Tree mortality and forest-atmosphere interactions under a warming climate

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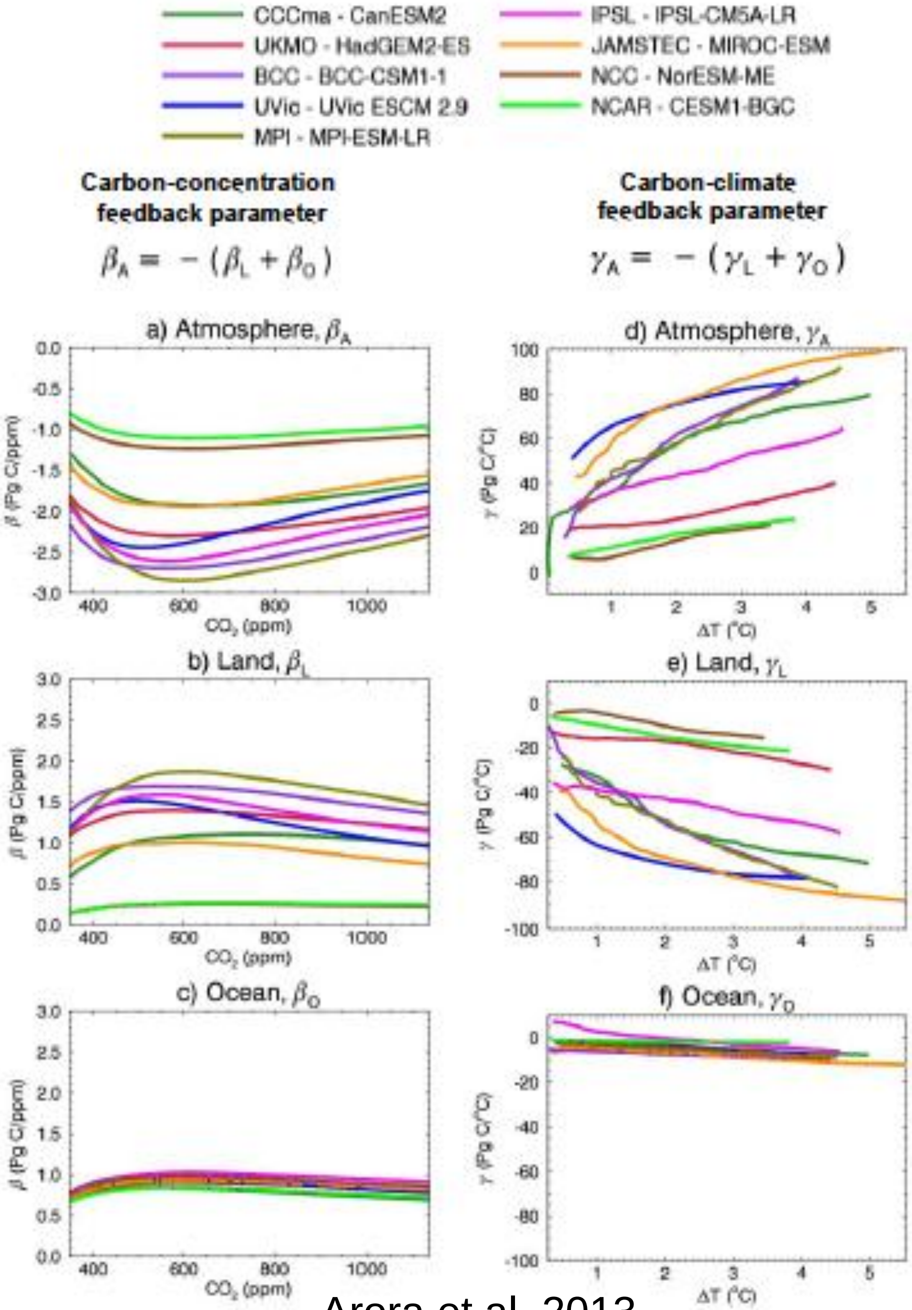
Tree mortality and feedback parameters



Arora et al. 2013

***β*: Tree mortality defines the loss term when calculating landscape carbon balance. Critical to test model predictions against field observations on the spatial and temporal variation in b.**

***γ*: climate-carbon feedbacks expected to increase in importance relative to b as the climate warms, yet few models even have the basic structures for evaluating g feedbacks. Many models treat mortality as a constant 1-2% yr^{-1}, or have simplistic treatments of a few processes (e.g. drought)**

Presentation Overview

Overall motivating questions

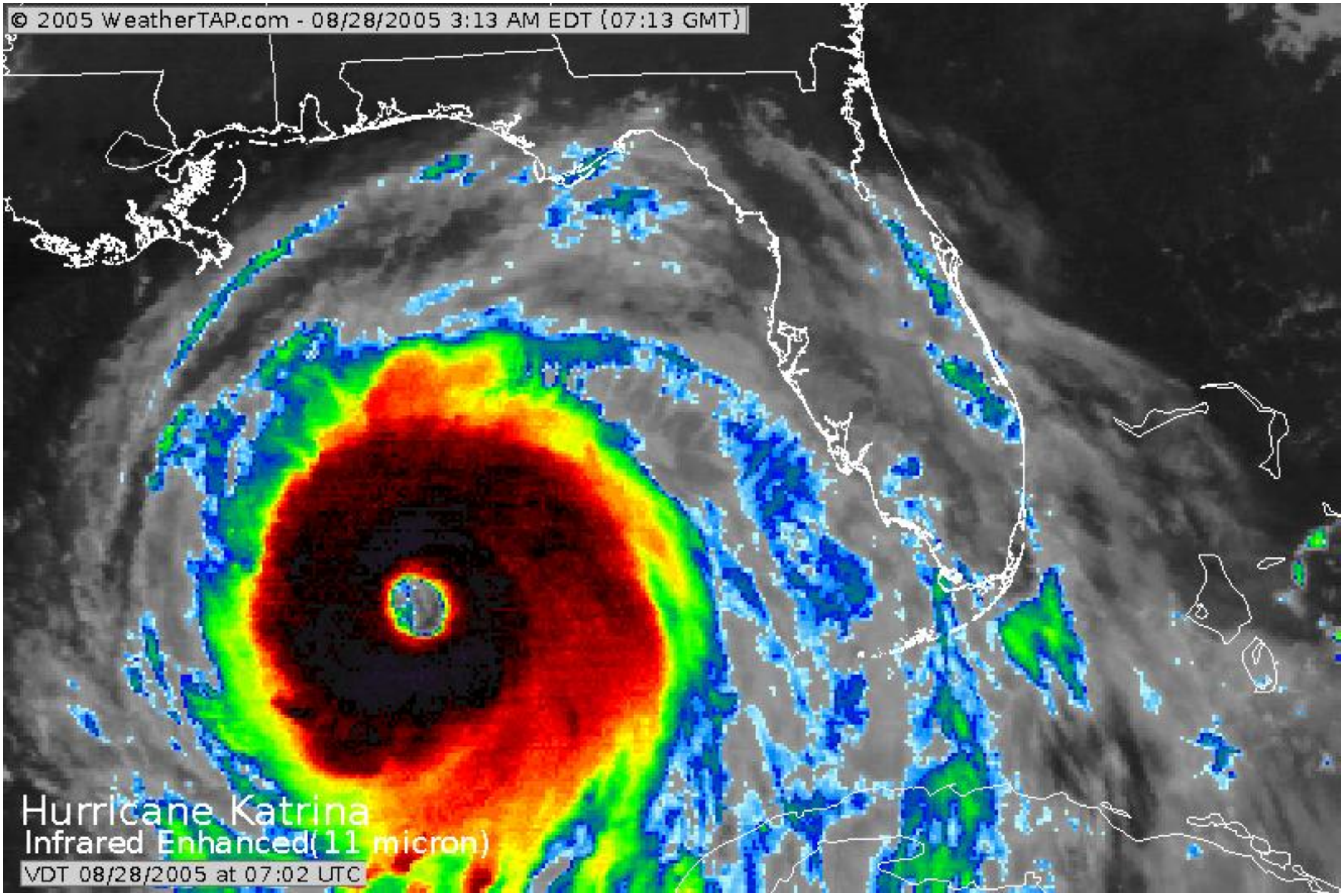
- **How will the key drivers of tree mortality change under a warming climate, and**
- **How will the altered disturbance regimes affect forest-atmosphere interactions?**
- **How do we models tree mortality in ESMs?**

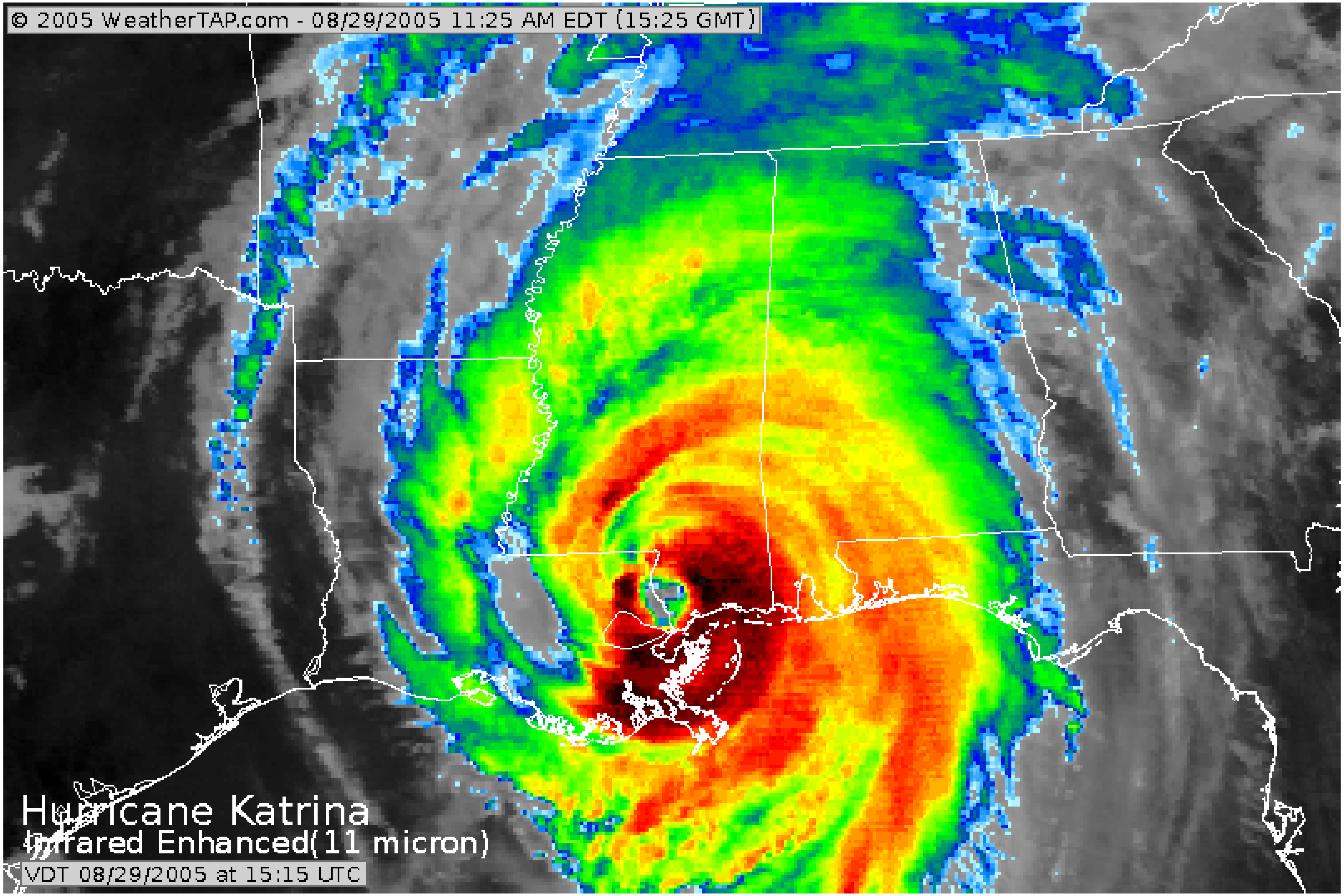
Key drivers of mortality

- **Wind – hurricanes and overall increased storm intensity**
- **Drought – focus on tropical forests**
- **Fire – including changes with tropical land-use**
- **Pests and pathogens – Jeff Hicke's talk on biotic disturbance agents**
- **Temperature – complex interactions with all processes**

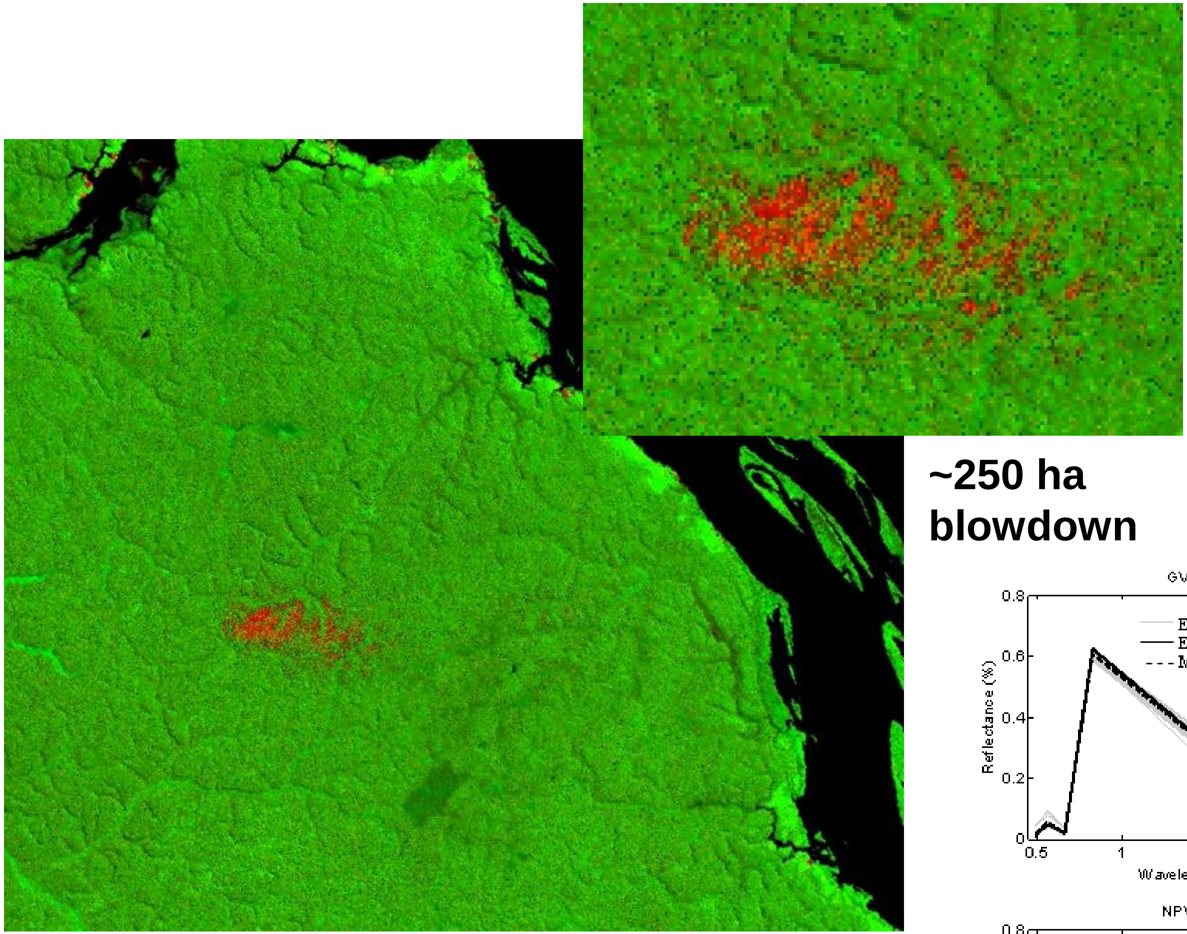
These processes define the terrestrial *g* response of Earth system models. For many of these processes, terrestrial ecosystem models lack the structures much less effective parameterizations.

What terrestrial carbon reservoirs are vulnerable to rapid release with a warming climate?


© 2005 WeatherTAP.com - 08/28/2005 3:13 AM EDT (07:13 GMT)
Hurricane Katrina
Infrared Enhanced(11 micron)
VDT 08/28/2005 at 07:02 UTC


© 2005 WeatherTAP.com - 08/29/2005 11:25 AM EDT (15:25 GMT)
Hurricane Katrina
Infrared Enhanced(11 micron)
VDT 08/29/2005 at 15:15 UTC

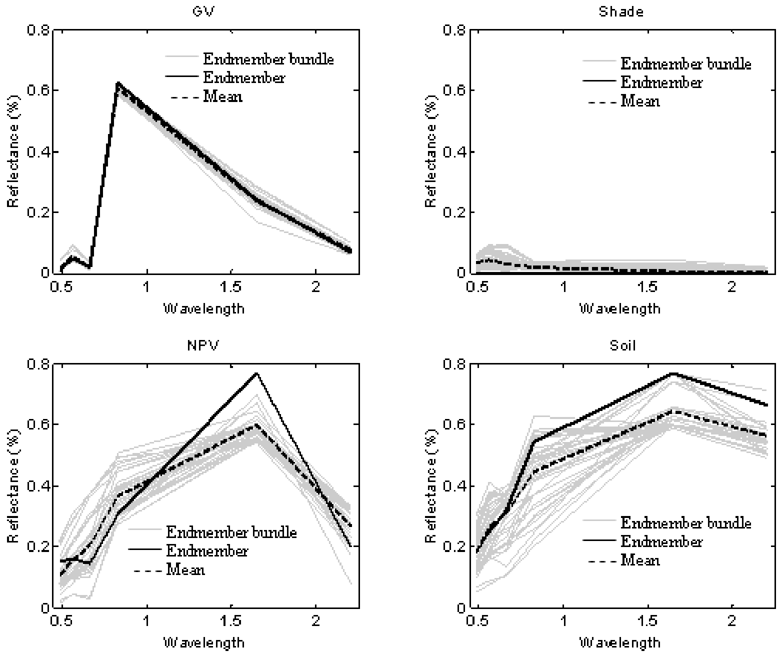
Detecting Forest Disturbance with Multispectral Imagery

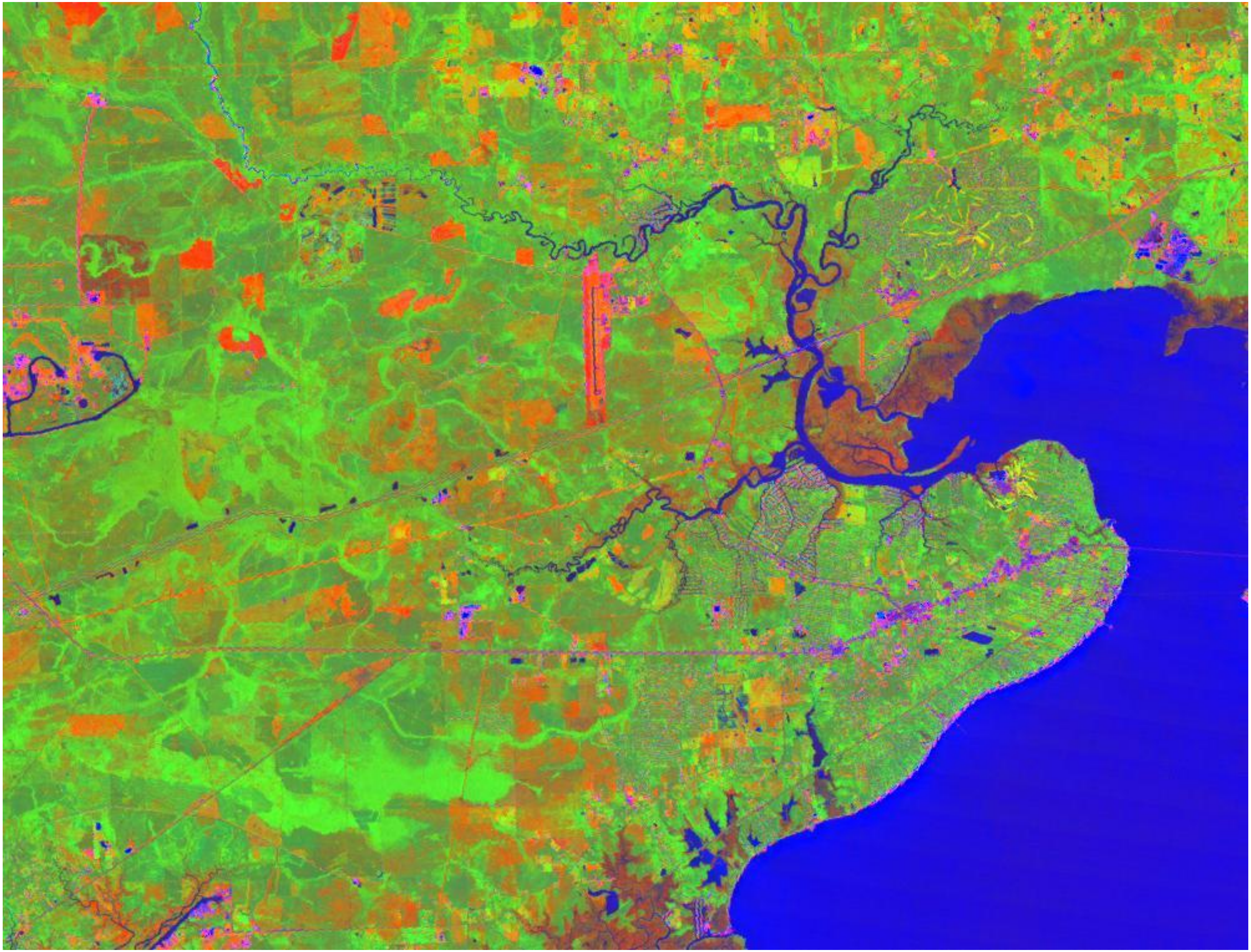


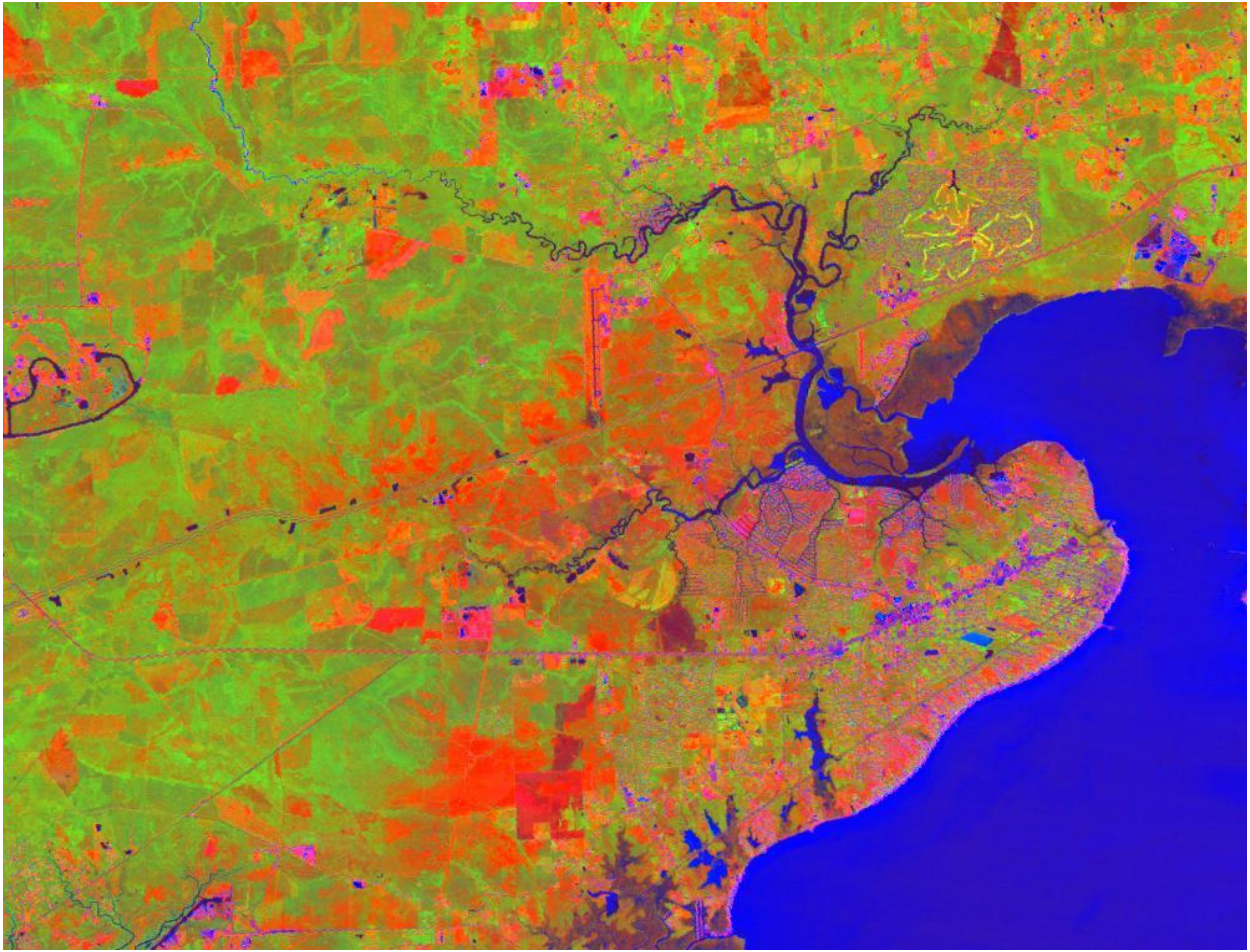
~250 ha blowdown

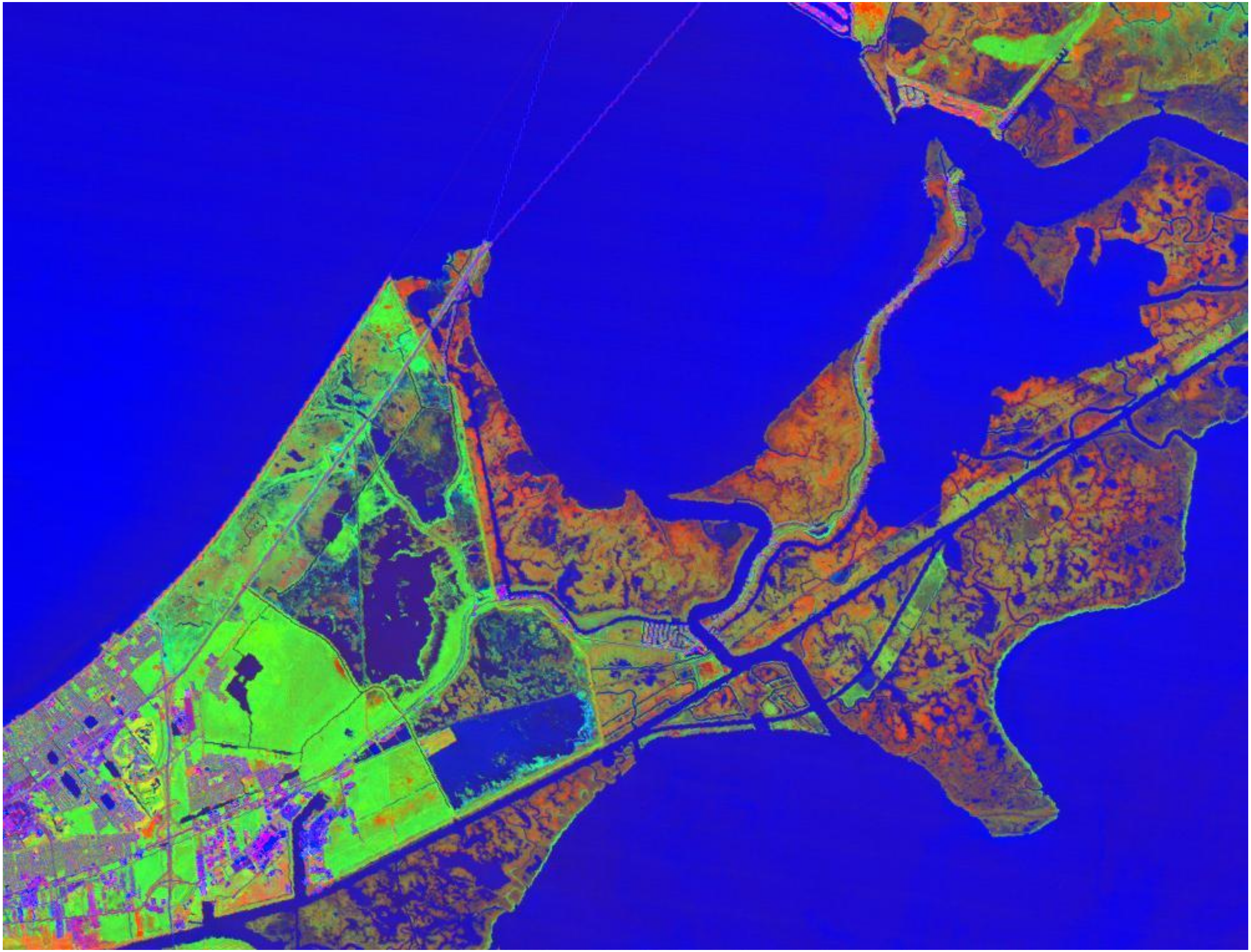
Landsat sub-image from 2001 image – west bank of Rio Negro north of Manaus

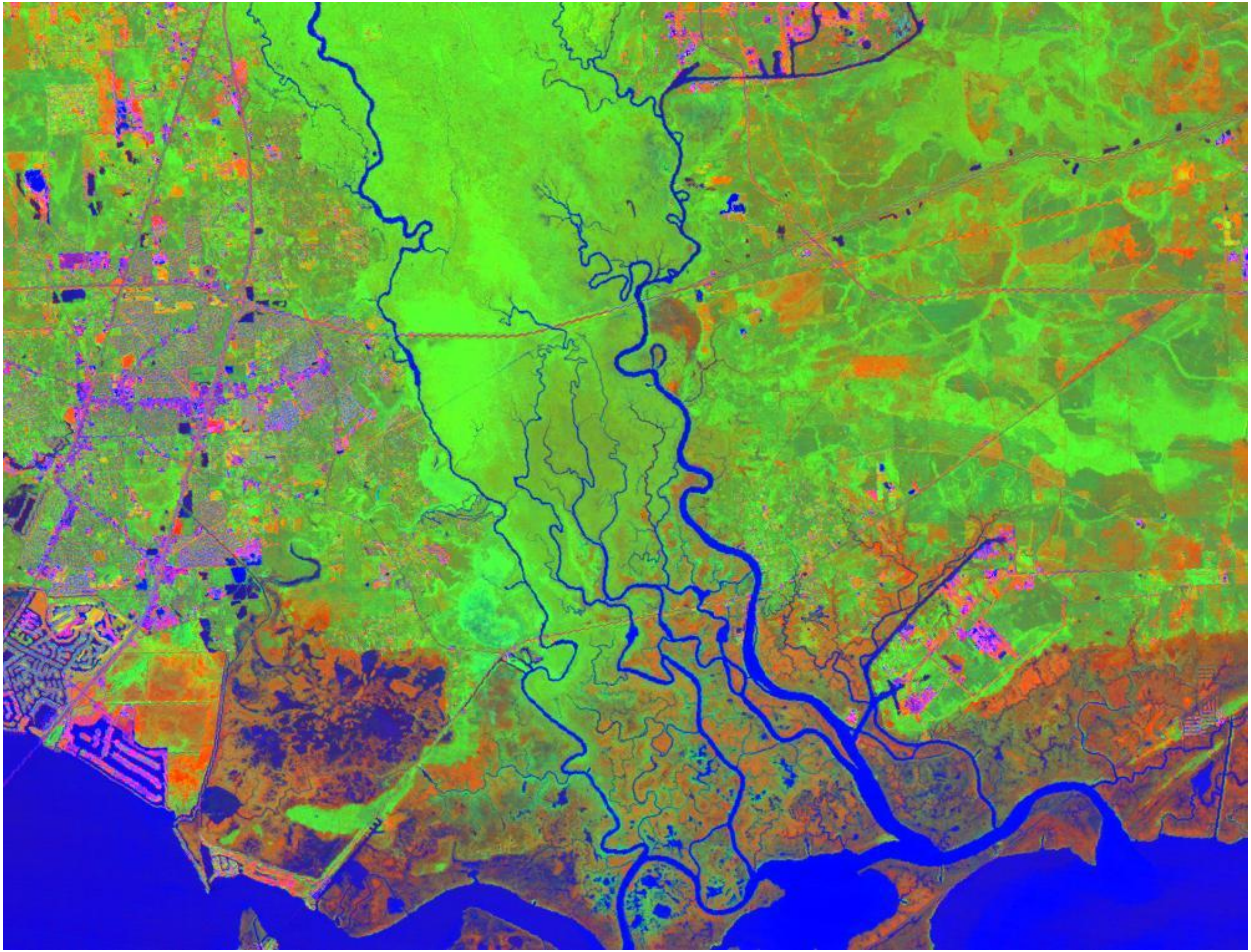
Spectral mixture analysis (SMA) for forested areas using image-derived endmember spectra for green vegetation (GV), non-photosynthetic vegetation (NPV), soil, and shade in a linear mixture model

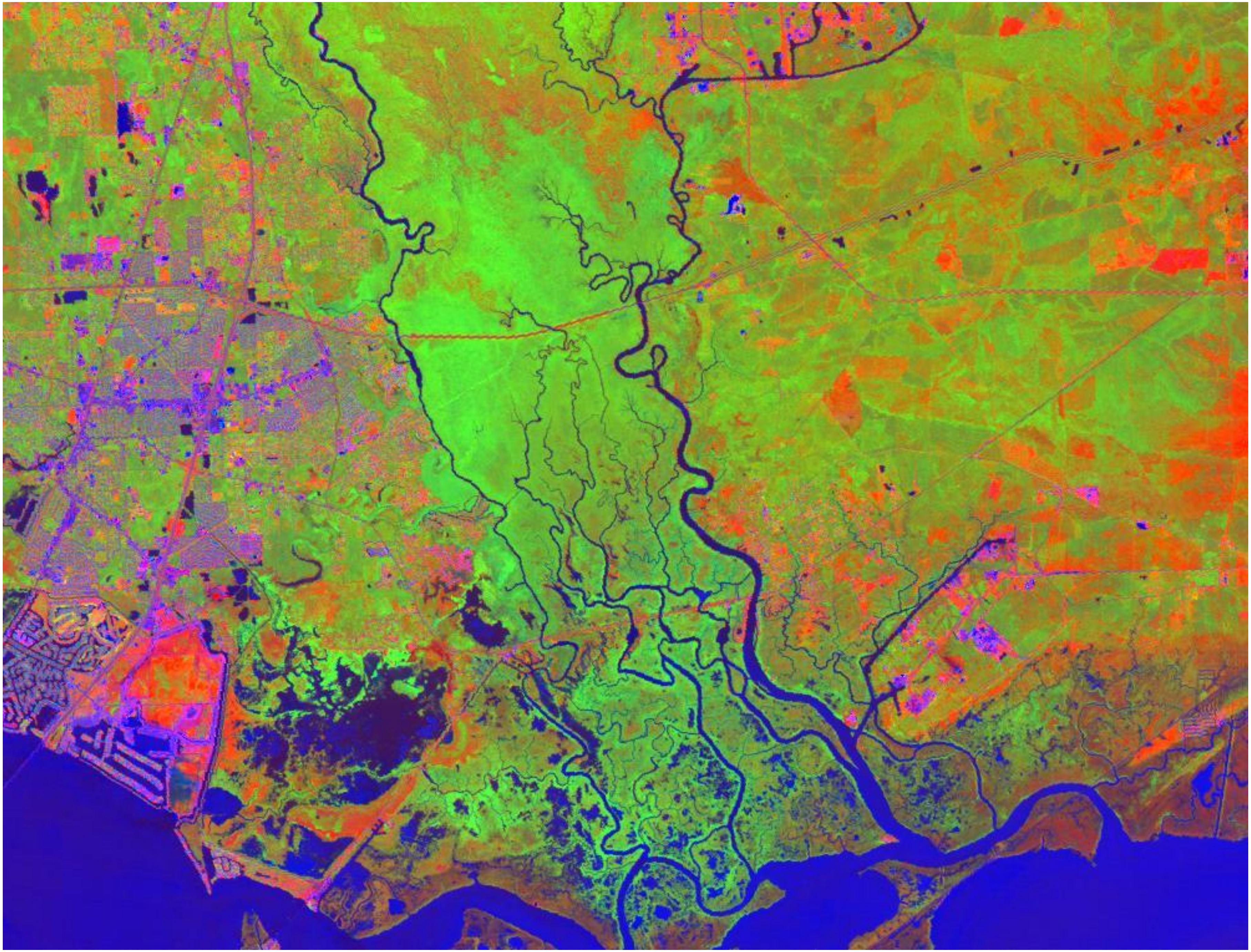






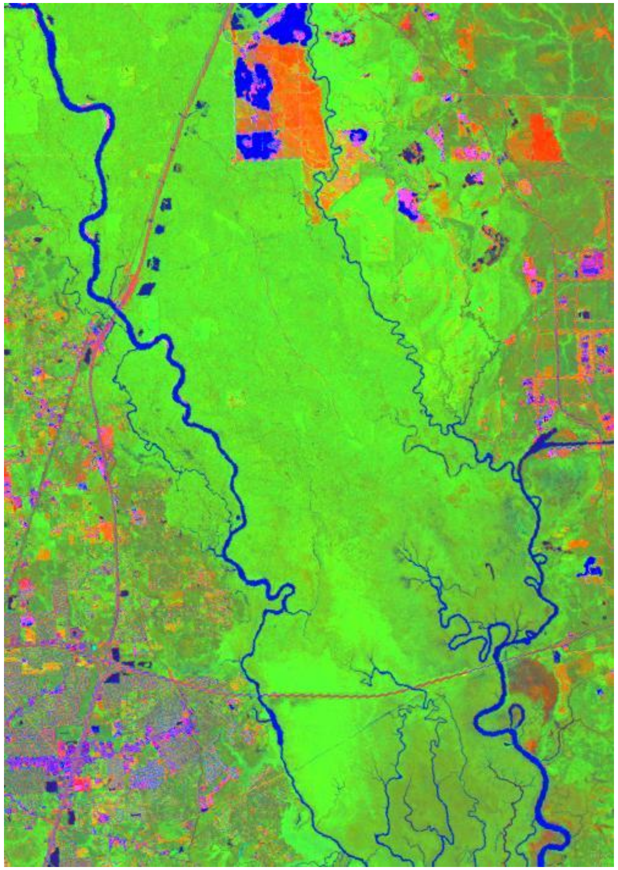




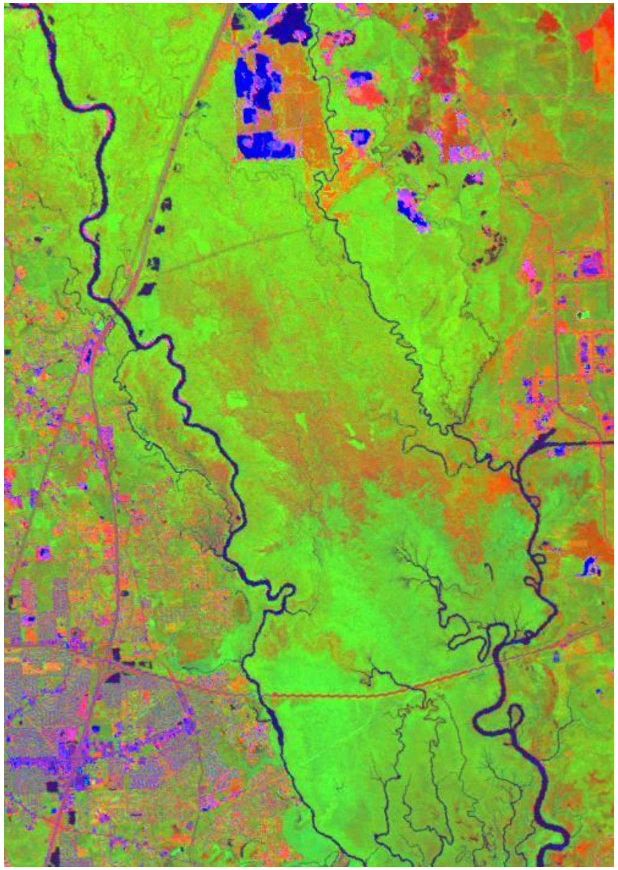


Hurricane Katrina impact in the Pearl River Basin

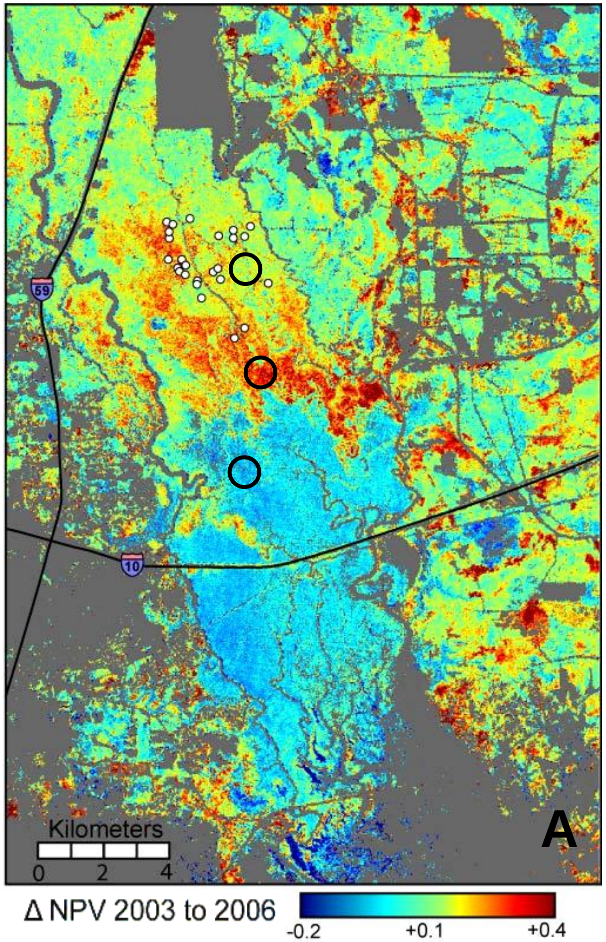
Pre-Katrina: GV, NPV, Soil+



Post-Katrina: GV, NPV, Soil+

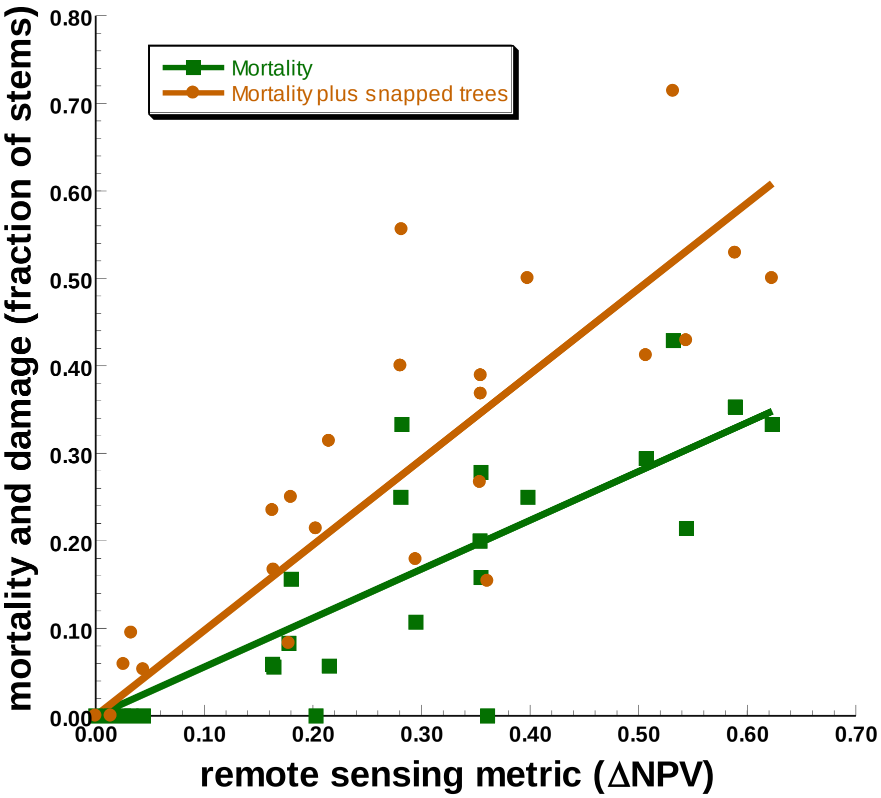


ΔNPV: change in wood, CWD, and litter reflectance



Stratified random sampling of hurricane tree mortality impact using ΔNPV

Tree mortality and damage quantified in the field

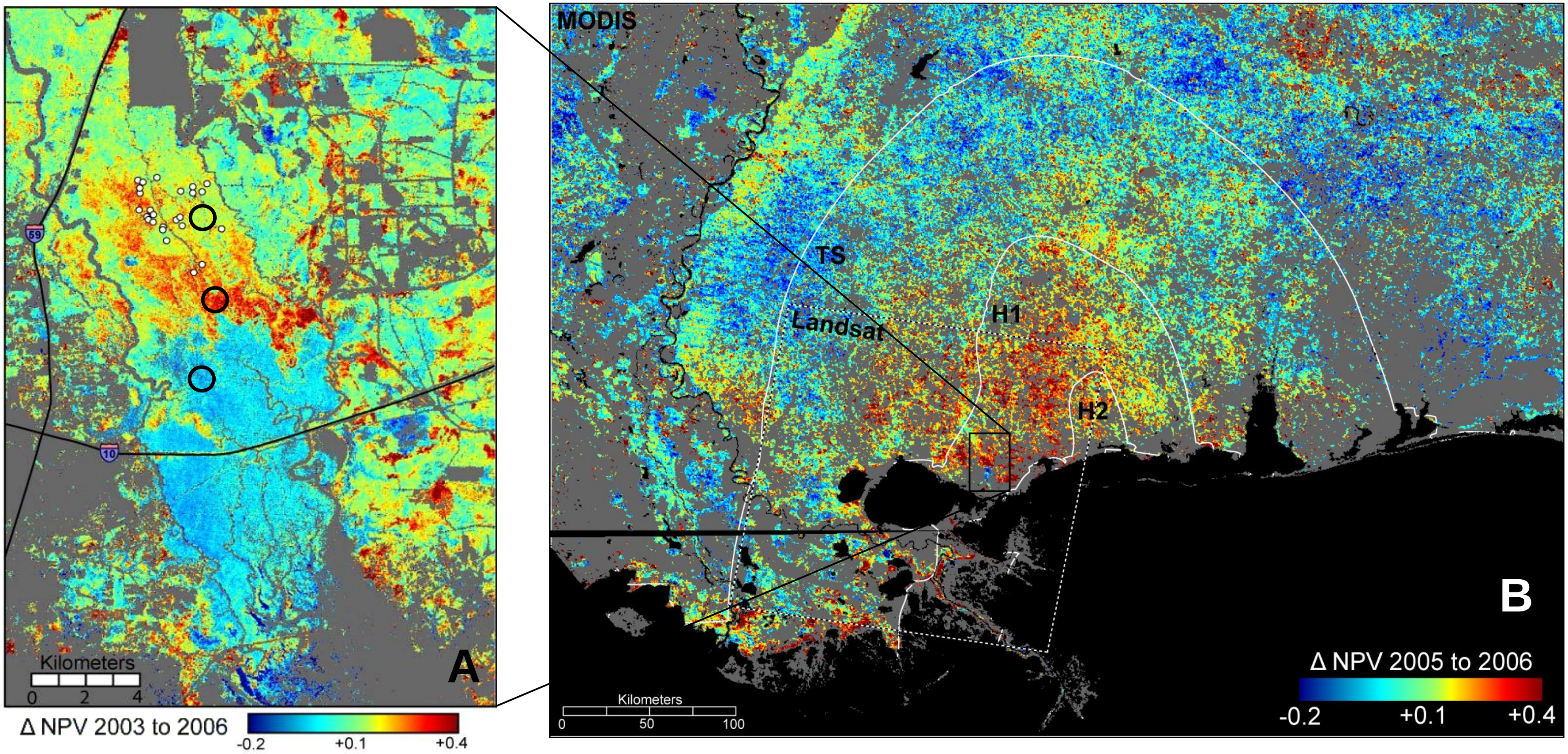


Remote sensing metric ΔNPV enabled plot establishment across the entire disturbance gradient

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

Jeffrey Q. Chambers,[1]* Jeremy I. Fisher,[1,2] Hongcheng Zeng,[1] Elise L. Chapman,[1]
David B. Baker,[1] George C. Hurtt[2]

SCIENCE VOL 318 16 NOVEMBER 2007



- 320 million trees dead or severely damaged – 100 Tg C of dead wood
- Annual net U.S. forest tree carbon sink = 100 Tg C
- Biological climate feedback hypothesis: Increasing CO_2, stronger storms, more dead trees, elevated ecosystem respiration, increasing CO_2.

Linking hurricane wind-fields and forest tree mortality in ESMs

Impacts of tropical cyclones on U.S. forest tree mortality and carbon flux from 1851 to 2000

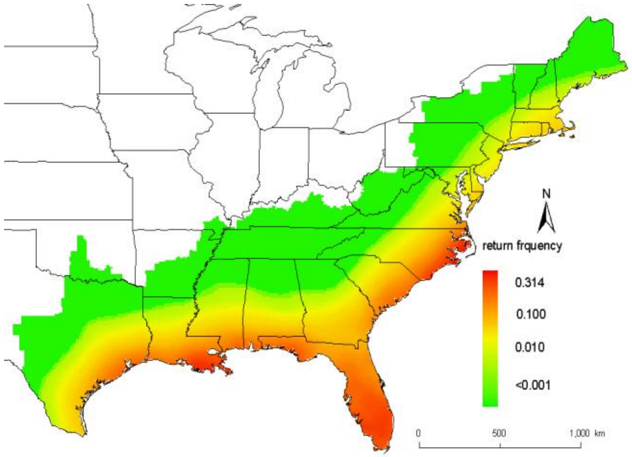
Hongcheng Zeng[a,1], Jeffrey Q. Chambers[a], Robinson I. Negrón-Juárez[a], George C. Hurtt[b], David B. Baker[a], and Mark D. Powell[c]

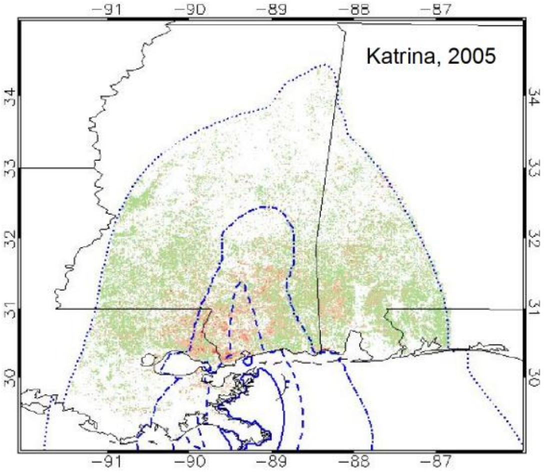
7888–7892 | PNAS | May 12, 2009 | vol. 106 | no. 19

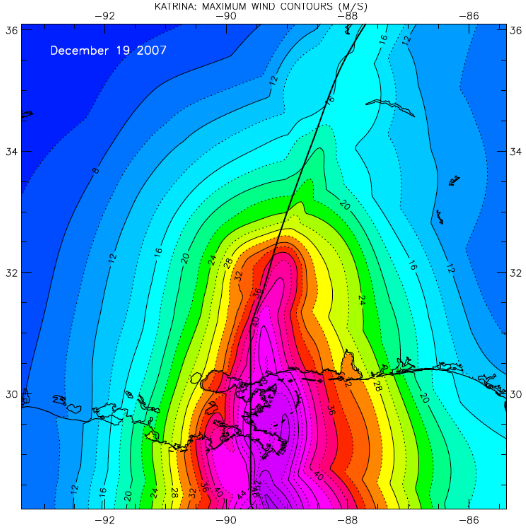
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, G04030, doi:10.1029/2009JG001221, 2010

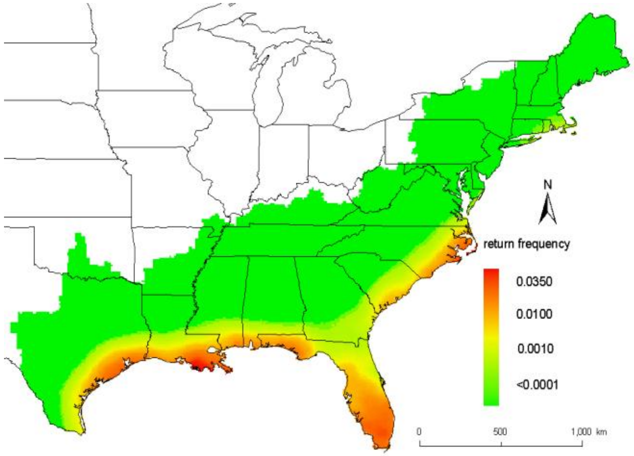
Assessing hurricane-induced tree mortality in U.S. Gulf Coast forest ecosystems

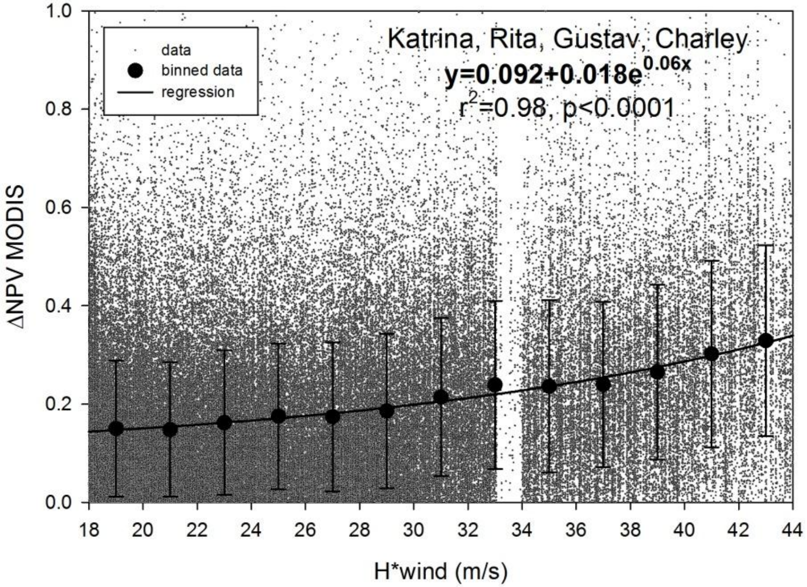
Robinson Negrón-Juárez,[1] David B. Baker,[1] Hongcheng Zeng,[1,2] Theryn K. Henkel,[1] and Jeffrey Q. Chambers[1,3]











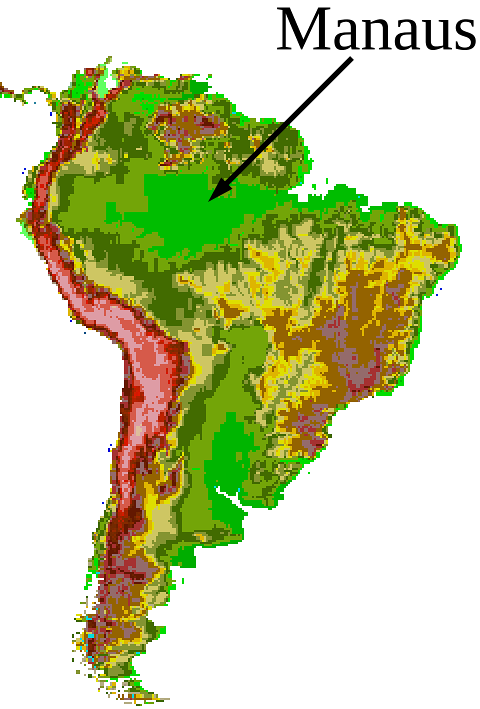
Variable tree species resistance to the damaging effects of hurricane wind

Moderate mortality: rarely flooded bottomland hardwood forest (*Quercus michauxii, Quercus nigra, Ulmus americana, Liquidambar stryacifluia, Carpinus caroliniana, Carya illinoensis*)

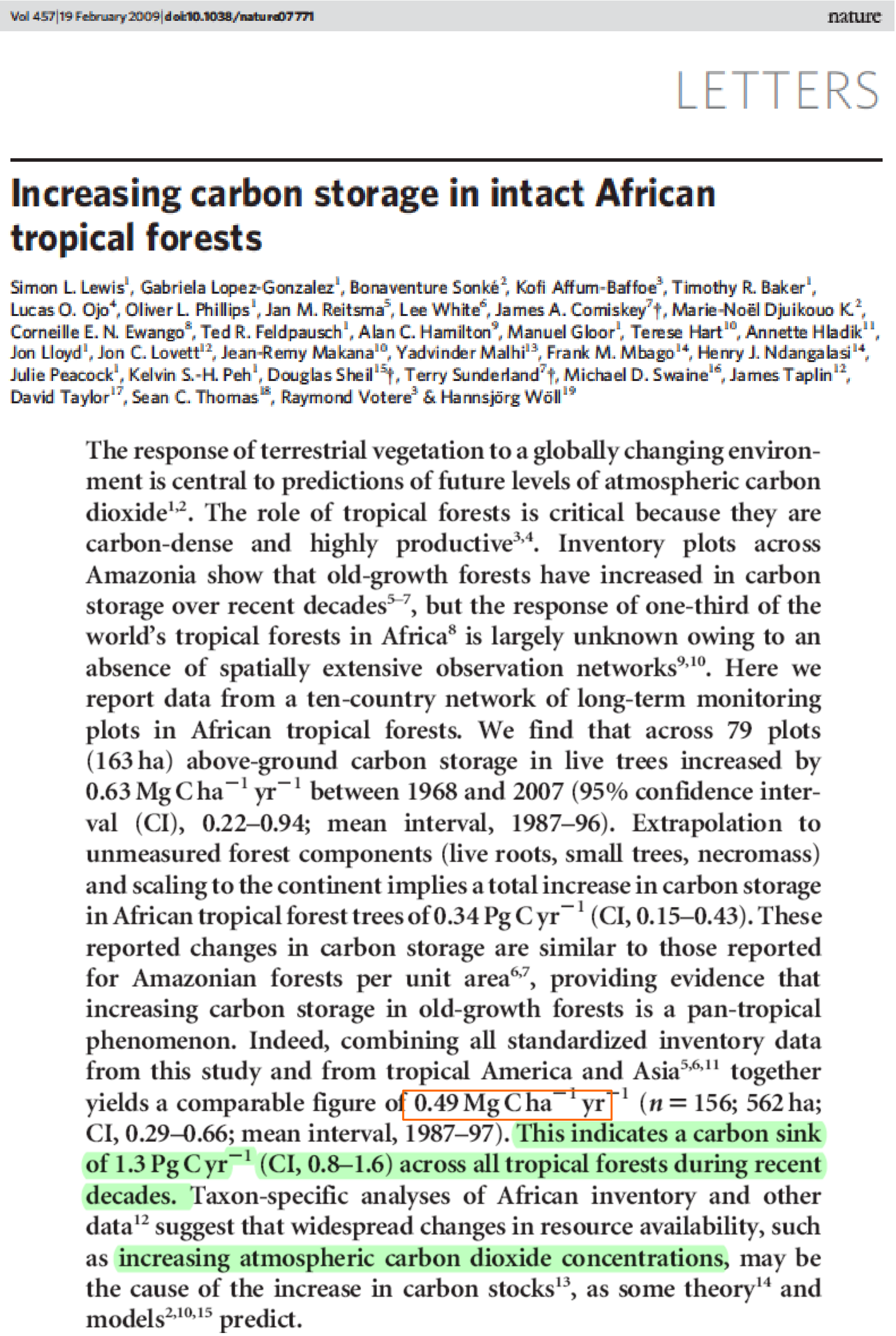
Heavy mortality: frequently flooded bottomland hardwood forest (*Acer rubrum, Carpinus caroliniana, Fraxinus pennsylvanica, Liquidambar styraciflua, Quercus laurifolia, Quercus lyrata,Carya aquatica*)

Low mortality: constantly flooded cypress/tupelo forested wetland (*Taxodium distichum and Nyssa aquatica*)

The Central Amazon



Research carried out on reserves managed by Instituto Nacional de Pesquisas da Amazônia (INPA – National Institute of Amazon Research)



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LETTERS

Increasing carbon storage in intact African tropical forests

Simon L. Lewis[1], Gabriela Lopez-Gonzalez[1], Bonaventure Sonké[2], Kofi Affum-Baffoe[3], Timothy R. Baker[1], Lucas O. Ojo[4], Oliver L. Phillips[1], Jan M. Reitsma[5], Lee White[6], James A. Comiskey[7]†, Marie-Noël Djuikouo K.[2], Corneille E. N. Ewango[8], Ted R. Feldpausch[1], Alan C. Hamilton[9], Manuel Gloor[1], Terese Hart[10], Annette Hladik[11], Jon Lloyd[1], Jon C. Lovett[12], Jean-Remy Makana[10], Yadvinder Malhi[13], Frank M. Mbago[14], Henry J. Ndangalasi[14], Julie Peacock[1], Kelvin S.-H. Peh[1], Douglas Sheil[15]†, Terry Sunderland[7]†, Michael D. Swaine[16], James Taplin[12], David Taylor[17], Sean C. Thomas[18], Raymond Votere[3] & Hannsjörg Wöll[19]

The response of terrestrial vegetation to a globally changing environment is central to predictions of future levels of atmospheric carbon dioxide[1,2]. The role of tropical forests is critical because they are carbon-dense and highly productive[3,4]. Inventory plots across Amazonia show that old-growth forests have increased in carbon storage over recent decades[5–7], but the response of one-third of the world's tropical forests in Africa[8] is largely unknown owing to an absence of spatially extensive observation networks[9,10]. Here we report data from a ten-country network of long-term monitoring plots in African tropical forests. We find that across 79 plots (163 ha) above-ground carbon storage in live trees increased by 0.63 Mg C ha^{-1} yr^{-1} between 1968 and 2007 (95% confidence interval (CI), 0.22–0.94; mean interval, 1987–96). Extrapolation to unmeasured forest components (live roots, small trees, necromass) and scaling to the continent implies a total increase in carbon storage in African tropical forest trees of 0.34 Pg C yr^{-1} (CI, 0.15–0.43). These reported changes in carbon storage are similar to those reported for Amazonian forests per unit area[6,7], providing evidence that increasing carbon storage in old-growth forests is a pan-tropical phenomenon. Indeed, combining all standardized inventory data from this study and from tropical America and Asia[5,6,11] together yields a comparable figure of 0.49 Mg C ha^{-1} yr^{-1} ($n = 156$; 562 ha; CI, 0.29–0.66; mean interval, 1987–97). This indicates a carbon sink of 1.3 Pg C yr^{-1} (CI, 0.8–1.6) across all tropical forests during recent decades. Taxon-specific analyses of African inventory and other data[12] suggest that widespread changes in resource availability, such as increasing atmospheric carbon dioxide concentrations, may be the cause of the increase in carbon stocks[13], as some theory[14] and models[2,10,15] predict.

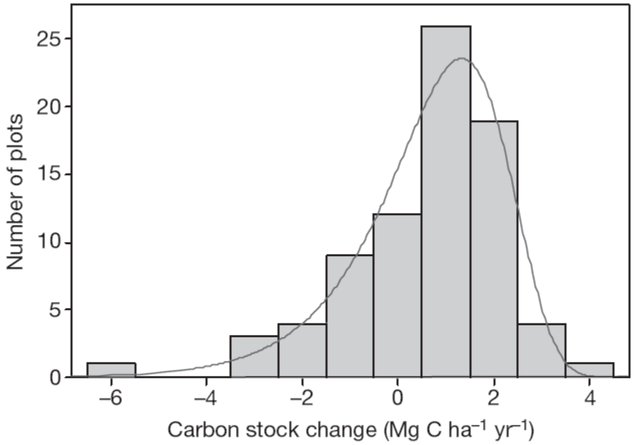
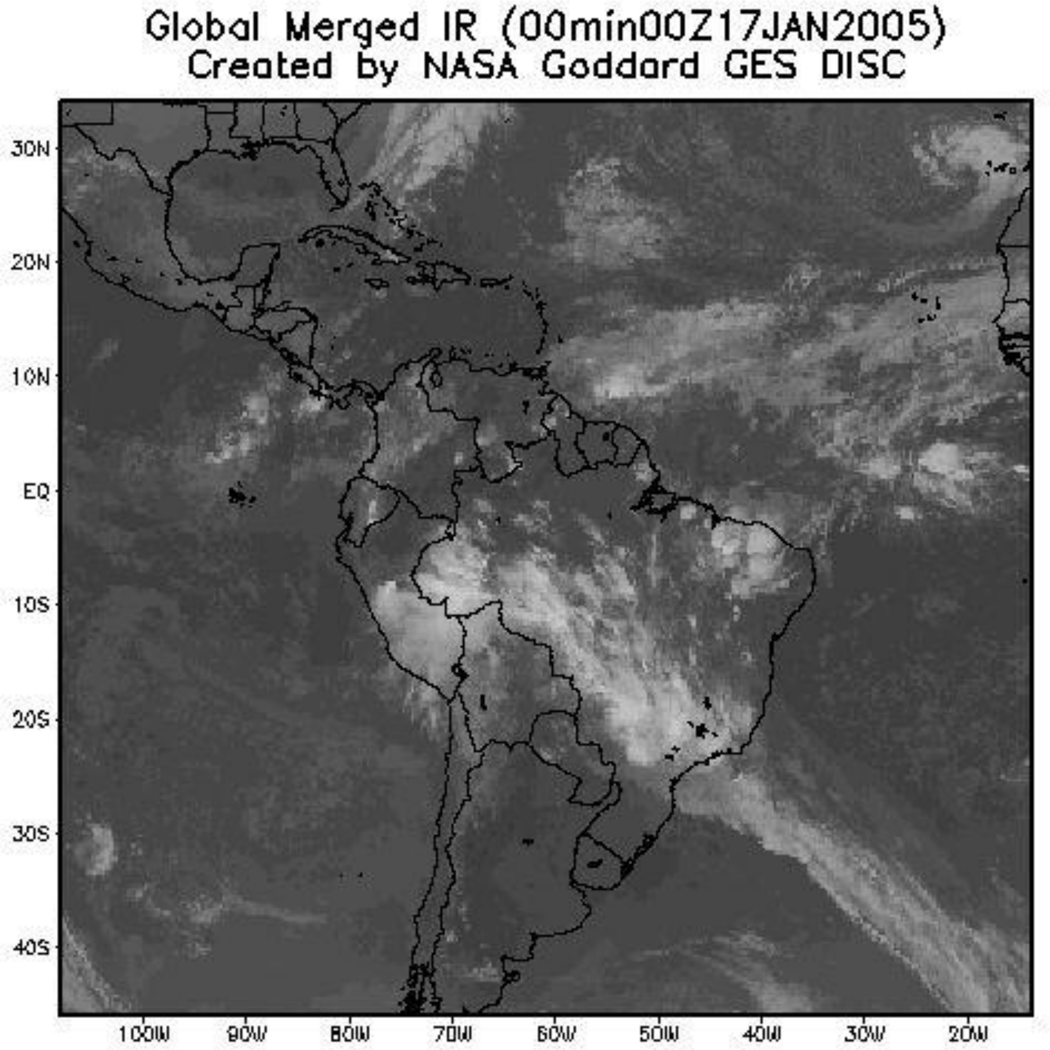


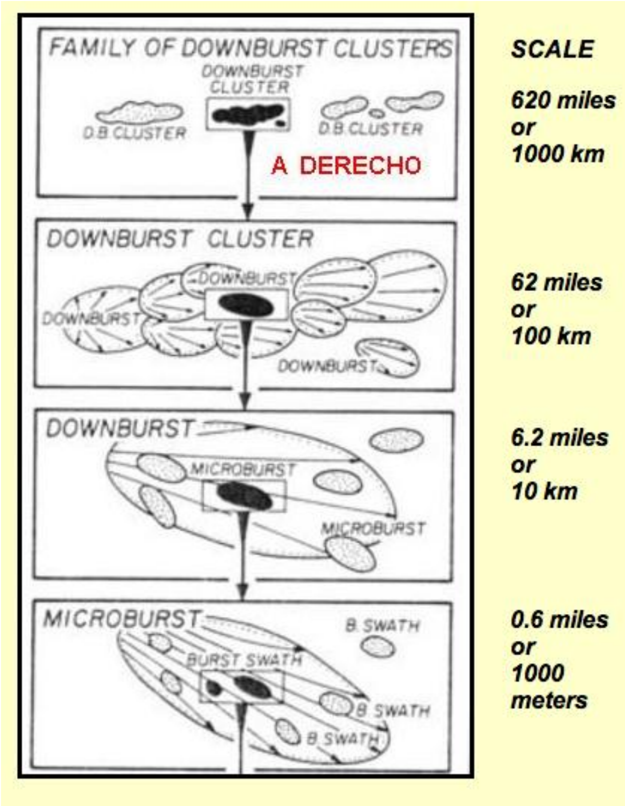
Figure 1 | Histogram of annualized change in carbon stocks from 79 long-term monitoring plots across 10 countries in Africa. Results presented are weighted by sampling effort (plot size and census-interval length), and fitted three-parameter Weibull distribution.

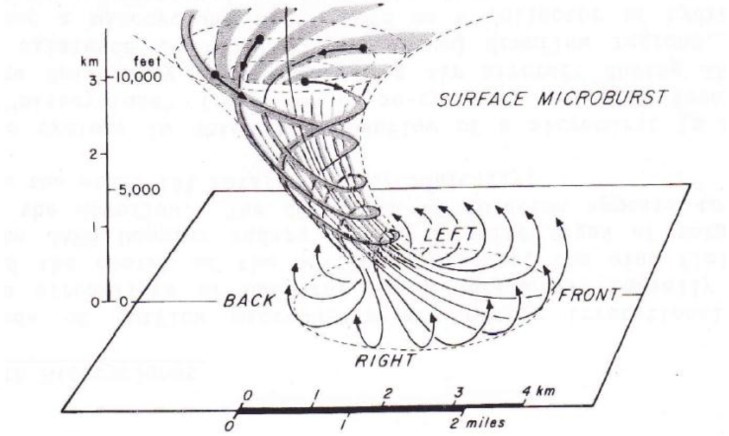
GEOPHYSICAL RESEARCH LETTERS, VOL. 37, L16701,

Widespread Amazon forest tree mortality from a single cross-basin squall line event

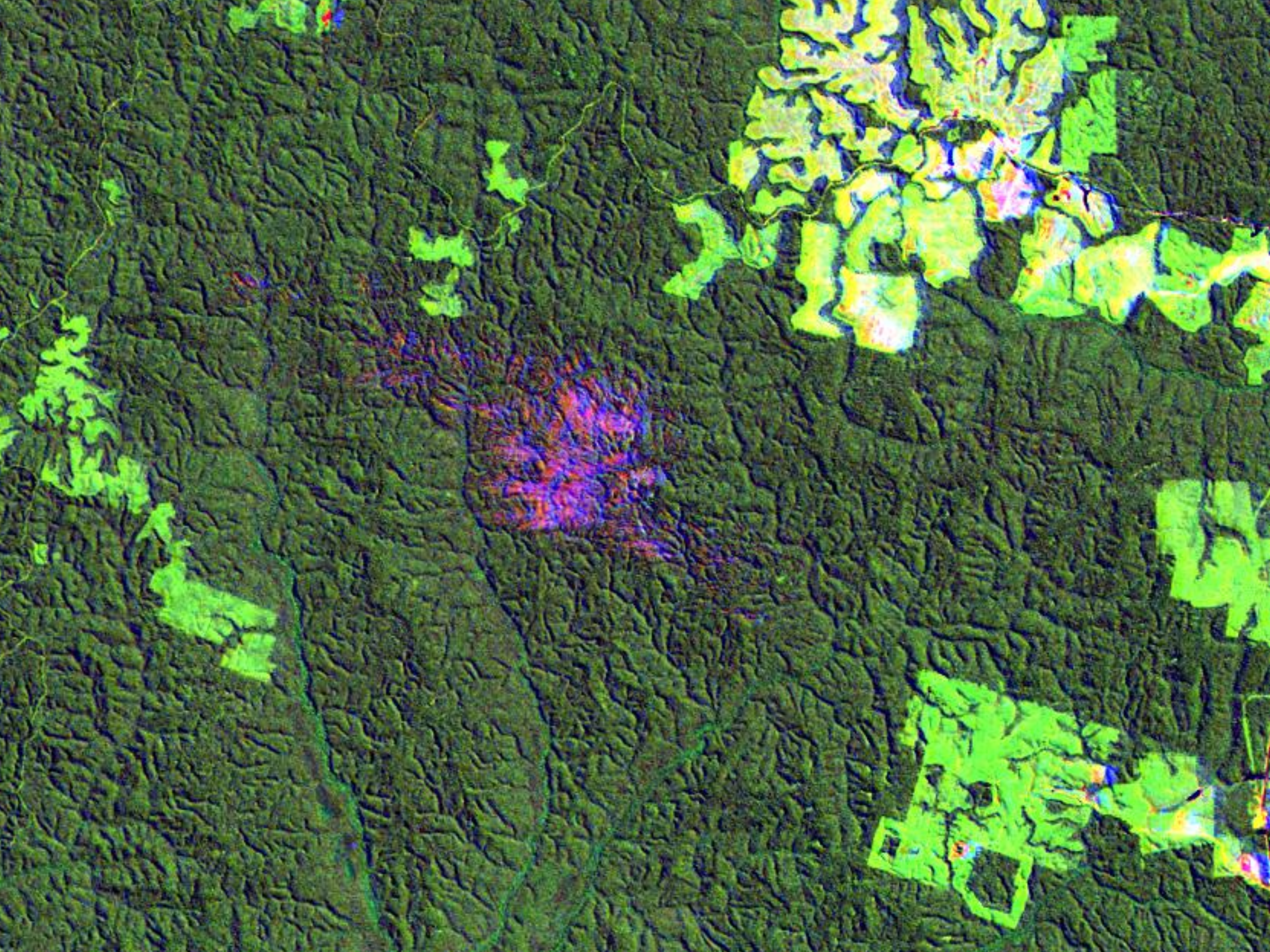
Robinson I. Negrón-Juárez,[1] Jeffrey Q. Chambers,[1,2,3] Giuliano Guimaraes,[2] Hongcheng Zeng,[4] Carlos F. M. Raupp,[5] Daniel M. Marra,[2] Gabriel H. P. M. Ribeiro,[2] Sassan S. Saatchi,[6] Bruce W. Nelson,[2] and Niro Higuchi[2]

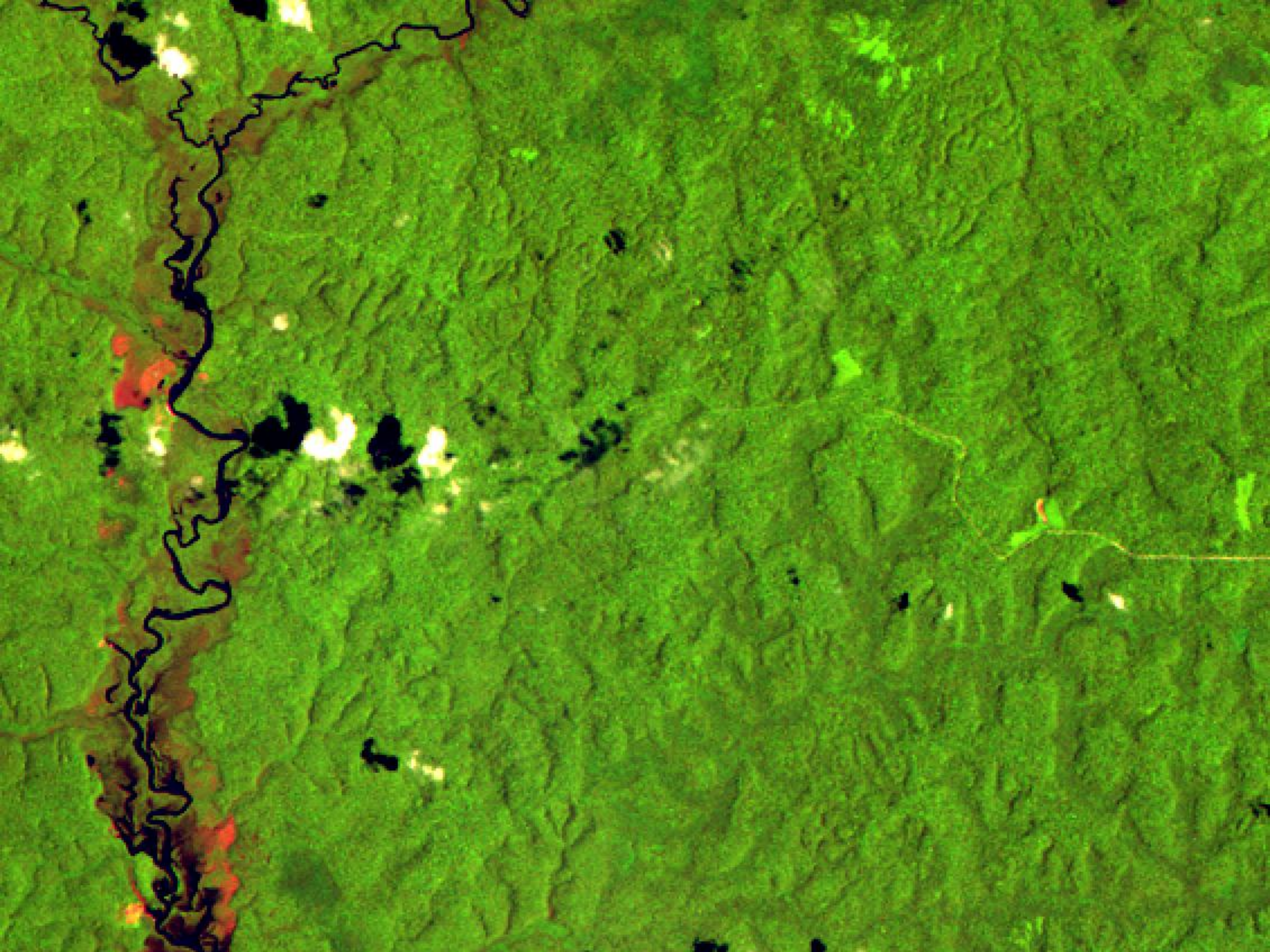


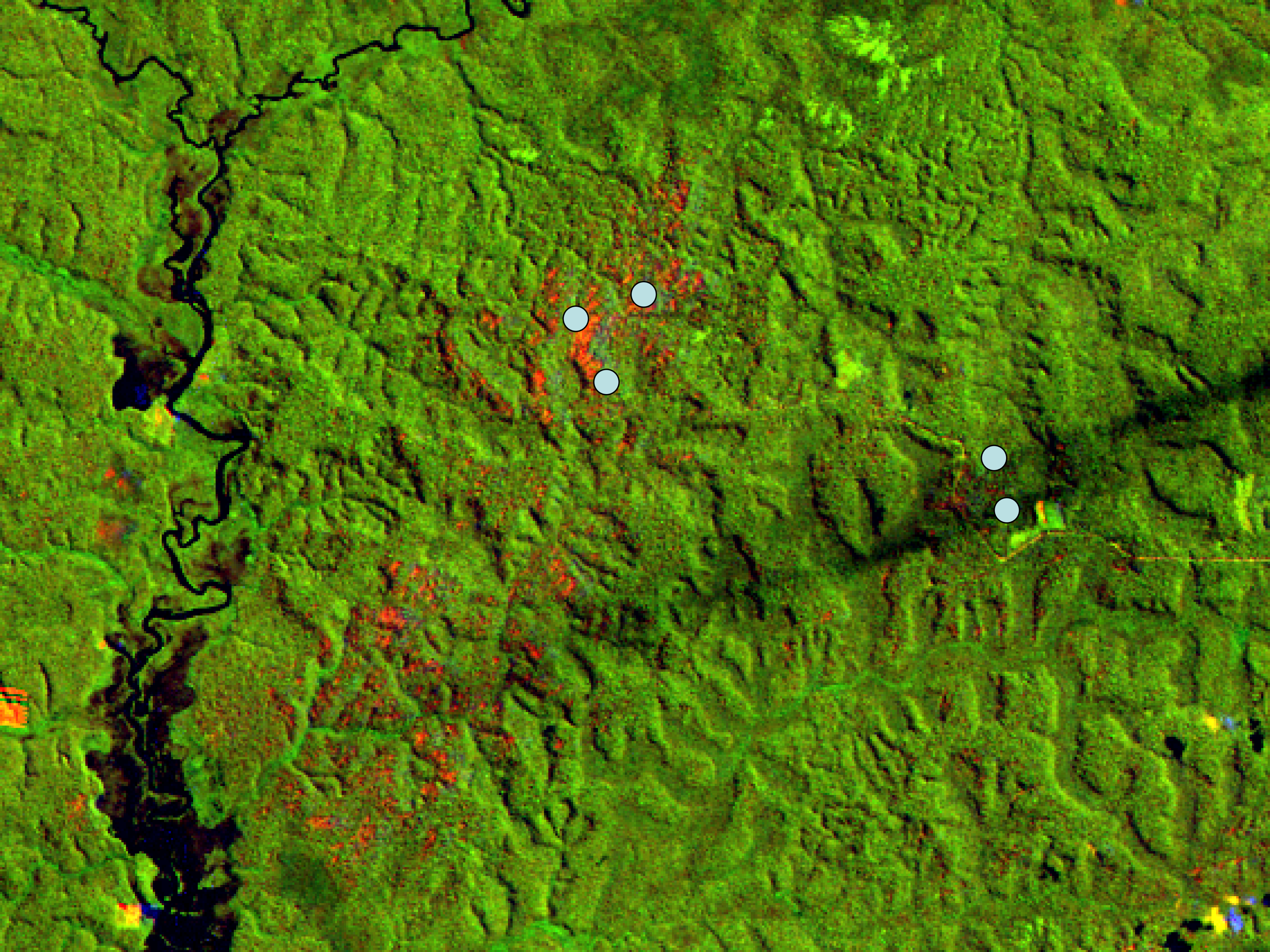




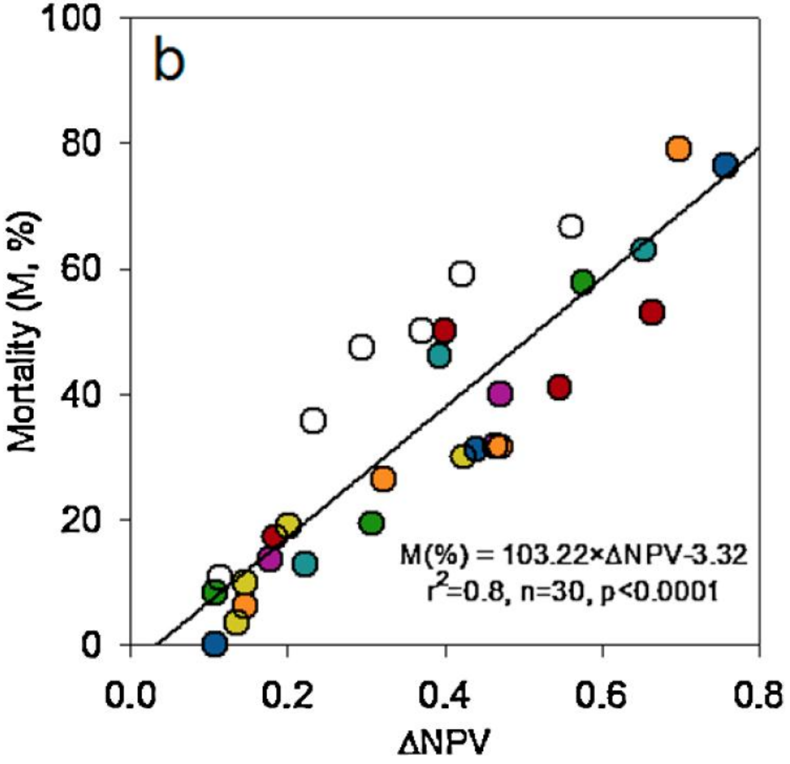
Fujita , 1985





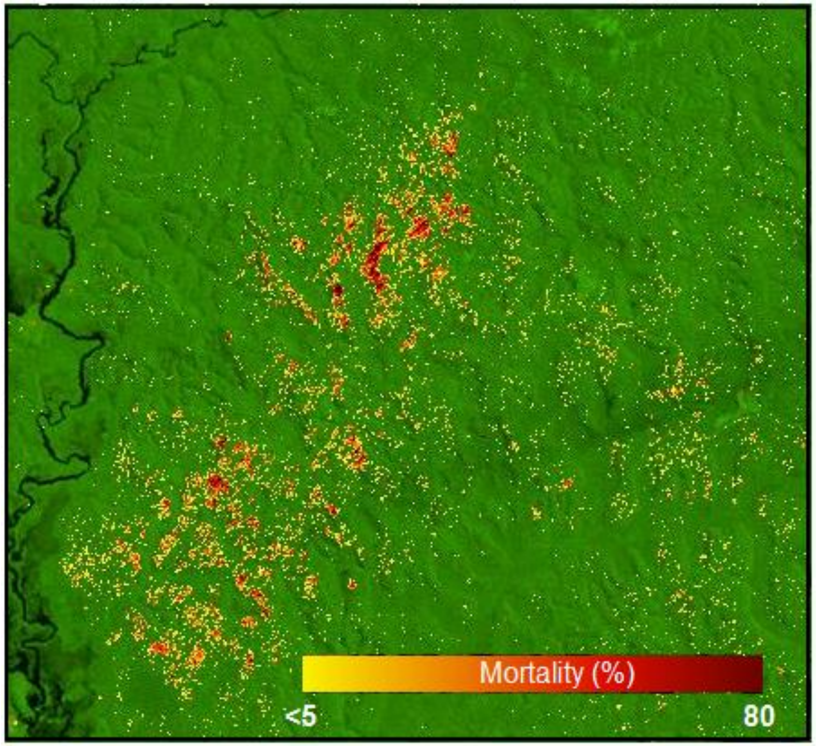


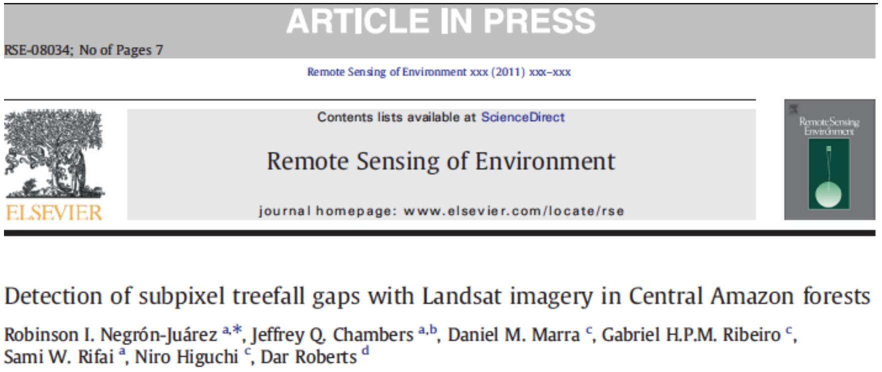
Developing relationships between remote sensing metrics and field-based mortality rates



Each point represents a randomly placed 400 m^2 inventory plot randomly stratified by ΔNPV to ensure repeated sampling of the entire disturbance gradient.

Key features of the disturbance regime for a Central Amazon landscape





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Remote Sensing of Environment xxx (2011) xxx–xxx

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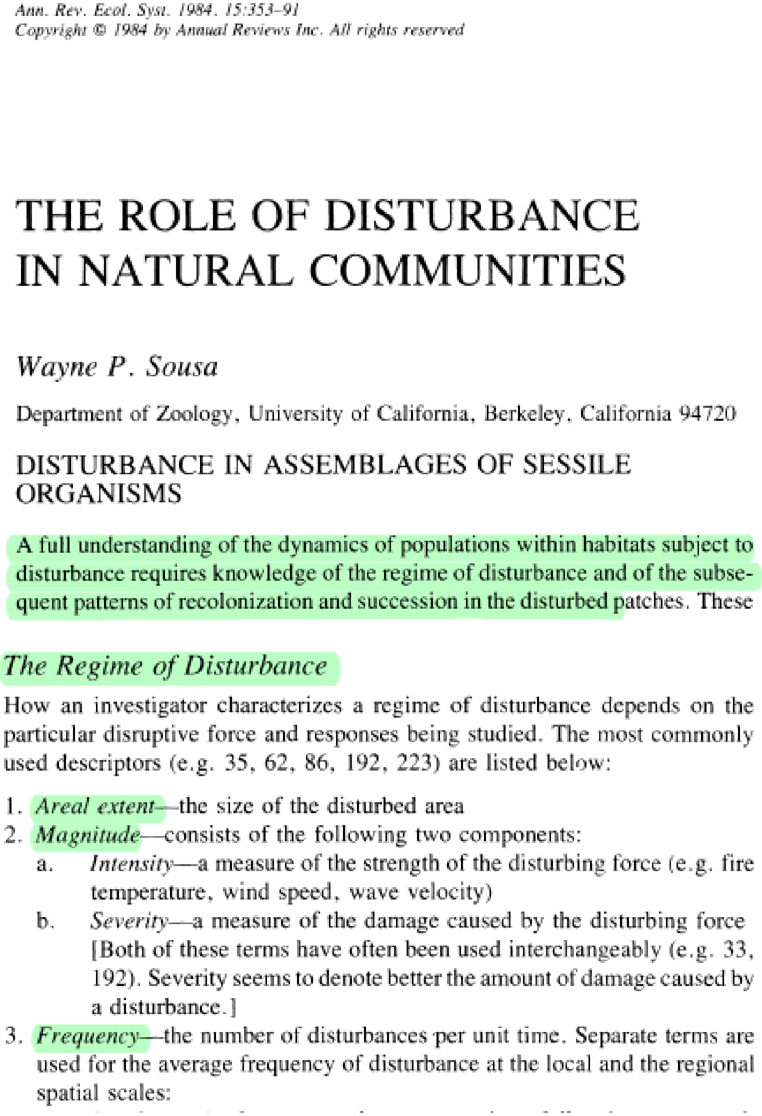
journal homepage: www.elsevier.com/locate/rse

ELSEVIER

Detection of subpixel treefall gaps with Landsat imagery in Central Amazon forests

Robinson I. Negrón-Juárez [a,*], Jeffrey Q. Chambers [a,b], Daniel M. Marra [c], Gabriel H.P.M. Ribeiro [c], Sami W. Rifai [a], Niro Higuchi [c], Dar Roberts [d]



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THE ROLE OF DISTURBANCE IN NATURAL COMMUNITIES

Wayne P. Sousa

Department of Zoology, University of California, Berkeley, California 94720

DISTURBANCE IN ASSEMBLAGES OF SESSILE ORGANISMS

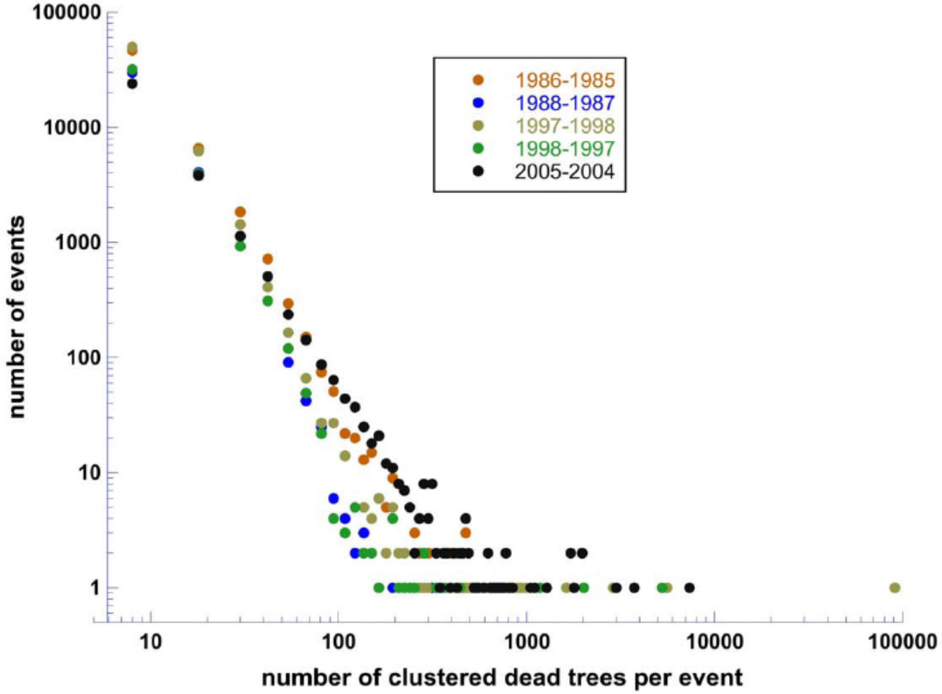
A full understanding of the dynamics of populations within habitats subject to disturbance requires knowledge of the regime of disturbance and of the subsequent patterns of recolonization and succession in the disturbed patches. These

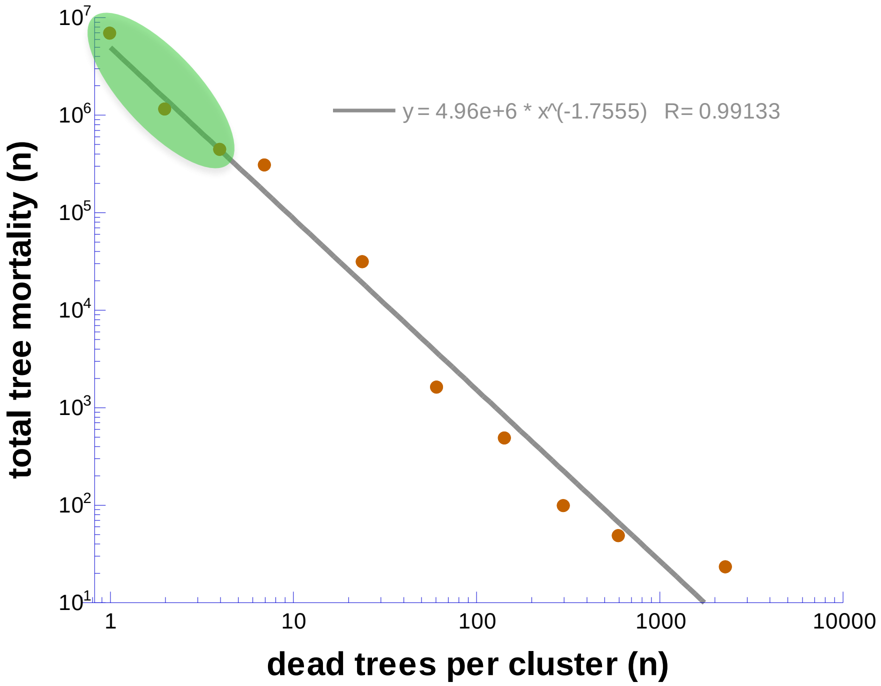
The Regime of Disturbance

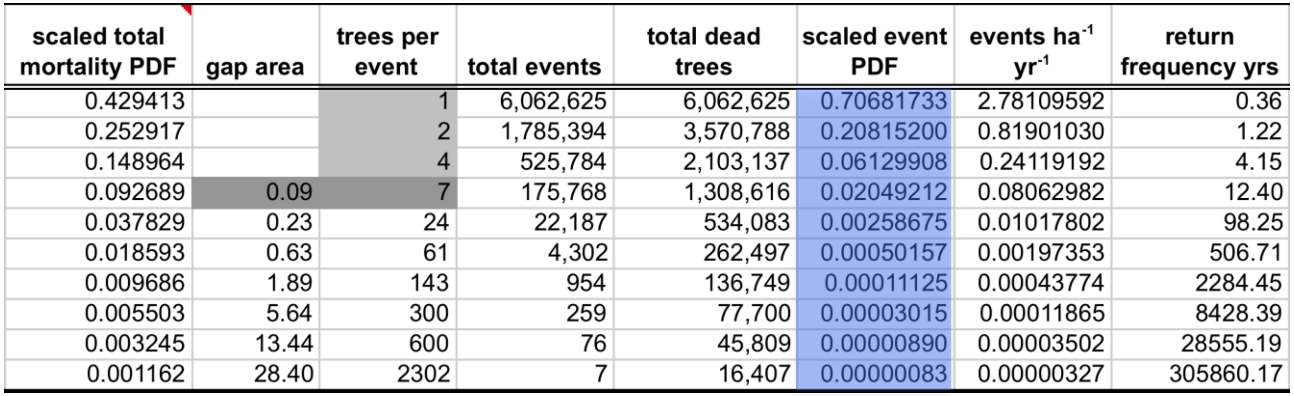
How an investigator characterizes a regime of disturbance depends on the particular disruptive force and responses being studied. The most commonly used descriptors (e.g. 35, 62, 86, 192, 223) are listed below:

1. *Areal extent*—the size of the disturbed area
2. *Magnitude*—consists of the following two components:
   a. *Intensity*—a measure of the strength of the disturbing force (e.g. fire temperature, wind speed, wave velocity)
   b. *Severity*—a measure of the damage caused by the disturbing force [Both of these terms have often been used interchangeably (e.g. 33, 192). Severity seems to denote better the amount of damage caused by a disturbance.]
3. *Frequency*—the number of disturbances per unit time. Separate terms are used for the average frequency of disturbance at the local and the regional spatial scales:

Estimating Tree Rates Mortality Over Large Spatial Scales: Single Trees to Large Blowdowns

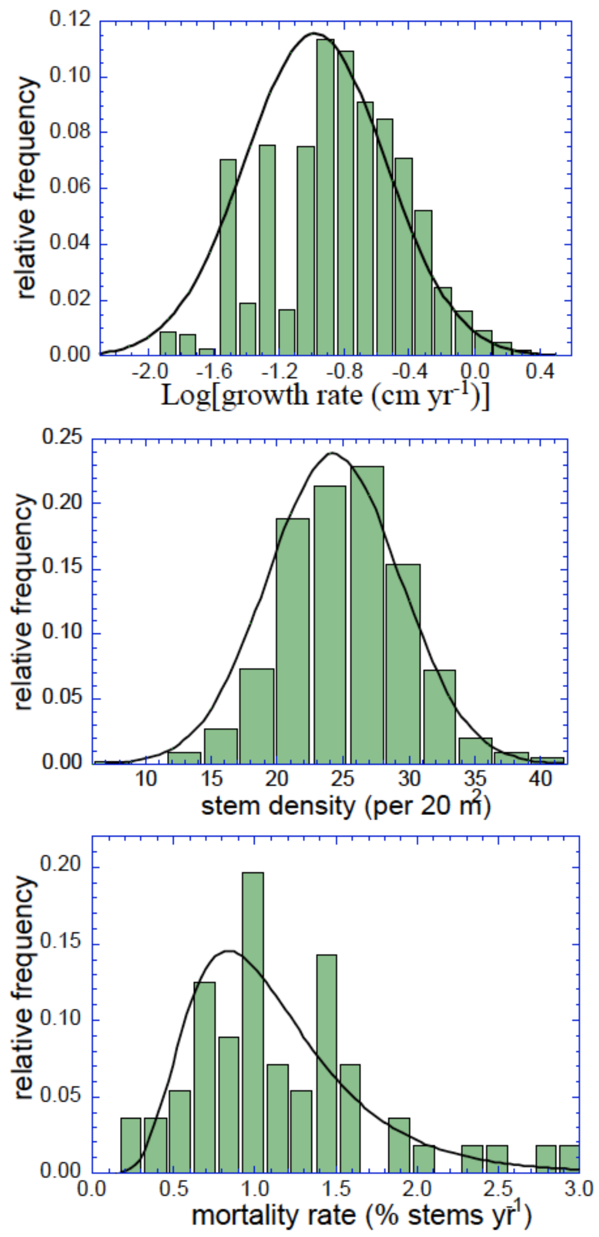


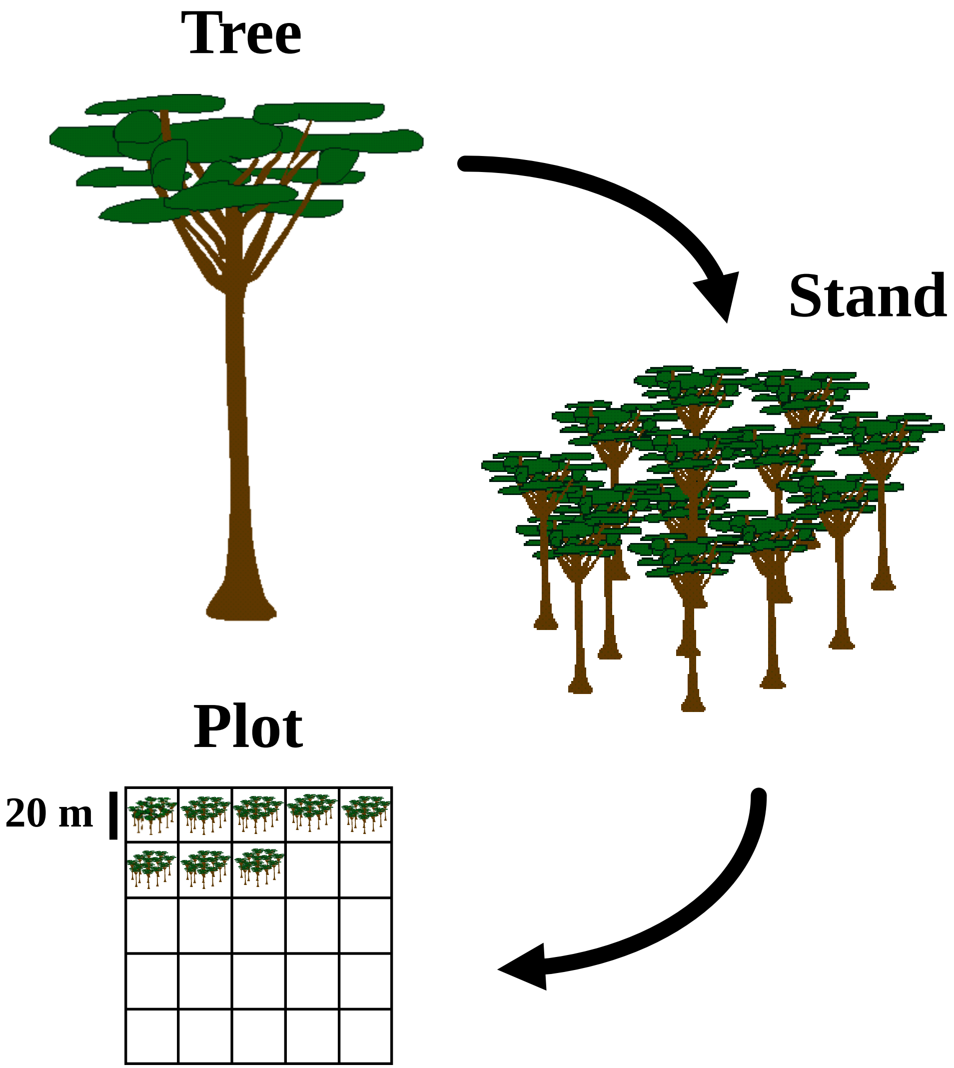




scaled total mortality PDF	gap area	trees per event	total events	total dead trees	scaled event PDF	events ha^{-1} yr^{-1}	return frequency yrs
0.429413		1	6,062,625	6,062,625	0.70681733	2.78109592	0.36
0.252917		2	1,785,394	3,570,788	0.20815200	0.81901030	1.22
0.148964		4	525,784	2,103,137	0.06129908	0.24119192	4.15
0.092689	0.09	7	175,768	1,308,616	0.02049212	0.08062982	12.40
0.037829	0.23	24	22,187	534,083	0.00258675	0.01017802	98.25
0.018593	0.63	61	4,302	262,497	0.00050157	0.00197353	506.71
0.009686	1.89	143	954	136,749	0.00011125	0.00043774	2284.45
0.005503	5.64	300	259	77,700	0.00003015	0.00011865	8428.39
0.003245	13.44	600	76	45,809	0.00000890	0.00003502	28555.19
0.001162	28.40	2302	7	16,407	0.00000083	0.00000327	305860.17

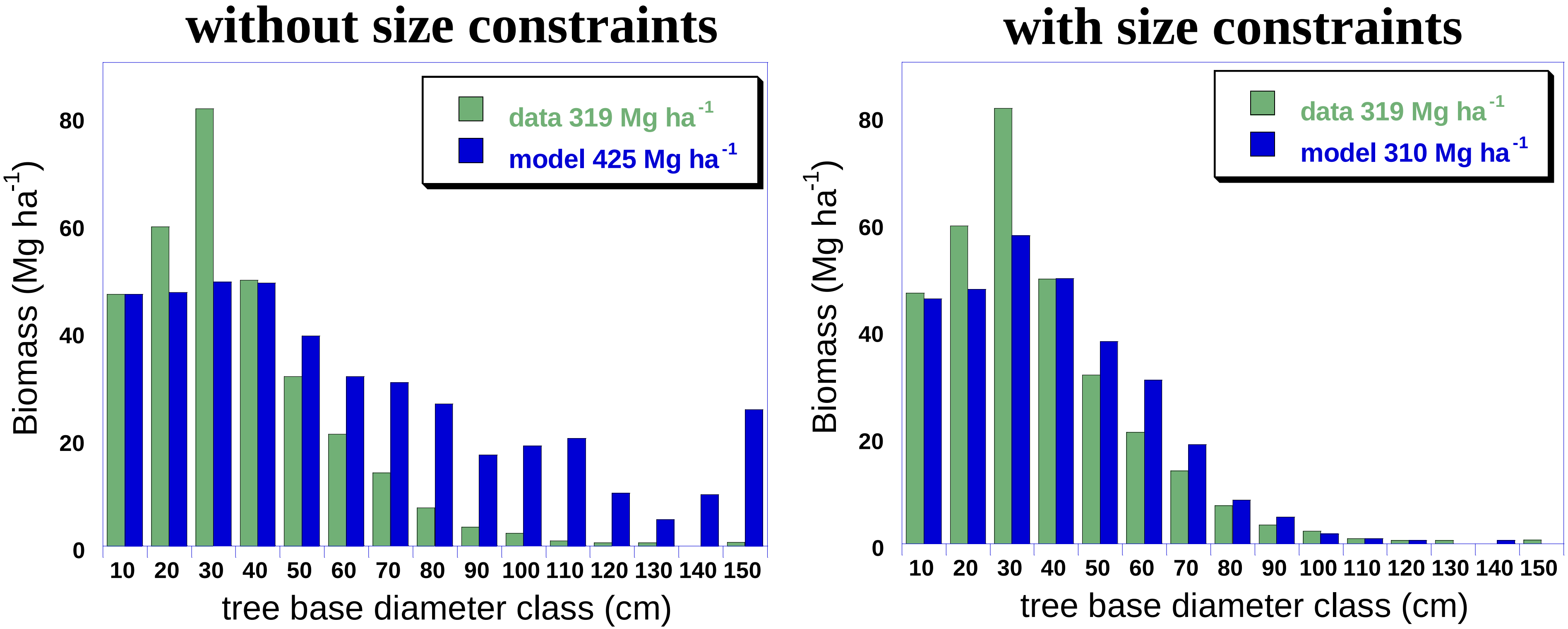
Tropical Tree Ecosystem and Community Simulator (TRECOS)





Simple stand dynamics model over-predicted the number of large massive trees

Species Matter



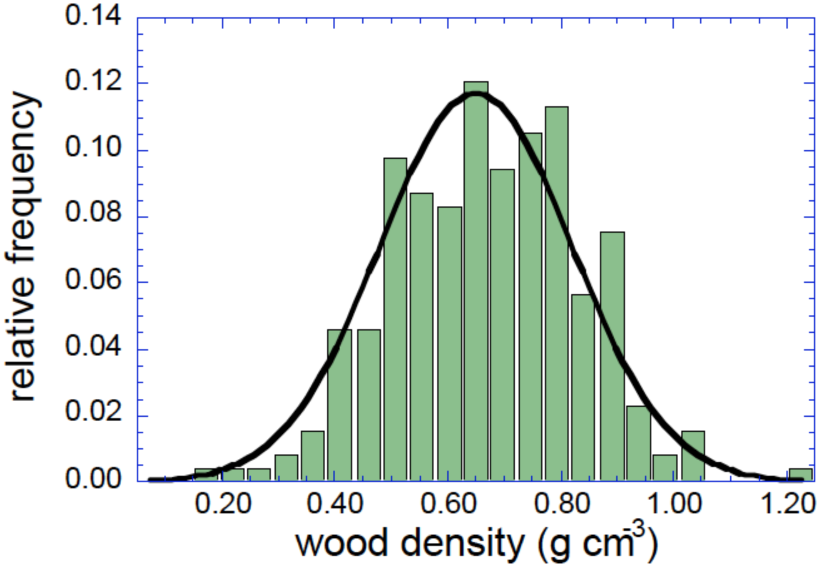
without size constraints

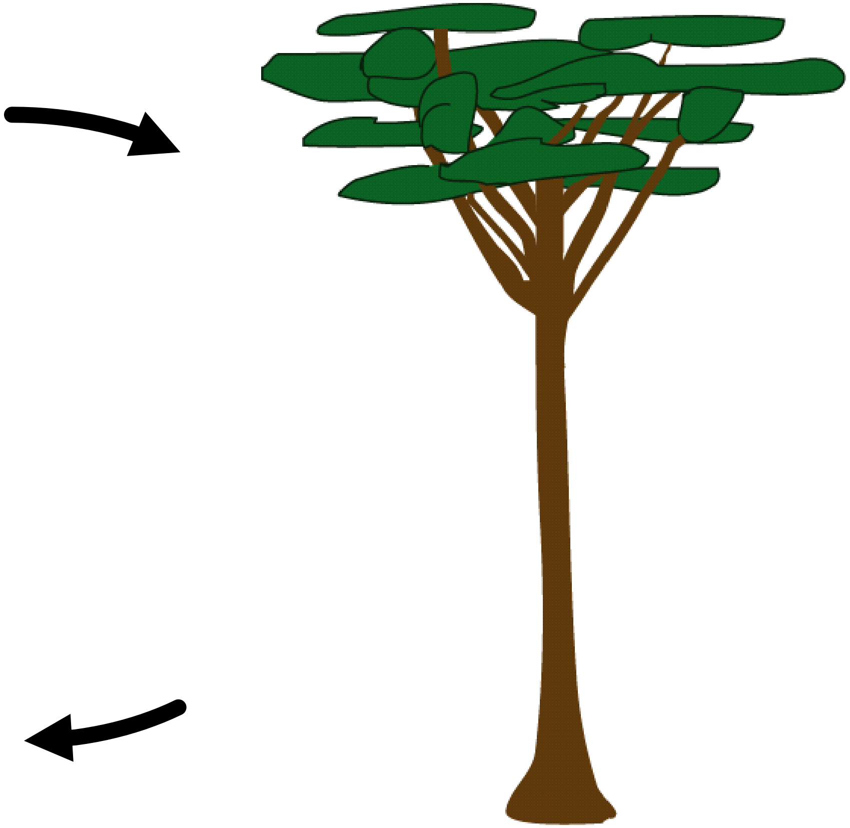
with size constraints

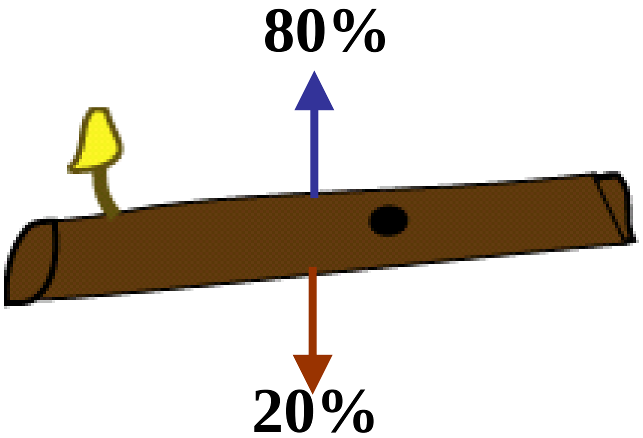
Forest biomass distribution predicted much better with species information on maximum size

Model also predicted that maximum age should be > 1000 years.

Modeling Coarse Litter Decomposition and Respiration







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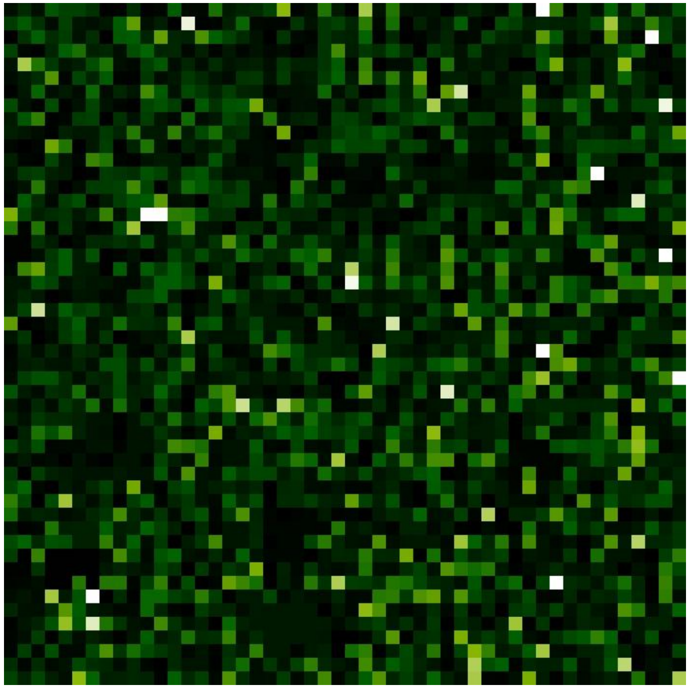
Chambers, J. Q., N. Higuchi, L. V. Ferreira, J. M. Melack, and J. P. Schimel. 2000. Decomposition and carbon cycling of dead trees in tropical forests of the central Amazon. **Oecologia** 122:380-388.

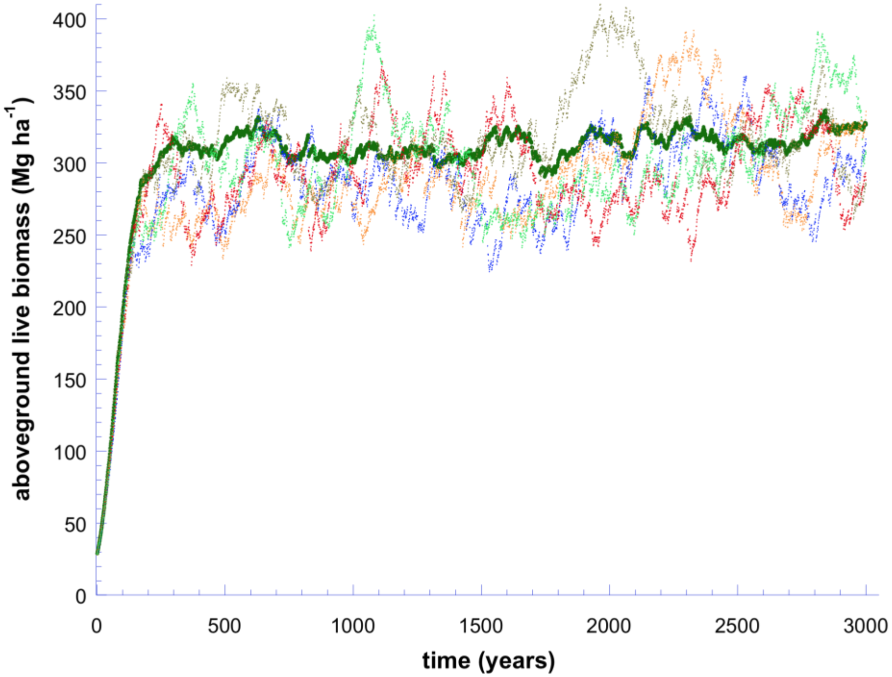
Chambers, J. Q., J. P. Schimel, and A. D. Nobre. 2001. Respiration from coarse wood litter in central Amazon forests. **Biogeochemistry** 52:115-131.

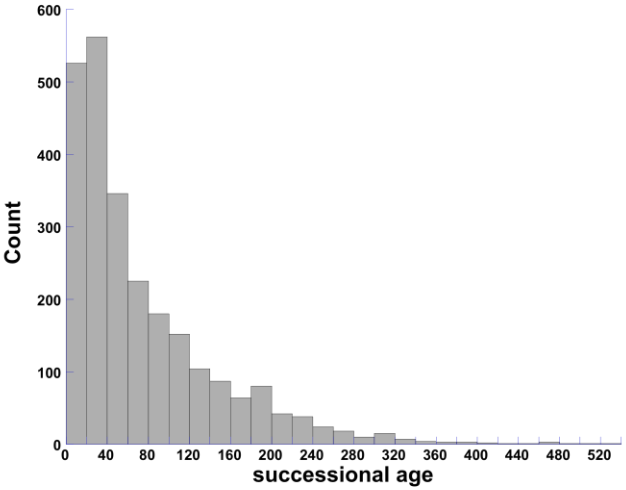
The steady-state mosaic of disturbance and succession across an old-growth Central Amazon forest landscape

| March 5, 2013 | vol. 110 | no. 10 | 3949–3954

Jeffrey Q. Chambers[a,b,c,1], Robinson I. Negron-Juarez[b], Daniel Magnabosco Marra[c,d], Alan Di Vittorio[a], Joerg Tews[e], Dar Roberts[f], Gabriel H. P. M. Ribeiro[c], Susan E. Trumbore[d], and Niro Higuchi[c]





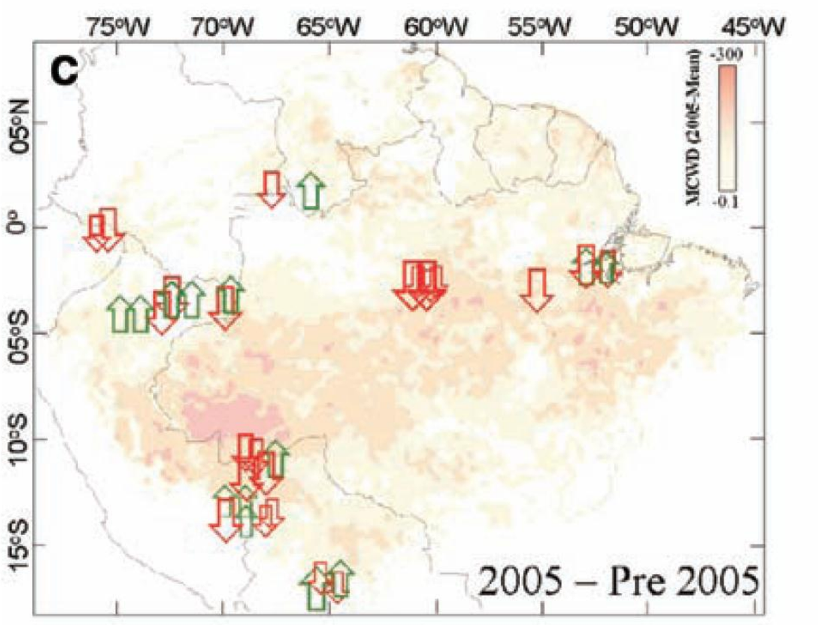


What is the appropriate forest sampling methodology for detecting temporal trends in above-ground carbon stocks?

REPORTS

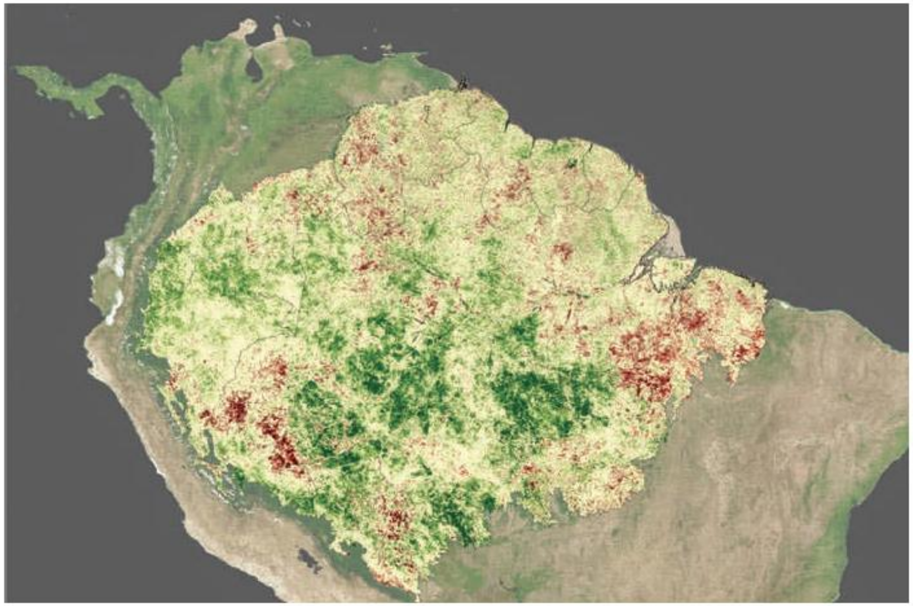
Drought Sensitivity of the Amazon Rainforest

Oliver L. Phillips,[1]* Luiz E. O. C. Aragão,[2] Simon L. Lewis,[1] Joshua B. Fisher,[2] Jon Lloyd,[1]
et al.



NATURE|Vol 466|22 July 2010 **NEWS**

Amazon drought raises research doubts

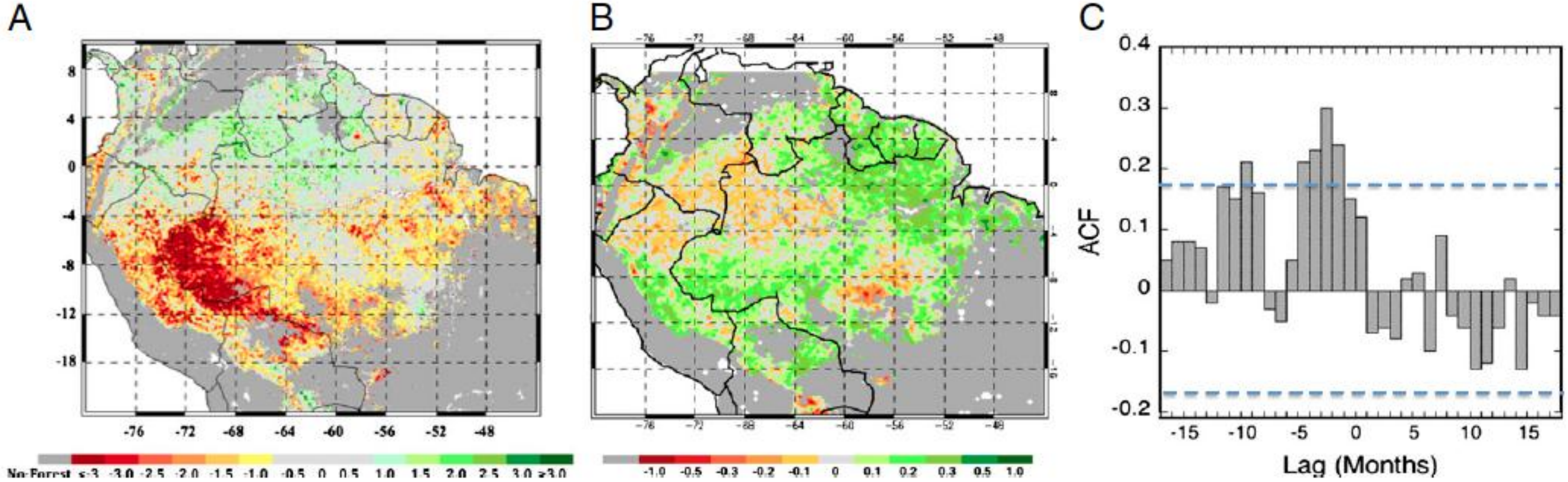


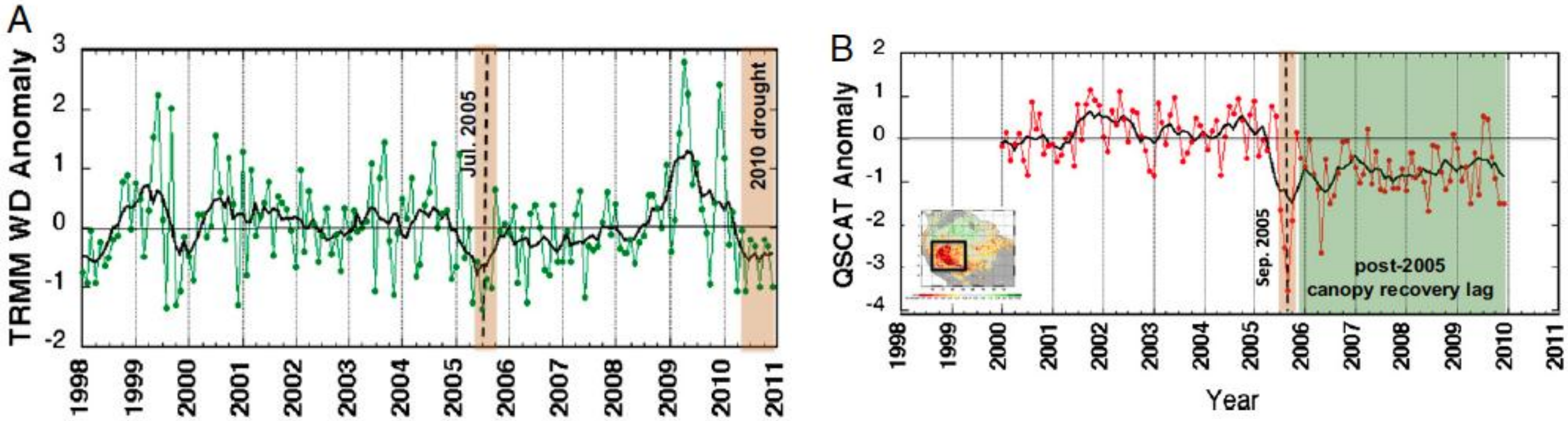
A controversial 2007 study found increased 'greening' in the Amazon rainforest during a drought in 2005.

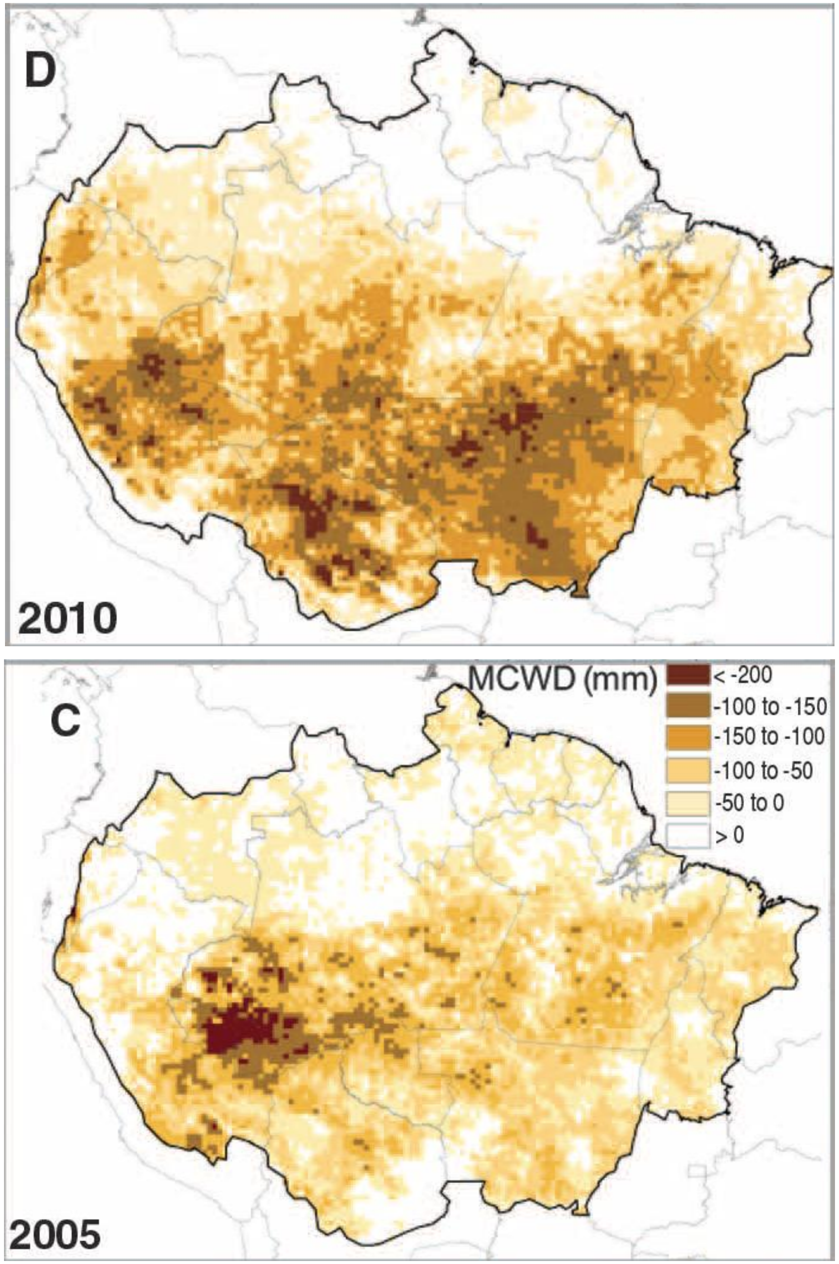
Many factors at play in Amazon forest response to drought

Persistent effects of a severe drought on Amazonian forest canopy

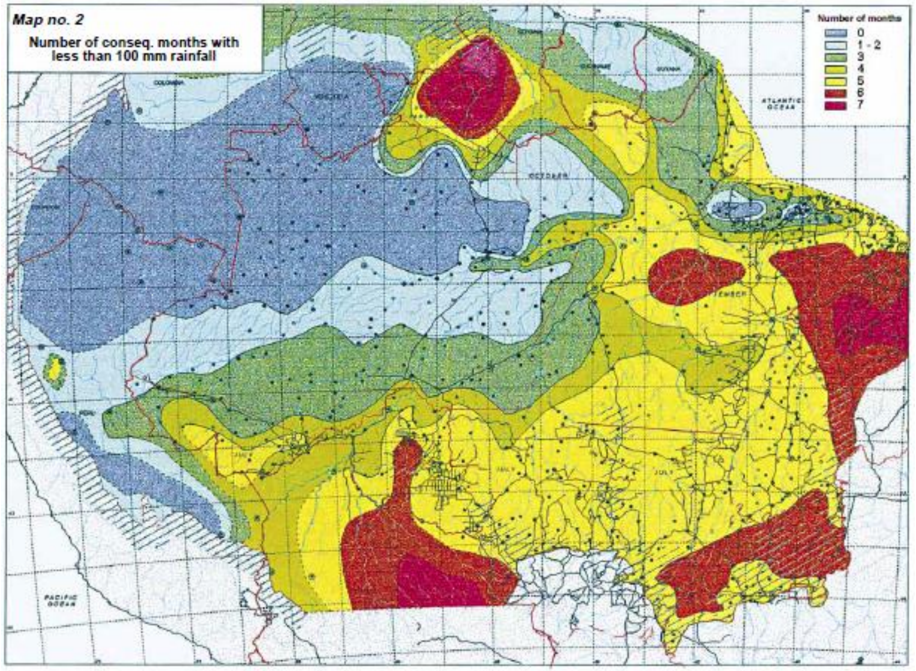
Sassan Saatchi[a,b,1], Salvi Asefi-Najafabady[b], Yadvinder Malhi[c], Luiz E. O. C. Aragão[d], Liana O. Anderson[c,e], Ranga B. Myneni[f], and Ramakrishna Nemani[g]







Lewis et al, 2011, Science

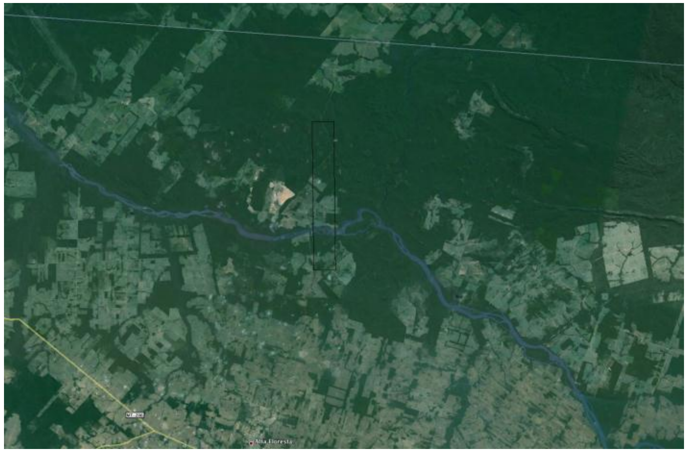


Sombroek, 2001, Ambio

Hypothesis: Amazon trees in regions with a consistent annual drought less susceptible to drought-induced mortality.

Question: How does the mortality threshold vary with precipitation seasonality across the Amazon basin?


French Guiana
Roraima
Amazonas
Maranhao
Para
Brazil
Piaui
Acre
Rondonia
Mato Grosso
Tocantins
Bahia
Beni
Bolivia
La Paz
Santa Cruz
Goias
Brasilia
Minas Gerais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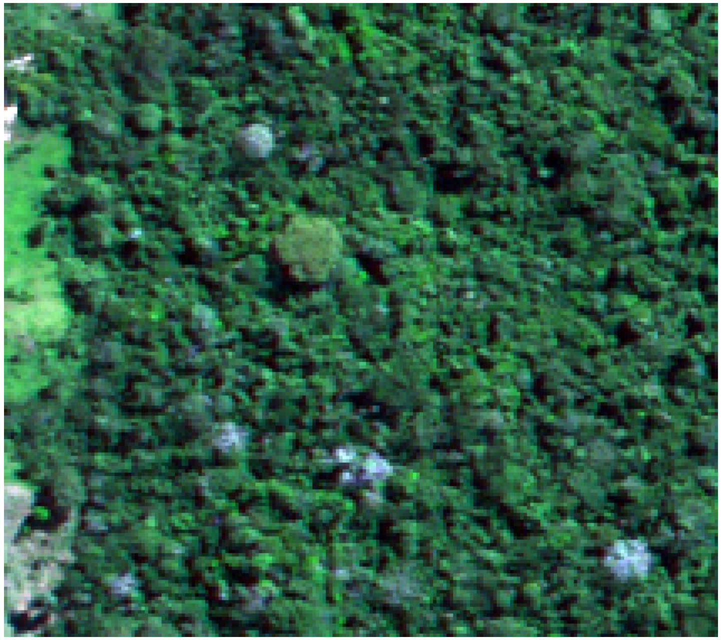

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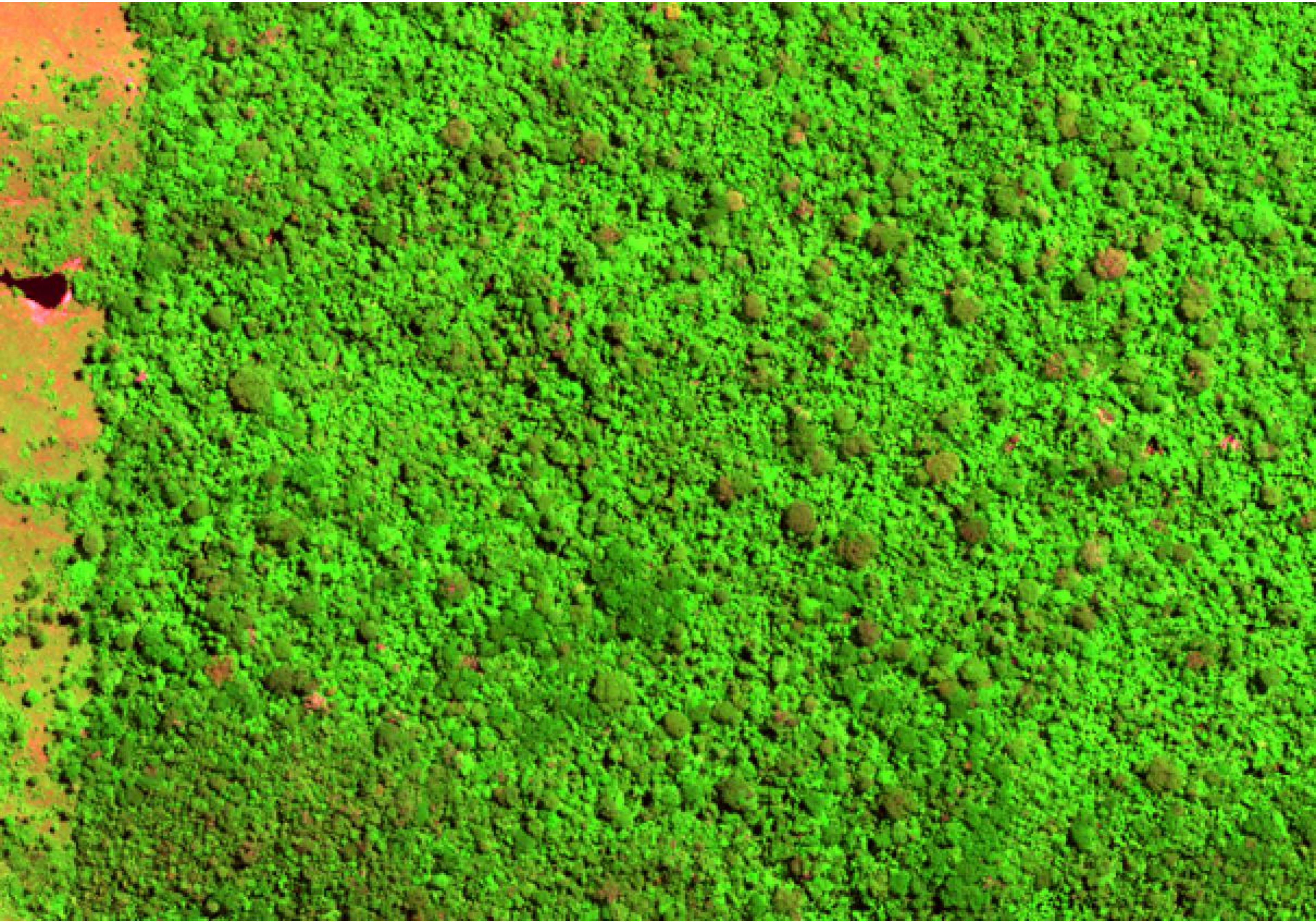

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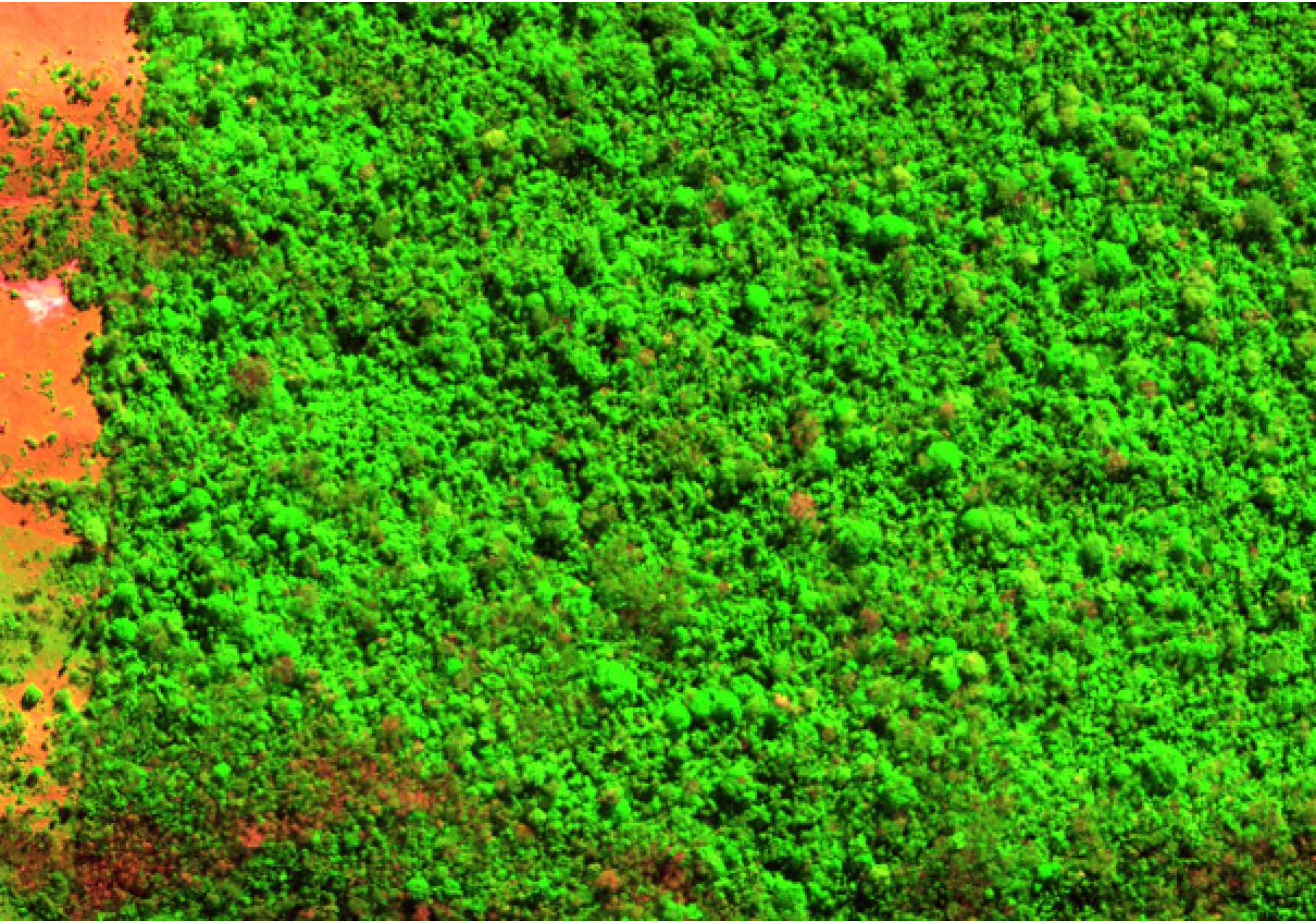

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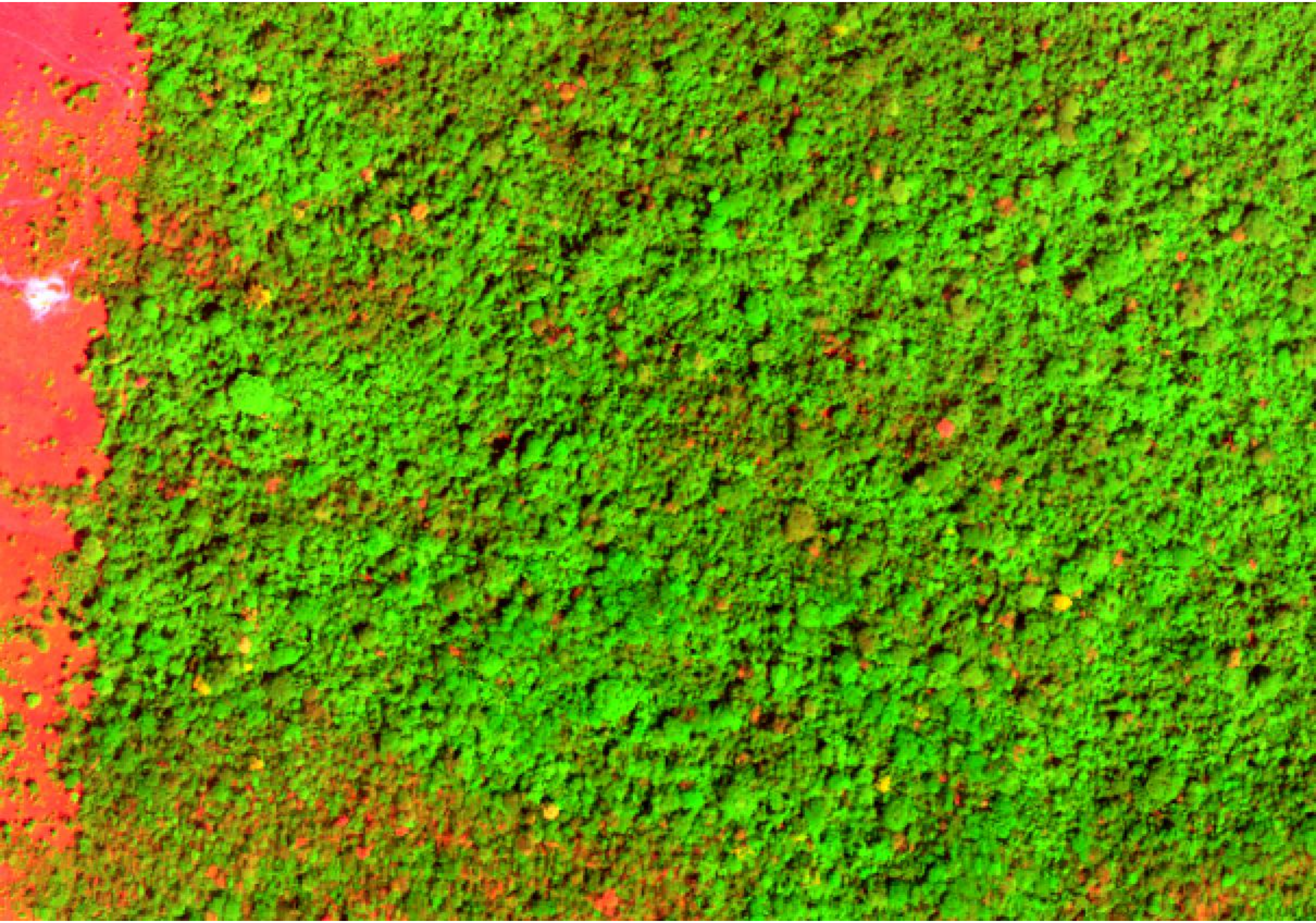
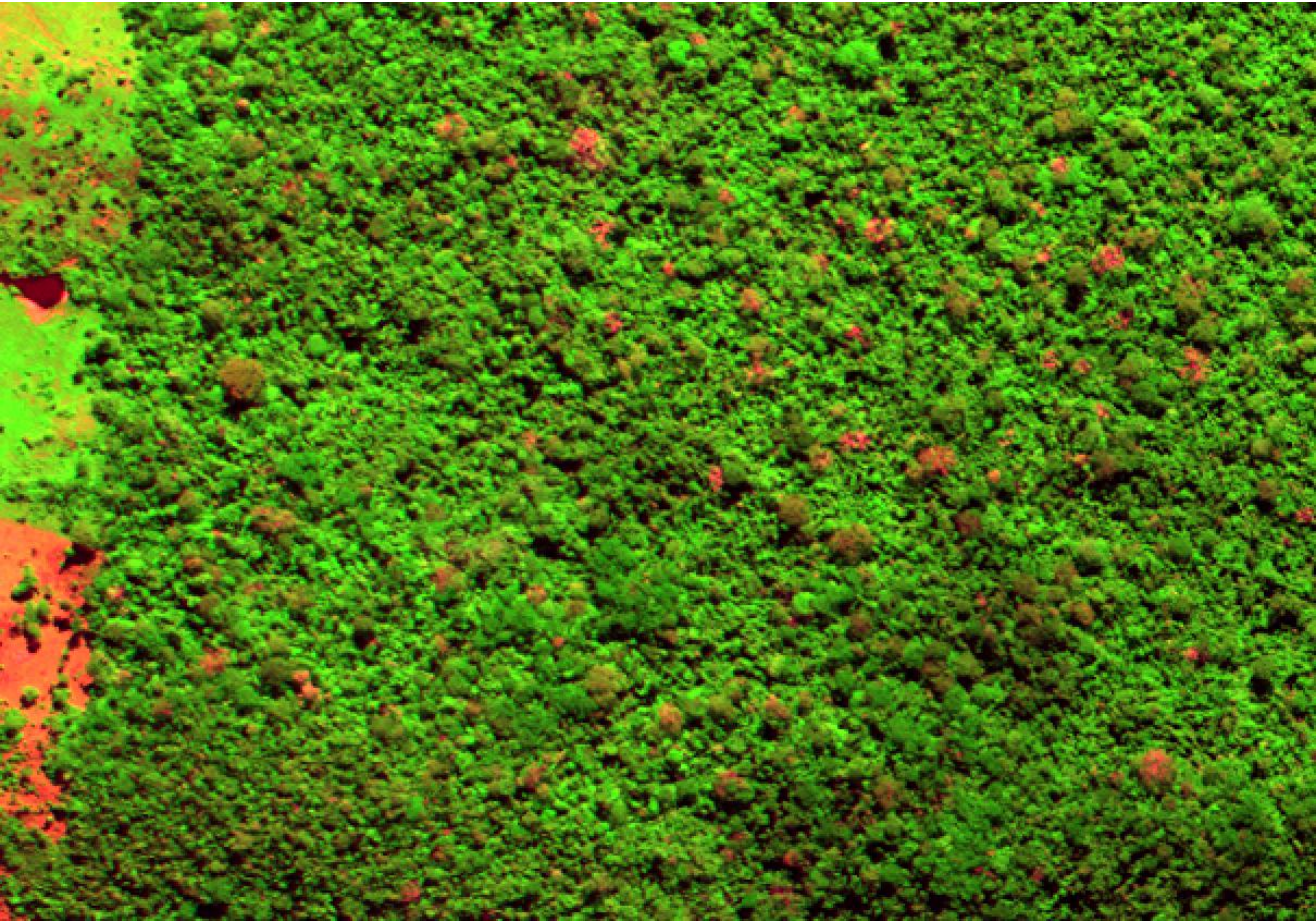


May 2011



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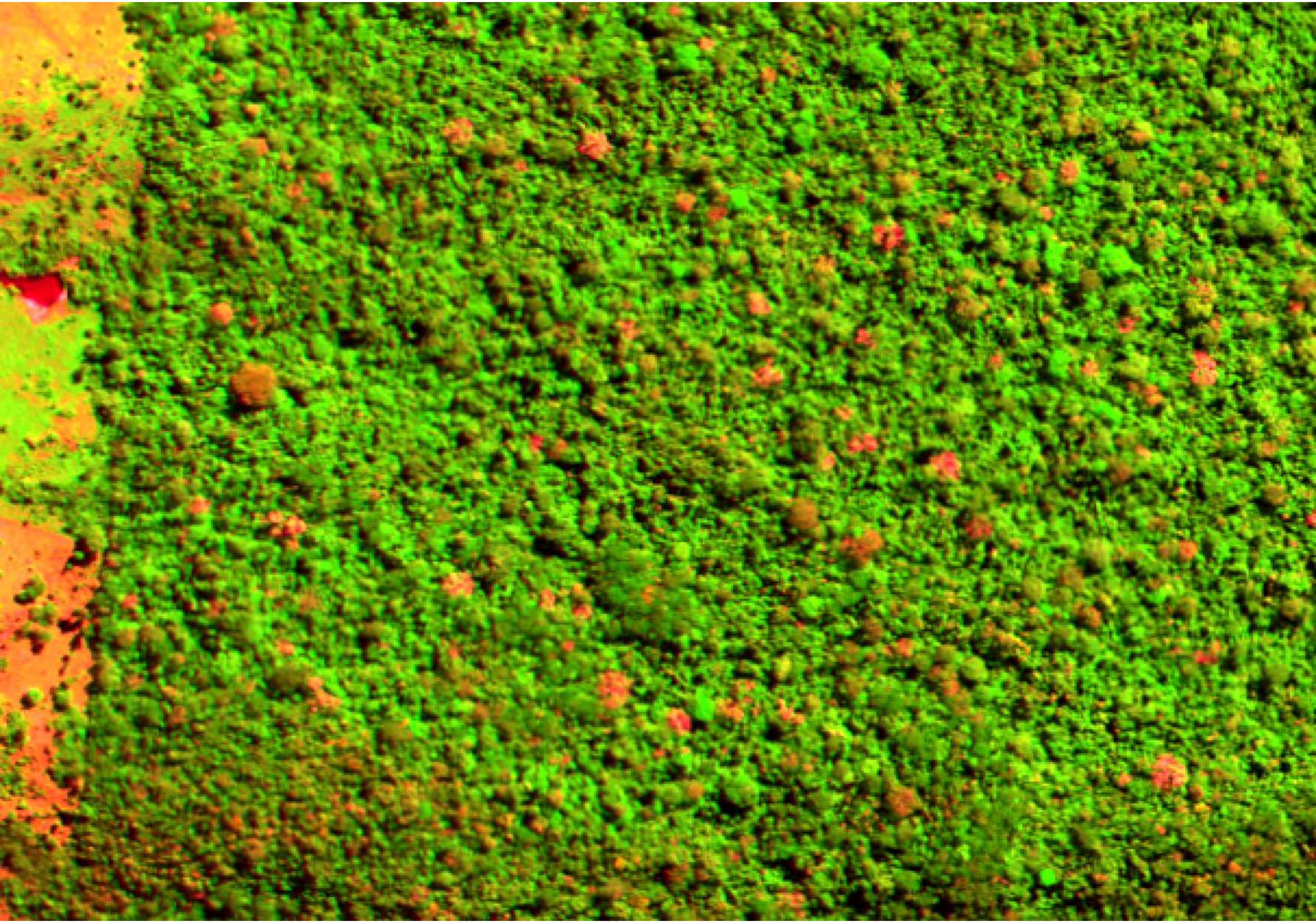
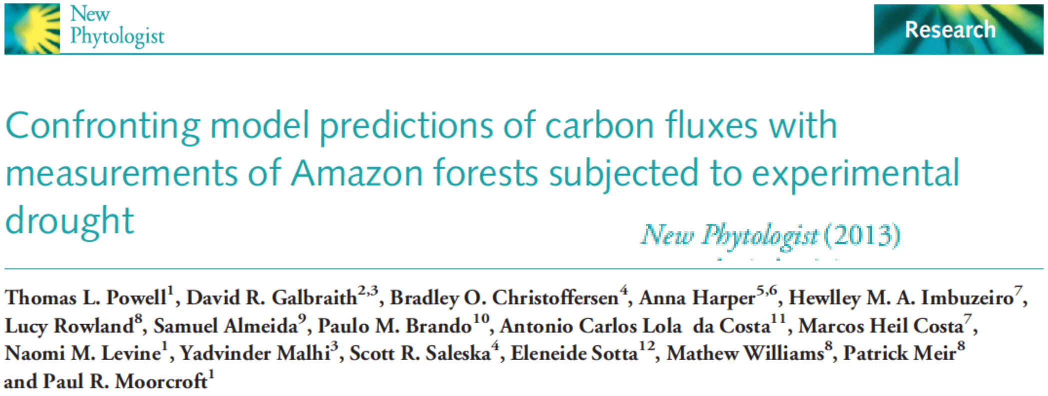


Modeling drought effects on tropical forests



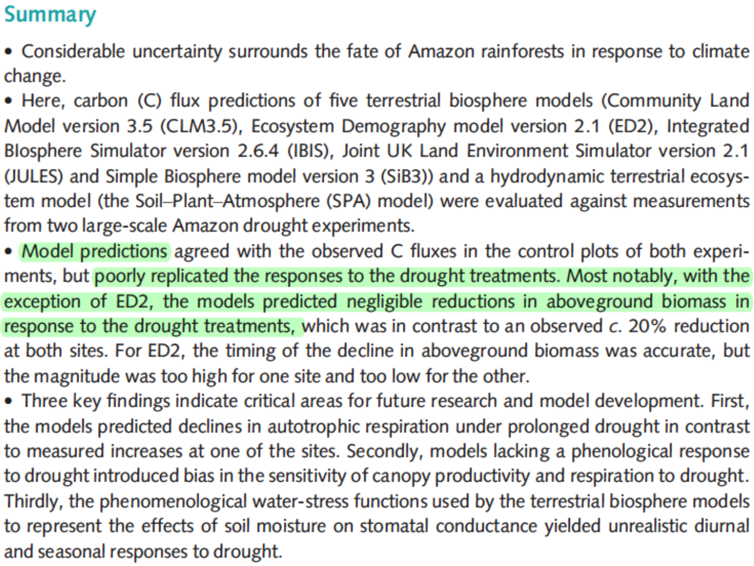
New Phytologist

Research

Confronting model predictions of carbon fluxes with measurements of Amazon forests subjected to experimental drought

New Phytologist (2013)

Thomas L. Powell[1], David R. Galbraith[2,3], Bradley O. Christoffersen[4], Anna Harper[5,6], Hewlley M. A. Imbuzeiro[7], Lucy Rowland[8], Samuel Almeida[9], Paulo M. Brando[10], Antonio Carlos Lola da Costa[11], Marcos Heil Costa[7], Naomi M. Levine[1], Yadvinder Malhi[3], Scott R. Saleska[4], Eleneide Sotta[12], Mathew Williams[8], Patrick Meir[8] and Paul R. Moorcroft[1]



Summary

- Considerable uncertainty surrounds the fate of Amazon rainforests in response to climate change.
- Here, carbon (C) flux predictions of five terrestrial biosphere models (Community Land Model version 3.5 (CLM3.5), Ecosystem Demography model version 2.1 (ED2), Integrated BIosphere Simulator version 2.6.4 (IBIS), Joint UK Land Environment Simulator version 2.1 (JULES) and Simple Biosphere model version 3 (SiB3)) and a hydrodynamic terrestrial ecosystem model (the Soil–Plant–Atmosphere (SPA) model) were evaluated against measurements from two large-scale Amazon drought experiments.
- Model predictions agreed with the observed C fluxes in the control plots of both experiments, but poorly replicated the responses to the drought treatments. Most notably, with the exception of ED2, the models predicted negligible reductions in aboveground biomass in response to the drought treatments, which was in contrast to an observed *c.* 20% reduction at both sites. For ED2, the timing of the decline in aboveground biomass was accurate, but the magnitude was too high for one site and too low for the other.
- Three key findings indicate critical areas for future research and model development. First, the models predicted declines in autotrophic respiration under prolonged drought in contrast to measured increases at one of the sites. Secondly, models lacking a phenological response to drought introduced bias in the sensitivity of canopy productivity and respiration to drought. Thirdly, the phenomenological water-stress functions used by the terrestrial biosphere models to represent the effects of soil moisture on stomatal conductance yielded unrealistic diurnal and seasonal responses to drought.

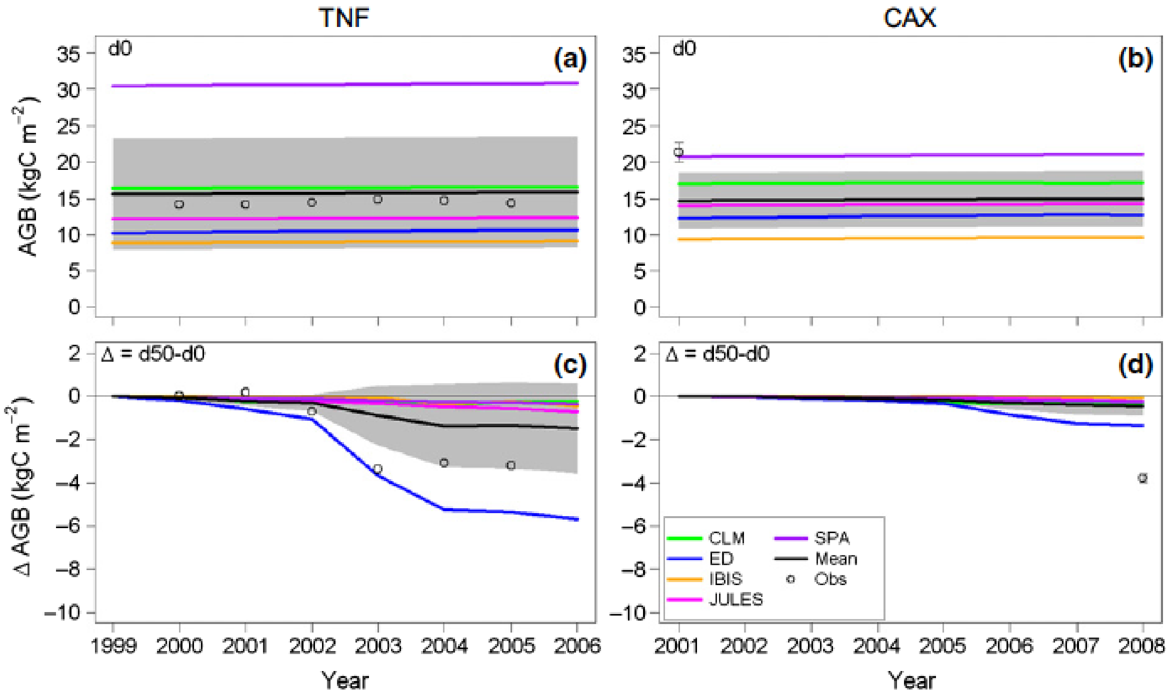
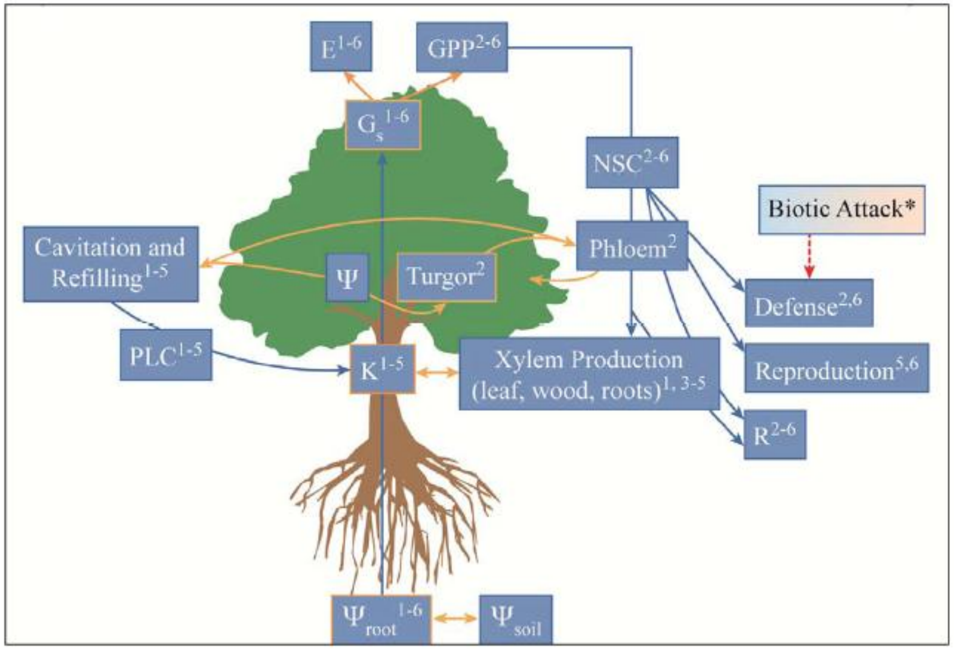


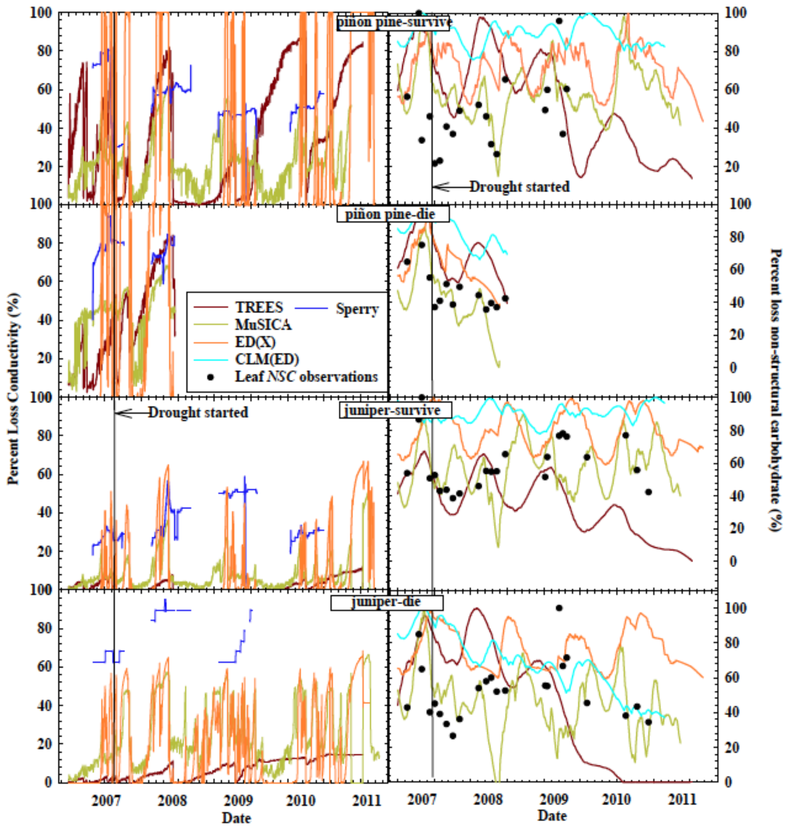
Fig. 1 Annual aboveground biomass (AGB; kg C m^{-2}) predicted for Tapajós (TNF; left side) and Caxiuanã (CAX; right side) National Forests. Colored lines are individual model predictions and the black line is the five-model ensemble mean. The shaded area is the 95% confidence interval (CI) of the models. Open symbols are published observations (mean ± 95% CI (when reported); TNF: Brando *et al.*, 2008; CAX: da Costa *et al.*, 2010). d0 and d50 are drought levels indicating a 0 and 50% reduction in precipitation, respectively. The Δ plots (c, d) show the amount the control (a, b) AGB was altered by the 50% drought treatment.

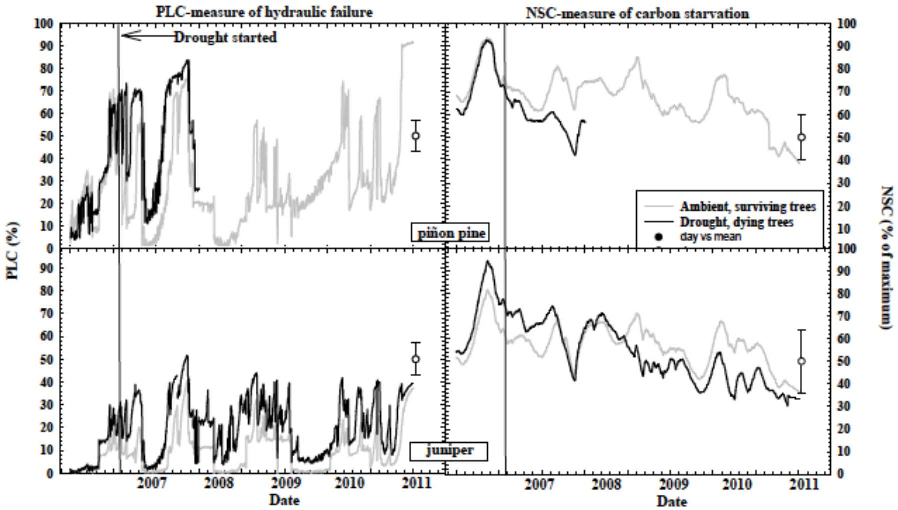
Evaluating theories of drought-induced vegetation mortality using a multi-model-experiment framework.

Nate G. McDowell[1], Rosie A. Fisher[2], Chonggang Xu[1], J.C. Domec[3,4], Teemu Hölttä[5], D. Scott Mackay[6], John S. Sperry[7], Amanda Boutz[8], Lee Dickman[1], Nathan Gehres[8], Jean Marc Limousin[8], Alison Macalady[9], Jordi Martínez-Vilalta[10,11], Maurizio Mencuccini[12,13], Jennifer A. Plaut[8], Jérôme Ogée[14], Robert E. Pangle[8], Daniel P. Rasse[15], Michael G. Ryan[16], Sanna Sevanto[1], Richard H. Waring[17], A. Park Williams[1], Enrico A. Yepez[18], William T. Pockman[8]

Figure 1. A generalized simulation scheme for modeling plant hydraulic failure, carbon starvation, and their interdependence. The numbers within each box indicate inclusion by the following models: [1]Sperry model, [2]FINNSIM, [3]TREES, [4]MuSICA, [5]ED(X), and [6]CLM(ED). Orange-bordered boxes and orange arrows indicate interdependencies, or bi-directional carbon-water fluxes,that are simulated by the models. Allocation of *NSC* to defense, reproduction, respiration, and growth are not listed in priority order, because that remains a subject of debate. Abbreviations are canopy transpiration (*E*), canopy-scale stomatal conductance (G_s), leaf area index (*LAI*), non-structural carbohydrate (*NSC*), hydraulic conductance (*K*), percent loss conductivity (*PLC*) soil and root water potential (Ψ_{soil} and Ψ_{root}), gross primary production (*GPP*), and autotrophic respiration (*R*). *Biotic attack was not included in any of the models used in this study, but is included to highlight the need for this critical model development (red arrow). Feedbacks between biotic attack and plant physiology are not highlighted here.







Widespread Increase of Tree Mortality Rates in the Western United States

Phillip J. van Mantgem,[1]*†‡ Nathan L. Stephenson,[1]*† John C. Byrne,[2] Lori D. Daniels,[3]
Jerry F. Franklin,[4] Peter Z. Fulé,[5] Mark E. Harmon,[6] Andrew J. Larson,[4]
Jeremy M. Smith,[7] Alan H. Taylor,[8] Thomas T. Veblen[7]

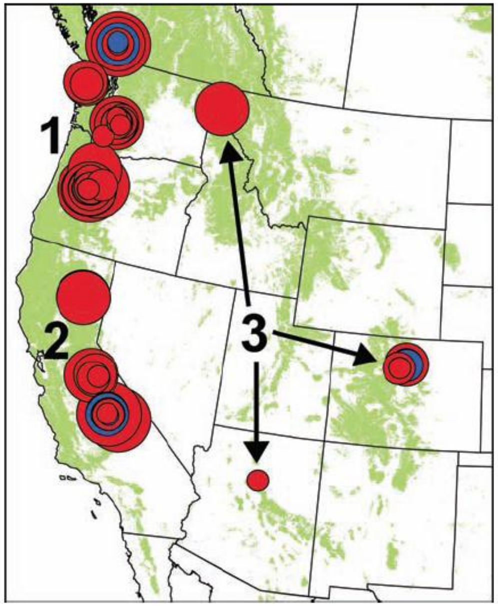


Fig. 1. Locations of the 76 forest plots in the western United States and southwestern British Columbia. Red and blue symbols indicate, respectively, plots with increasing or decreasing mortality rates. Symbol size corresponds to annual fractional change in mortality rate (smallest symbol, <0.025 year^{-1}; largest symbol, >0.100 year^{-1}; the three intermediate symbol sizes are scaled in increments of 0.025 year^{-1}). Numerals indicate groups of plots used in analyses by region: (1) Pacific Northwest, (2) California, and (3) interior. Forest cover is shown in green.

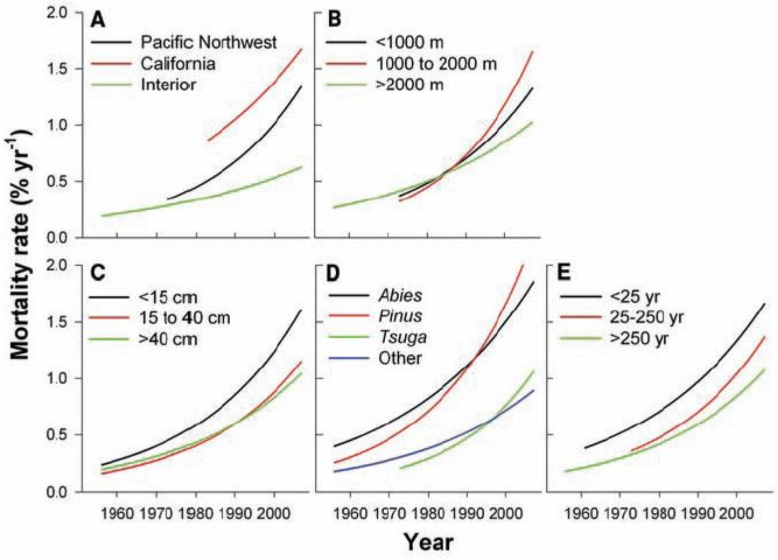


Fig. 2. Modeled trends in tree mortality rates for **(A)** regions, **(B)** elevational class, **(C)** stem diameter class, **(D)** genus, and **(E)** historical fire return interval class.

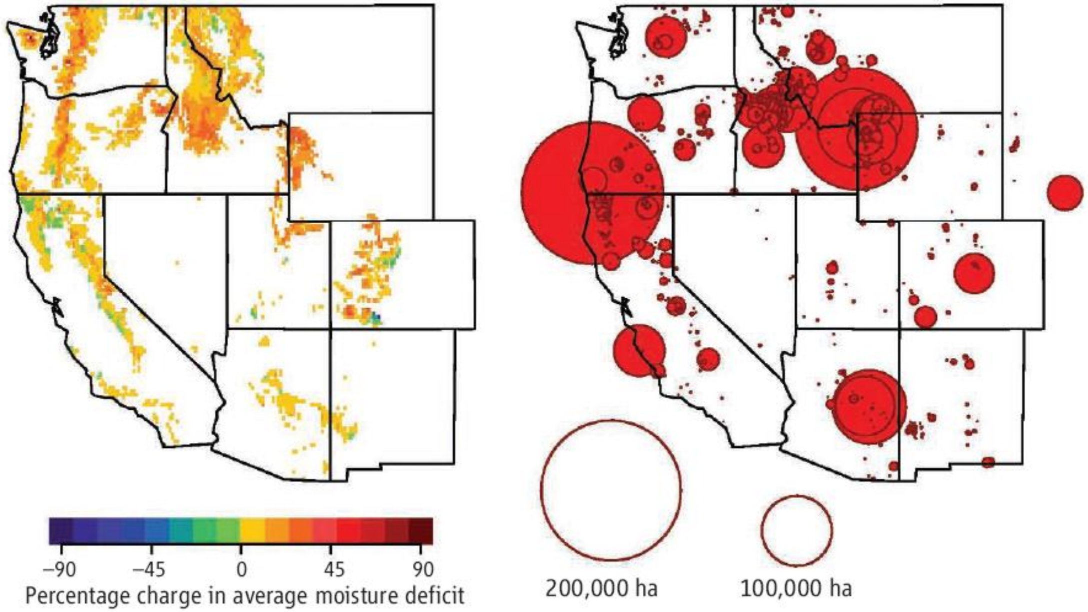
Persistent changes in tree mortality rates can alter forest structure, composition, and ecosystem services such as carbon sequestration. Our analyses of longitudinal data from unmanaged old forests in the western United States showed that background (noncatastrophic) mortality rates have increased rapidly in recent decades, with doubling periods ranging from 17 to 29 years among regions. Increases were also pervasive across elevations, tree sizes, dominant genera, and past fire histories. Forest density and basal area declined slightly, which suggests that increasing mortality was not caused by endogenous increases in competition. Because mortality increased in small trees, the overall increase in mortality rates cannot be attributed solely to aging of large trees. Regional warming and consequent increases in water deficits are likely contributors to the increases in tree mortality rates.

Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity

A. L. Westerling,[1,2]* H. G. Hidalgo,[1] D. R. Cayan,[1,3] T. W. Swetnam[4]

18 AUGUST 2006 VOL 313 **SCIENCE** www.sciencemag.org

Western United States forest wildfire activity is widely thought to have increased in recent decades, yet neither the extent of recent changes nor the degree to which climate may be driving regional changes in wildfire has been systematically documented. Much of the public and scientific discussion of changes in western United States wildfire has focused instead on the effects of 19th- and 20th-century land-use history. We compiled a comprehensive database of large wildfires in western United States forests since 1970 and compared it with hydroclimatic and land-surface data. Here, we show that large wildfire activity increased suddenly and markedly in the mid-1980s, with higher large-wildfire frequency, longer wildfire durations, and longer wildfire seasons. The greatest increases occurred in mid-elevation, Northern Rockies forests, where land-use histories have relatively little effect on fire risks and are strongly associated with increased spring and summer temperatures and an earlier spring snowmelt.



Less moisture—more fires. Between 1970 and 2003, spring and summer moisture availability declined in many forests in the western United States (**left**). During the same time span, most wildfires exceeding 1000 ha in burned area occurred in these regions of reduced moisture availability (**right**). [Data from (*4*)]

CLIMATE CHANGE

Is Global Warming Causing More, Larger Wildfires?

Higher spring and summer temperatures and earlier snowmelt are extending the wildfire season and increasing the intensity of wildfires in the western United States.

Steven W. Running

Vol 452|24 April 2008|**doi:10.1038/nature06777** nature

LETTERS

Mountain pine beetle and forest carbon feedback to climate change

W. A. Kurz[1], C. C. Dymond[1], G. Stinson[1], G. J. Rampley[1], E. T. Neilson[1], A. L. Carroll[1], T. Ebata[2] & L. Safranyik[1]

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins, Coleoptera: Curculionidae, Scolytinae) is a native insect of the pine forests of western North America, and its populations periodically erupt into large-scale outbreaks[1–3]. During outbreaks, the resulting widespread tree mortality reduces forest carbon uptake and increases future emissions from the decay of killed trees. The impacts of insects on forest carbon dynamics, however, are generally ignored in large-scale modelling analyses. The current outbreak in British Columbia, Canada, is an order of magnitude larger in area and severity than all previous recorded outbreaks[4]. Here we estimate that the cumulative impact of the beetle outbreak in the affected region during 2000–2020 will be 270 megatonnes (Mt) carbon (or 36 g carbon m^{-2} yr^{-1} on average over 374,000 km^2 of forest). This impact converted the forest from a small net carbon sink to a large net carbon source both during and immediately after the outbreak. In the worst year, the impacts resulting from the beetle outbreak in British Columbia were equivalent to ~75% of the average annual direct forest fire emissions from all of Canada during 1959–1999. The resulting reduction in net primary production was of similar magnitude to increases observed during the 1980s and 1990s as a result of global change[5]. Climate change has contributed to the unprecedented extent and severity of this outbreak[6]. Insect outbreaks such as this represent an important mechanism by which climate change may undermine the ability of northern forests to take up and store atmospheric carbon, and such impacts should be accounted for in large-scale modelling analyses.

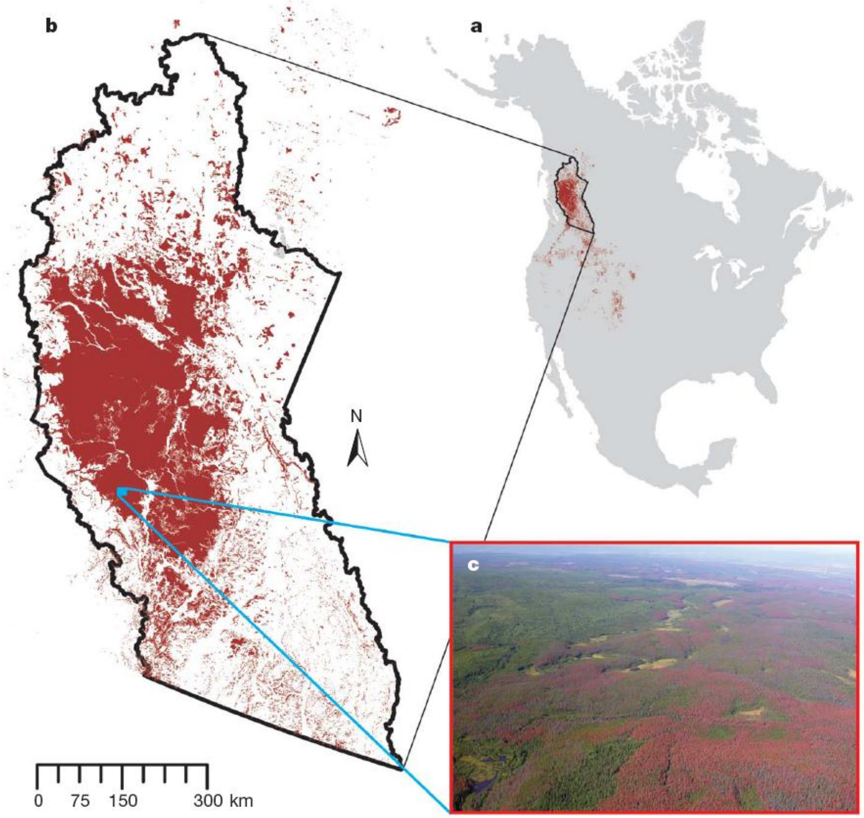
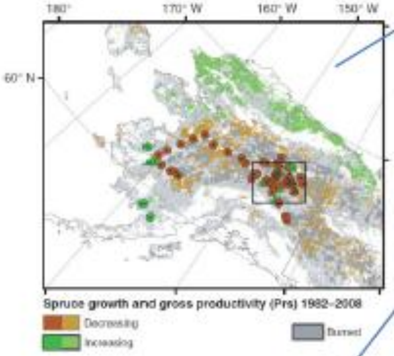
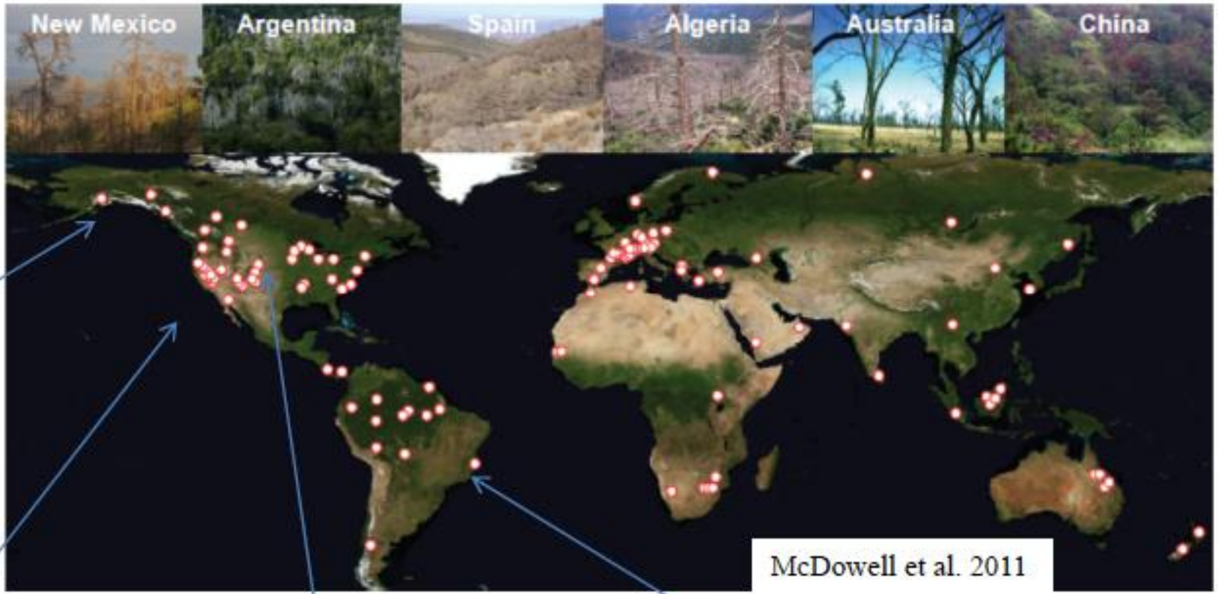


Figure 1 | Geographic extent of mountain pine beetle outbreak in North America. a, Extent (dark red) of mountain pine beetle. **b**, The study area includes 98% of the current outbreak area. **c**, A photograph taken in 2006 showing an example of recent mortality: pine trees turn red in the first year after beetle kill, and grey in subsequent years. Photo credit: Joan Westfall, Entopath Management Ltd.

Forest mortality is accelerating globally due to drought and heat

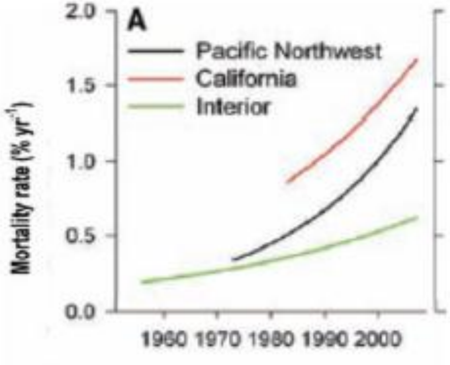
Beck et al. *Eco Let.* 2011





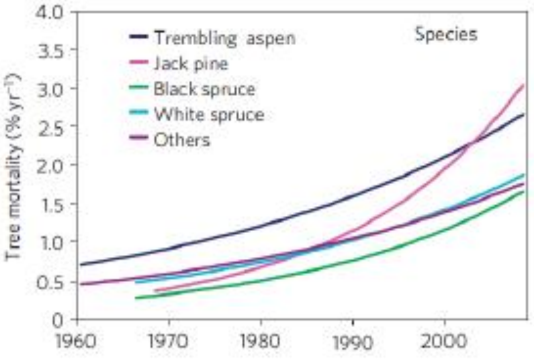
McDowell et al. 2011

Western USA



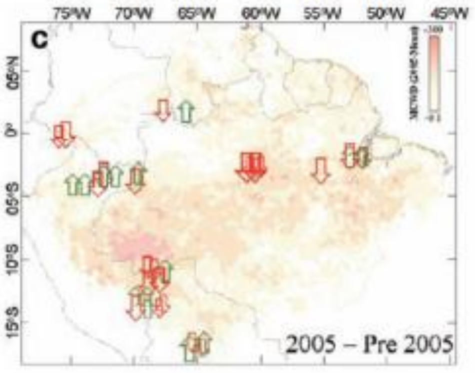
Van Mantgem et al. *Science* 2011

Canada boreal forests



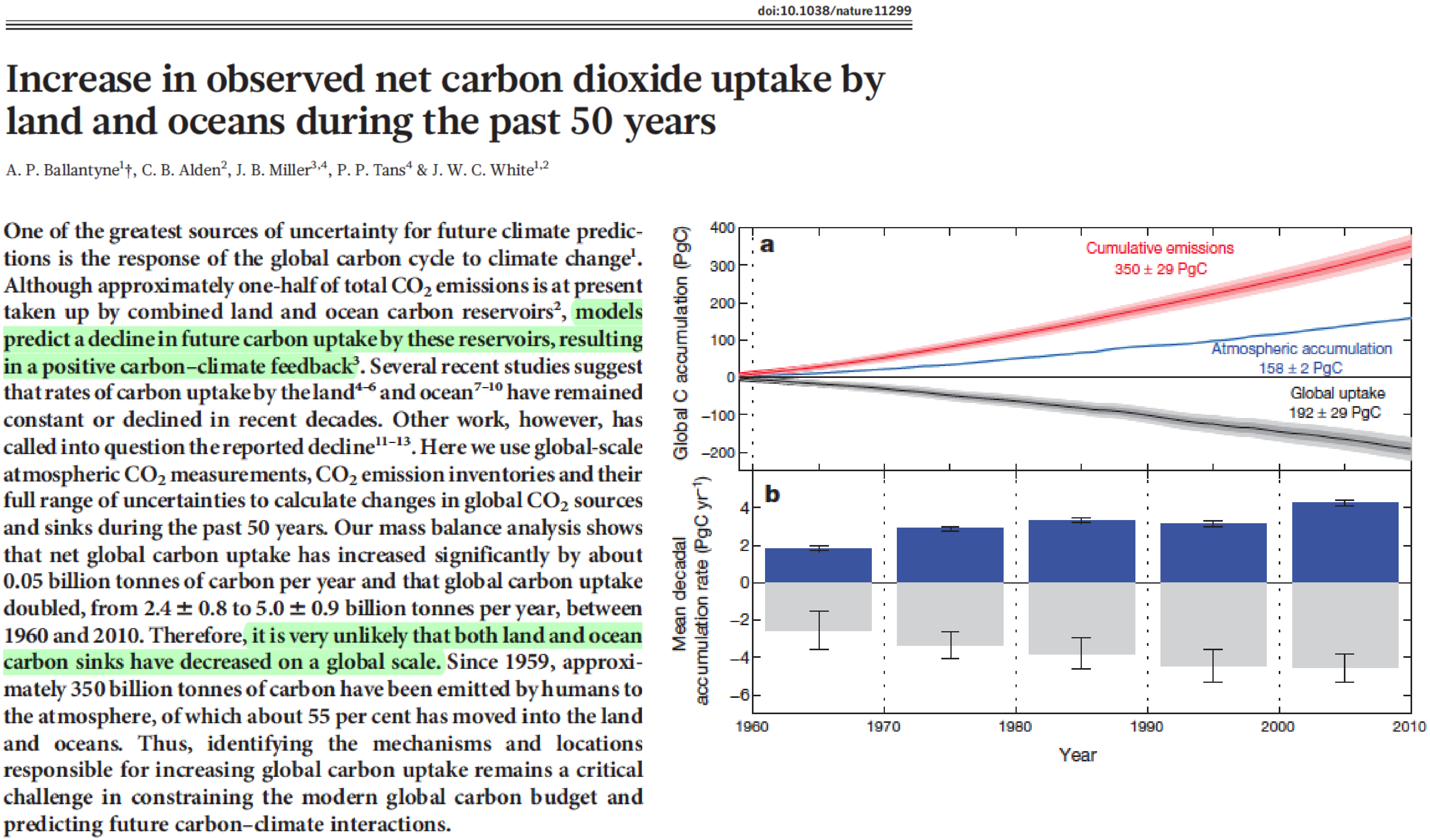
Peng et al. *Nature Climate Change* 2011

Amazon 2005 drought



Phillips et al. *Science* 2009

Tree Mortality the Airborne Fraction



doi:10.1038/nature11299

Increase in observed net carbon dioxide uptake by land and oceans during the past 50 years

A. P. Ballantyne[1]†, C. B. Alden[2], J. B. Miller[3,4], P. P. Tans[4] & J. W. C. White[1,2]

One of the greatest sources of uncertainty for future climate predictions is the response of the global carbon cycle to climate change[1]. Although approximately one-half of total CO_2 emissions is at present taken up by combined land and ocean carbon reservoirs[2], models predict a decline in future carbon uptake by these reservoirs, resulting in a positive carbon–climate feedback[3]. Several recent studies suggest that rates of carbon uptake by the land[4–6] and ocean[7–10] have remained constant or declined in recent decades. Other work, however, has called into question the reported decline[11–13]. Here we use global-scale atmospheric CO_2 measurements, CO_2 emission inventories and their full range of uncertainties to calculate changes in global CO_2 sources and sinks during the past 50 years. Our mass balance analysis shows that net global carbon uptake has increased significantly by about 0.05 billion tonnes of carbon per year and that global carbon uptake doubled, from 2.4 ± 0.8 to 5.0 ± 0.9 billion tonnes per year, between 1960 and 2010. Therefore, it is very unlikely that both land and ocean carbon sinks have decreased on a global scale. Since 1959, approximately 350 billion tonnes of carbon have been emitted by humans to the atmosphere, of which about 55 per cent has moved into the land and oceans. Thus, identifying the mechanisms and locations responsible for increasing global carbon uptake remains a critical challenge in constraining the modern global carbon budget and predicting future carbon–climate interactions.

Are tree mortality rates increasing with a warming climate, and will effects on the carbon cycle cause an observed increase in the airborne fraction?

Summary

- Tree mortality processes, which largely define the climate-carbon g feedback, are only rudimentarily treated in terrestrial models.

- Synthetic landscape-scale studies are needed that combine modeling, remote sensing, field studies, and manipulative experiments to develop an improved mechanistic understanding of tree mortality processes.

- Shifts in background mortality rates (say from a 1% to a 2% regime) can be just as important as episodic/catastrophic events in determining key climate-relevant forest-atmosphere interactions under a changing climate.

- As climate change accelerates, it will become increasingly difficult for model development and evaluation to keep pace with real-time change. The DOE’s Next Generation Ecosystem Experiment (NGEE) approach (model-inspired field studies and experiments) one way to meet this challenge.

- How are we going to model these complex tree mortality processes? (CAM5 video)

Niro Higuchi, Robinson Negron-Juarez, Alan di Vittorio, Daniel Marra, Joerg Tews, Dar Roberts, Giuliano Guimarães, Hongcheng Zeng, Nate McDowell, Sassan Saatchi, Vilany Carneiro, George Hurtt, Adriano Nogueira, Gabriel Ribeiro, Roseana da Silva, Susan Trumbore and Joaquim dos Santos

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Questions?