



Supporting Online Material for

Hurricane Katrina's Carbon Footprint on U.S. Gulf Coast Forests

Jeffrey Q. Chambers,* Jeremy I. Fisher, Hongcheng Zeng, Elise L. Chapman, David B. Baker, George C. Hurtt

*To whom correspondence should be addressed. E-mail: chambers@tulane.edu

Published 16 November 2007, *Science* **318**, 1107 (2007)

DOI: 10.1126/science.1148913

This PDF file includes:

Materials and Methods

Fig. S1

Table S1

References

Hurricane Katrina's Carbon Footprint of Gulf Coast Forests

Supporting Online Material

MATERIALS AND METHODS

Hurricane Katrina caused extensive forest damage ranging from downed and dead trees, snapped boles, fractured crowns, and stripped leaves. Here we briefly describe the methodology for quantifying and regionalizing these impacts including: (i) building a Landsat-resolution (30 m) Δ NPV disturbance map, (ii) sampling tree mortality and damage across the disturbance gradient using the Landsat Δ NPV map, (iii) constructing scaling relationships among field, Landsat and MODIS (500 m) data, and (iv) developing a Monte-Carlo modeling approach for regionalizing tree damage and mortality estimates.

Two Landsat 5 scenes were acquired from the USGS for May 29th, 2003 and June 6th, 2006. Scenes were atmospherically corrected with ACORN software (ImSpec LLC), and geometrically corrected with state-provided road data to pixel-level accuracy. Forested regions were identified using supervised classification of the pre-Katrina scene. Landsat scenes were decomposed using an unconstrained four-endmember spectral mixture analysis (SMA) following Fisher et al. (SI), using scene-based endmembers of green vegetation (GV), non-photosynthetic vegetation (NPV), soil, and shade. Δ NPV was calculated as the difference in the NPV fraction of 2006 and 2003. Regions within the hurricane windfield which had been subjected to land-use change between 2003 and 2006 were excluded.

The Landsat Δ NPV map was used to conduct stratified random field sampling across the disturbance gradient. Forest inventory plots (400 m²) were established in five randomly chosen pixels from each of five intensity classes (n = 25) and located in the field using a handheld GPS receiver accurate to ~5 m. Plot measurements included species identification, diameter at breast

height (DBH at 1.3 m), tree condition (dead, snapped but sprouting, damaged, leaning, etc.), height of the remaining portion of snapped boles (using a Laser rangefinder), and percentage of crown loss for damaged trees distributed among five damage classes (S2). Height of snapped trees that were sprouting (i.e. not dead) was used to estimate partial tree volume and biomass loss using methods similar to Chambers et al. (S3). Mortality and damage quantified in the 25 plots was highly correlated with Δ NPV (Fig. S1), enabling development of quantitative landscape disturbance maps.

MODIS 500m 7-band reflectance (MOD09A) data were obtained from the NASA DAAC in eight day composites from January 1st, 2004 to December 31st, 2006 (138 scenes). Endmembers for GV, NPV, and soil were selected using published methods (S4), and SMA fractions were generated. To compare Landsat and MODIS Δ NPV estimates, Landsat data were aggregated to MODIS cell size, and only those MODIS pixels comprising > 75% forested Landsat pixels in 2003 were selected. These data were used to quantify the relationship between MODIS and Landsat Δ NPV for scaling field-derived mortality and damage to the entire impacted region.

A novel phenological tool was employed to determine the probability that any given pixel was forested. The GV of a deciduous pixel has a high value in the summer and a low value after senescence, while evergreens maintain relatively level GV values throughout the year, and urban and non-vegetated regions have constantly low GV. When graphed on a scatterplot in fraction space as GV in summer (GV_{\max}) vs. GV in winter (GV_{\min}), most regions fall into a coherent ternary region, with corners represented by pure deciduous, evergreen (primarily pine), and non-vegetated behavior (Fig. S2). Deciduous and evergreen points were selected to represent pure deciduous and evergreen behavior, respectively, while areas between these two points

represented mixed forests. Absolute perpendicular distance from the forest line was taken as a measure of the proximity to forest, and modeled probabilistically.

Data from the (i) processed MODIS imagery, (ii) additional field plots established in the Pearl River basin before the hurricane (38 plots, 1870 trees), and (iii) the USDA Forest Service's Forest Inventory Analysis (FIA) plots (fia.fs.fed.us) were employed to simulate tree mortality, damage and biomass loss for the entire area impacted by hurricane Katrina using a Monte-Carlo approach. First, each forested MODIS pixel was assigned a number of trees based on a random draw from stem density datasets for both evergreen and deciduous forest. Next, biomass loss from tree mortality and damage was estimated using published allometric equations predicting species-specific whole tree dry-weight biomass, including estimates of partial biomass loss from snapped trees and damaged crowns (S2). Iterating through each forested MODIS pixel, the total number of dead and damaged trees, and total biomass loss were estimated for the entire impacted region. A sensitivity analysis of minimum and maximum values for 9 key parameters (Table S1) enabled constraining mortality and biomass loss values to a range of plausible results.

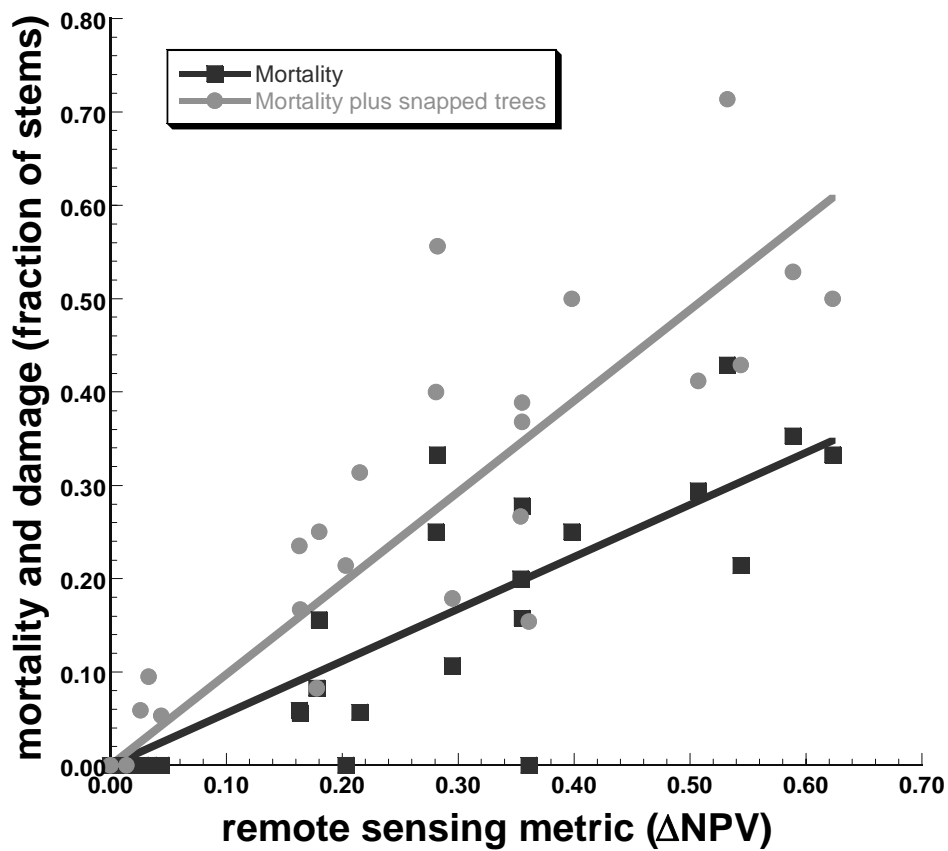


Figure S1. Tree damage and mortality rates from the 25 forest inventory plots and Landsat-derived ΔNPV . Linear regressions for tree mortality (black line: $N_M = 0.553 \cdot \Delta\text{NPV}$, $r^2_{\text{adj}} = 0.85$, $p < 0.0001$) and total tree mortality plus snapped trees (i.e. severe forest structural damage) (grey line: $N_T = 0.996 \cdot \Delta\text{NPV}$, $r^2_{\text{adj}} = 0.88$, $p < 0.0001$) enabled estimating tree mortality and damage from the ΔNPV remote sensing metric.

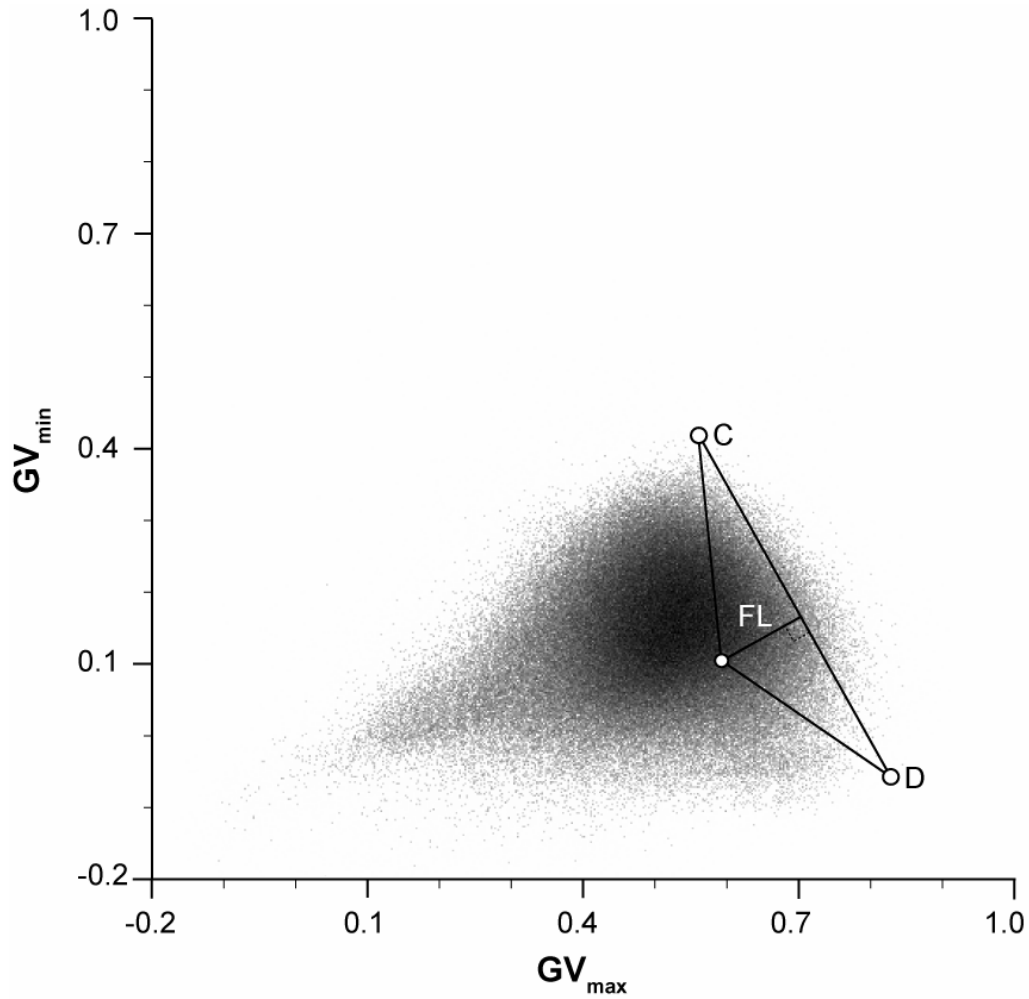


Figure S1. Scatter-plot showing the density of all non-water points (including non-forested) in the overall MODIS image. Point *C* represents maximum evergreen phenological behavior, and *D* deciduous behavior, with a randomly placed example point with a distance 0.13 from the forest line (well within the "acceptable" forest bounds), and a distance of 0.27 from *D* and 0.33 from *C*, identifying a forest with a predicted composition of 45% deciduous and 55% evergreen species.

Table S1. Principal parameters for developing the Monte-Carlo model for predicting the number of dead and damaged trees and total biomass loss in the Katrina impact region. L_{\max} and L_{\min} are the “distance to forest” from the MODIS data scatter plot (Fig. S2), describing the probability of a MODIS pixel being forested, b_{tot} is the total number of dead and snapped trees from the upper regression line of Fig. 1b, ρ_{stem} is mean stem density (trees ha⁻¹) for evergreen and deciduous forests, $\text{Ln}(B_{\text{tree}})$ is natural-log transformed mean tree biomass, f_{dead} is the fraction of dead stems from the total dead and snapped, f_{snap} is the mean biomass loss from a snapped live tree (i.e. not considered mortality), f_{crown} is fractional increase in the number of crown damaged trees from the total number of dead and snapped trees, and a - b_{NPV} are the slope and intercept for scaling MODIS to Landsat ΔNPV . Model runs for nominal (best estimate) values, and max and min values for each parameter, provided an error analyses of model predictions.

Parameters	Nominal Paramter Values	Low Paramter Values	Total trees (million)	Dead trees (million)	Snap trees (million)	Biomass Loss (Tg)	Carbon (Tg)	High Paramter Values	Total trees (million)	Dead trees (million)	Snap trees (million)	Biomass Loss (Tg)	Carbon (Tg)
L_{\max}	0.126	0.0707	290	100	82	187	93	0.15	332	115	94	214	107
L_{\min}	0.43	0.324	286	99	81	184	92	0.52	340	118	96	219	109
b_{tot}	0.996	0.847	292	101	83	190	95	1.145	352	122	100	225	112
ρ_{stem}	deciduous 283 coniferous 384	deciduous 273 coniferous 372	310	108	88	200	100	deciduous 292 coniferous 395	332	115	94	214	107
$\text{Ln}(B_{\text{tree}})$	deciduous 5.45 coniferous 5.54	deciduous 5.37 coniferous 5.51	321	111	91	199	100	deciduous 5.52 coniferous 5.56	321	111	91	215	107
f_{dead}	0.55	0.454	317	92	108	205	103	0.646	321	131	72	211	105
f_{snap}	0.809	0.793	321	111	91	206	103	0.826	321	111	91	208	105
f_{crown}	0.588	0.423	321	111	91	201	101	0.752	321	111	91	217	108
a - b_{NPV}	intercept 0.180 slope 0.72	intercept 0.176 slope 0.69	314	109	89	204	102	intercept 0.182 slope 0.73	329	114	93	213	106
nominal			321	111	91	207	104						

References

- S1. J. I. Fisher, J. F. Mustard, M. A. Vadeboncoeur, *Remote Sens Environ* 100, 265 (Jan 30, 2006).
- S2. E. L. Chapman, Masters Thesis, Tulane University (2006).
- S3. J. Q. Chambers, J. Santos, R. J. Ribeiro, N. Higuchi, *Forest Ecology and Management* 152, 73 (2001).
- S4. J. I. Fisher, J. F. Mustard, *Remote Sens Environ* 109, 261 (2007).