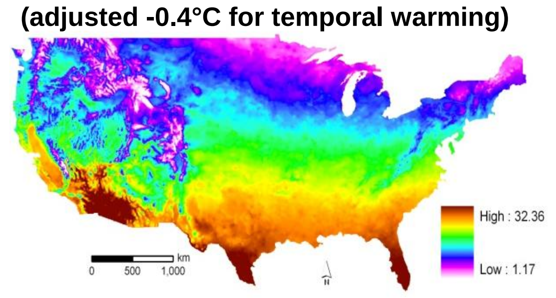
Abstract

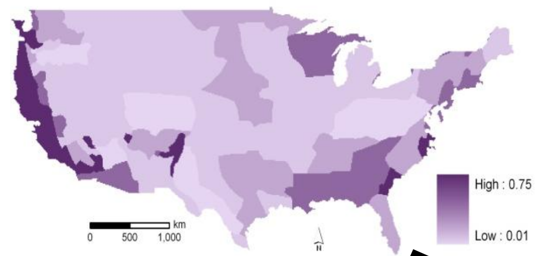
A Calibration of Temperature and Fire Frequency. A predictive model of fire frequency in North America using climate and human population density shows promise in estimating the importance of fire at broad temporal and spatial scales. Over 5 thousand fire scars from 127 sites and nine forest ecosystems were used to empirically derive and test a fire interval regression model. Three predictor variables were selected: a temporal proxy of annual mean maximum temperature, annual precipitation, and human population density. The model was calibrated using mean fire intervals that document the presence of fire in a 1 to 3 km^2 area during the two centuries prior to Euro-American settlement. This period allows for a more accurate calibration of temperature and fire frequency because of the reduced effects of land use, fire suppression, and other technological factors on fire events. Fifty-five percent of the variance in mean fire intervals was explained by annual mean maximum temperature, 10 percent by annual precipitation, and an additional 11 percent by human population density (model r-square = 0.70). Although coarse (256 km^2 cells), mean fire interval estimates provide a empirically derived and plausible depiction of the continental variability in historic U.S. fire frequency. Based on the regression diagnostics and spatial patterning in fire frequencies it is apparent that temperature is one of the most important factors influencing long term differences in fire regimes. We discuss the role of temperature as a 'master' variable for understanding multiple fire regime characteristics such as the rate of fuel combustion (the Arrhenius equation), the length of the fire season, and the broad scale variability of fire events.

---------------------------Predictor variables and model---------------------

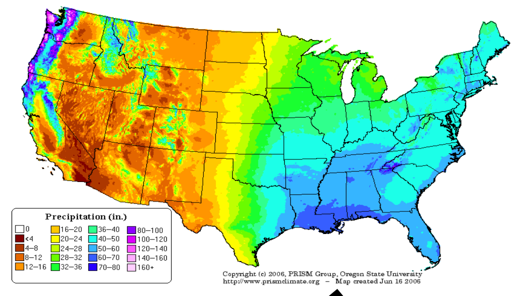
Mean maximum temperature C
(adjusted -0.4°C for temporal warming)

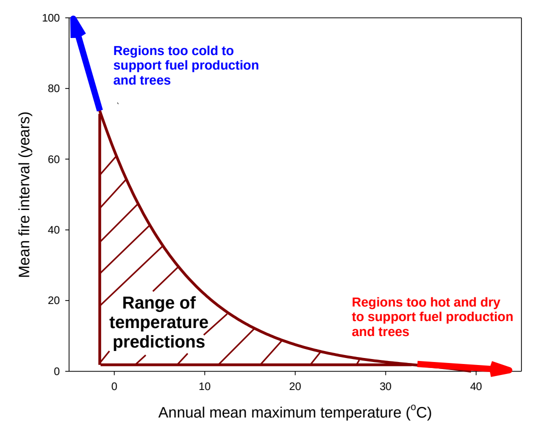


Human population density (contact)
(humans/km^2)



Annual precipitation



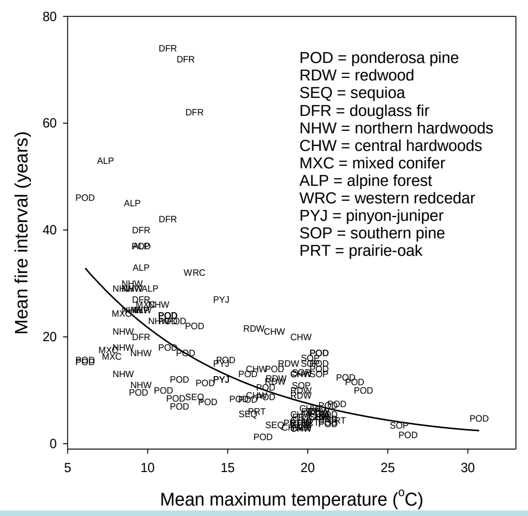


(Above) The limits of the temperature-wildland fire relationship.

$$MFI = \exp^{(4.19 - (0.111*maxt) - (3.54*pop) + (0.00715*precip))}$$

Empirically derived and tested regression model

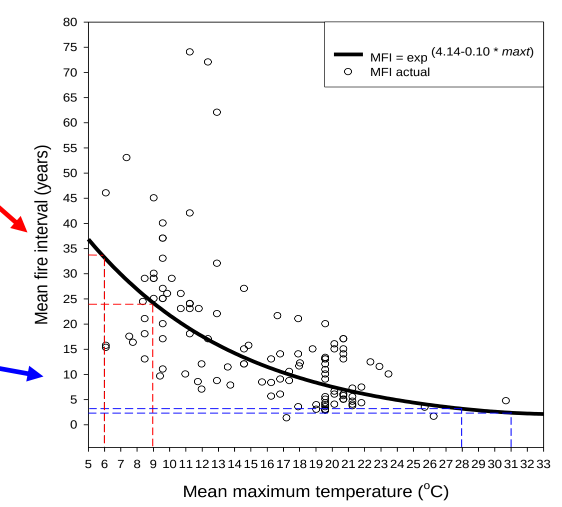
where: **MFI** is the mean fire interval (years), (model r^2 = 0.77, **tested 0.70**)
maxt is average maximum temperature (°C) (partial r^2 = 0.55),
pop is human population density (humans per km^2) (partial r^2 = 0.11),
precip is annual precipitation (cm) (partial r^2 = 0.10).
period of calibration is between 1600 and 1850 A.D.,
number fire history sites = 123.



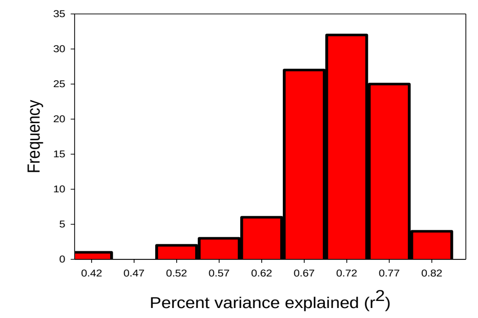
(Above) The non-linear relationship between temperature and fire intervals in different vegetation types.

A **10 year** difference in fire frequency with a 3 °C temperature difference

A **1 year** difference in fire frequency with a 3 °C temperature difference



(Above) The non-linear relationship between temperature differences and fire.

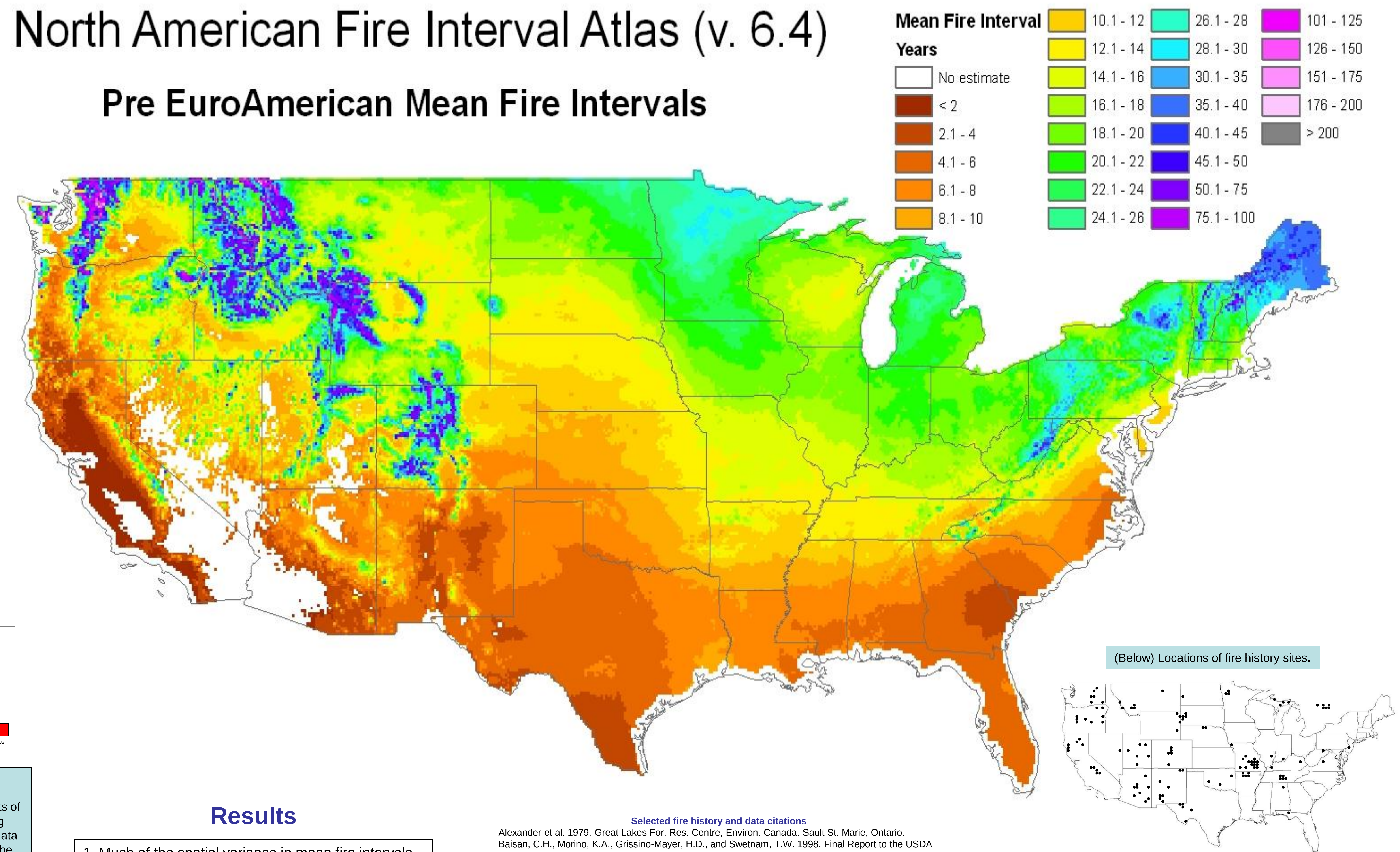


Model Verification

The distribution of 100 coefficients of determination calculated using randomly chosen halves of the data with replacement indicate that the regression model is stable and explains an average of 70 percent of the variance in mean fire intervals for the 123 fire history sites.

North American Fire Interval Atlas (v. 6.4)

Pre EuroAmerican Mean Fire Intervals



(Below) Locations of fire history sites.

Why is temperature the most important variable?

1. Temperature influences snow cover, fuel production and decay, and the drying rates of fuels. 2. Temperature is part of combustion and ignition reactions that control he physical chemistry of fire reactions (the Arrhenius equation, below).

In the lab: A_o is the pre exponential molecular collision frequency On the landscape: A_o has much larger distances and structures and is affected by fuel concentration, wind, and elevation

In the lab: E_a is in KJ / mol and the ignitions are applied by humans, On the landscape: E_a is affected by the timing and ignitions of humans In both the lab and landscape humans have experiential knowledge of the energy and mass requirements of E_a

In the lab: it's the temperature the reactants, On the landscape: the average temperature of the reactants (fuels and O_2) and *T* effects on other ecosystem processes

$$k = A_o \exp^{-Ea/RT}$$

where:
the mean fire interval (MFI) is 1/k,
k = rate constant for wildland fires in s^{-1} or yrs^{-1}
A_o = pre-exponential ($3.31 * 10^{11} s^{-1}$)
exp = 2.718
E_a = activation energy (69.5 kJ per mol)
R = gas constant (0.008314 J K^{-1} mol^{-1})
T_{max} = mean maximum temperature in °K

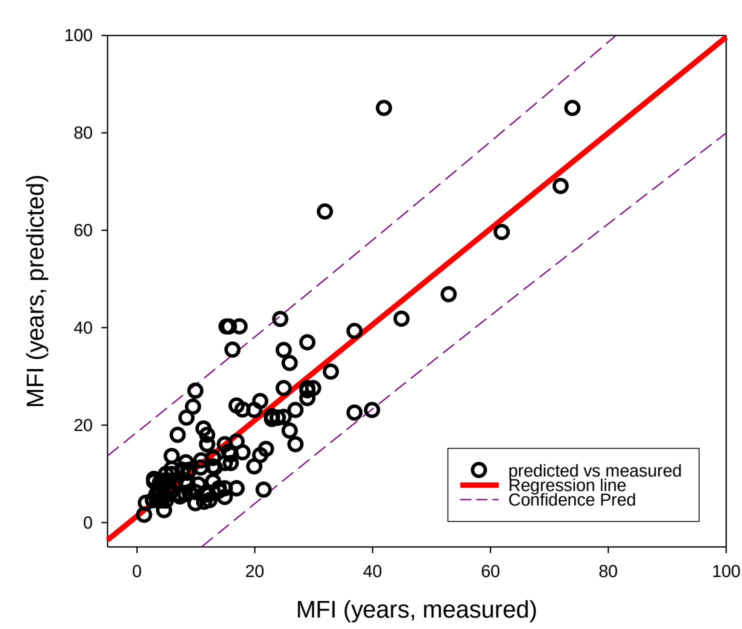
Scaling thermal reactions from the laboratory to the landscape

Methods: model development

The first iteration of the model was empirically derived from available fire scar data at 38 eastern North America sites. Although this data set showed predictive power, the eastern fire history data alone was inadequate in the range and distribution of the variables and did not meet the assumption of statistical normality. Thus, we used pre Euro-American fire scar interval data from an additional 123 sites and included the Western United States. These additional data extended the range of temperature and fire interval observations, increased the normality of the distribution of temperature means, more than doubled the statistical power of the regression, and served to examine the hypothesis under a much broader set of conditions. Multicollinearity among predictor variables was negligible. We used published mean fire intervals, calculated estimates by dividing the period of record by the number of fires to estimate mean fire intervals. Since the variables we used in this analysis are being refined and more fire data is forthcoming from investigators and regions we present this model as a work in progress. We used fire history data from more than 75 studies and climate data from PRISM products (OSU). Thirty-year (1971 - 2000) climate means and totals were used as proxy climate variables in the regression modeling.

Results

1. Much of the spatial variance in mean fire intervals between ~ 1650 and 1850 can be explained temperature, population density and moisture.
2. An empirically derived multiple regression model can be used to map mean fire intervals.
3. Mapped and predicted mean fire intervals are statistically significant and within the range of interval estimates documented in the literature.
4. The model conforms to the laws of physical chemistry concerning the rates of chemical reactions (the Arrhenius equation) formulated over 100 years ago.



(Above) Predicted versus actual mean fire interval show a strong relationship over many forest types.

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Approach

Our approach was to estimate fire intervals using an empirically derived model based on climate and human population density. The value of this approach and a continental model (version 6.4) is that mean fire intervals can be estimated for regions and sites that have no potential for fire scar histories because of the lack of old trees or wood. Based on regression analysis it appears that strong continental trends exist that link climate and human population to historic fire frequency. Local fire regime factors will likely cause deviations from this broad scale record, both in time and space. This point is demonstrated in the landscape model where high variability occurs within a small spatial extent (5000 km^2).

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