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# Ecosystem disturbance modeling: a systems approach

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Tropical forests cycle more energy, water and carbon dioxide ($CO_2$) than any other ecosystems and currently are the largest carbon sinks in the world. Whether they remain net carbon sinks or switch to being net carbon sources will define tipping points in the Earth system. Forests in other regions, including the semi-arid forests of the US Southwest, play key roles in regional meteorology, precipitation and hydrology. Disturbances such as drought, insect outbreaks, flooding, wildfires and harvesting as well as elevated $CO_2$ levels, rising temperatures and changing precipitation patterns can change the energy and resource balances that govern forest productivity and thus exacerbate or dampen vulnerability of these ecosystems. However, poor representation of coupling between micrometeorological and forest canopy processes responsible for mass, momentum and energy exchange between forests and atmosphere, as well as plant physiological responses to micrometeorological shifts currently prevents characterization of the feedbacks and identification of potentially disastrous tipping points. To identify the ecosystem/atmospheric feedbacks that dictate forest resilience, a novel modeling framework is developed through the coupling of a plant biophysics model with a computational fluid dynamics (CFD) tool. In this new model paradigm, plant physiological response is captured at the leaf scale, accounting for plant hydraulics and photosynthesis as well as the economics of carbon uptake and water loss under stomatal regulation, which govern the mass and energy exchange between foliage and the atmosphere. Actual canopy structural data collected from field campaigns are used to simulate forested landscapes, where turbulent flow-fields are resolved through heterogeneous vegetation at sub-meter scales. This will enable simulating high-resolution three-dimensional effects of canopy disturbance-induced (natural or anthropogenic) forest structure changes on the critical forest/atmosphere exchange processes. Dynamic heterogeneous conditions such as wind speed, air temperature, relative humidity, soil moisture, radiation, light availability and $CO_2$ concentrations are used to drive a two-way coupled plant biophysics model. This biophysics model represents the response of plant tissue temperature, transpiration, respiration and carbon assimilation as well as the moisture, $CO_2$ and thermal feedbacks to the atmosphere (source/sink terms in CFD model). Characterization of the sensitivity of the two-way feedbacks to disturbances and local environment changes is a critical missing science for identification of tipping points and positive/negative feedback mechanisms that can cascade or buffer ecotype shifts. The proposed spatially-explicit (accounting for three-dimensional canopy heterogeneity) coupled biophysics/atmosphere capability is critical to address questions related to future climate, hydrology, and landscape dynamic questions. Current top-down Earth and climate-system models do not capture the leaf-to-landscape-scale processes in fine enough detail to account for evolving heterogeneities. Thus, the proposed bottom up modeling framework will bridge a major science gap.