Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2019-451-AC3, 2020


Biogeosciences Discussions

Open Access



# *Interactive comment on* "Landsat NIR band and ELM-FATES sensitivity to forest disturbances and regrowth in the Central Amazon" *by* Robinson I. Negrón-Juárez et al.

**Robinson I. Negrón-Juárez et al.**

robinson.inj@lbl.gov

Received and published: 1 June 2020

Anonymous Referee #2 GENERAL COMMENTS The paper titled 'Landsat NIR band and ELM-FATES sensitivity to forest disturbances and regrowth in the Central Amazon' examines the use of Landsat satellite data as a tool for quantifying post-disturbance tropical forest recovery following clear-cut logging, burning, and windthrow events in the Central Amazon. The study also compares modeled post-disturbance recovery to the satellite observations, using ELM-FATES (a dynamic global vegetation model), to evaluate whether the model accurately represents differences in forest recovery pathways. The main claims are as follows: 1. The near infrared (NIR) band provides



Printer-friendly version

Discussion paper

a useful metric for mapping disturbance events and quantifying the temporal dynamics of post-disturbance recovery. 2. Changes in the NIR band reflect tropical forest succession dynamics following a disturbance event, demonstrated by a decrease in the NIR band that corresponds to the timing of tree loss, a rapid increase in the NIR as tree growth occurs during recovery, followed by a linear decline in NIR back to pre-disturbance conditions over the course of several decades. 3. Clear-cut logging and windthrow events simulated using the version of ELM-FATES in this analysis reproduces Landsat-derived post-disturbance recovery dynamics. This study offers two valuable contributions: 1. It provides a methodological contribution for identifying how remote sensing data can be used to evaluate demography model performance. 2. It offers an evaluation of ELM-FATES simulated disturbance dynamics and postdisturbance recovery processes following three important disturbance processes. The study yields interesting results and a useful discussion around the capacity to remotely sense and model tropical forest regrowth following disturbances. The inclusion of spectral leaf reflectance as model output using radiative transfer schemes for direct comparison with remotely sensed data is a welcome idea. I do, however, have several major concerns about the methods and the presentation and interpretation of results, described in detail below. In general, the manuscript would benefit from reorganization and a tighter framing of the narrative. Several paragraphs could be cut down, with unnecessary detail removed, while some descriptions and background information would benefit from greater specificity and detail.

Authors: We thank the reviewer for the comments provided. Our responses to the reviewer comments are in blue and the changes included in the text manuscript are in red.

SPECIFIC COMMENTS 1. Why use only raw bands? I recognize the importance of understanding band behavior, but as Referee # 1 mentioned, it would be incredibly useful to also look at vegetation indices (e.g. NDVI, NIRv, EVI) and/or spectrally unmixed bands (e.g. photosynthetic vegetation, non-photosynthetic vegetation, and bare soil) to compare more direct metrics of productivity. Given the amount of non-photosynthetic information in a 30x30 m pixel (e.g. bare soil, branches, etc.), direct comparison of the NIR band to model output like LAI is tricky. NIRv (or EVI, NDVI) is an approach for estimating GPP that will offer a more direct comparison with model output. See: - Badgley, G., Field, C.B. and Berry, J.A., 2017. Canopy near-infrared reflectance and terrestrial photosynthesis. Science advances, 3(3), p.e1602244.

Response: Vegetation indexes (VI) and RS metrics are based on band reflectance and therefore it is important to understand the band behavior (Tucker, 1979). For instance the figure bellow shows the NDVI for the windthrows, clearcut and cut+burn sites (we removed the standard deviation at each point in time for clarity). In the figure it can be observed a dynamics of regrowth for each disturbance but does not provide information about that is driving the regrowth.

To address the reviewer concern, we have included this figure as supplementary material. We have included the following in the revised manuscript: [line 579] In lieu of this development, we show that with successional aging, modeled forest structure returns to pre-disturbed values (through canopy closure) with similar recovery time as NIR, which can be compared against remote sensing metrics like vegetation indices (see Supplementary Figure 1). Nevertheless, the extent to which vegetation index (e.g., Normalized Difference Vegetation Index (Rouse et al., 1973), Enhanced Vegetation Index (Huete et al., 2002)) properly represent the successional pathways remains an important area of study.

2. Why run 20 independent simulations with single PFTs, but no runs with multiple PFTs? It seems highly relevant to look at changes in modeled composition / successional changes to see whether the model qualitatively gets those dynamics right.

Response. ELM-FATES is a newly tested demographic model and newly coupled to a land surface model. It was best, at this stage of model application, to understand how tropical forest dynamics play out for each individual PFT type, so investigating solely early successional recovery behavior or solely late successional behavior, under the same environmental and climate conditions. This will give us a better idea of how to interpret and improve future model results from simulations that combines all PFTs with interacting competition. This is the goal of our next modeling study. We understand your point, and we wanted to reserve parsing out the correlations and dependencies of multiple PFT trait-based competition for other manuscript. Our goal in this manuscript is to determine whether ELM-FATES represent the observed patterns of regrowth.

3. L57-58: A quick Google Scholar search reveals several studies using Landsat time-series to map and analyze forest disturbance and recovery dynamics. See, for example: o Huang, C., Goward, S.N., Masek, J.G., Thomas, N., Zhu, Z. and Vogelmann, J.E., 2010. An automated approach for reconstructing recent forest disturbance history using dense Landsat time series stacks. Remote Sensing of Environment, 114(1), pp.183-198. o Schroeder, T.A., Wulder, M.A., Healey, S.P. and Moisen, G.G., 2011. Mapping wildfire and clearcut harvest disturbances in boreal forests with Landsat time series data. Remote Sensing of Environment, 115(6), pp.1421-1433. o Hansen, M.C., Krylov, A., Tyukavina, A., Potapov, P.V., Turubanova, S., Zutta, B., Ifo, S., Margono, B., Stolle, F. and Moore, R., 2016. Humid tropical forest disturbance alerts using Landsat data. Environmental Research Letters, 11(3), p.034008. o Sen, S., Zipper, C.E., Wynne, R.H. and Donovan, P.F., 2012. Identifying revegetated mines as disturbance/recovery trajectories using an interannual Landsat chronosequence. Photogrammetric Engineering & Remote Sensing, 78(3), pp.223-235.

Response. There are several references on disturbance and pathways of regrowth. It would be impossible to include all of them. We have included those that are relevant to our study of disturbances and pathways of regrowth in tropical forests.

4. L84-85: The manuscript would benefit from a more detailed description of the 'range of successional regrowth pathways.' For example, describe what is meant by pathway (recovery of lost/disturbed vegetation to pre-disturbance vegetation), and how pathways could potentially differ (timing, species composition, forest structure, etc.). This

will also help clarify how (i) and (ii) differ in L88-89.

Response. Pathway is the pattern of vegetation change with time. The process involved is well described in the Introduction section, first paragraph, second last sentence.

We have included the following:

[line 42] In general, it is known that forest pathways of regrowth (the pattern of regrowth) initiate with fast-growing and shade-intolerant species (pioneers) that establish from seeds and dominate a few years after disturbance, followed by recruitment and establishment of shade-tolerant species, and finally a closed-canopy old growth forest (Chazdon, 2014;Denslow, 1980;Mesquita et al., 2001;Swaine and Whitmore, 1988).

5. L146-163 & L178-191: Much of the information in each of these paragraphs can be tightened.

Response. We believe that is appropriated to provide those detail.

6. L188-189: Move L211-213 here so that the different boxes within each site are more clearly linked to the edge effects question. Clarify the distance to edge for each clear cut A1, A2, A3, and burned A1 and A2.

Response. We have done the changed suggested by the reviewer.

7. L212-213: clear-cut should read, “selected three areas”, while burned site should read, “two areas”.

Response. As indicated in the same lines there are four areas for clearcut ( A1, A2, A3, and AT) and three areas for cut+burn (A1, A2, and AT)

8. L250-251: It’s really too bad that burned area recovery could not be simulated. It would be nice to at least see some discussion of the differences in remotely sensed recovery pathways at all three sites, and how burned area simulations might be expected to differ or not given existing fire models in related DGVMs (e.g. ED), or what as-

pects of recovery differed at the burn site that should be evaluated in future data-model comparisons.

We understand that it's unfortunate there are not simulations of recovery from burned areas. The fire model is not yet completed or fully tested in the ELM-FATES model. Jacquelyn Shuman (co-author) is developing and finishing the ELM-FATES fire model and has been working diligently on fire modeling and multiple research questions. ELM-FATES uses a modification of the SPITFIRE module from (Thonicke et al., 2010), and development has required adaptation of SPITFIRE for the patch framework of FATES. We did not want to put an unfinished version of recovery after fire in this manuscript prior to that. We will make this clearer in the revision.

[Section 2.3, 2nd paragraph, 6th sentence]: The fire module in ELM-FATES is currently under final development and testing and therefore burned simulations are not included in this study."

9. L316-318: Too much detail for the Results section. Move to Discussion.

Response. We have moved the sentence to discussion. We have done the following change.

[line 472] Our results show that Landsat reflectance observations were sensitive to the initial changes of vegetation following windthrows, clearcut, and cut+burn, three common disturbances in the Amazon. Specifically, a decrease in NIR and an increase in SWIR1 were the predominant spectral changes immediately (within a few years) following disturbances. The increase in SWIR1 was different among the disturbances with the maximum increase observed in the cut+burn, followed by clearcut and then the windthrow site. The highest increase in SWIR1 in cut+burn sites may be related to the highest thermal emission of burned vegetation (Riebeek, 2014). Likewise, the relatively higher moisture content of woody material in the windthrow site decreases the reflection of SWIR2. On the other hand, in our control (old-growth) forests, we observed typically high NIR reflectance due to the cellular structure of leaves (Chapter





Printer-friendly version

Discussion paper

7 in Adams and Gillespie, 2006), absorption of red radiation by chlorophyll (Tucker, 1979), and absorption of SWIR1 by the water content in leaves (Chapter 7 in Adams and Gillespie, 2006).

10. L319-320: But L5/L7 data do not reveal anything about species composition. This sentence is misleading.

Response. Our control forest are located in old-growth forests. Due to edaphic and climate similarities it is very likely that the spectral similarities is related to comparable structure and floristic composition. We have done the following change.

[line 319] The similarity of spectral signatures for the control forests previous to the disturbances suggests comparable structure and floristic composition.

11. L480: What is the biophysical motivation/basis for this? Please include a very brief explanation of the relationship.

Response: Due to lack of leaf SWR1 increase and details are included in Section 4, 1st paragraph.

Clarification requested 12. L102-103: Provide slightly more descriptive, albeit brief definitions of clear-cut and burned areas. As an example, are clear-cut areas stand-level clearance events where every stem/tree is removed? Is soil compacted by heavy machinery? For burned areas, what is the severity of the fire? Is this typical of fire events in the region? Do all stems/trees burn or is it primarily a brush fire? In addition, please include the complete extent of each disturbance.

Response. We have redefine the term burned as cut+burn in all the manuscript. Soil compacts easily so machinery was avoided the BDFFP (Lessons from Amazonia: The Ecology and Conservation of a Fragmented Forest, Chapter 4, The Biological Dynamics of Forest Fragment Project). We have included this reference in the manuscript. Areas of disturbances are shown in Figure 1. Windthrows, clearcut and cut+burn are typical in the region as mentioned in the manuscript. Further details are in the second paragraph of section 2.1

We have included the following changes in the revised manuscript:

[line 100] Forests in the Central Amazon affected by windthrow (Figure 1), clearcut, and cut+burn were addressed in this study. In clearcut areas, forests are cut and cleared and in cut+burn areas forest are cleared and burned (Mesquita et al., 2001;Mesquita et al., 2015;Lovejoy and Bierregaard, 1990).

[line 125] The BDFFP was established and managed in early 1980's by Brazil's National Institute for Research in Amazonia (INPA) and the Smithsonian Institution, and is the longest running experiment of forest fragmentation in the tropics (Bierregaard et al., 1992;Lovejoy et al., 1986;Laurance et al., 2011;Tollefson, 2013;Laurance et al., 2018). Further details of the BDFFP are in Bierregaard et al. (2001).

13. L104: Define 'upland' in terms of meters/elevation. Are upland forests characteristic of the region or are lowland (see 50-105 m asl in L136)? L105: Define 'same geographic region.' L105: Provide more detail/background information on site characteristics either in the main body of the manuscript or in Supplementary Material. For example, how were the minimal differences in climatic, edaphic, and floristic characteristics determined? What data were used? Provide quantitative comparisons. Additional information on things like AGB, basal area, stem density, etc. will allow the reader to evaluate how similar or different these sites are from one another and how representative they are of the broader landscape. L134-142: Describe this information for each site separately (e.g. soil characteristics, species diversity/composition, topographic characteristics, mean canopy height, stem density, background mortality rates, etc.).

Response. We have integrated these four comments since they occur in the same paragraph. Upland refers to no flooding. We have change geographical region to region. Region refers to a land area that has common features. This features are mentioned in the same sentence. The last paragraph in Section 2.1 describe these features with proper references for readers that would like a detailed description. Following the reviewer suggestion we have included the basal area for old-growth forest trees with DBH ïĆş 10 cm that for the BDFFP was assessed by Laurence et al. 2010 and for the Tumbira windthrow was published in the PhD thesis of Daniel Magnabosco Marra and for other windthrows in the area by the same author.

We have done the following changes:

[line 103] The windthrow, clearcut, and cut+burn sites used in this study were selected based on the following conditions: (a) prior to disturbance they were upland (no flooding) old-growth forest and located in the same region, with similar climatic, edaphic, and floristic differences; (b) long-term records of satellite imagery and corresponding field data before and after disturbance are available; and (c) no subsequent disturbance has occurred.

[line 134] In the Manaus region the mean annual temperature is 27°C (with higher temperatures from August to November, and peak in October) and the mean annual rainfall is 2,365 mm with the dry season (rainfall < 100 mm month-1 (Sombroek, 2001)) from July to September (Negrón-Juárez et al., 2017). The topography is relatively flat with landforms ranging from 50-105 m above sea level (Laurance et al., 2011;Renno et al., 2008;Laurance et al., 2007), and the mean canopy height is $\sim$ 30 m, with emergent trees reaching 55 m (Laurance et al., 2011;Lima et al., 2007;Da Silva, 2007). The soil in this region are ferrosols (Quesada et al., 2011;Bierregaard et al., 2001;Ferraz et al., 1998) (Food and Agriculture Organization FAO classification) and with similar floristic composition (Bierregaard et al., 2001;Carneiro et al., 2005;Vieira et al., 2004;Higuchi et al., 2004). In the BDFFP, and for old-growth forest trees with DBH $\geq$ 10 cm, there are 261ïĆś18 species per hectare, the stem density is 608 ïĆś 52 stems ha$-$1 and the basal area is $\sim$ 28 m2 ha-1 (Laurance et al., 2010). These values are representative of the region (da Silva et al., 2002;Vieira et al., 2004;Carneiro et al., 2005;Magnabosco Marra et al., 2014;Magnabosco Marra et al., 2018;Magnabosco Marra, 2016). In this region 93% of stems are between 10 and 40 cm in DBH (Higuchi et al., 2012) and the





Printer-friendly version

Discussion paper

annual tree mortality is of 8.7 trees ha$-1$ for trees $\geq$ 10 cm in DBH (Higuchi et al., 1997).

14. L113: Why 3x3 windows? Provide an explanation and perhaps compare results using a range of window sizes to evaluate the robustness of results.

Response. Windows of these size capture better the spectral signature of events under study. The standard deviation from these windows is small, corroborating their use. These windows are also based on our experience in this type of analysis.

15. L157: Provide very brief explanation of why “especially in tropical forests”.

Response. Due to high atmospheric effects, tropical forest show higher differences in surface reflectance between L5 and L7.

We have included the following in the manuscript:

[line 156 ] Though L5 and L7 use the same wavelength bands they are different sensors and differences in surface reflectance may exist, especially in tropical forests due to high atmospheric effects (Claverie et al., 2015).

16. L170-172: Were all Landsat scenes truly cloud free / 0% cloud cover? This seems unlikely. If not, please provide a brief description of what was done to [cloud] mask the data.

Response. As explained in the manuscript: Only images with cloud free, cloud shadow free, and haze free over our disturbed areas were used to eliminate errors associated with these elements. For this procedure, visual inspection of visible bands and quality information from L5 and L7 were used. The following lines also mentioned the dates of the images: The dates of L5 images used were (Landsat 5 operational imaging ended in 2011) 6/1/1984, 7/6/1985, 7/12/1987, 8/2/1989, 7/20/1990, 8/8/1991, 7/31/1994, 6/21/1997, 7/26/1998, 7/13/1999, 7/24/2003, 8/4/2007, 8/6/2008, 7/27/2010, and 8/31/2011.

17. L194-196: Show the real data and gap filled data (in Supplementary Material?). Response. It is shown in Figure 3.

18. L198 & L341: I am confused about the use of L7 data. Please clarify in the description of the L5 and L7 data precisely when one or both are used.

Response. As mentioned in the manuscript (lines 155-156), L7 images were used to corroborated our predictions.

19. L205: Briefly explain why these years were selected, e.g. refer to Fig. 3 (d-f).

Response. It was described in lines 119-132.

20. L220-221: What field observations? What comparisons were made? How was this assessed? Please provide more detail.

Response. Section 2.1 contains this information. For accuracy we have include the following changes:

[lines 219] The predictions were compared with published field observations (Section 2.1) where data were available and L7 images were used to assess the reliability of our predictions.

21. L245-250: Aren't there data for the actual sites where analyses were conducted? If so, please provide actual values of mortality, etc. for each site to directly compare the model simulations to the site disturbances.

Response. Such data is provided in the same lines with proper mention of the references.

22. L294-296: This logic is unclear to me. When benchmarking a model against observations, it's usually a good practice to evaluate multiple model outputs. Therefore, we wanted to report the model outputs of multiple forest variables. With respect to observational data we concluded that biomass, stem density, and tree crowns with live foliage were appropriate model results to explore. Further logic behind this approach

is that multiple forest characteristics can contribute to NIR reflectance, and NIR is not necessarily directly tied to one variable (Ollinger, 2011). NIR can change based on the density of vegetation, biomass levels, and amount of tree crown that is live. This comparison to NIR is another reason we chose to explore multiple model outputs. We have introduced the following change in the manuscript: [line 293] We suggest that testing an array of modeled forest variables provides a robust approach for comparison to NIR, due to multiple forest characteristics contributing to and affecting NIR reflectance (Ollinger 2010), and reduces model unknowns and biases that can arise when using only one model variable. 23. L357-361: Are 0.15 and 0.13 mixed up? 0.15 > 0.13. For clarity, it would be useful to compare the relative change in percent reflectance across sites.

Response. In windrown areas NIR decrease as 0.13% y-1 but then double (0.26% y-1). In clearcut the decrease is 0.4% y-1. For the cut+burn site the decrease is 0.15% y-1. The decrease of NIR is lower in the cut+burn site. For clarity we have include the following in our manuscript

[line 357] During the first 12 years following the windthrow, the spline curve fitted to the NIR data decreased by ~0.13% y-1 after which the rate of decrease doubled (0.26% y-1, Figure 4).

24. L361: should this read 0.15% yr-1?

Response. Yes. It is 0.15% y-1. Thanks for the correction. We have included it in the manuscript.

25. Figs 4-6: These seem to indicate that exactly the same control / old growth values reflectance values were used for each site, although Fig. 1 and earlier descriptions indicate that different control plots were used at each site, which would presumably have different values. Please clarify as this will influence results.

Response. As mentioned in Section 3.2, 2nd paragraph we used the average NIR and





Printer-friendly version

Discussion paper

the variability from all old-growth forest sites is shown in the gray bar in Figures 4-6.

26. L388-L389: I don't understand how the rate of change can be higher but take longer? Were the starting biomass values different across sites?

Response. Your assumption is correct about different starting biomass values between the two sites (windthrow and clearcut). This can be seen in Figure 7a, where the biomass for clearcut starts at near-zero, and the biomass for windthrows starts around 30 MgC ha-1. We have also updated the sentence to make this point clearer. [line 390] which was due to the clearcut site recovering from initial biomass of near-zero and proportionally greater contribution of fast-growing pioneer species."

27. L415-417: State this earlier, perhaps on the previous page?

Response. We are comparing modeled changes in LAI and the NIR. We believe that as organized, the sentences provide a better flow.

28. Figure 7: This figure, particularly the AGB panel, seems to imply that the model simulations have not achieved equilibrium after 50 years. Why were simulations cut off at 50 years? How might this impact your results?

Response. We were mainly interested in determining how long the simulations took to recover to pre-disturbance levels so that the simulations could be compared to the remote sensing reflectance, and when the reflectance returned to old-growth forest values. We did happen to run simulations out to 100 years to observe longer patterns in regrowth. The simulated biomass, after both disturbances, did reach an equilibrium around ∼90 years.

29. L533: Should this read "higher peaks of post-disturbance stem: : :" instead of "initial stem: : :"? Response. Yes. We have rewritten the sentence as: [line 532] The strongest agreement, which can be used for future benchmarking, occurred because ELM-FATES predicted higher peaks of post-disturbance stem density and LAI in clearcuts than in windthrows, consistent with the higher peak of NIR from clearcuts

(Figure 5 vs. Figure 4).

Species composition

30. The changes in species composition at each site is mentioned several times (see L129, L131, L488-490, L492-509). However, it is unclear whether the literature cited to support the differences in pioneer species at each site, and the general changes in composition overlaps directly with the sites included in this study/evaluated using Landsat data.

Response. After clearcut the area is dominated by Cecropia and after cut+bur by Vismia. This is described in section 2.1. We have also included that in windthrows our published observational studied shown that Cecropia is a dominant pioneer. We have done the following change in the manuscript:

[line 121] At this site, data on forest regrowth including forest structure and species composition for trees ≥10 cm DBH (diameter at breast height, 1.3 m) were collected since 2011 covering disturbed (dominated by the genus Cecropia) and undisturbed areas (Magnabosco Marra et al., 2018).

31. L488-490: Reword this sentence. This conclusion is overstated based on the data and results reported in the manuscript. Without showing the data on trends in species composition at these sites, this cannot be stated with this much certainty. o Similarly, L492-509 & L525-528 are all speculation unless you are able to provide the data for these sites. Please clarify that these are speculations or report site-specific data.

Response. In the Discussion we are placing our result in context relative to previous studies that in turn (the previous studies) were properly referenced.

32. Given that changes in species composition provides an important model benchmark, it is unclear why only single PFT simulations were conducted. The manuscript would greatly benefit from additional simulations that include a combination of (at least) early and late successional PFTs.

We decided that it would be best, at this stage of model application, to understand how tropical forest dynamics play out for each individual PFT type, so investigating solely early successional recovery behavior or solely late successional behavior, under the same environmental and climate conditions. We understand your concern, however we wanted to reserve parsing out the many correlations and dependencies of multiple PFT trait-based competition for other manuscript. The ELM-FATES model is continually being developed, and it was decided that including combined interactions of many PFTs, and evaluating any changes to composition, wouldn't lead to robust results at this time.

Timing of disturbances and data availability

33. L120-132: The different dates associated with each disturbance (1982 – clear-cut, 1984 – burned area, 1987 – windthrow) should be addressed explicitly. Clarify whether analyses (e.g. changes in NIR) are quantified based on recovery since disturbance date or recovery since start of data availability. For example, in Fig. 5 the x-axis title states, "Years since 1984", which is the start date of L5 data, but 2 years after the clear-cut disturbance.

Response. We thank the reviewer for this observations. Due to cloud cover over the windthrown area there is no data in 1984 for this disturbance. We have included the following clarification.

[line 174]: The dates of L5 images used were (Landsat 5 operational imaging ended in 2011) 6/1/1984 (except for the windthrow), 7/6/1985, 7/12/1987, 8/2/1989, 7/20/1990, 8/8/1991, 7/31/1994, 6/21/1997, 7/26/1998, 7/13/1999, 7/24/2003, 8/4/2007, 8/6/2008, 7/27/2010, and 8/31/2011. The dates of L7 images used were 8/7/2011, 6/22/2012, 6/12/2014, 8/2/2015 and 8/7/2017.

34. L311-312: Yet you don't have Landsat data immediately following every single disturbance event. Please clarify wording.

Response. We are describing here a process observed for windthrows. Also, thought the spectral response to fires encompasses several references we have decided to use one reference that is a review. We have included the following:

[line 310] This decrease in NIR was due to exposed woody material and dry leaves (typical after windthrow and clearcutting) that have been observed in windthrows (Negrón-Juárez et al., 2010a; Negrón-Juárez et al., 2011) or the dark surface following burning (Pereira et al. 1997). For windthrows, such effects last about one year after which vegetation regrowth covers the ground surface (Negrón-Juárez et al., 2010a;Negrón-Juárez et al., 2011).

35. Similarly, if the burned area was used as pastureland until 1987, wouldn't the post-disturbance recovery start data be 1987 instead of 1984 for the burned area site (see L130-131)?

Response: Yes, and this is specified in line 205 of the manuscript.

36. Fig. 3 highlights the lack of Landsat 5 data for the 1982 clear-cut and 1984 burned area disturbance dates. Given that the L5 launch date was in 1984, there is nothing that can be done about the lack of data prior to 1984. However, I recommend extending the x-axis on Fig. 3 (d-f) back to 1982 to avoid misrepresentation of the data coverage. Including a vertical line at the year of each disturbance in these plots would further clarify this.

Response. We have included the reviewer suggestion. The new Figure 3 is :

Figure 3: L5 (LEDAPS SR Landsat 5) spectral characteristics for (a) windthrow (July 12, 1987), (b) clearcut (June 1 , 1984), and (c) cut+burn (July 12, 1987) (in red) and control (old-growth) forests (in green) sites. Time series of each L5 spectral bands for (d) windthrow, (e) clearcut, and (f) cut+burn sites. The bars represent the standard deviation from all pixels from all 3ïĆť3 boxes comprising the respective disturbances showed in Fig. 1. Vertical dashed lines represent the year of the disturbance.

37. L131: Instead of “some” years, could this read 2 or 3 years?

Response. We have included the reviewer suggestion:

[line 130] The cut+burn site is located in the Dimona farm (Figure 1d), which was clearcut and burned in September 1984 and maintained as pasture for 2 or 3 years and then abandoned. By 1993 this site was 6 years old and dominated by the pioneer tree genus Vismia (Mesquita et al., 1999;Mesquita et al., 2001).

38. L309: Replace “with” with something like “immediately after” or “within X years of: : :”

Response. We have included the reviewer suggestion.

Overall, all L5 bands showed an increase in surface reflectance immediately after windthrow, clearcut, and burned sites e

39. L122: The authors mention in situ data collection on forest structure and species composition since 2011 at the windthrow site. 2011 is well after this forest has recovered. How are these data relevant to this analysis? It is unclear whether they are used directly in analyses in this manuscript. Please clarify.

Response. Based on this data we assessed the time of recovery of windthrows that is later used to compare with our RS results that is described in our Discussion. Provide these details is important since allow a comparison of our RS data with observations.

TECHNICAL CORRECTIONS

40. L30-32: This statement does not seem fully supported by the results given that observations and model output yielded opposites rate of recovery for clear-cut and windthrow disturbances. What does ‘appropriate fidelity’ refer to here?

Response. We have modified or sentence as:

The similarity of ELM-FATES predictions of regrowth patterns after windthrow and clearcut to those of the NIR results suggest that the patterns of forest regrowth for these disturbances are well represented within ELM-FATES.

41. L51: Replace horizontal resolution with spatial resolution

Response. We have included the reviewer suggestion.

42. L70: The use of Vegetation Demographic Models (VDMs) as an acronym is unfamiliar. Perhaps replace with Dynamic Vegetation Models (DVMs) or Dynamic Global Vegetation Models (DGVMs).

Response. VDM is a new acronym that is being introduced to the vegetation modeling community that is based on the Fisher et al. (2018) review manuscript ("Vegetation Demographics in Earth System Models: A review of progress and priorities"). The term VDM is also being used in all current and future papers including FATES, and we wanted to be consistent. We are choosing to adopt this acronym, and its slightly updated definition of including "demographic". FATES is not classified as a DGVM, because first generation DGVMs do not capture many demographic processes considered important for predicting ecosystem composition and function, including canopy gap formation, vertical light competition, competitive exclusion, and successional recovery from disturbance. 43. L120: Include GPS coordinates for the windthrow site, similar to the burned area and clear-cut sites.

Response. We have included the coordinates

44. L147: : : :and Landsat 7 ETM+? Response. It is mentioned in the following sentences in the same paragraph. 45. L154: Add 'bands' so that it reads, "L5 bands are derived using: : :"

Response. Bands and subsequent changes suggested were included.

46. L159-160: remove "has", "promptly", and "have" so this sentence reads, "We used LEDAPS since a long time series of data is available with high spectral performance: : :"

Response. The suggested change was introduced in the manuscript.

47. L168: Insert “dry season” before “months present less cloud cover”?

Response. We included the change suggested by the reviewer.

48. L173: Mention that all sites are in a single Landsat scene and include the path and row, as is done in the Figure 1 legend.

Response. The suggested addition was included in the respective sentence.

49. L178: replace “several boxes” with “n = X boxes.”

Response. We included the suggested change.

50. L179-181: Confusing, reword sentence.

Response. We have done the following change:

[line 178] Spectral characteristics for old-growth forest for each site were determined from boxes located in the same position of the disturbance but previous to disturbance and/or from adjacent areas.

51. L187: include year – “: : :containing the highest level of SWIR1 in year XXX: : :”

Response. The year 1987 was included in the sentence

52. L193: The numbers 27 and 12 don’t seem to make sense given the 1984 start of data acquisition to _2019.

Response. In line 173 of the submitted manuscript we mentioned that Landsat 5 stop its operation in 2011, 28 years of data since 1984. In that period we got 15 images to use over our study areas listed in lines 174 and 175.

We have included the following changes in the manuscript:

[Line 193 ] L5 data for the windthrow, clearcut, and cut+burn sites encompass a period of 28 years with 13 years of missing data

53. L202: Insert “in the Manaus region” before “affected by windthrows are dominated: : :”

Response. We inserted the words suggested by the reviewer.

54. L213: Insert “Time series of: : :” before “L5 bands were.”

Response. Done

55. L297: Insert “modeled” after “we averaged.”

Response. Done

56. L298: Replace “influence the” with “are more comparable to 30 m: : :”

Response. We have done the following change:

[line 297] In addition, we averaged modeled outputs of crown area, stem density, and LAI since each of these variables influence the reflectance of forests, and defining this average as the modeled ‘canopy-coverage’

57. L301-303: Confusing sentence, reword.

Response. The sentence was modified as:

Modeled diameter growth (cm y-1) for trees with DBH $\geq$10 cm is also show to provide information of the successional dynamics of forest stands within ELM-FATES.

58. L314: Replace “behavior” with “response.”

Response. Done.

59. L330: Clarify at the start of this sentence whether you are referring to all three disturbance types.

Response. We have done the following change:

About six years after the disturbances,

60. L332-333 / Figure 3: Include NIR band values in Fig 3 (d-f) for control plots for direct comparison to emphasize "return to pre-disturbance values".

Response. Figures 4-6 show exactly this comparison.

61. L338: Replace "become" with "became." Response. Done.

Figure 1: Show inset with all three site locations in the Manaus region together to illustrate their spatial proximity (i.e. a close up of the yellow box in Fig. 1a).

62. Response. Based on the reviewer suggestion the new Figure 1 is:

63. Table 2: Replace "Bolt" with "Bold."

Response. Done. Thanks.

64. Table 3: Swap the "NIR" and "Model average of forest structure" columns. Response. Done. Thanks.

References Adams, J. B., and Gillespie, A. R.: Remote Sensing of Landscapes with Spectral Images: A Physical Modeling Approach Cambridge University Press, Cambridge, UK, 2006. Bierregaard, R., Gascon, C., Lovejoy, T., and Mesquita, M. R.: Lessons from Amazonia: The Ecology and Conservation of a Fragmented Forest, Yale University Press, New Haven, Connectivut, USA, 496 pp., 2001. Bierregaard, R. O., Lovejoy, T. E., Kapos, V., Dossantos, A. A., and Hutchings, R. W.: The biological dynamics of tropical rainf-forest fragments, Bioscience, 42, 859-866, 10.2307/1312085, 1992. Carneiro, V. M. C., Lima, A. J. N., Pinto, A. C., Santos, J., Teixeira, L. M., and Higuchi, N.: Floristic composition and structural analisis of terr firme forests in Manaus, Amazonas, Brazil, V Congresso FlorestalNacional: A Floresta e as Gentes, Viseu, Portugal, 2005. da Silva, R. P., dos Santos, J., Tribuzy, E. S., Chambers, J. Q., Nakamura, S., and Higuchi, N.: Diameter increment and growth patterns for individual tree growing in Central Amazon, Brazil, Forest Ecology and Management, 166, 295-301, 2002. Da Silva, R. P.: Allometry, storage and biomass dynamics of primary and secondary forests in the Manaus Region (AM) [in Portuguese], PhD, Universidade Federal do Amazonas, 135 pp., 2007. Ferraz, J., Oht, S., and Salles, P. C.: Distribuição dos solos ao longo de dois transectos em floresta primária ao norte de Manaus (AM), in: Pesquisas Florestais para a Conservação da Floresta e Reabilitação de Áreas Degradadas da Amazônia, edited by: Higuchi, N., Campos, M. A. A., Sampaio, P. T. B., and Santos, J., INPA, Manaus, 111-143, 1998. Fisher, R. A., Koven, C. D., Anderegg, W. R. L., Christoffersen, B. O., Dietze, M. C., Farrior, C. E., Holm, J. A., Hurtt, G. C., Knox, R. G., Lawrence, P. J., Lichstein, J. W., Longo, M., Matheny, A. M., Medvigy, D., Muller-Landau, H. C., Powell, T. L., Serbin, S. P., Sato, H., Shuman, J. K., Smith, B., Trugman, A. T., Viskari, T., Verbeeck, H., Weng, E. S., Xu, C. G., Xu, X. T., Zhang, T., and Moorcroft, P. R.: Vegetation demographics in Earth System Models: A review of progress and priorities, Global Change Biology, 24, 35-54, 10.1111/gcb.13910, 2018. Higuchi, F. G., Siqueira, J. D. P., Lima, A. J. N., Figueiredo, A., and Higuchi, N.: The effect of plot size on the precision of the Weibull distribution of diameters in the primary forest of the central Amazon, FLORESTA, 2, 599-606, 2012. Higuchi, N., Dos Santos, J., Ribeiro, R. J., Freitas, J. V., Vieira, G., and Cornic, A.: Crescimento e Incremento de uma Floresta Amazônica de Terra-Firme Manejada Experimentalmente, INPA, Manaus, Brazil, 89-132, 1997. Higuchi, N., Chambers, J. Q., Santos, J., Ribeiro, R. J., Pinto, A. C., Silva, R. P., Rocha, R. M., and Tribuzy, E. S.: Carbon balance and dynamics of primary vegetation in the central Amazon, Floresta, 34, 295-304, 2004. Laurance, S. G. W., Laurance, W. F., Andrade, A., Fearnside, P. M., Harms, K. E., Vicentini, A., and Luizao, R. C. C.: Influence of soils and topography on Amazonian tree diversity: a landscape-scale study, Journal of Vegetation Science, 21, 96-106, 10.1111/j.1654-1103.2009.01122.x, 2010. Laurance, W. F., Nascimento, H. E. M., Laurance, S. G., Andrade, A., Ewers, R. M., Harms, K. E., Luizao, R. C. C., and Ribeiro, J. E.: Habitat Fragmentation, Variable Edge Effects, and the Landscape-Divergence Hypothesis, PloS one, 2, 10.1371/journal.pone.0001017, 2007. Laurance, W. F., Camargo, J. L. C., Luizao, R. C. C., Laurance, S. G., Pimm, S. L., Bruna, E. M., Stouffer, P. C., Williamson, G. B., Benitez-Malvido, J., Vasconcelos, H. L., Van Houtan, K. S., Zartman, C. E., Boyle, S. A., Didham, R. K., Andrade, A., and Lovejoy, T. E.: The fate of Amazonian forest fragments: A 32-year investigation, Biological Conservation, 144, 56-67, 10.1016/j.biocon.2010.09.021, 2011. Laurance, W. F., Camargo, J. L. C., Fearnside, P. M., Lovejoy, T. E., Williamson, G. B., Mesquita, R. C. G., Meyer, C. F. J., Bobrowiec, P. E. D., and Laurance, S. G. W.: An Amazonian rainforest and its fragments as a laboratory of global change, Biological Reviews, 93, 223-247, 10.1111/brv.12343, 2018. Lima, A. J. N., Teixeira, L. M., Carneiro, V. M. C., Santos, J., and Higuchi, N.: Biomass stock and structural analysis of a secondary forest in Manaus (AM) region, ten years after clear cutting followed by fire, Acta Amazonica, 37, 49-54, 2007. Lovejoy, T. E., Bierregaard, R., Rylands, A., Malcolm, J., Quintela, C., Harper, L., Brown, K., Powell, A., Powell, G., Schubart, H., and Hays, M.: Edge and other effects of isolation on Amazon forest fragments, in: Conservation Biology: The Science of Scarcity and Diversity, edited by: Soulé, M. E., Sinauer Associates Inc., Sunderland, Massachusetts, U.S.A, 257-285, 1986. Lovejoy, T. E., and Bierregaard, R.: Central Amazonian forests and the minimum critical size of ecosystem project, in: Four neotropical rainforests, edited by: Gentry, A., Yale University Press, New Haven, 60-71, 1990. Magnabosco Marra, D., Chambers, J. Q., Higuchi, N., Trumbore, S. E., Ribeiro, G. H. P. M., dos Santos, J., Negron-Juarez, R. I., Reu, B., and Wirth, C.: Large-Scale Wind Disturbances Promote Tree Diversity in a Central Amazon Forest, PloS one, 9, e103711, 10.1371/journal.pone.0103711, 2014. Magnabosco Marra, D.: Effects of windthrows on the interaction between tree species composition, forest dynamics and carbon balance in Central Amazon, PhD, Institute of Biology, Leipzig University, Leipzig, Germany, 210 pp., 2016. Magnabosco Marra, D., Trumbore, S. E., Higuchi, N., Ribeiro, G. H. P. M., Negron-Juarez, R. I., Holzwarth, F., Rifai, S. W., Dos Santos, J., Lima, A. J. N., Kinupp, V. F., Chambers, J. Q., and Wirth, C.: Windthrows control biomass patterns and functional composition of Amazon forests, Global Change Biology, doi:10.1111/gcb.14457, 2018. Mesquita, R. C. G., Delamonica, P., and Laurance, W. F.: Effect of surrounding vegetation on edge-related tree mortality in Amazonian forest fragments, Biological Conservation, 91, 129-134, 10.1016/s0006-3207(99)00086-5, 1999. Mesquita, R. C. G., Ickes, K., Ganade, G.,





Printer-friendly version

Discussion paper

and Williamson, G. B.: Alternative successional pathways in the Amazon Basin, Journal of Ecology, 89, 528-537, 10.1046/j.1365-2745.2001.00583.x, 2001. Mesquita, R. D. G., Massoca, P. E. D., Jakovac, C. C., Bentos, T. V., and Williamson, G. B.: Amazon Rain Forest Succession: Stochasticity or Land-Use Legacy?, Bioscience, 65, 849-861, 10.1093/biosci/biv108, 2015. Negrón-Juárez, R. I., Jenkins, H. S., Raupp, C. F. M., Riley, W. J., Kueppers, L. M., Magnabosco Marra, D., Ribeiro, G., Monteiro, M. T. F., Candido, L. A., Chambers, J. Q., and Higuchi, N.: Windthrow Variability in Central Amazonia, Atmosphere, 8, 10.3390/atmos8020028, 2017. Ollinger, S. V.: Sources of variability in canopy reflectance and the convergent properties of plants, New Phytologist, 189, 375-394, 10.1111/j.1469-8137.2010.03536.x, 2011. Quesada, C. A., Lloyd, J., Anderson, L. O., Fyllas, N. M., Schwarz, M., and Czimczik, C. I.: Soils of Amazonia with particular reference to the RAINFOR sites, Biogeosciences, 8, 1415-1440, 10.5194/bg-8-1415-2011, 2011. Renno, C. D., Nobre, A. D., Cuartas, L. A., Soares, J. V., Hodnett, M. G., Tomasella, J., and Waterloo, M. J.: HAND, a new terrain descriptor using SRTM-DEM: Mapping terra-firme rainforest environments in Amazonia, Remote Sensing of Environment, 112, 3469-3481, 10.1016/j.rse.2008.03.018, 2008. Riebeek, H.: Why is that Forest Red and that Cloud Blue? How to Interpret a False-Color Satellite Image, https://earthobservatory.nasa.gov/Features/FalseColor/printall.php, 2017, 2014. Sombroek, W.: Spatial and temporal patterns of Amazon rainfall - Consequences for the planning of agricultural occupation and the protection of primary forests, Ambio, 30, 388-396, 10.1639/0044-7447(2001)030[0388:satpoa]2.0.co;2, 2001. Thonicke, K., Spessa, A., Prentice, I. C., Harrison, S. P., Dong, L., and Carmona-Moreno, C.: The influence of vegetation, fire spread and fire behaviour on biomass burning and trace gas emissions: results from a process-based model, Biogeosciences, 7, 1991-2011, 10.5194/bg-7-1991-2010, 2010. Tollefson, J.: SPLINTERS OF THE AMAZON, Nature, 496, 286-289, 2013. Tucker, C. J.: Red and photographic infrared linear combinations for monitoring vegetation, Remote Sensing of Environment, 8, 127-150, 10.1016/0034-4257(79)90013-0, 1979. Vieira, S., de Camargo, P. B., Selhorst, D., da Silva, R., Hutyra, L., Chambers, J. Q., Brown, I. F.,



Printer-friendly version

Discussion paper

Higuchi, N., dos Santos, J., Wofsy, S. C., Trumbore, S. E., and Martinelli, L. A.: Forest structure and carbon dynamics in Amazonian tropical rain forests, Oecologia, 140, 468-479, 10.1007/s00442-004-1598-z, 2004.

Please also note the supplement to this comment:
https://www.biogeosciences-discuss.net/bg-2019-451/bg-2019-451-AC3-supplement.pdf

---

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2019-451, 2019.

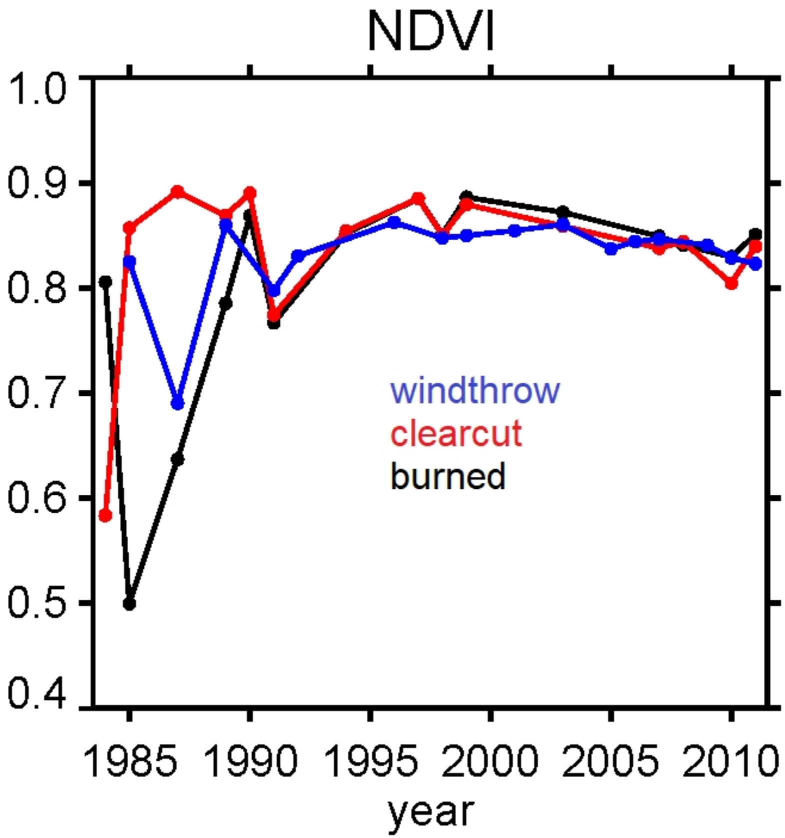


**Fig. 1.** Fig 1. Supp Fig 1

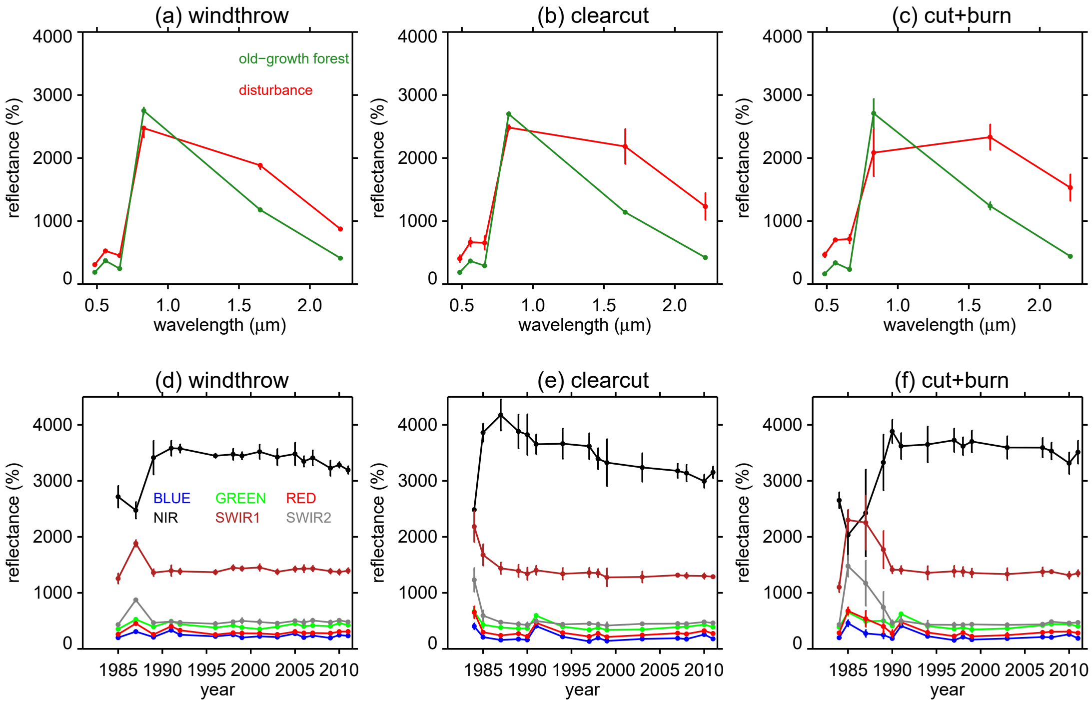


**Fig. 2.** New Figure 3

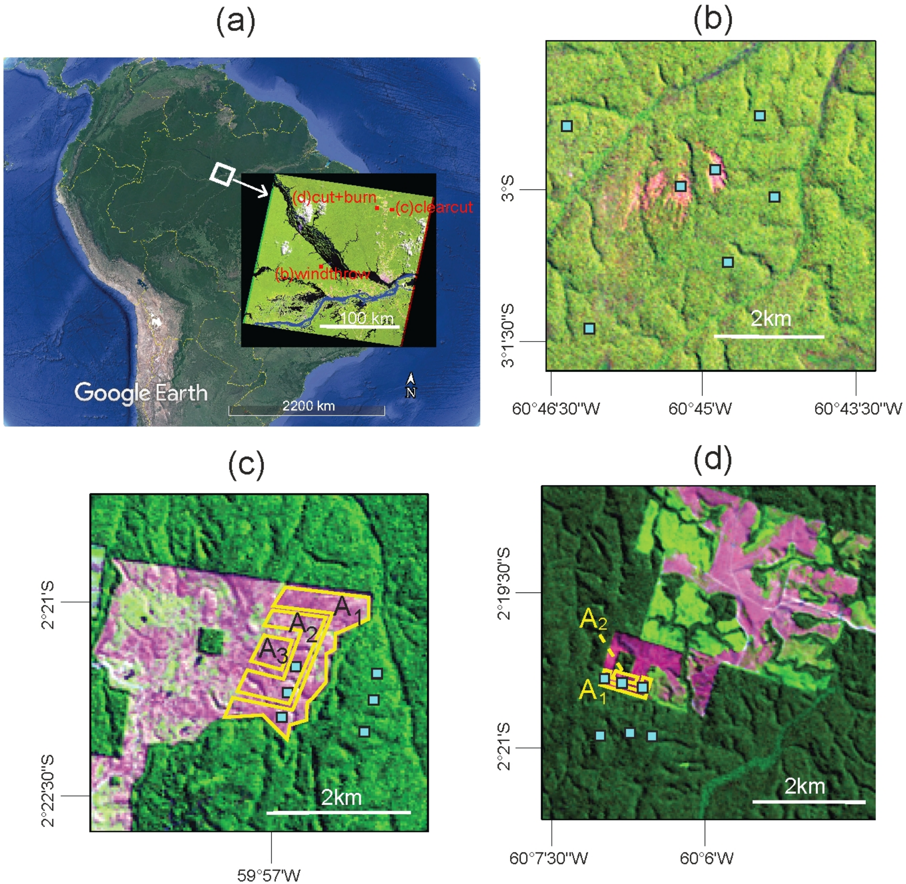


**Fig. 3.** New Figure 1