Wildfires of Siberia

Problem description

Boreal wildfires pose an escalating threat to the environment, infrastructure, and human societies in northern regions. In addition, they constitute about 10% of global fire carbon dioxide emissions. Understanding and identifying the environmental drivers of boreal fires is a necessary step to issue reliable predictions and, where possible, envisage appropriate mitigation actions. On the other hand, given that most boreal areas are remote and difficult to access, the information provided by remote sensing observations becomes crucial. In our work we identified the drivers influencing the extent of the burned area in Southern Siberia, using data analysis and empirical correlation-based models, and including both satellite estimates and ground measurements of environmental and climate-related variables.

Proposed solution

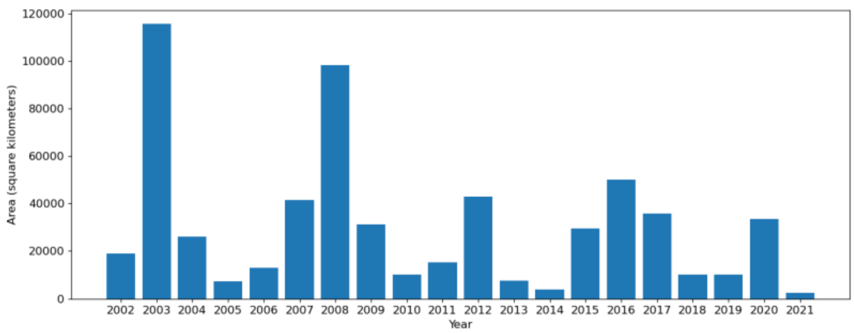

Fig 1. Total burned area (BA) in years 2002 - 2021 classified using MODIS surface reflectance images.

To build the fire history dataset, time series of MODIS reflectance data were used. The choice of MODIS was based on its long history of observations and the reliability of data. We employed all MODIS surface reflectance products (MOD09A1) for the period 2002 – 2021. Since the study area is obscured by clouds or covered with snow for most of the year, we selected the time window that maximized the number of available frames across most years. Hence, only images acquired between the 145th and 241st day of each year (corresponding to the spring-summer period) were retained for further processing. Burned area (BA) was classified using algorithm developed in CBK PAN. This method makes use of images acquired before and after fire events.

In our study we tested environmental drivers that were estimated from either satellite observations (i.e. Land Cover, Evapotranspiration, Normalized Difference Vegetation Index, Snow Extent, Land Surface Temperature, Precipitation) or ground weather stations (Maximum Temperature, Minimum Temperature, Standardized Precipitation Evapotranspiration Index.

To find the best BA predictors, first we checked the pair correlations of BA with different temporal aggregations of the driver variables, thus identifying the best matches. To estimate the significance of the correlation, we randomly shuffled the BA time series 1000 times, then computing the correlation between the shuffled BA series and the potential driver. The drivers for which more than 95% of the random permutations led to a lower correlation (in absolute value) than the true data were selected as potentially significant (at the 5% level). Then, we performed multilinear regressions using every possible combination of the potentially significant drivers, selecting the combinations providing the lowest Akaike Information Criterion and, at the same time, exhibiting a low cross-correlation between the drivers. The models predicted out-of-sample the BA over the total study area and separately for the three dominant vegetation classes (forests, sparsely wooded areas and grasslands) using only a few driving variables, which are mostly related to fuel accumulation and moisture.

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Main features

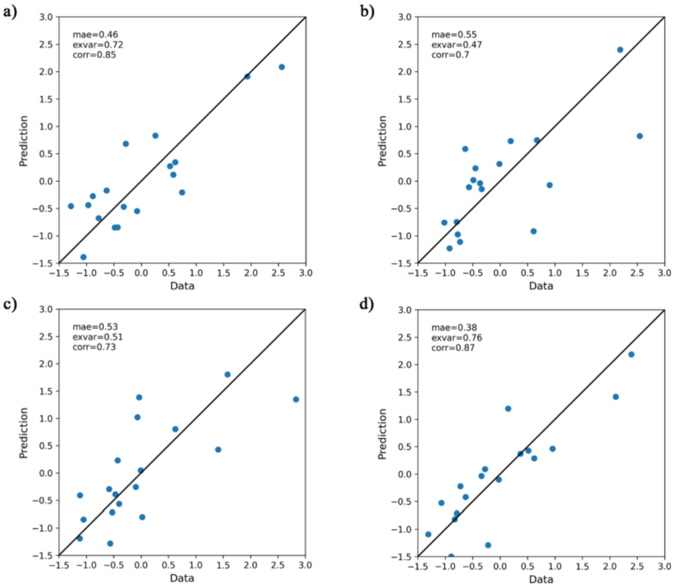

Fig 2. Comparison between actual BA data and model results for the leave-one-out burned area predictions for a) forests (drivers: ET, ET2, NDVI), b) sparsely wooded areas (drivers: ET2, NDVI, Tmin), c) grasslands (drivers: ET, ET2, Tmin), d) total area (drivers: ET, ET2, Tmin, Snow extent).

Figure 2 shows the comparison between the actual BA data and the modelling results obtained using the leave-one-out procedure. The highest correlation between data and model results was obtained for forests (0.85) and for the total area, when all land cover (LC) classes are combined (0.87). Slightly lower agreement was obtained for sparsely wooded areas and grasslands. Evapotranspiration and vegetation greenness (represented by NDVI) were identified as the most important variables, with evapotranspiration playing an opposite role in winter and spring. The correlation of burned area with autumn and spring temperature is particularly relevant for grasslands, whereas it is negligible for forests.

Since fire prone conditions and fire spread depend not only on the situation at the time of fire, but also on the complex history that the ecosystem underwent in the preceding months, we tested different aggregation periods for each driver variable. To account for the possible differences between the different vegetation classes affected by fires, we separately considered the three dominant land cover classes, i.e. forests, sparsely wooded areas and grasslands.

The most important driver selected for all classes was evapotranspiration. However, evapotranspiration enters the picture with two different roles: a positive correlation with burned area in the winter months preceding the summer fire season, and a negative correlation for the spring months immediately before the fire season. On the one hand, evapotranspiration is related to the amount of active (i.e. living) vegetation, so that a positive anomaly of evapotranspiration implies high biomass accumulation that can enhance fire propagation in the following summer. On the other hand, water stress may reduce plant activity and therefore evapotranspiration, thus a negative anomaly of evapotranspiration in spring points to the accumulation of dry fuel that can foster fire spread. This double role of evapotranspiration can explain the positive correlation between BA and evapotranspiration in February for the forest class (fuel accumulation), and the negative correlation in April and May for all classes (fuel desiccation).

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