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Impacts of Forest Degradation on Water, Energy, and Carbon Budgets in Amazon Forest

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Forest degradation as a result of logging, fire, and fragmentation not only alters carbon stocks and fluxes in tropical forests, but also impacts physical land-surface properties such as albedo and roughness length that impact boundary layer dynamics and the exchanges of water and energy fluxes between the land and atmosphere. Such impacts are poorly quantified to date due to difficulties in accessing and maintaining observational infrastructures, and the lack of proper modeling tools for capturing the interactions among biophysical properties, ecosystem demography, and biogeochemical cycling in tropical forests.

To address these limitations, we developed and applied two land surface/ecosystem models capable of simulating such interactions: the Ecosystem Demography Model (ED-2) and the Functional Assembled Terrestrial Ecosystem Simulator (FATES) coupled to the Community Land Model. To evaluate the models' ability to represent short-term impacts of forest degradation, we parameterized both models to reproduce the selective logging experiment carried out at the Tapajos National Forest in Brazil. Both models were spun up until they reached steady state, and simulations with and without logging were compared with the eddy covariance flux towers located at the logged and intact sites. The sensitivity of simulated water, energy, and carbon fluxes to key parameters associated with soil properties and plant functional traits were quantified by perturbing the parameters within their documented ranges from literature. The sensitivity to initial conditions is also assessed by initializing the models from forest inventory data.

Our results suggest that both models were able to reproduce water and carbon fluxes in intact forests, although sensible heat fluxes were overestimated, even using the best parameter set within the ensemble. The effect of degradation levels on fluxes, including conventional and reduced impact logging, were assessed by specifying different disturbance parameters in the models (e.g., size-dependent mortality rates associated with timber harvest, collateral damage, and mechanical damage for infrastructure construction). The model projections suggest that even though most degraded forests rapidly recover water and energy fluxes compared with old-growth forests, the recovery times for carbon stocks, forest structure and composition are much longer. In addition, the recovery trajectories are highly dependent on choices of parameter values.

Our study highlights the advantages of an Earth system modeling approach, constrained by observations, to quantify the complex interactions among forest degradation, ecosystem recovery, climate, and environmental factors. This pilot study provides a roadmap to improve the representation of forest degradation in FATES.