SAR-BASED DETECTION OF SMALL FOREST DISTURBANCE EVENTS IN AMAZON: THE DETER-R COLLECTION 2

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ABSTRACT

In this study, we present and evaluate the results of Collection 2 of DETER-R, a fully automated Near Real-Time forest disturbance detection system based on Sentinel-1 (S1) data. The main difference from Collection 1 is the change of the Minimum Mapping Unit from 1.0 to 0.4 ha. This change led to the detection of a higher number of smaller warnings, at the cost of including commission errors. During three months of tests, Collection 2 emitted 19,312 warnings, totaling 38,533.5 ha. It is estimated that, after a period of stabilization, around 10% of the number of warnings and 5% of the area do not correspond to real forest disturbance events. This was considered an acceptable compromise, which prompted the substitution of Collection 1 for Collection 2 in August 2022.

Keywords – *Amazon, forest monitoring, Synthetic Aperture Radar, deforestation, forest degradation.*

1. INTRODUCTION

Forest disturbance events in the Amazon, e.g. the deforestation and degradation of the primary forest, can threaten important ecosystem services such as biodiversity maintenance, carbon storage, regulation of water flux, and regulation of the regional and global climates [1,2]. In Brazil, reducing and controlling forest disturbance events has been greatly supported by INPE's Near Real-Time Deforestation Detection System (DETER) [3]. Nonetheless, as DETER is based on optical data, it can be severely affected by the near-constant cloud cover in certain parts of the Amazon during given periods of the year [4].

Synthetic Aperture Radar (SAR) systems can acquire information about land cover in almost every atmospheric condition [5], thus being a valuable tool for the continuous monitoring of highly cloud-covered areas. To help bridge the observational gap caused by cloud cover, the National Institute for Space Research (INPE) launched, in 2021, the DETER companion system based on SAR data, called DETER-Radar (DETER-R) [6]. DETER-R is a fully automated Near Real-Time (NRT) forest disturbance detection system based on Sentinel-1 (S1) data. In its first operational phase, DETER-R has issued 91,809 forest disturbance warnings from April 2021 to July 2022, grouped in the so-called Collection 1.

One key aspect of DETER systems is their ability to alert priority disturbance events in near-real time with a low false-positive rate. Nonetheless, recent research [6, 7] found that DETER-R has a relatively high omission rate when compared to other SAR-based NRT disturbance systems. This characteristic was attributed mainly to the relatively high Minimum Mapping Unit (MMU) adopted by DETER-R, of 1.0 ha in Collection 1.

In this study, we present the Collection 2 of forest disturbance warnings issued by DETER-R, which operates with a smaller MMU of 0.4 ha, and evaluate its results by comparing them with the ones obtained by Collection 1 in the same test period. This analysis was conducted in a real monitoring scenario, as detailed in Section 2. The comparison between results with different MMUs are illustrated and discussed in Section 3. Section 4 presents the main conclusions of this study.

2. MATERIALS AND METHODS

DETER-R monitors the forested area within the Brazilian Amazon biome. This area of interest excludes flood-prone, non-forest, or previously deforested areas. Previously deforested areas include data from the Program for Deforestation Monitoring in the Brazilian Legal Amazon (PRODES) and areas previously detected by DETER-R.

Currently, DETER-R operates within the Google Earth Engine (GEE) platform [8]. New images are treated and analyzed daily, as described in detail by Doblas et al. [6]. After the automated analysis, the system vectorizes clusters of pixels flagged as forest disturbances, and those with areas higher than the MMU are further assessed and sent to the National Center for Monitoring and Environmental Information (CENIMA) within the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA). Currently, DETER-R typifies forest disturbance warnings in two categories:

1. *High Intensity*: areas with a relative decrease in backscattering higher than 7 dB. Those areas generally correspond to clear-cut deforestation with burning, as well as areas heavily burned/that have suffered several successive fires.

2. *Low Intensity*: detected areas with a decrease in backscattering equal to or lower than 7 dB. Those areas represent areas probably suffering a forest degradation process, such as fires or initial slashing, but without the observation of clear-cut events.

Between April 05, 2022, and July 4, 2022, DETER-R ran two parallel and independent sets of forest disturbance detection. The first one corresponds to the Collection 1

of DETER-R data, at the time the one being sent to CENIMA/IBAMA. The second one corresponds to the tests that would configure Collection 2. Both sets were processed considering the same images and dates. There are two main differences between the collections: 1) the MMU, set as 1.0 ha for Collection 1 and 0.4 ha for Collection 2; and 2) Collection 1 data is post-processed using erosion and dilatation raster filters that artificially unite proximate polygons. These were removed in Collection 2.

The warnings issued by both collections were validated daily, considering both optical DETER data and visual interpretation of optical images. Firstly, polygons with 50% or more of superposition with the ones detected at the time by the optical DETER as deforestation were automatically validated as *Recent Deforestation*. Then, up to 400 (the biggest 100 + randomly selected 300) of the remaining non-evaluated polygons per day and set were selected for validation by visual interpretation. In this last step, the warnings were labeled as [6]:

1. *Recent Deforestation*: complete and recent removal of the forest cover due to clear-cut or as the result of successive disturbance events.
2. *Recent Degradation*: partial loss of forest canopy.
3. *Burnt areas*: forested areas impacted by fire. It may or may not contain arboreal vegetation.
4. *Residue*: old deforestation process that can be detected in the images used by PRODES in the previous year.
5. *Water/flooded areas*: previously forested areas that have been flooded or engulfed by river dynamics.
6. *Non-forest formations*: recent alterations occurring in areas not originally covered by forests.
7. *False positive*: forested areas with no detectable forest disturbances.
8. *Cloud*: warnings that could not be assessed due to clouds in the optical images used for validation.
9. *No reference data*: areas that could not be evaluated due to the absence of recent optical images at the validation time.

Validated results were then cross-tabulated and assessed in four categories [6]:

1. Agreement: warnings of forest disturbances of *High* or Low Impact correctly detected as *Recent deforestation* or *Recent degradation/Burnt areas*, respectively.
2. Minor disagreement: Warnings of forest disturbances of *High* or Low Impact detected as *Recent degradation/Burnt areas* or *Recent deforestation*, respectively.
3. Major disagreement: warnings that do not correspond to forest disturbances, i.e. those validated as *Water-flooded areas*, *Non-forest formations*, or *False positives*.
4. Not Evaluated: warnings that could not be evaluated, i.e. classes *Cloud* and *No reference data*.

The area and number of warnings from each collection were then compared considering each agreement category.

3. RESULTS AND DISCUSSION

During the test period, between April 05, 2022, and July 04, 2022, DETER-R issued 4,284 forest disturbances warnings in Collection 1, totaling 27,022.2 ha, and 19,312 warnings in Collection 2, totaling 38,553.5 ha. The number of warnings issued in Collection 2 far exceeded the one in Collection 1. However, the total area of the warnings presents closer values. This behavior was expected since smaller forest disturbances events were not observed by Collection 1. The number and area (ha) of warnings issued by week from each collection are illustrated in Figures 1 and 2, respectively.

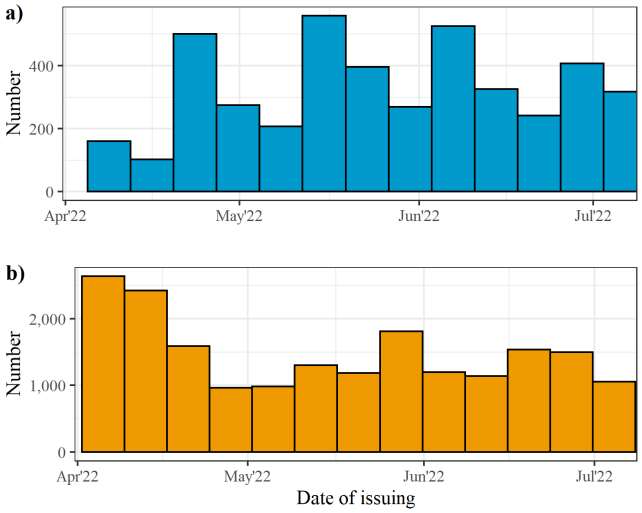

Figure 1: Number of warnings issued by week during the test period: a) Collection 1; b) Collection 2.

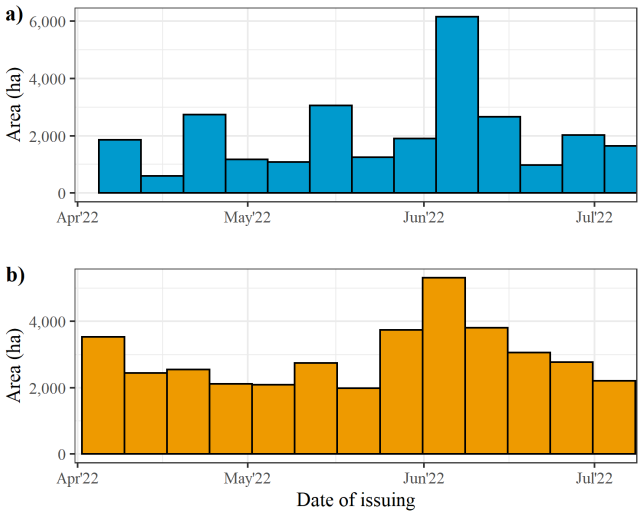

Figure 2: Total area (ha) of warnings issued by week during the test period: a) Collection 1; b) Collection 2.

As can be seen in these figures, Collection 2 issued a higher number of small warnings in the first two weeks

of processing. These corresponded, in great part, to *water/flooded areas* and *residues*, not previously included in the DETER-R mask due to their sizes being smaller than the MMU. The system started to stabilize after two weeks, as seen by the smaller quantity of issued warnings in Collection 2 from the third week. This time frame roughly corresponds to the time needed for the system to observe two time-consecutive S1 images in the same area (around 12 days), which is needed to issue a confirmed warning [6].

The number and area of validated warnings issued per week in each collection are illustrated in Tables 1 and 2. Whereas all warnings from Collection 1 were validated, resource constraints allowed the validation of 14,801 warnings (76.6%) in Collection 2. Non-evaluated polygons are not equally distributed during the time, and the selection may be biased in Collection 2 from week 9 of the test period, so we considered only the results from weeks 1 to 8 in this analysis.

Figure 3 presents the area of warnings from each collection validated as forest disturbances, i.e. those validated as *Agreements* and *Minor disagreements*. As can be seen, Collection 2 tends to issue a higher area of warnings than Collection 1. Considering the total amount of warnings issued during the test period (including non-validated ones), Collection 2 detected 13,815.4 ha of warnings not flagged by Collection 1, whereas 2,284.2 ha flagged by Collection 1 were not seen by Collection 2. The areas seen by Collection 1 not seen by Collection 2 were caused mainly by differences in polygons format, as exemplified in Figure 4.

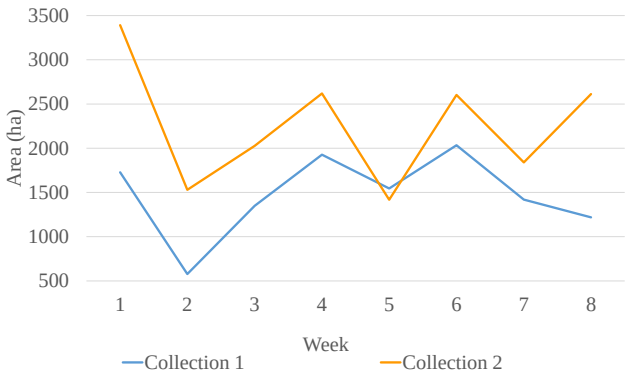

Figure 3: Area (ha) of warnings validated as forest disturbances (Agreements+Minor disagreements).

Besides a higher proportion of warnings corresponding to *Major disagreements*, the data in Collection 2 also present higher rates of misclassification between areas of *Low* and *High Impact*, as denoted by the values of *Minor disagreements*. These rates are illustrated in Figure 5. The tendency of Collection 2 to flag *water/flooded areas* and *residues* in the first two weeks of the test period can be seen in this figure, reflected as the higher percentages of warnings evaluated as *Major disagreements* during this period. These values stabilize around 10% of the total number of warnings and less than 5% of the area around the third week.

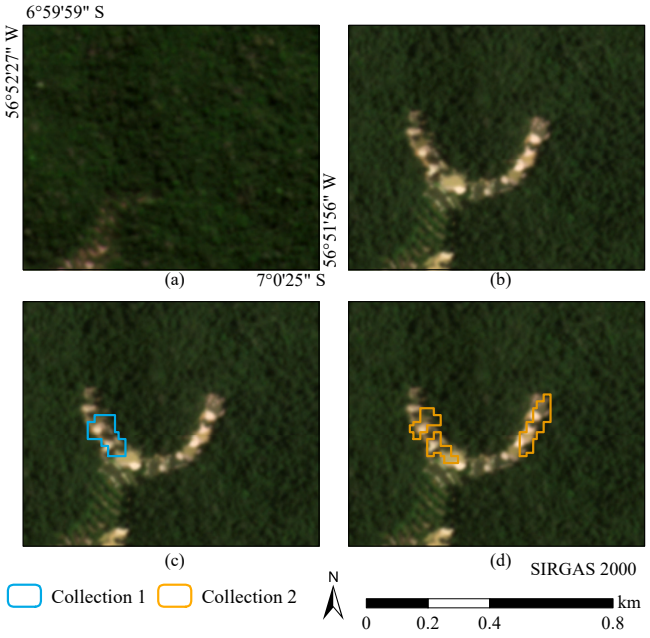

Figure 4: Example of forest disturbance warning. a) Planet mosaic (July 2021); b) Planet mosaic (March 2022); c) warning issued by Collection 1 + Planet mosaic (March 2022); d) warning issued by Collection 2 + Planet mosaic (July 2021). Mosaics correspond to Planet Medres Visual data in original true-color composition and contrast.

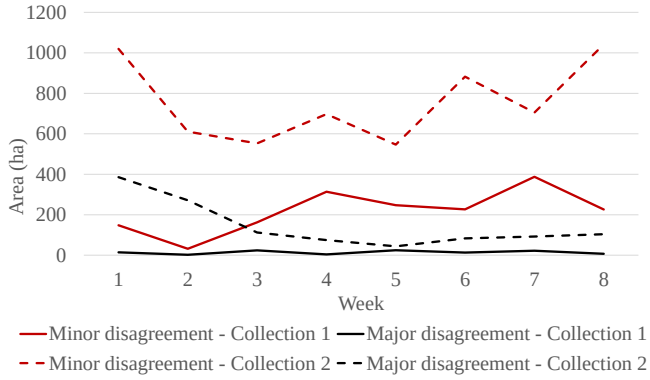

Figure 5: Area (ha) of warnings validated as disagreements.

4. CONCLUSIONS

Collection 2 is able to detect a higher number of forest disturbance events happening in smaller areas, thus increasing the system producer's accuracy. However, this improvement provokes a slight increase on false alerts, decreasing the user's accuracy. This kind of trade-off between commission errors and omissions is a common issue on all NRT systems.

During 8 weeks of tests, the system has stabilized with a rate of emission of warnings not correspondent to forest disturbances of around 10% of the total number of warnings and less than 5% of the area. This was considered an acceptable compromise between gain in the detection of smaller areas *vs* commission errors in the system, which prompted the substitution of Collection 1 for Collection 2 in August 2022.

		Week							
		1	2	3	4	5	6	7	8
Collection 1	Agreement	66.0	81.0	80.7	65.7	71.3	75.6	55.8	72.8
	Minor disagreement	19.5	14.0	14.9	30.3	24.1	21.5	38.7	24.2
	Major disagreement	6.9	2.0	3.9	1.1	4.0	2.6	4.3	1.9
	Not Evaluated	7.5	3.0	0.6	2.9	0.6	0.3	1.2	1.1
Collection 2	Agreement	39.4	34.0	46.1	38.1	35.8	40.3	36.7	37.9
	Minor disagreement	42.5	44.2	41.6	50.5	54.7	50.1	50.0	52.4
	Major disagreement	16.0	19.1	10.8	9.3	8.4	8.1	10.5	8.4
	Not Evaluated	2.1	2.7	1.5	2.1	1.1	1.5	2.7	1.2

Table 1: Number of validated warnings per week (%) for each collection.

		Week							
		1	2	3	4	5	6	7	8
Collection 1	Agreement	85.1	93.4	85.9	82.6	82.3	88.2	71.1	80.7
	Minor disagreement	8.0	5.4	11.8	16.1	15.7	11.1	26.7	18.3
	Major disagreement	0.8	0.4	1.8	0.2	1.6	0.7	1.5	0.6
	Not Evaluated	6.2	0.7	0.5	1.1	0.5	0.1	0.6	0.4
Collection 2	Agreement	62.2	50.0	68.5	70.9	59.4	63.8	58.2	57.6
	Minor disagreement	26.7	33.2	25.7	25.7	37.2	32.7	36.1	38.2
	Major disagreement	10.1	14.8	5.2	2.8	3.0	3.1	4.7	3.8
	Not Evaluated	1.0	1.9	0.6	0.7	0.4	0.4	0.9	0.5

Table 2: Area of validated warnings per week (%) for each collection.

We also observed a higher rate of detection of real forest disturbance events in the wrong category within the system. Future studies should investigate if changes in detected warnings demand changes in the threshold that typifies the warnings issued by DETER-R. Furthermore, future changes in the system could allow the system to run more than one collection in parallel, which in turn would enable the system to issue forest disturbance sets with different rates of omission and accuracy, accommodating the demands of different users.

5. ACKNOWLEDGMENTS

To the National Council for Scientific and Technological Development (CNPq), project "Monitoring Brazilian Biomes by Satellite–Building new capacities"/process 444418/2018-0, INPE's support, and the Coordination for the Improvement of Higher Education Personnel-Brazil (CAPES)-Finance Code 001. The authors would also like to thank the continuous support of the CENIMA/IBAMA team.

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