# Evaluating the Sensitivity of Spectral and Synthetic Aperture Radar-based Forest Degradation Products in the Peruvian Amazon Forest

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**Abstract**

Detection and monitoring of tropical forest degradation is crucial to climate change mitigation and biodiversity conservation efforts. Several algorithms have been recently developed to monitor forest degradation and disturbance using remote sensing. However, these algorithms differ in local predictions due to the variation in the biogeophysical parameters used as degradation proxies. It is crucial to assess their relative performance and shortcomings in order to develop a clear understanding of the conditions under which each algorithm will detect a disturbance. In this study, we used GEDI lidar data on forest structure to examine the sensitivity of widely used forest disturbance and degradation products in a frontier tropical forest landscape in the Peruvian Amazon. We compared a leading spectral-based degradation algorithm (Continuous Degradation Detection (CODED)) with a radar-based algorithm (ALOS-2 PalSAR-2 based Radar Forest degradation Index (RFDI)). Given the sensitivity of radar to canopy cover and volume, we hypothesized that a single radar observation may detect degradation better than a long spectral time series. We first identified stable forests for reference structure in two ways: using disturbance stratification data from CODED, and using Peruvian protected areas. Our analysis showed that CODED performed below expectations in detecting forest degradation, often including patches that were regrowing after clear-felling in its "degraded" class. As CODED classified spectral changes over time rather than capturing structural variability, it classified 82% of palm plantations area as "degraded." CODED also failed to detect degradation in forest areas that were likely partially disturbed (i.e., with low height and high cover). By contrast, the PalSAR-2 RFDI showed a significant relationship with forest height (detecting low height in degraded forests), although its predictive ability was limited due to high variability and signal saturation. Our study supports the conclusion that radar-based observation can detect forest degradation that the time series observation failed to detect. Given the limited correspondence between radar and spectral algorithms, we suggest that integrations of spectral and radar data may be beneficial for mapping forest degradation.

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## How well does cloud-penetrating single-date SAR detect tropical forest degradation?

Forest disturbances contribute about 12% of global carbon emissions (van der Werf et al. 2009). Forest degradation contributes one-third of total carbon emissions from forest disturbance.

Forest degradation is generally defined as a reduction in forest's capacity to produce ecosystem services such as carbon storage and wood products (Thompson et al. 2013). Forest degradation can potentially be detected in two ways:

1. Historical time series of optical satellite data (CODED; Bullock et al. 2020)
2. Single-date Radar Forest Degradation Index (RFDI; Saatchi 2019)
   * ALOS2/PalSAR2 L-band synthetic aperture radar (SAR) data
   * Sentinel-1 C-band SAR data

We are aware of no studies that have attempted to compare these optical and SAR-based distinct methods of assessing forest degradation.

**Specific Questions:**

1. Which degradation index is more predictive of present-day forest structure (derived from GEDI LiDAR)?
2. What differences exist in degradation magnitude and extent between the optical and SAR data?
3. To what extent do degradation patterns in standing forests correlate with forest fragmentation?

## Workflow

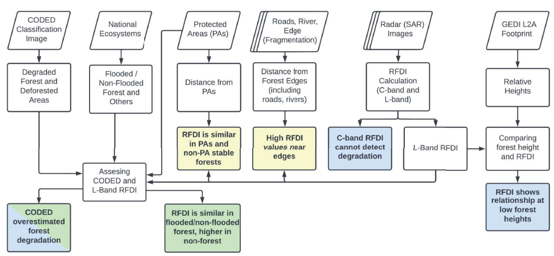
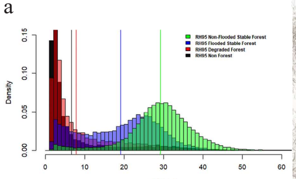



Figure 1: Workflow of the research methods; blue color box representing answer to research question 1, green color representing answer to question 2, and sand color is representing answer to question 3.

## Observed forest height from GEDI LiDAR

Forest height derived from GEDI LiDAR differed widely among forest types (p<0.05, ANOVA with Tukey HSD at 95% confidence interval across forest types) derived from Peru National Ecosystems data and CODED degradation data. Flooded forest had low height compared to non-flooded stable forest.



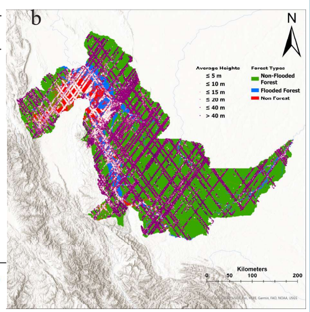




Figure 2: (a) Histogram of relative height at GEDI footprints in non-flooded stable forest, flooded stable forest, degraded forest, and non-forest. (b) Average tree canopy height (relative height at 95% energy) at GEDI footprints in forest and non-forest areas.

## Optical time-series over-predicted degradation

* 82% of palm plantation is mis-classified as degradation by CODED
* Clear felled patches that are regrowing are also mis-classified as degraded forests (CODED misclassified 35% of the clear felled patches as degraded)

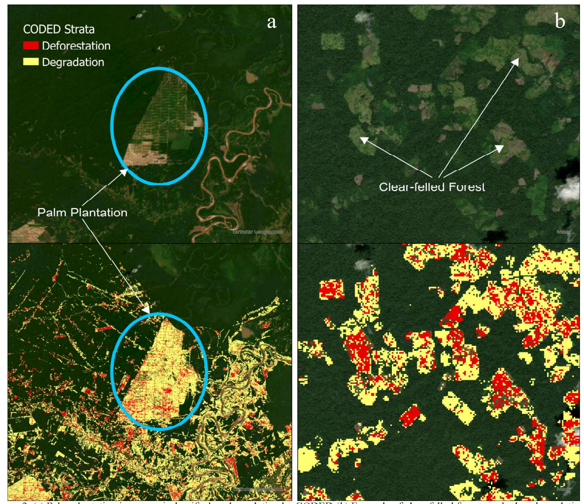



Figure 3: (a) Palm plantation in peru misclassified as degradation by CODED (b) Example of clear-felled forest marked as degradation by CODED (Basemap source: ESRI, year: 2015)

## Sentinel-1 performed poorly, PalSAR detected non/forest more accurately

The Radar Forest Degradation Index (RFDI) from Sentinel 1 is not suitable for distinguishing intact forest, degraded forest, and deforested area classes (Fig. 4a). PalSAR-2 RFDI can distinguish forest from non-forest (p<0.05, ANOVA with Tukey HSD at 95% confidence interval across land cover types), supported by the histogram showing thresholds of RFDI across land cover types (Fig. 4b).

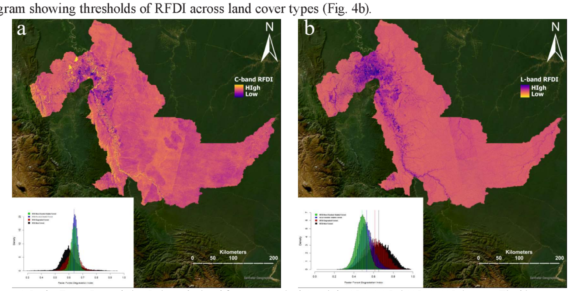



Figure 4: Radar Forest Degradation Index calculated from (a) Sentinel-1 and (b) ALOS-2 PalSAR-2 SAR images. The histogram with each map is representing the mean RFDI at GEDI footprints across upland (non-flooded) stable forest, flooded stable forest, degraded forest and non-forest.

## PalSAR-2 saturates at taller canopy heights, across all forest types

* Radar Forest Degradation Index ranges from 0 to 1 where high values indicate deforestation or forest degradation and low index values indicate stable forests.
* RFDI decreases with increasing forest height ($p<0.001$, $F(1, 141007) = 68236$).
* RFDI can detect very low canopy height (<5 M; nonforest) but saturates at greater heights (Fig.5).
* The fitted line is showing a flat pattern for canopy height above ~25m. This phenomenon is relevant to the saturation of L-band SAR backscatter in dense vegetation.

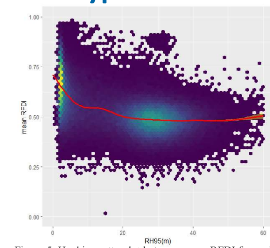



Figure 5: Hexbin scatterplot between mean RFDI for each GEDI footprints against relative height, across all forest types.

## PalSAR-2 weakly detected edge-driven declines in forest height

We examined the distance from edge to evaluate, if we were able to detect a known signal of forest degradation. GEDI showed low forest height close to edges. RFDI (in inverse) also declined near edges. However, RFDI signal is weaker compared to the height distribution as going in from the edges

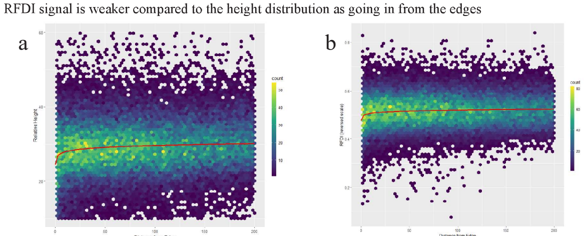



Figure 6: (a) Hexbin scatterplot between distance from edge and relative height at GEDI foot prints with a fitted GAM line. b) Hexbin scatterplot between distance from edge and Radar Forest Degradation Index invered (low value representing high degradation and high value representing stable/undisturbed forest).

## Lessons Learned

* Optical data (CODED) mis-classified agriculture and clear-felled forests as forest degradation
* Single date C-band SAR (Sentinel-1) is not suitable for mapping tropical forest degradation, likely because of poor canopy penetration.
* L-band SAR data can identify non-forest areas (deforestation) but saturates in degraded forests with taller canopy height.
* RFDI showed some potential in detecting edge degradation patterns in forests, but variability was high.

**Next step:** Investigating optical and radar data using GEDI L2B data, which has vertical profiles of forest canopy cover and other relevant metrics.

### References

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