Amazon Forests Green-Up During 2005 Drought

Scott R. Saleska,[1]*† Kamel Didan,[2]* Alfredo R. Huete,[2] Humberto R. da Rocha[3]

Large-scale numerical models that simulate the interactions between changing global climate and terrestrial vegetation predict substantial carbon loss from tropical ecosystems (*1*), including the drought-induced collapse of the Amazon forest and conversion to savanna (*2*).

Model-simulated forest collapse is a consequence not only of climate change–induced drought but also of amplification by the physiological response of the forest: Water-limited vegetation responds promptly to initial drought by reducing transpiration (and photosynthesis), which in turn exacerbates the drought by interrupting the supply of water that would otherwise contribute to the recycled component of precipitation (*2*). This physiological feedback mechanism should be observable as short-term reductions in transpiration and photosynthesis in response to drought under current climates.

We used satellites to observe whether an Amazon drought in fact reduced whole-canopy photosynthesis (*3*). The enhanced vegetation index (EVI) from the Terra satellite's Moderate Resolution Imaging Spectroradiometer (MODIS) is a composite of leaf area and chlorophyll content that does not saturate, even over dense forests. Properly filtered to remove atmospheric aerosol and cloud effects, EVI tracks variations in canopy photosynthesis, as confirmed by ecosystem flux measurements on the ground (*3*, *4*).

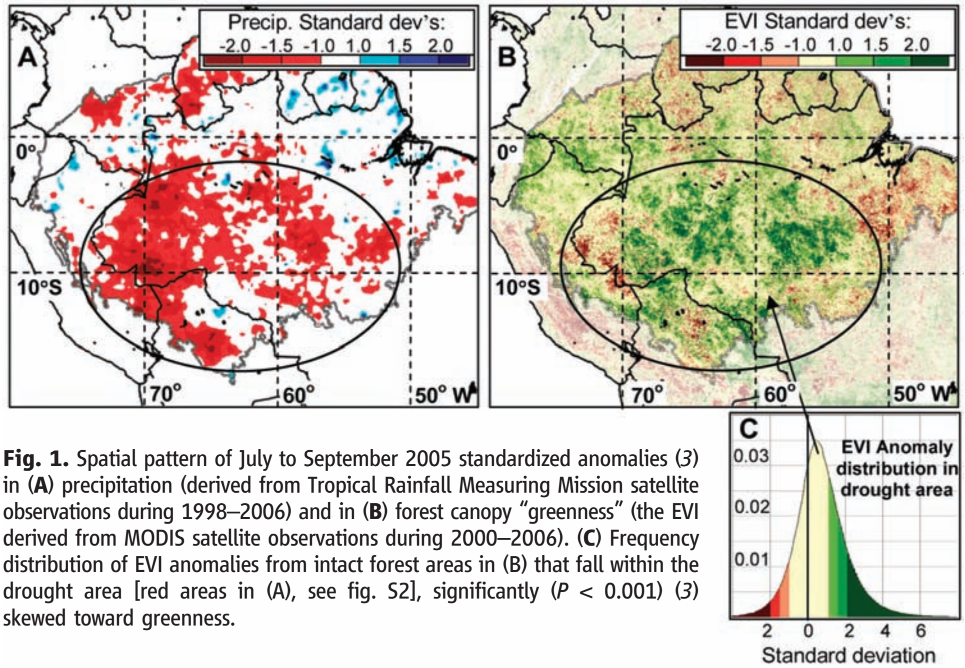

Fig. 1. Spatial pattern of July to September 2005 standardized anomalies (*3*) in (**A**) precipitation (derived from Tropical Rainfall Measuring Mission satellite observations during 1998–2006) and in (**B**) forest canopy "greenness" (the EVI derived from MODIS satellite observations during 2000–2006). (**C**) Frequency distribution of EVI anomalies from intact forest areas in (B) that fall within the drought area [red areas in (A), see fig. S2], significantly ($P < 0.001$) (*3*) skewed toward greenness.

A widespread drought occurred in the Amazon in 2005 (*5*), the first such climatic anomaly since the launch of the Terra MODIS sensor in 1999, providing a unique opportunity to compare actual forest drought response to expectation at large scales.

Drought intensity peaked during dry season onset (July to September), primarily in southwest and central Amazônia (Fig. 1A) [the drought's temporal evolution is depicted in (*5*)]. If drought had the expected negative effect on canopy photosynthesis, it should have been especially observable during this period, when anomalous interannual drought coincided with the already seasonally low precipitation. The observations of intact forest canopy "greenness" in the affection areas, however, are dominated by a significant increase ($P < 0.0001$) (*3*) not a decline (Fig. 1, B and C). Much of the smaller area exhibiting decline is heavily affected by human activity or consists of different vegetation types (fig. S2).

Increased greenness is inconsistent with expectation if trees are limited by water but follows from increased availability of sunlight (due to decreased cloudiness) when water is not limiting—if, for example, trees are able to use deep roots and hydrologic redistribution to access and sustain water availability during dry extremes (*6*, *7*).

These observations suggest that intact Amazon forests may be more resilient than many ecosystem models assume, at least in response to short-term climatic anomalies. This work does not alter the growing understanding of how Amazon forests are vulnerable to stressors such as deforestation and fire, a vulnerability observed to increase dramatically during the 2005 drought (*5*). But it does suggest that forest vulnerability to climatic effects alone needs to be carefully assessed with studies aimed at improving models by integration with observations. Especially important for future work are observations to address the critically important question of forest response to longer-term drought (*8*), such as may be induced by strong El Niño events or longer-term climate change.

References and Notes

1. P. Friedlingstein *et al.*, *J. Clim.* **19**, 3337 (2006).
2. R. A. Betts *et al.*, *Theor. Appl. Climatol.* **78**, 157 (2004).
3. Materials and methods are available on *Science* Online.
4. A. R. Huete *et al.*, *Geophys. Res. Lett.* **33**, L06405 (2006).
5. L. E. O. C. Aragão, Y. Malhi, R. M. Roman-Cuesta, S. Saatchi, Y. E. Shimabukuro, *Geophys. Res. Lett.* **34**, L07701 (2007).
6. D. C. Nepstad *et al.*, *Nature* **372**, 666 (1994).
7. A. M. Makarieva, V. G. Gorshkov, *Hydrol. Earth Syst. Sci.* **11**, 10133 (2007).
8. D. C. Nepstad, I. M. Tohver, D. Ray, P. Moutinho, G. Cardinot, *Ecology* **88**, 2259 (2007).
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Supporting Online Material

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Materials and Methods
Figs. S1 to S3

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[1] Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, AZ 85721, USA. [2] Department of Soil, Water, and Environmental Science, University of Arizona, Tucson, AZ 85721, USA. [3] Department of Atmospheric Science, University of São Paulo, São Paulo, SP Brasil Cep 05508-090.

*These authors contributed equally to this work.

†To whom correspondence should be addressed. E-mail: saleska@email.arizona.edu