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Paulette L. Ford  
*U.S. Department of Agriculture*

Charles Jackson  
*New Mexico State University*

Matthew Reeves  
*U.S. Department of Agriculture*

Benjamin Bird  
*U.S. Department of Agriculture*

David Turner  
*Cove NDR LLC*

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## Landscape-scale patterns of fire and drought on the High Plains, USA

Paulette Ford<sup>1\*</sup>, Charles Jackson<sup>2</sup>, Matthew Reeves<sup>1</sup>, Benjamin Bird<sup>1</sup>, David Turner<sup>3</sup>

<sup>1</sup>\*USDA Forest Service, Rocky Mountain Research Station, United States

<sup>2</sup>Department of Geography, New Mexico State University, Las Cruces, United States

<sup>4</sup>Cove NDR LLC, Cove, United States

\*Corresponding author e-mail : plford@fs.fed.us

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### Introduction

We examine 31 years (1982-2012) of temperature, precipitation and natural wildfire occurrence data for Federal and Tribal lands to determine landscape-scale patterns of drought and fire on the southern and central High Plains of the western United States. The High Plains states of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas and Wyoming have been in the midst of ongoing extreme drought, experiencing below normal precipitation and above normal temperatures for the past several years. Climate change is predicted to have multiple effects on fire regimes. Longer periods of drought conditions, coupled with hot, dry and windy weather, provide the conditions for wildfire (Ford *et al.*, 2012), and megafires, or large-scale fires that significantly exceed those of recent decades are now occurring in grassland, shrubland and desert ecosystems (Chambers and Pellant, 2008). Our objective is to relate the frequency and size of wildfires to precipitation, temperature and latitudinal gradients to increase understanding of wildfire and drought interactions on the Great Plains in a changing climate.

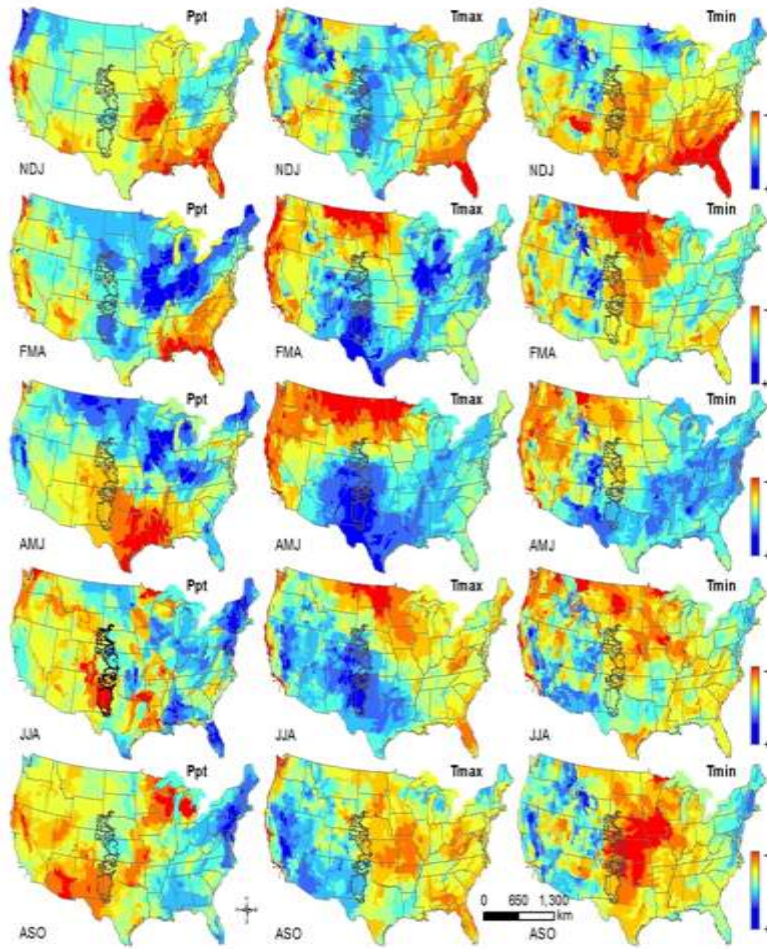
### Materials and Methods

Climate data-- Three decades of annual and seasonal climate trends were quantified for the North American Terrestrial Level III High Plains Ecoregion using Parameter-elevation Regressions on Independent Slopes Model (PRISM) climate datasets. Monthly precipitation (mm, Ppt) and mean monthly maximum and minimum temperature (°C, Tmax, Tmin, respectively) were obtained from the PRISM Climate Group for the time period from 1982 to 2012. Monthly climate data were aggregated into northern and southern zones. In addition to spatial aggregation, monthly climate data were grouped into five ecologically relevant time periods corresponding to November-December-January (NDJ), February-March-April, (FMA), April-May-June (AMJ), June-July-August (JJA) and August-September-October (ASO) (Figure 1). For each zone, the trend for Tmin, Tmax and Ppt was estimated for 31 sequential years for each time period. In order to obtain unbiased estimates of the standard errors of the trend estimates, autoregressive error models were fit to each of the 15 time series. First-order autoregressive disturbances were estimated using the Yule-Walker method.

Fire data-- Natural wildfire frequency data were obtained from The United States Department of Interior's Federal Fire Occurrence Website, <http://wildfire.cr.usgs.gov/firehistory/contact.html> provided by the United States Geological Survey. Changes in wildfire frequency and size over the 31-year period were tested with Poisson and normal Generalized Estimating Equation (GEE) models (Højsgaard *et al.*, 2006), respectively, including autoregressive errors and offsets for exposed land by state. A generalized additive model (GAM) (Wood, 2011) with thin plate splines for spatial and temporal effects was used to predict log(hectares) burned as a function of precipitation, maximum and minimum temperatures, latitude and longitude and year (Figure 2).

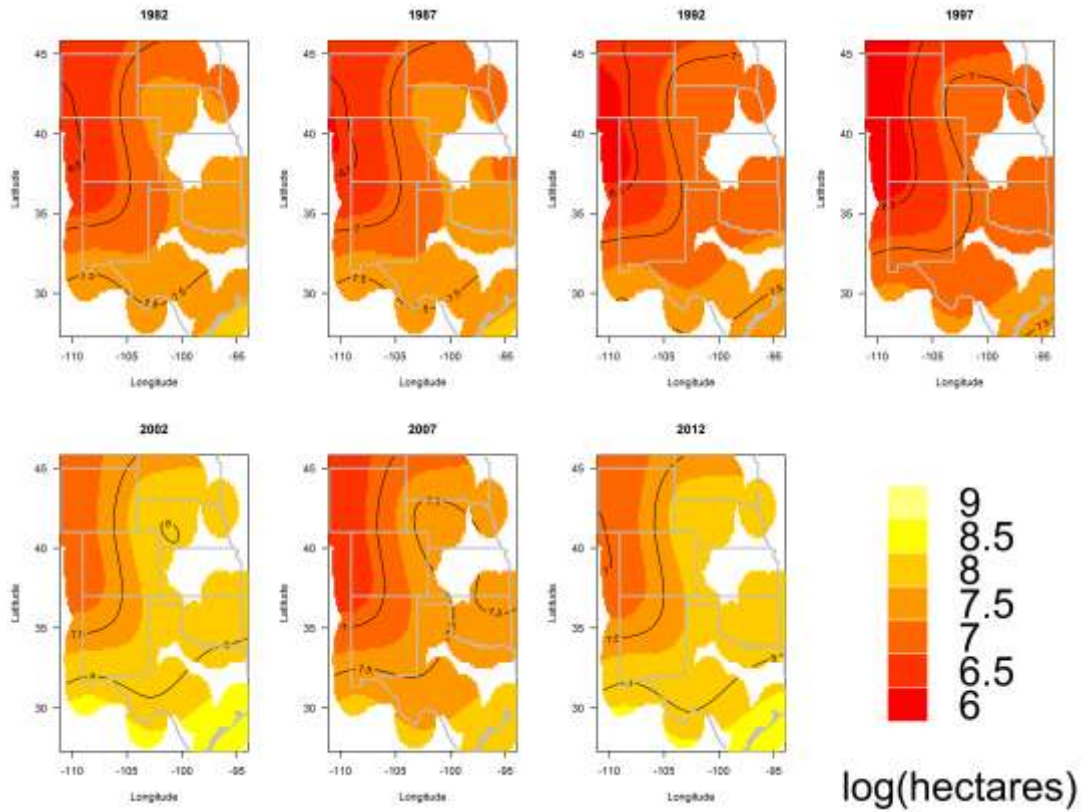
### Results and Discussion

Climate trends-- Overall trends in Ppt, Tmax and Tmin across the study area and conterminous United States are shown in Figure 1. At the same time that temperatures have been significantly increasing during the growing season ( $p \leq 0.1$ ), Ppt has been significantly decreasing ( $p \leq 0.1$ ), especially during the JJA time period suggesting drier conditions overall. The trends for increasing Tmax and decreasing Ppt during the AMJ and JJA periods are particularly pronounced when compared with the surrounding region. The pattern is less pronounced for Tmin since much of the southern United States has experienced widespread increases in minimum temperature. Another notable feature is the latitudinal gradient across the study area associated with increasing temperatures and decreasing precipitation from north to south.



**Fig 1.** Trends in seasonal precipitation, maximum and minimum temperature from 1982 to 2012 derived from the PRISM dataset. The High Plains Ecoregion is outlined in black or grey. Cool colors represent increasing trends while warm colors represent decreasing trends from 1982 to 2012.

Wildfire trends-- Of these 48,862 natural wildfires that occurred on Federal and Tribal lands in the eight states from 1982 through 2012, the Southern Rockies, Colorado Plateau and Arizona/New Mexico Mountain ecoregions contained the greatest number of wildfires (27, 23 and 17% of the total, respectively). Greatest areas burned were reported for the Arizona/New Mexico Mountains, Middle Rockies, and the Southern Rockies (18, 18 and 12%, respectively). Number of wildfires and area burned were not equally distributed among the ecoregions with some regions showing a greater tendency for very large fires. The predominantly shortgrass steppe wildfires within the High Plains accounted for only 1.36% of total wildfires, but those fires covered an area more than half the total hectares burned in the mostly forested Southern Rockies Ecoregion. Overall, there was a significant increase in number of fires from 1982 until circa 2005. After 2005 there was a slight decrease or leveling off in the number of fires. The total area burned increased until 1991-92, and then roughly plateaued until 2007, when it began to increase again. Figure 2 depicts contour plots of predicted log (hectares burned) for large fires ( $\geq 405$  hectares). Although the adjusted  $R^2$  (0.0762) and deviance explained (11.1%) were small, there appeared to be a small but meaningful year effect and significant trend over time for this population of fires. Plots of the predicted values from this model indicate interesting overall trends: from 1982-2012, wildfires have increased in size and in total hectares burned. Results are congruent with studies indicating United States ecoregions with increasing trends in the number of large fires and total fire area also displayed increasing trends in drought severity (Dennison *et al.*, 2014).



**Fig 2.** Contour plots of predicted log (hectares burned) for large fires ( $\geq 405$  hectares). The eight states are outlined in grey. The lighter the color, the larger the average number of hectares burned.

## Conclusion

Trends over the last three decades point to reduced precipitation and increased temperatures in the High Plains Ecoregion, with more and larger fires in these eight High Plains states. Grassland and steppe ecoregions tended to have fewer but larger fires than forested ecoregions. Our results will be used to improve predictive forecasts of Great Plains wildfires, which are prone to uncertainties related to current climate projections and a paucity of information on grassland fire-climate relationships.

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