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Global pyrogeography: Macro-scaled models of fire-climate relationships for understanding current and future conditions

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Maps of the global distribution of fire impulsively raise questions of how climatic variation contributes to explaining the patterns we observe. Can collections of global environment data be used to quantify global pyrogeography? What are the variables that strongly discriminate between fire-prone and fire-free parts of the world? We undertook a study to estimate the relationship between global fire occurrence, variation in conditions (climate) and resources (biomass) at a coarse spatio-temporal resolution. Our focus was not to build the best predictive model of observed fire occurrence, but to uncover relatively simple fire-environment relationships.

We used existing records of fire (ESA ATSR World Fire Atlas), climate normals calculated for 17 variables, a biomass index (NPP) and an index of human influence (WCS human footprint) to develop distribution models that identify environmental characteristics that ally fire-prone parts of the planet. We included vegetation fires caused by humans and lightning since the two types are not discernable in satellite data. The sampling unit had a spatial resolution of 100 km and temporal resolution of eleven years (1996–2006). We used two types of models to describe the distribution of fire: generalized additive models (gams) and maximum entropy models (maxent). These models were trained using ten subsets of the global data, each containing a 15% random sample of the data; this sub-sampling served to retain data for model testing/validation and also reduced spatial autocorrelation. We implemented a used versus available sampling framework, where the available sites were equal in number to the observed, used sites. For the gams we used the Akaike Information Criterion

and the principle of parsimony to select key environmental variables that explained the most variation in the data using the simplest functional forms. We contrasted these results to maxent, a machine learning approach, where all variables were retained and allowed to take complex shapes and interactions to fit the training data.

All models indicated that variation in resources (biomass) and conditions (climate) contributed to the observed distribution of fire across the planet. The overall spatial distribution of the expected relative probability of fire was very similar between the gams and maxent, however our gams included fewer variables with simpler functional forms. The dominant variable was always biomass (NPP); the availability of resources to burn is the primary determinant of the global distribution of fire. After accounting for the availability of combustible resources, three climate variables systematically discerned fire-prone parts of the world in the majority of gams: mean temperature of the warmest month, annual precipitation and mean temperature of the wettest month. These variables fit the data with relatively simple functional forms (e.g., second or third order polynomials) and illustrated where extreme climate conditions regulate the global niche of fire. A handful of other variables appeared in some of the models. The maxent results predicted similar spatial patterns in the relative probability of fire. The top variables mirrored those selected in the gams suggesting that a few, key climate gradients are able to describe a large amount of spatial variation in fire patterns at this macro-ecological scale. This work sets a broad, global stage to frame our understanding of environmental controls on pyrogeography at many nested scales (e.g., spatial, temporal, taxonomic (regime types)) and is a springboard for projections of global fire distribution with climate change.