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A hydroclimatic model of global fire patterns

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Satellite-based earth observation is providing an increasingly accurate picture of global fire patterns. The highest fire activity is observed in seasonally dry (sub-)tropical environments of South America, Africa and Australia, but fires occur with varying frequency, intensity and seasonality in almost all biomes on Earth. The particular combination of these fire characteristics, or fire regime, is known to emerge from the combined influences of climate, vegetation, terrain and land use, but has so far proven difficult to reproduce by global models. Uncertainty about the biophysical drivers and constraints that underlie current global fire patterns is propagated in model predictions of how ecosystems, fire regimes and biogeochemical cycles may respond to projected future climates.

Here, I present a hydroclimatic model of global fire patterns that predicts the mean annual burned area fraction (F) of 0.25° x 0.25° grid cells as a function of the climatic water balance. Following Bradstock's four-switch model, long-term fire activity levels were assumed to be controlled by fuel productivity rates and the likelihood that the extant fuel is dry enough to burn. The frequency of ignitions and favourable fire weather were assumed to be non-limiting at long time scales.

Fundamentally, fuel productivity and fuel dryness are a function of the local water and energy budgets available for the production and desiccation of plant biomass. The climatic water balance summarizes the simultaneous availability of biologically usable energy and water at a site, and may therefore be expected to explain a significant proportion of global variation in F. To capture the effect of the climatic water balance on fire activity I focused on the upper quantiles of F, i.e. the maximum level of fire activity for a given climatic water balance.

Analysing GFED4 data for annual burned area together with gridded climate data, I found that nearly 80% of the global variation in the 0.99 quantile of F (i.e. F_0.99) was explained by two terms of the climatic water balance: i) mean annual actual evapotranspiration (AET), which is a proxy for fuel productivity, and ii) mean annual water deficit (D=PET-AET, where PET is mean annual potential evapotranspiration), which is a measure of fuel drying potential. As expected, F_0.99 was close to zero in environments of low AET (e.g. deserts) or low D (e.g. wet forests), due to strong fuel productivity or fuel dryness constraints, and maximum for environments of intermediate AET and D (e.g. tropical savannas).

The topography of the F_0.99 response surface was analysed to explore how the relative importance of fuel productivity and fuel dryness constraints varied with the climatic water balance, and geographically across the continents. Consistent with current understanding of global pyrogeography, the hydroclimatic fire model predicted that fire activity is mostly constrained by fuel productivity in arid environments with grassy fuels and by fuel dryness in humid environments with litter fuels derived from woody shrubs and trees. The model provides a simple, yet biophysically-based, approach to evaluating potential for incremental change in fire activity or transformational change in fire types under future climate conditions.