Quantifying the immediate carbon emissions from El Niño mediated wildfires in humid tropical forests

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Supplementary material

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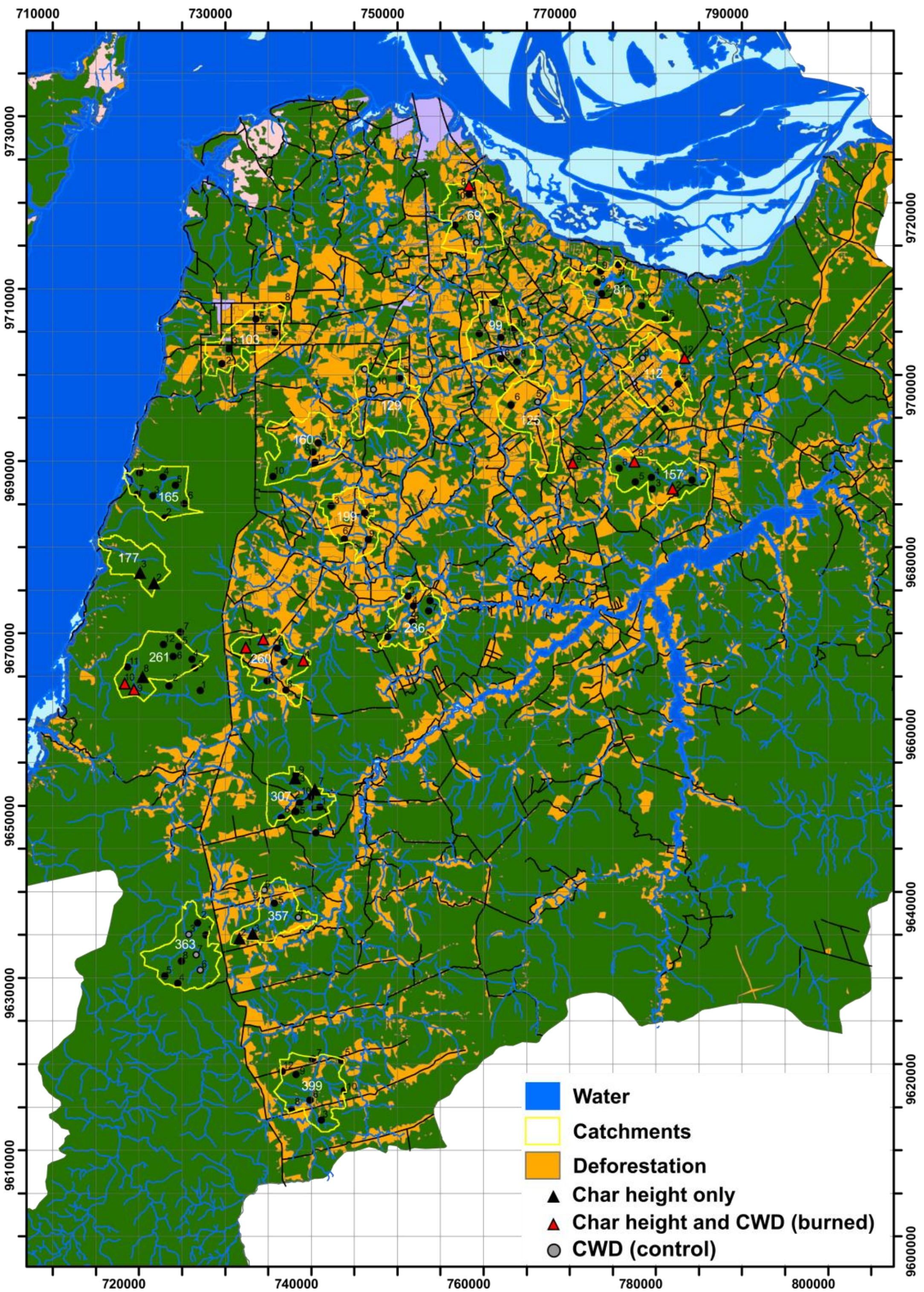

Figure S1. Plot location in the municipalities of Belterra, Mojuí dos Campos and Santarém in the Brazilian Amazon. Necromass was assessed in 113 forest plots in 2010. CWD was monitored in 18 of these plots until 2016. Char height was assessed in 17 plots that burned during the 2015-16 El Niño.

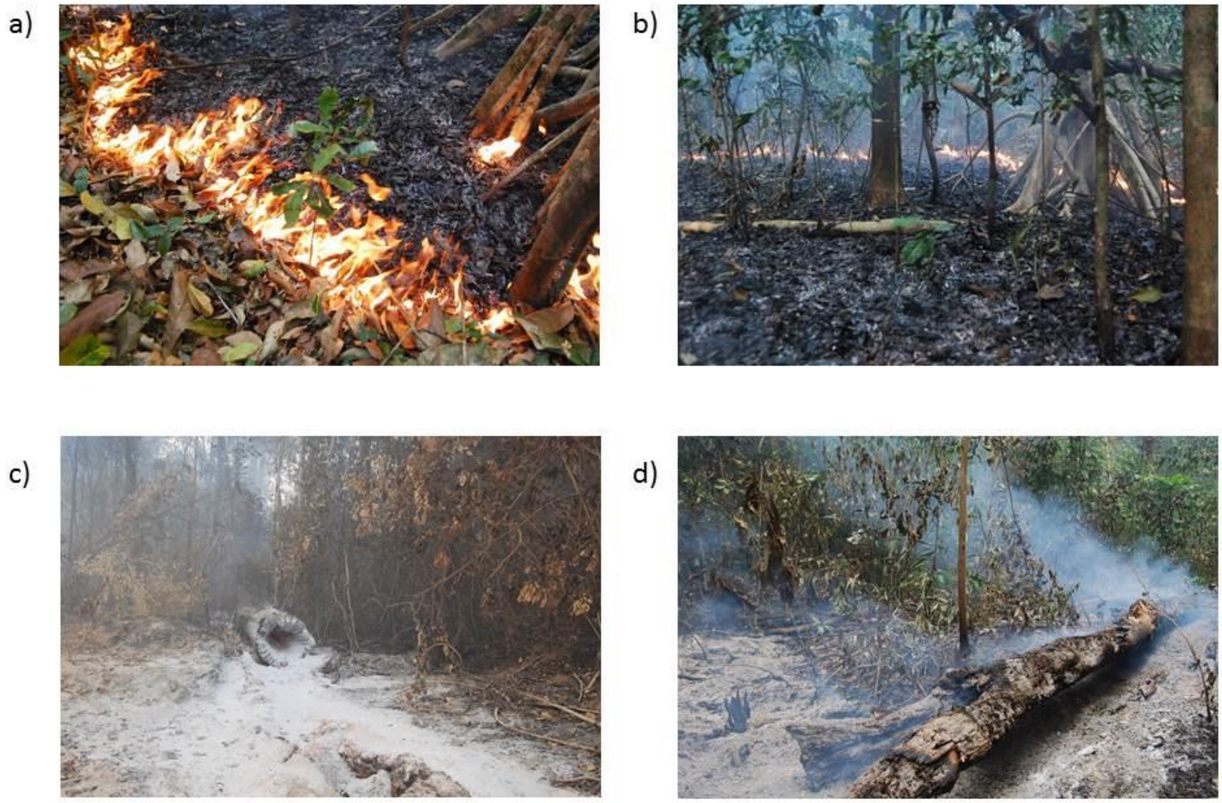

Figure S2. Personal observations of combustion completeness. A-B) The forest floor immediately after the fireline has passed in a previously logged forest. C-D) Smoldering coarse woody debris surrounded by a forest floor covered in ashes. All photos were taken during the 2015-16 El Niño in the Santarém region by E. Berenguer.

3. Carbon estimates

Total aboveground biomass (TAGB): TBGB of the large vegetation (≥ 10 cm) was estimated at each of the sampled forest sites following Hughes et al. [1] with the model:

$TAGB_t = TAGB_{max} (1 - \exp(-b1 \times t))^{b2}$

where $TAGB_t$ represents the total aboveground biomass at a given time; $TAGB_{max}$ is the potential maximum of TAGB; b1 controls the mean annual ABA, while b2 controls the inflection point of the accumulation curve.

Biomass of dead palms: The biomass of dead palms was calculated by using the Cummings et al. [2] allometric equations:

$[(\exp(1.321 \times \ln(D^2) + 3.2758)) \times 1.0931]/10^6$ for small palms (<10 cm DBH); and

$((\pi r^2 \times H) \times sg\_/10^6$ for large palms (≥ 10 cm DBH);

where D represents the DBH (cm); H is the height (m); sg is the specific gravity of wood (g cm^{-3}) and r is the radius (cm).

Coarse woody debris (CWD): We estimated the volumes of each CWD piece by applying the Smalian's formula [3]:

$V = L_{CWD} [(\pi(D_1/2)^2 + \pi(D_2/2)^2)/2]$

Where L_{CWD} (m) represents the length of a CWD piece, and D the diameter (cm) at either end.

Table S1. Forest classes included in each scenario and their associated sample sizes.

Scenario	FL_{CWD}	CC_{CWD}	D_{CWD}	FL_{LLFWD}	BA
Prim1	All primary classes (n=74)	All primary classes (n=7)	All primary classes (n=7)	All primary classes (n=74)	All primary classes (n=15)
Prim2	Disturbed primary classes only (n=57)	Disturbed primary classes only (n=5)	Disturbed primary classes only (n=4)	Disturbed primary classes only (n=57)	Disturbed primary classes only (n=10)
Sec1	Secondary forests only (n=39)	All primary classes (n=7)	All classes (n=10)	Secondary forests only (n=39)	All classes (n=17)
Sec2	Secondary forests only (n=39)	All primary classes (n=7)	Secondary forests only (n=3)	Secondary forests only (n=39)	Secondary forests only (n=2)

Table S2. Landsat scenes and dates that were used.

227/062	227/63	228/062	228/063
L5 TM 07/31/2010	L5 TM 07/31/2010	L5 TM 07/22/2010	L5 TM 07/22/2010
L5 TM 06/16/2011	L5 TM 06/16/2011	L5 TM 06/07/2011	L5 TM 08/10/2011
L7 ETM 07/28/2012	L7 ETM 07/28/2012	L7 ETM 09/21/2012	L7 ETM 08/20/2012
L7 ETM 09/14/2012	L7 ETM 09/14/2012	L7 ETM 10/23/2012	L7 ETM 10/23/2012
L7 ETM 17/11/2012	L7 ETM 30/09/2012	L7 ETM 11/24/2012	L7 ETM 12/10/2012
L8 OLI 09/25/2013	L8 OLI 09/25/2013	L8 OLI 09/16/2013	L8 OLI 06/28/2013
L8 OLI 08/30/2014	L8 OLI 07/10/2014	L8 OLI 15/08/2013	L8 OLI 06/15/2014
L8 OLI 10/30/2014	L8 OLI 03/23/2015	L8 OLI 06/15/2014	L8 OLI 05/17/2015
L8 OLI 01/02/2015	L8 OLI 06/27/2015	L8 OLI 05/17/2015	L8 OLI 07/20/2015
L8 OLI 07/29/2015	L8 OLI 07/29/2015	L8 OLI 06/02/2015	L8 OLI 07/06/2016
L8 OLI 06/29/2016	L8 OLI 07/31/2016	L8 OLI 06/18/2015	L8 OLI 08/07/2016
L8 OLI 08/16/2016	L8 OLI 08/16/2016	L8 OLI 09/24/2016	

6. Burned area estimation

For our burned area estimation, we used 48 Landsat images (Table S2) from Landsat 5, 7, and 8 between the years 2010 and 2016. These images covered an area of 6.48 million ha and included 14 municipalities in central-eastern Amazonia: Aveiro, Barreirinha, Belterra, Itaituba, Juruti, Mojuí dos Campos, Monte Alegre, Nhamundá, Parintins, Placas, Prainha, Rurópolis, Santarém, and Uruará. We performed pixel-by-pixel unsupervised k-means classifications (MacQUEEN, 1967, Drake and Jonathan, 2012) of each Landsat image with six classes and 10 interactions in ERDAS IMAGE v.16 (2016), to classify primary forest (including both undisturbed and disturbed), secondary forest, burn scars (from the 2015-16 El Niño-mediated fires), deforested areas, bodies of water, and non-forest (figure 1). We used the following as input variables: spectral bands including the visible to the medium infrared, Normalised Difference Vegetation Index (NDVI), Soil Adjusted Vegetation Index (SAVI), Enhanced Vegetation Index (EVI), and the Normalised Burn Ratio 2 (NBR2) [34]. Imagery from Landsat 7 and 8 were used in combination with the panchromatic band (Landsat 7 & 8) to improve their spatial resolution. The classified rasters were then imported and vectorised in ArcGIS v.10.2 (ESRI 2014), where a visual inspection of the automatic classification was made to correct any classification errors. Each individual band and all possible combinations in RGB composites were used to identify classifier errors. Following the correction of these errors, we calculated the cumulative area of primary and secondary forest that experienced understorey wildfires during 2015-16 in the Santarém region (figure 1).

7. GFED and GFAS comparison methods

We compared our CO_2 emission estimates to two fire emissions databases frequently used in Earth Systems models and carbon budgets. First, we compared our estimates to those of the Global Fire Emissions Database version 4.1s (GFED4.1s) (van der Werf et al. 2017), which is based on the MODIS burned area algorithm of Giglio et al. (2013) and is boosted for small fires using active fire estimates following Randerson et al. (2012). Second, we compared our estimates to those of the Global Fire Assimilation System (GFAS) version 1.1 (Kaiser et al. 2012).

We acquired GFED4.1s data files for the year 2015 and 2016 in the .hdf5 format from the following URL: https://www.geo.vu.nl/~gwerf/GFED/GFED4/. We then extracted the monthly emissions layers for our study period (August 2015 – July 2016) from these files and cropped them to our study region in central-eastern Amazonia. For each month, we calculated the per cell carbon emissions. We then downscaled the resolution, corrected the cell values accordingly, and finally re-cropped to our study area to avoid overestimating the emissions due to the mismatch in the resolutions between the GFED data and our own. Finally, we summed all cells across all months to calculate the cumulative carbon emissions for our study region and period.

We acquire Wildfire flux of Carbon Dioxide files from the European Centre for Medium-Range Weather Forecasts (ECMWF) from the following URL: http://apps.ecmwf.int/datasets/data/cams-gfas/.

8. Supplementary results

(a) Time into study period (i.e. fire season) was not correlated with char height, our proxy for fire intensity ($r = 0.06$; d.f. = 7; $P = 0.88$). Though it must be noted that date of burn is only an approximate estimate.

(b) Time in to study period (i.e. fire season) was not correlated to our estimate of plot-level burn area ($r = -0.31$; d.f. = 7; $P = 0.42$). Though it must be noted that date of burn is only an approximate estimate

(c) Time into study period was not correlated with our combines estimate of necromass (leaf litter, FWD, and CWD) combustion completeness ($r = 0.13$; d.f. = 5; $P = 0.78$). Though it must be noted we only have approximate dates for the seven plots for which we have combustion completeness values.

(d) Pre-El Niño necromass stocks were not correlated with char height, our proxy for fire intensity ($r = 0.29$; d.f. = 5; $P = 0.52$). Though it must be noted we only have approximate dates for the seven plots for which we have pre-El Niño necromass stock values.

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