A Fire Mitigation Management Tool: Predicting Wildfire Suppression Costs

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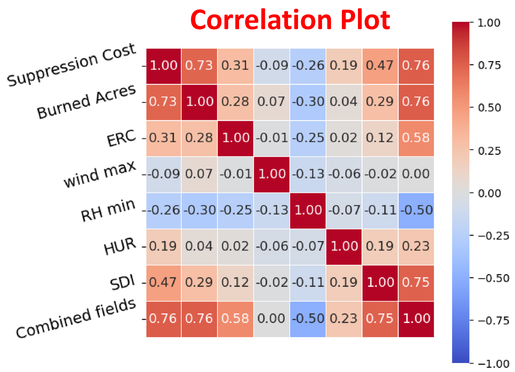
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Introduction

Using 7 years of wildfire data**, A Markov Chain Monte Carlo (MCMC) model provides a probabilistic forecast of fire suppression cost in consideration of SPC fire outlook area**. The model is constructed using distributions of the number of wildfires per unit area and burn area per wildfire, each for which a Weibull curve is fit. Based on 10,000 random simulations, probability density functions (PDFs) are generated that provide a probabilistic forecast of total burn area for an SPC outlook of a given areal extent. This prediction of burn area is either used alone or in consideration of other fire impact and environmental variables to formulate a statistically-viable suppression cost for each of the 10,000 simulations, resulting in a PDF of forecast suppression cost for wildfires of a specific SPC outlook.

Fields Influencing Suppression Cost



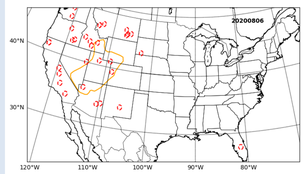
Variable	Description	Data Source
	(All variables are either a sum total or a percentile of field distribution within an SPC fire outlook area)	
Suppression Cost [$, log10]	sum total suppression costs for active fires	ICS-209 Plus (St. Denis et al. 2023)
Burned Acres [acres, log10]	sum total burned area for active wildfires	ICS-209 Plus (St. Denis et al. 2023)
ERC	95th percentile of Energy Release Component (ERC)	GridMet
wind max [m/s]	95th percentile of 24-hour maximum wind	RTMA
RH min [%]	5th percentile of 24-hour minimum relative humidity	RTMA
HUR [log10]	95th percentile of Housing Unit Risk (HUR): integrates wildfire likelihood and intensity, home susceptibility and density (Jaffe et al.	U.S. Dept. of Agriculture
SDI	Wildfire Suppression Difficulty Index (SDI): degree of difficulty in fighting fire in considreation of: topography, fuels, expected fire behavior, fuel types, and accessibility (Rodriguez y Silva et al. 2020)	U.S. Forest Service

References

- Jaffe, M. R., Scott, J. H., Callahan, M. N., Dillon, G. K., Karau, E. C., Lazarz, M. T., 2024: Wildfire risk to communities: Spatial datasets of wildfire risk for populated areas in the United States. 2nd Edition. Updated 10 September 2024. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2020-0060-2.
- Rodriguez y Silva, F., O'Connor, C. D., Thompson, M. P. Martinez, J. R. M.; Calkin, D. E. 2020: Modelling suppression difficulty: Current and future applications. International Journal of Wildland Fire., 29, 739–75, doi: 10.1071/WF19042.
- St. Denis, L. A., Short, K. C., McConnell, K.; Cook, M. C., Mietkiewicz, N. P.; Buckland, M.; Balch, J. K., 2023: All-hazards dataset mined from the US National Incident Management System 1999-2020. Scientific Data. 10, 112.

MCMC Model: Predict Fire Suppression Cost Probability

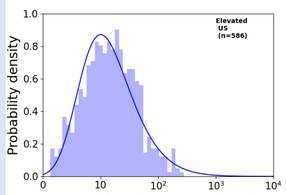
7 years (2014-2020) of data associated with wildfires occurring within SPC fire outlook areas to generate histograms and associated probability density functions (PDFs); 80% data for training, 20% for testing.



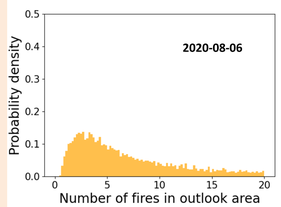
SPC elevated fire outlook (yellow) and observed wildfires (red) for 2020-08-06

Generate probability density distributions for selected SPC fire outlook area: **number of fires, total burn area, total suppression cost**.

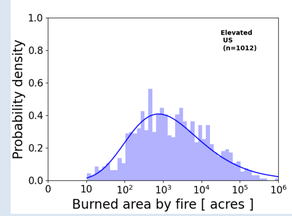
Step 1: Predict number of wildfires within SPC outlook



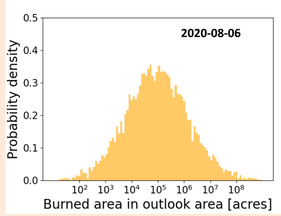
- Randomly select fire density, multiply by SPC outlook area
- Repeat 10,000 times
- Populate a distribution of predicted number of fires



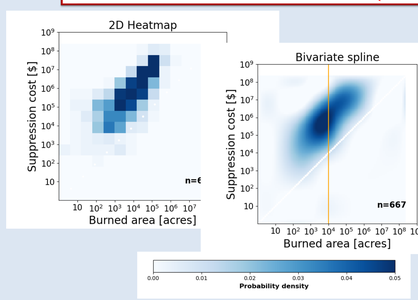
Step 2: Predict total burned area within SPC outlook



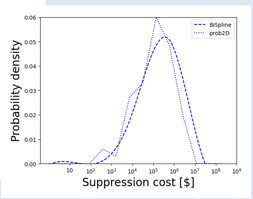
For each wildfire of the 10,000 simulated scenarios:
- Randomly select burn area
- Populate a distribution of predicted total burn area for given SPC outlook



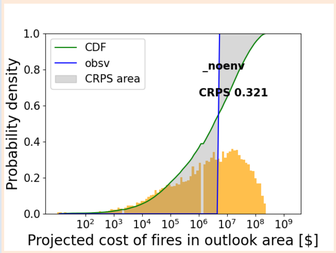
Step 3A (Bivariate spline method): Predict suppression cost based (solely) on burned area



Convert 2D histogram to a continuous 2D surface using bivariate spline.



For each 10,000 predicted burn area values, identify a suppression cost PDF and randomly select one cost value.

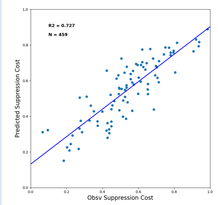


Step 3B (Linear regression method): Predict suppression cost based on burn area, environmental data, and fire impact data

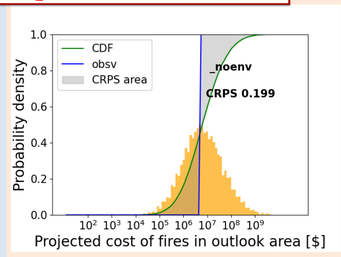
Linear regression (LR) model

$$\log10(cost) = m_1 * \log10(burn\ area) + m_2 * ERC + m_3 * max_{wind} + m_4 * minRH + m_5 * log10(HUR) + m_6 * SDI + c$$

Trained using 80% of data cases.

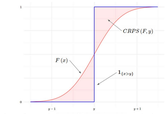


Calculated cost for test cases (20% of data) compared to observed.



Validation Method

Continuous Ranked Probability Score (CRPS) is used for verification of a probabilistic forecast of a continuous variable. Lower values are better. A positive Continuous Ranked Probability Skill Score (CRPSS) indicates relative forecast improvement as compared to climatology. A climatology model here is trained using 7 years historical data of suppression costs without consideration of SPC outlooks.



Taken from https://www.towardsdatascience.com

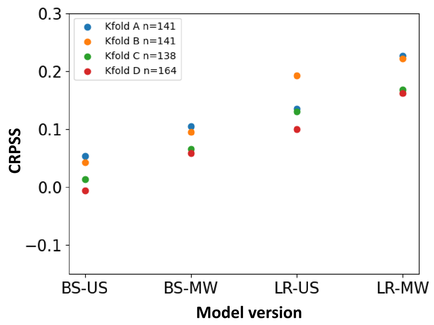
$$CRPS(F, y) = \int (F(x) - 1_{\{x \geq y\}})^2 dx$$

$$CRPSS = \frac{1 - CRPS}{CRPS_{climo}}$$

Results

Accumulated CRPSS across test cases

- Test cases: randomly selected 20% of total cases 2014-2020
- Models trained and tested using 4 training/test cases (K-folds)
- Separate models trained for CONUS, US West (west of lat. 105)



US = CONUS model
MW = regional (Mt. West) model
BS = Bivariate Spline model
LR = Linear regression model

Summary

- CRPSS values are near zero for the BS-US model, which uses bivariate spline to represent the relationship with burn area and with no influence of other fields, predicts suppression cost nearly the same as climatology.
- The LR model, which invokes a linear regression approach with input from 6 fire impact or environmental fields, registers higher skill over climatology than the BS model.
- CRPSS values increase for both the BS and LR models that are trained regionally.

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