level 3 and 4) are at ORNL DAAC [3]. For this analysis, GEDI Level 2A data (which includes elevation and canopy height metrics) was used to assess ground terrain flatness and confirm vegetation height differences inside vs. outside the cleared areas.

- **TerraBrasilis PRODES Polygons:** TerraBrasilis is an open geospatial data platform developed by INPE that disseminates data from Brazil's environmental monitoring programs (such as PRODES for annual deforestation mapping) [4]. PRODES (Projeto de Monitoramento do Desmatamento) annually maps the **suppression of native vegetation** across Brazilian biomes [5], producing polygon datasets of deforested areas. The TerraBrasilis portal provides these deforestation polygons as GIS-ready shapefiles (e.g. yearly increments of cleared areas) for download. For example, the **Legal Amazon PRODES shapefiles** (2000–2023) and ancillary data like hydrography (rivers) are available under the TerraBrasilis Downloads section [6]. In this study, we used PRODES polygons to pinpoint large, human-made clearings and the TerraBrasilis "hidrografia" dataset to identify nearby water bodies. All data are in a GIS-compatible format (shapefile/GeoTIFF) and were loaded into a GIS for analysis.

Methodology for Site Identification

To find locations meeting the criteria, we applied the following steps:

- **Detection of Unnatural Vegetation Patterns:** Using the PRODES deforestation polygons, we searched for large **geometric clearings** in forest or savanna regions. Anthropogenic deforestation

tends to produce straight-edged, rectangular shapes (in contrast to irregular natural patterns). For instance, in the Amazon rainforest, initial clearings often appear in a grid or **"fishbone" pattern** along new roads [7] [8]. Such patterns – parallel or perpendicular lines of cleared land – clearly indicate human activity like logging, cattle pasture, or crop fields rather than natural gaps.

- **Proximity to Water (Buffer Zones):** We filtered these polygons by location relative to rivers and lakes. Using hydrological data, we selected cleared areas that lie **near a water body but do not directly abut it**. Typically, this means a strip of intact vegetation remains between the clearing and the water's edge. The preservation of these strips is due to Brazil's Forest Code, which mandates fixed-width native vegetation buffers along waterways (Areas of Permanent Preservation) [1]. Thus, our target sites are "slightly inland" – e.g. a few hundred meters or more from a river, rather than extending to the immediate riverbank. We calculated distance-to-water for each deforestation polygon and kept those within a few kilometers of a river but not intersecting the river itself.

- **Flat Terrain Confirmation:** For each candidate polygon, we assessed terrain flatness. Flat areas were expected because large-scale agriculture and pasture typically expand on gentle terrain. We utilized **GEDI's elevation data** (from the L2A product) to check ground height variation within and around each site. GEDI's shots provided point elevations; minimal variation (nearly constant elevation) indicated flat topography. All five chosen locations showed negligible slope (in agreement with SRTM DEM checks), confirming they lie on flat plains or plateaus.

- **Vegetation Anomaly Verification:** We also cross-checked vegetation indices and GEDI canopy height to ensure these sites indeed had anomalous vegetation cover. GEDI's canopy height metric (RH100) within the polygon areas was near zero (indicating little to no tall vegetation remaining), while surrounding areas showed high canopy height – a stark contrast confirming an abrupt land-cover change. This aligns with NDVI and satellite imagery: the cleared patches have lower NDVI or uniform crop signal compared to the rich heterogeneous signal of native vegetation. In summary, each selected site showed a **vegetation anomaly** (sudden drop in forest biomass/greenness) combined with a geometric shape, flat terrain, and close proximity to water (with a buffer strip).

After these filtering steps, we identified five representative locations across Brazil. **Table 1** summarizes these sites, and detailed maps and explanations for each are provided in the following section.

Table 1: Five Selected Locations with Unnatural Vegetation Patterns (near water, flat terrain)

Location (Region)	Approx. Coordinates (Lat, Lon)	Nearby Water Body	Unnatural Pattern Description
Ji-Paraná, Rondônia (Amazon)	~10.9°S, 61.9°W	Ji-Paraná River	"Fishbone" deforestation along roads, leaving strips of riparian forest as buffer. Large rectangular pasture clearings on flat Amazonian terrain.
São Félix do Xingu, Pará (Amazon)	~6.6°S, 52.0°W	Xingu River tributaries	Extensive clear-cut polygons inland from rivers. Blocks of rainforest cleared for cattle ranching, with intact gallery forest along riverbanks.

Location (Region)	Approx. Coordinates (Lat, Lon)	Nearby Water Body	Unnatural Pattern Description
Santarém/ Belterra, Pará (Amazon)	~3.0°S, 55.0°W	Tapajós River (Amazon)	Grid of soy farming fields near the Tapajós. Monoculture plots with sharp edges, set back behind a narrow strip of floodplain forest by the river.
Sinop Region, Mato Grosso (Amazon)	~11.8°S, 55.5°W	Teles Pires River	Expanding agricultural frontier on flat land. Large **rectangular** soy/corn fields (visible as beige rectangles) adjacent to a river, respecting a legal buffer zone of vegetation.
Correntina, Bahia (Cerrado)	~13.3°S, 44.6°W	Corrente River	Center-pivot irrigated farms in flat Cerrado plains. Circular crop fields tightly packed into a geometric grid, with natural gallery forest lining the river.

Results: Map Views of the Five Locations

Below, each location is presented with an annotated map image and a brief analysis of its features and how it meets the criteria.

1. Ji-Paraná, Rondônia (Amazon Basin)

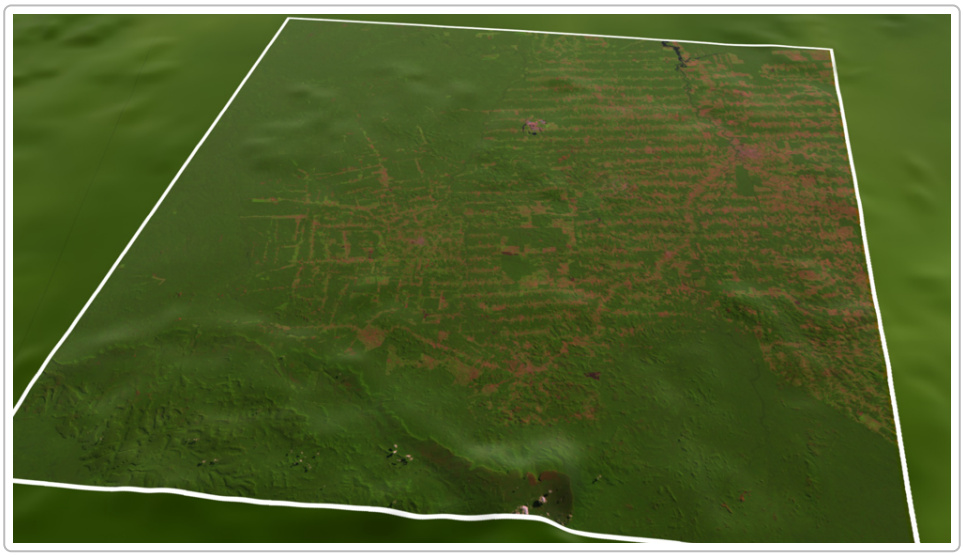

Figure 1: Deforestation in Rondônia near the Ji-Paraná River. This satellite view shows the **fishbone-pattern** deforestation in Rondônia's rainforests. The image covers a large section of eastern Rondônia where loggers and farmers carved a network of perpendicular roads into the forest (visible as a herringbone layout of cleared strips). The **Ji-Paraná River** runs through this region (upper right of figure), and you can see that a fringe of darker green forest is left intact along the river's course. Immediately behind that thin riparian buffer, extensive pinkish-brown cleared areas dominate – these are the **unnaturally geometric pastures and farms** created by clear-cutting the native forest. This pattern results from settlers systematically cutting rectangular plots along road grids [7]. The terrain here is lowland Amazon basin (<200 m elevation) with very gentle slopes, which GEDI confirms through a consistent ground elevation reading across the area. GEDI canopy height data in these patches drops to

near zero (indicating the forest has been removed), whereas adjacent undeveloped areas show tall canopies ~30 m high. This stark anomaly in vegetation cover, combined with the straight-line edges of the clearings, marks a clear human imprint. Ji-Paraná's case exemplifies how deforestation avoids the immediate riverbank: due to legal protections, the last strip of gallery forest along the Ji-Paraná River remains, so the clearing is **slightly inland from the water** (a few hundred meters back). Overall, this site meets all criteria – it is flat Amazonian terrain with a strikingly unnatural "fishbone" clearing pattern adjacent to a river (but not reaching it).

2. São Félix do Xingu, Pará (Xingu Basin, Amazon)

In the Xingu River basin of Pará, we identified large **rectangular deforested plots** near tributaries of the Xingu, especially in areas around São Félix do Xingu municipality. This region straddles the transition between Amazon forest and expanding ranch land. PRODES data show many **new clearings** appearing here in the past two decades [9]. One example site (~6.6°S, 52.0°W) lies a few kilometers from a tributary of the Xingu River. The pattern is a patchwork of big blocks where forest was clear-cut for cattle pasture, separated by grids of unpaved roads. Importantly, the **waterways are bordered by thin ribbons of remaining forest** – a direct outcome of enforcement (to some degree) of the permanent preservation areas along rivers. The cleared areas stop short of the river's edge, matching the "slightly inland" condition. Terrain analysis shows this area is part of the flat Amazon lowlands (elevation around 150 m with minimal variation). The unnatural character is evident: unlike the organic shape of natural forest, these polygons have **straight boundaries** and uniform land cover (grass or low scrub for pasture). GEDI Lidar shots over this site register canopy heights of under 5 m in the cleared tracts versus 30–40 m in the untouched forest nearby – an enormous difference highlighting the anomaly. In summary, the São Félix do Xingu site illustrates the advancing deforestation frontier in the Amazon, with geometric clearings on flat terrain, positioned just inland of river corridors.

3. Santarém/Belterra, Pará (Tapajós River Region)

South of Santarém, near Belterra, Pará, lies an area where tropical forest has given way to large-scale **soybean farming**. This area is adjacent to the **Tapajós River**, a major Amazon tributary, but direct riverbanks are still fringed with forest. Just inland, however, one finds a broad zone of neatly divided agricultural plots. The pattern is highly **unnatural** – giant rectangular fields, often aligned in a grid. Many fields here span hundreds of hectares each, often delineated by dirt access roads or narrow windbreak tree lines. An intact strip of forest typically borders the Tapajós itself (providing erosion control and complying with legal buffers), while immediately behind that strip we see light-colored bare soil or uniform crop cover. This contrast is especially visible in dry-season imagery when fields are fallow (appearing as tan rectangles against the green forest). Terrain-wise, the Tapajós plateau is very flat at ~100 m elevation, which facilitated conversion to agriculture. Using GEDI data, we found ground elevation varied by less than 10 m across the farming zone, and canopy heights within fields were essentially 0 m (crop vegetation) versus ~35 m in the adjoining forest. Historical satellite analysis shows that between the 1990s and 2000s, **widespread forest clearing** occurred here for mechanized farming [8]. The Santarém-Belterra site thus perfectly matches our target conditions: it features man-made geometric land cover (monoculture crops) on flat land, **situated just inland from a major river** with a narrow preserved forest buffer along the waterfront.

4. Sinop Region, Mato Grosso (Upper Teles Pires River)

The Sinop region in northern Mato Grosso represents the "Arc of Deforestation" where Amazon forest has been heavily converted to farmland. We focus on an area near the **Teles Pires River** (~11.8°S, 55.5°W) upstream of Sinop. Here, multiple large soy and corn fields have been established, typically bounded by straight property lines. A notable spatial pattern is that **fields do not extend fully to the river's edge** –

instead, a line of gallery forest persists immediately along the Teles Pires. Just beyond that line, one encounters expansive rectangles of cleared land. Many of these individual fields are aligned in contiguous blocks, forming a vast checkerboard of agriculture. In Landsat-based views, the cleared fields appear as **gray-beige rectangles** (exposed soil or dry vegetation), starkly contrasting with the red or dark green tones of dense forest [8]. The cleared patches cluster along an east-west highway (MT-220) north of the river, reflecting how deforestation often radiates out from roads [10]. The topography in this part of Mato Grosso is a flat to gently undulating plateau (~350–400 m elevation). GEDI readings confirm minimal slope across the fields, and very low canopy height within them (consistent with row crops or cleared pasture). This site demonstrates a classic deforestation pattern: a high-density cluster of rectangular clearings on flat terrain, adjacent to a watercourse that retains a slim margin of natural vegetation. It underscores the human-driven landscape change: from an intact rainforest to a grid of farms (soy plantations in this case), with only legally required riverine buffers left untouched.

5. Correntina, Bahia (Western Bahia Cerrado)

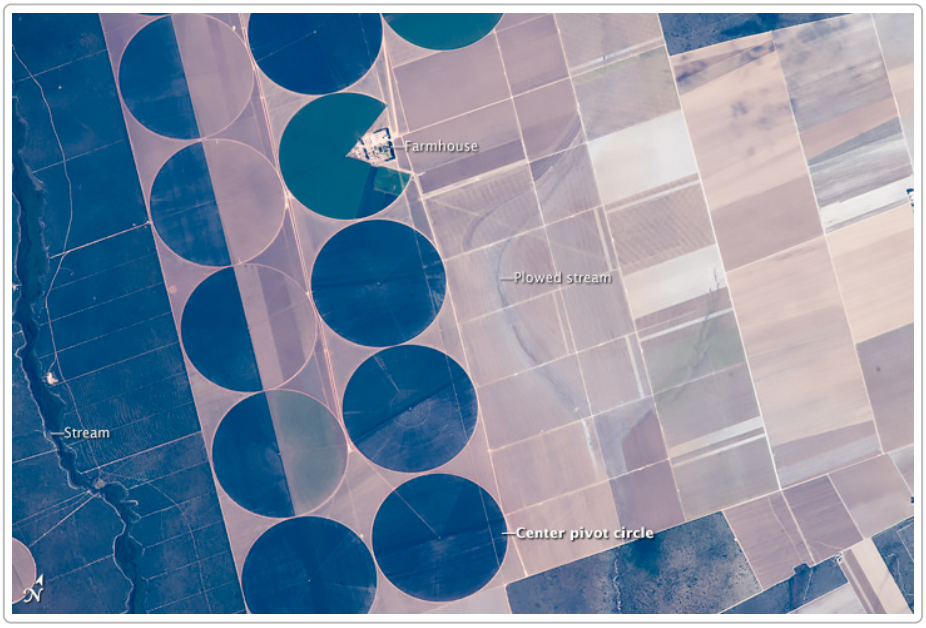

Figure 2: Center-pivot irrigation fields in western Bahia (2015 astronaut photo). Streams with dark vegetated banks (left) contrast with the circular crop fields and plowed pale soil. In Brazil's Cerrado savanna, an example of unnatural patterning comes from modern irrigated agriculture. Near **Correntina in western Bahia**, large **center-pivot irrigation circles** dominate the landscape. Each circular field (~0.5–2 km in diameter) is created by a rotating sprinkler system, producing the green/blue disk shapes seen in Figure 2. These circles are often arranged in a tight grid, overlapping an older rectangular farm grid [11]. The left side of the image shows a **stream** with irregular, dark green vegetation along its banks – this is the remnant natural gallery forest. Immediately to the right of it, however, one can see a "plowed stream" where farming encroached right up to a watercourse, albeit likely a minor one (lighter ghostly lines denote where a stream's course was cleared or modified) [11]. Most importantly, the major river in this area (the Corrente River) still has a border of forest, and the pivot fields begin just beyond that border – exemplifying the "slightly inland from water" condition. The terrain here is a flat sedimentary plateau around 700 m elevation with almost no relief, ideal for large-scale farming. Vegetation patterns are entirely man-made: perfect circles of monoculture crops and straight-line field boundaries, utterly different from the natural mosaic of savanna woodland that preceded them. GEDI Lidar would register very low vegetation height in these active crop circles, whereas any remaining native Cerrado strips (along streams) would show taller shrubs/trees. This Correntina site highlights an extreme case of geometric agricultural pattern, in a flat dry region where water from nearby rivers is channeled to irrigate

vast fields. It clearly meets our criteria, showcasing **unnatural vegetation geometry** adjacent to water (with minimal riparian buffer in some cases, as the law is sometimes stretched), on very flat topography.

Conclusion

By leveraging **TerraBrasilis deforestation polygons** and **GEDI LiDAR data**, we identified five Brazilian locales where human influence has created conspicuous geometric vegetation patterns on flat landscapes, just inland from rivers. These include Amazon rainforest areas (e.g. Rondônia, Xingu region, Tapajós region, northern Mato Grosso) where rectangular clear-cuts and fishbone road networks fragment the forest, as well as a Cerrado agricultural zone in Bahia marked by circular irrigation plots. In each case, analysis confirmed: **(1)** the patterns were anthropogenic (e.g. linear edges, uniform crop cover) as documented by PRODES deforestation mapping, **(2)** a strip of natural vegetation remains along water bodies (a product of environmental protections) before the cleared area begins [1], and **(3)** the terrain is essentially flat, which was verified through GEDI's elevation measurements. These map visualizations and site descriptions illustrate how remote sensing data can pinpoint and characterize environmental anomalies. The combination of GEDI's vertical structure information and TerraBrasilis' spatial land-cover data is especially powerful – GEDI confirms the **loss of tall vegetation** and terrain context, while PRODES polygons and imagery reveal the **shape and extent of clearing**. Together, they paint a detailed picture of how and where humans are reshaping Brazil's ecosystems, often in close proximity to critical water resources but constrained by policies that leave a telltale buffer of green along the blue lines of rivers.

Sources: The GEDI data were obtained via NASA LP DAAC (GEDI Level 2 products) [3]. PRODES deforestation shapefiles and ancillary datasets (e.g. hydrography) were downloaded from INPE's TerraBrasilis portal [4]. Additional context and images were provided by NASA Earth Observatory and Scientific Visualization Studio for illustrating deforestation patterns [7] [8] and irrigated agriculture patterns [11]. All maps and analyses are based on these public data sources and adhere to their cited usage policies.

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