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Synergistic effects of drought and fire on the carbon carrying capacity of tropical forests and woodlands

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More than half of the global forest carbon stock is held in tropical forests. A relatively large proportion of the tropical forest carbon is stored in plant biomass rather than in the soil, making these stocks particularly vulnerable to disturbances such as droughts, fires and cyclones. The frequencies, duration and intensities of such disturbances may change under future climates with poorly resolved but potentially significant (synergistic) effects on the carbon carrying capacity of tropical forests and thereby on global geochemical cycles.

In this study we analyse high-resolution global data sets for tropical forest biomass (Saatchi et al., 2011. PNAS) and fire affected areas (GFED4, Giglio et al.,2013. JGR 118), together with climate data (WorldClim, Hijmans et al., 2005. Int. J. Clim. 25), to quantify the sensitivity of tropical forest carbon stocks in South America, Africa and Asia/Australia to seasonal water deficits and fire. Here, the climatic water deficit (D), calculated as the difference between mean annual potential evapotranspiration and actual evapotranspiration, is used as a measure of seasonal water stress (i.e. evaporative demand not met by available water), while the mean annual burned area fraction (1995-2013) of grid cells is used as a measure of average fire activity.

Tropical forest carbon stocks are maximal, as expected, where water deficits are negligible. In those densely forested environments fire tends to be extremely rare as fuels are too wet to burn for most of the time. In all three continents, potential tropical forest carbon stocks are well predicted by a non-linear decreasing function of the mean annual climatic water deficit, with a steep drop in carbon stocks at D of 700-800 mm per year. At this threshold in the climatic water deficit we observe a strong increase in fire activity that is indicative of a critical change in vegetation structure (i.e. tree/grass ratio) and associated shift in the dominant climatic constraint on fire activity from fuel dryness to fuel productivity. By comparing predictions of potential forest carbon stocks (i.e. as a function of D only) with actual carbon stocks, we quantify the sensitivity of those stocks to increasing fire activity. Finally, we map the risk of losses in carbon carrying capacity of tropical forests under scenarios of future climate.