Impacts of Wildfires on Precipitation in Downwind Areas

Pinyuan Xiong, Benjamin Yang, Yuwei Zhao, Shengwei Dai

Aerosols Class Project - Spring 2023

Introduction

Wildfires and precipitation are two natural phenomena that are closely linked and can have a significant impact on each other. Since the 1980s, the number of areas burned by wildfires annually has increased in the U.S. (EPA, 2016). Wildfires can have devastating consequences including disrupting transportation, power, and water supply as well as causing a significant loss of natural resources and human and animal life (World Health Organization, 2023). Meanwhile, precipitation, namely rainfall, is essential for the survival of all living organisms on earth and plays a critical role in maintaining ecological balance.

Objectives

This study will improve our understanding on the mechanism and potential impacts of wildfire on precipitation patterns in distant areas, especially for hazardous extreme weather conditions. We seek to answer the following research questions:

- To what extent does wildfire smoke increase/decrease precip. in downwind areas?
- How does the relationship between downwind aerosols and precip. change during wildfire episodes compared to non-wildfire periods for different regions of the U.S.?
- What are the dynamic and thermodynamic mechanisms for how downwind precip., particularly of severe convective storms, is influenced by wildfire smoke?

Mechanism

Wildfires can increase precipitation by releasing moisture into the atmosphere:

- While burning, vegetation releases water vapor into the air
- Water vapor rise and cool, eventually condensing into clouds
- Clouds produce rainfall → extinguish the fire

Although wildfire smoke contains more aerosols or cloud condensation nuclei that can form more cloud droplets, these droplets are smaller and produce less rain than those in clean air (Twohy et al., 2021) → for shallow clouds

Aerosols can invigorate deep convective rain clouds:

→ Ice particles release latent heat aloft and reabsorb heat at lower levels

→ more rain (Rosenfeld et al., 2008)

Wildfires can also create their own weather patterns:

Intense heat → air to rise rapidly → low-pressure zone → pyrocumulonimbus storms (Fromm et al., 2022)

Recent model simulations have shown that aerosols and moisture from wildfires in the western U.S. can be transported long distances and enhance convective storms and thus heavy precipitation rates in the central U.S. (Zhang et al., 2022).

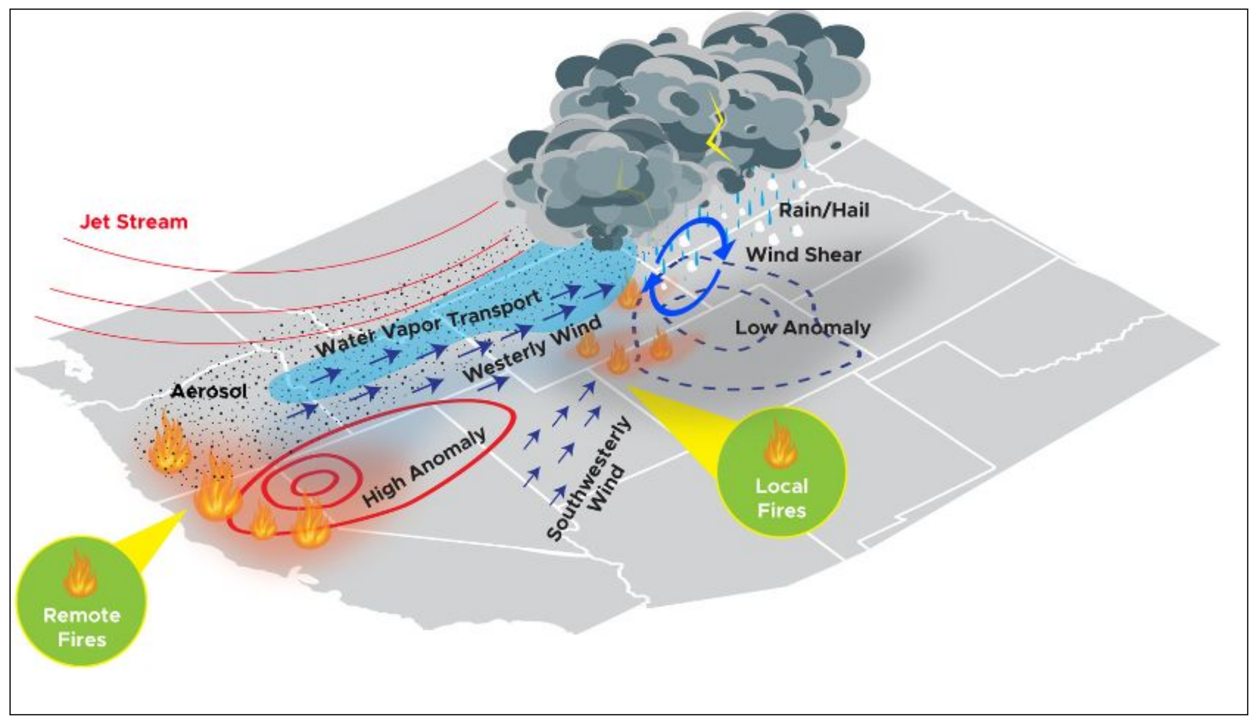

Figure 1. Diagram for Impact of Wildfire on Downwind Precipitation (Zhang et al., 2022)

Methodology

We propose to analyze the relationship between wildfires and precipitation using the data listed in Table 1 for the **entire contiguous U.S.** for a **ten-year period (2011-2021)**.

Project regime:

Wildfire smoke transported eastward across the U.S. during May-September, when most of the wildfire and thunderstorm events happens in the U.S.

Datasets:

Analysis of smoke transport:

- MODIS satellite data: aerosol optical depth (AOD)
- Environmental Protection Agency (EPA) data: fine particulate matter ($PM_{2.5}$)
- NOAA HYSPLIT model: backward trajectories

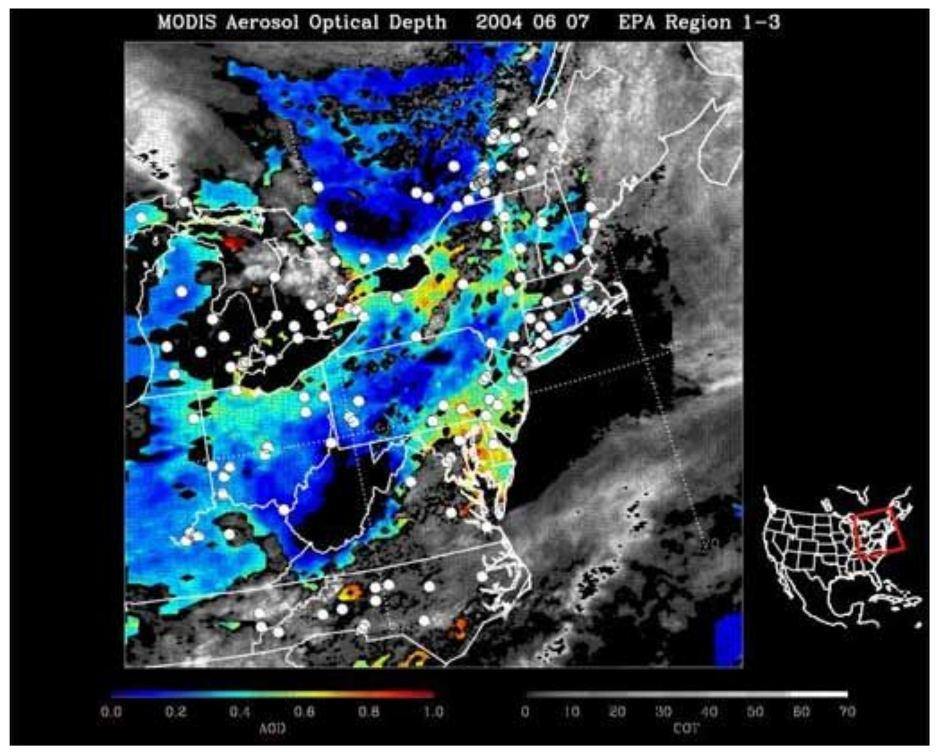

Figure 2. Sample Aerosol Optical Depth Data Map (Neil, D. O., 1970)

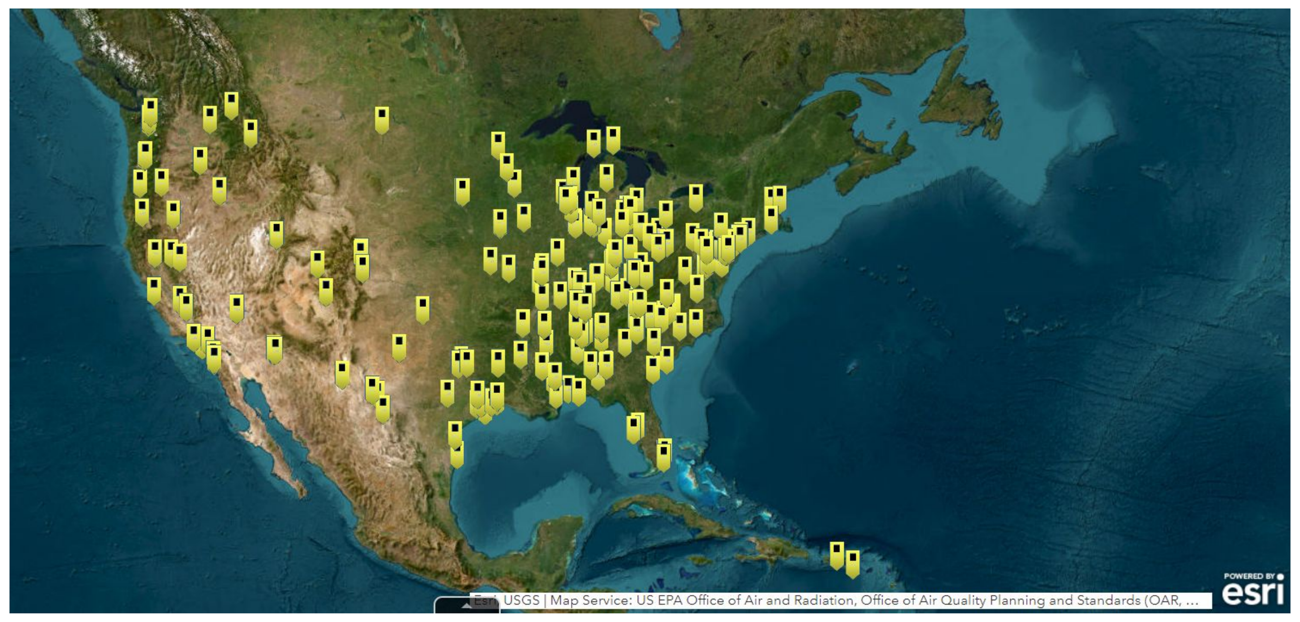

Figure 3. Screenshot of EPA Interactive Map of $PM_{2.5}$ Monitor Network (EPA, 2022)

Both AOD and fine particulate matter ($PM_{2.5}$) at EPA Air Quality System sites, providing columnar and surface aerosol information respectively, will be averaged over the duration of each smoke episode over each downwind region.

Precipitation:

- NOAA cooperative observer station: hourly precipitation data

Precipitation data will be matched to the nearest AOD grid box or $PM_{2.5}$ site and summed over each wildfire episode. For each downwind region, we will average AOD, $PM_{2.5}$, and rainfall for the corresponding time period of non-wildfire years (e.g. July 20-23, 20*xx*). The annual time series may be detrended to account for climate change.

In regression plots, the AOD and $PM_{2.5}$ averages will be compared against rainfall totals from wildfire and non-wildfire years by wildfire episode and downwind region, as well as all together. Finally, we will select a few case studies in which wildfire smoke coincides with severe convective storms (heavy precipitation) documented by NOAA and simulate these events (fires turned on vs. off) using the WRF-Chem model, following the approach of Zhang et al. (2022).

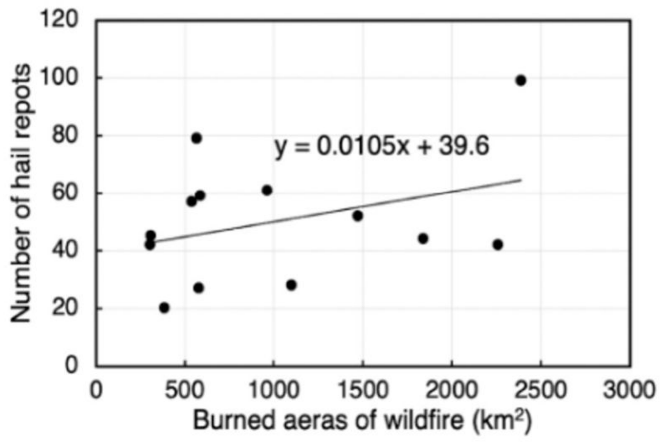

Figure 4. (B) Observed correlation of the number of daily hail reports in the CUS with the burned area of the WUS wildfires for the co-occurring events with storms occurring on ≥2 consecutive days (Zhang et al., 2022)

Model and Data Source Summary

Table 1. *Observational and model output data to be used in our proposed investigation*

Source	Product(s)
Forest Service Research Data Archive	Daily Spatial Wildfire Occurrence
Land Processes Distributed Active Archive Center	MODIS/Terra+Aqua AOD and Water Vapor From MAIAC
Environmental Protection Agency AirData	Daily Surface $PM_{2.5}$ FRM/FEM Mass and Speciation
National Centers for Environmental Information	Hourly Precipitation From U.S. Cooperative Observer Stations
National Centers for Environmental Information	Storms Events Database
Air Resources Laboratory	HYSPLIT Model Trajectories
Earth System Research Laboratories	WRF-Chem Model 1-km/3-km AOD, $PM_{2.5}$, and Rainfall

Acknowledgements

1) Climate Change Indicators: Wildfires. https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires (accessed Apr 25, 2023).
2) Fromm, M.; Servranckx, R.; Stocks, B. J.; Peterson, D. A. Understanding the Critical Elements of the Pyrocumulonimbus Storm Sparked by High-Intensity Wildland Fire. *Communications Earth & Environment* **2022**, *3* (1).
3) Rosenfeld, D.; Lohmann, U.; Raga, G. B.; O'Dowd, C. D.; Kulmala, M.; Fuzzi, S.; Reissell, A.; Andreae, M. O. Flood or Drought: How Do Aerosols Affect Precipitation? *Science* **2008**, *321* (5894), 1309–1313.
4) Twohy, C. H.; Toohey, D. W.; Levin, E. J.; DeMott, P. J.; Rainwater, B.; Garofalo, L. A.; Pothier, M. A.; Farmer, D. K.; Kreidenweis, S. M.; Pokhrel, R. P.; Murphy, S. M.; Reeves, J. M.; Moore, K. A.; Fischer, E. V. Biomass Burning Smoke and Its Influence on Clouds over the Western U. S. *Geophysical Research Letters* **2021**, *48* (15).
5) Wildfires. https://www.who.int/health-topics/wildfires#tab=tab_1 (accessed Apr 25, 2023).
6) Zhang, Y.; Fan, J.; Shrivastava, M.; Homeyer, C. R.; Wang, Y.; Seinfeld, J. H. Notable Impact of Wildfires in the Western United States on Weather Hazards in the Central United States. *Proceedings of the National Academy of Sciences* **2022**, *119* (44).