Machine learning analysis of western US fire impacts on hail in the central US

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Introduction

- Wildfires and severe convective storms are two types of extremes **causing significant property damage and economic losses** in US and are projected to increase in future climate change.
- Wildfires can impact severe convective storms (SCSs) through **two major pathways** at the time scales of days.

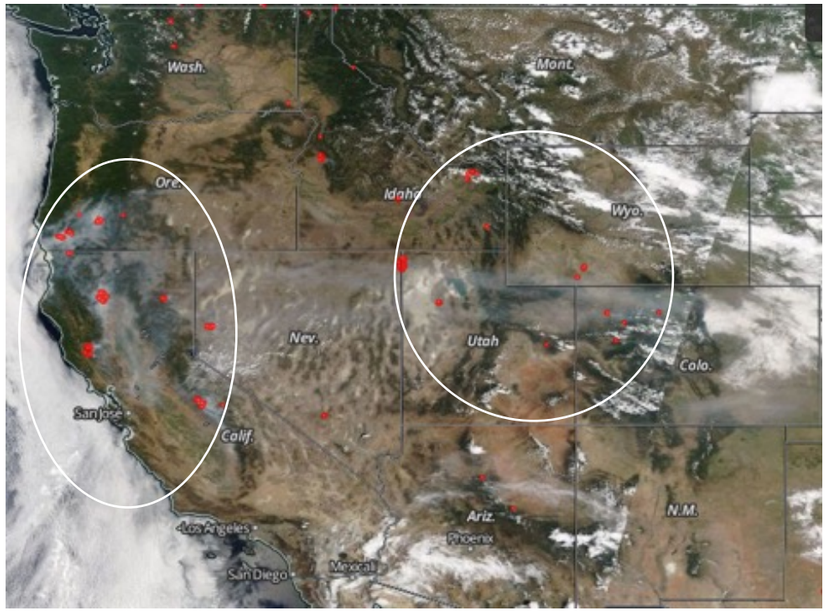
Release heat → Meteorology → Severe convective storm

Release and form aerosols → Aerosol – Radiation; Aerosol - Cloud → Severe convective storm

- The teleconnections between the two extremes are not studied much.

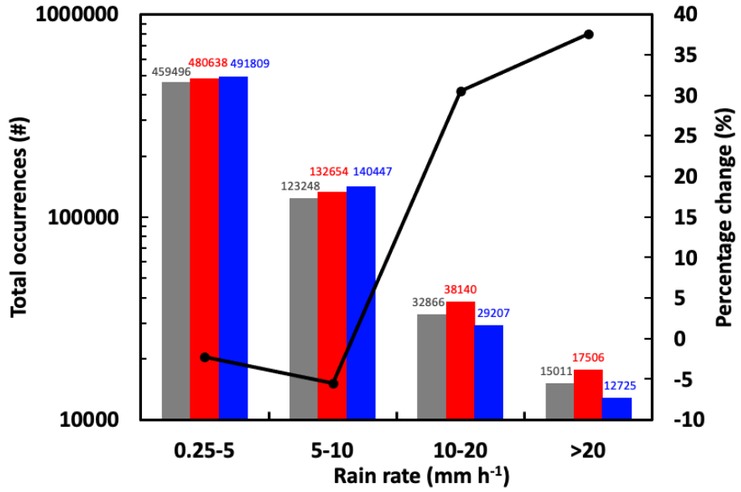
Case study via WRF-Chem-SBM modeling at 1 km grid demonstrates a notable effect

26-29 July, 2018

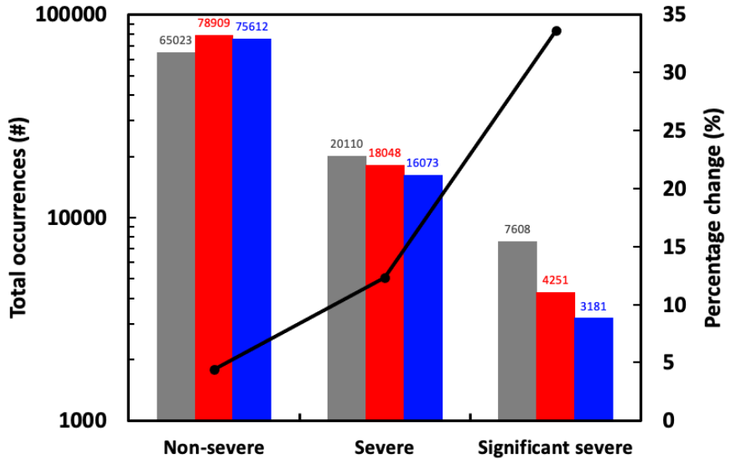


Zhang, Y., Fan, J., et al. (2022), PNAS

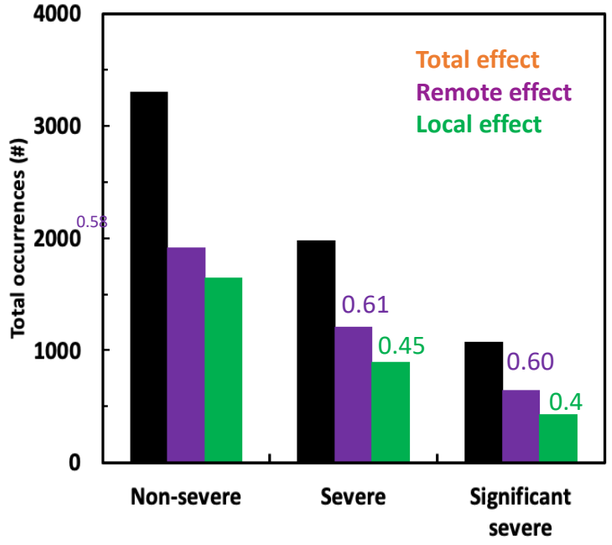
Occurrences of rain rates



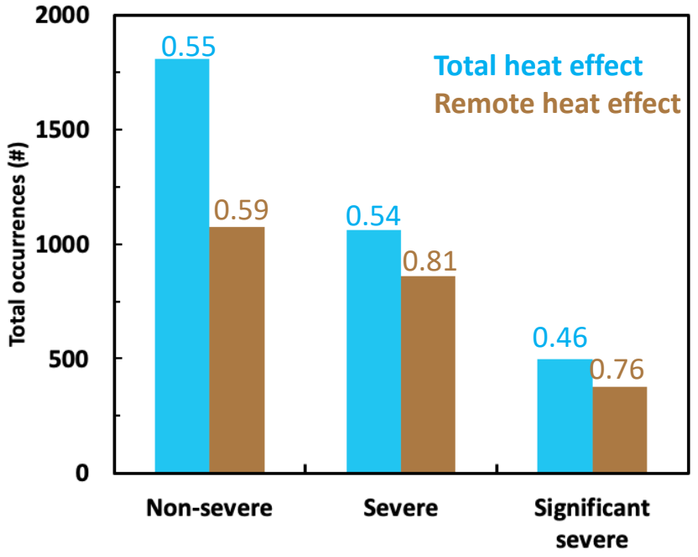
Occurrences of hail



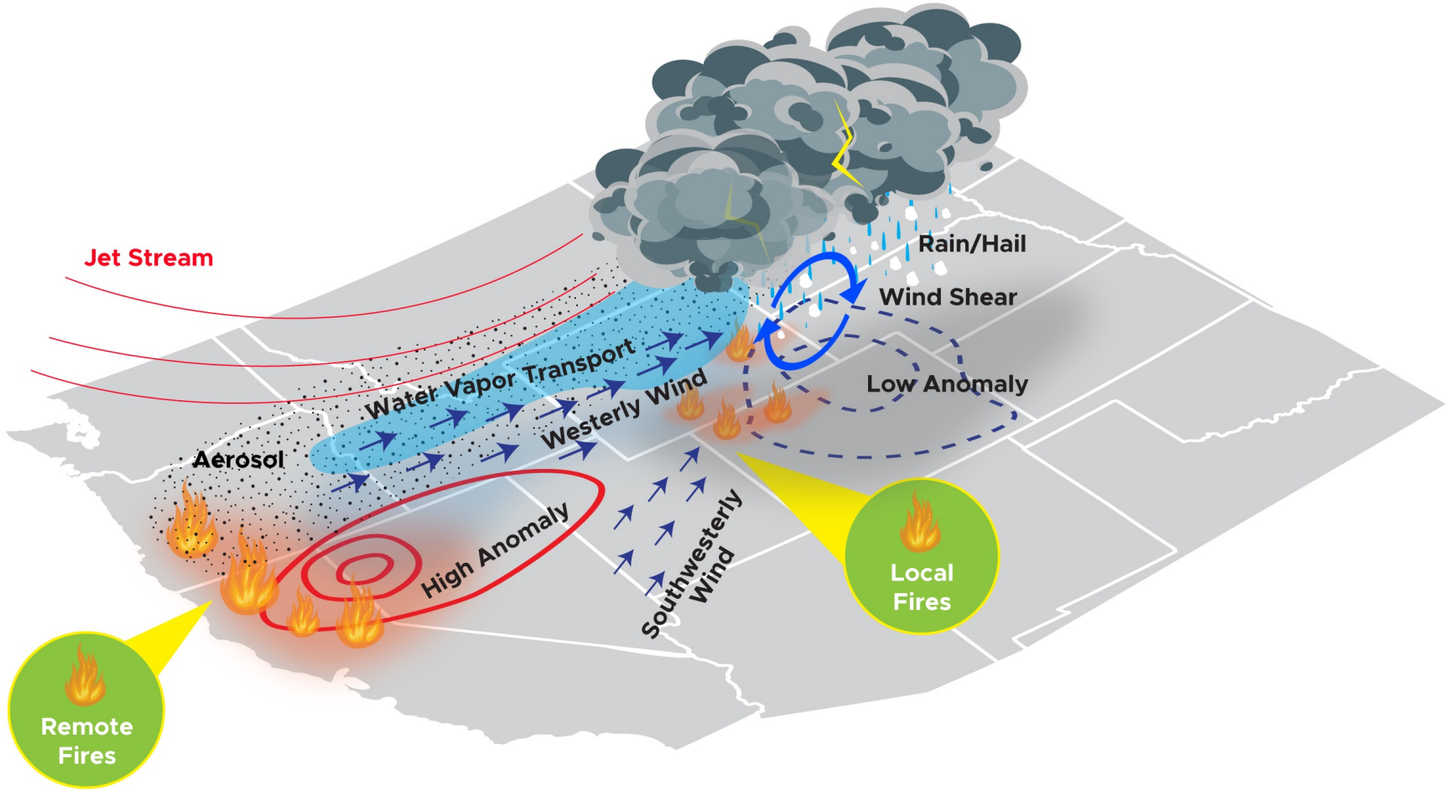
Mainly from Remote effect



Both heat and aerosol effects are important



Mechanisms indicated from model analysis



Zhang, Y., Fan, J., et al. (2022), PNAS

(1) **A meteorological condition** more conducive to severe convective storms (associated with enhanced westerly winds and moisture transport)

(2) **Increased aerosols:** aerosol-cloud interactions enhance storm intensity and hail size

Machine learning (ML) analysis of the impact of western fires on hail in the central US

Objective

- Following on the modeling study in Zhang et al. (2022), statistically examine the relationship between western **fires** and central hailstorms in the past two decades (2001-2020) using tree-based ML models - random forest (RF) and extreme gradient boosting (XGB).

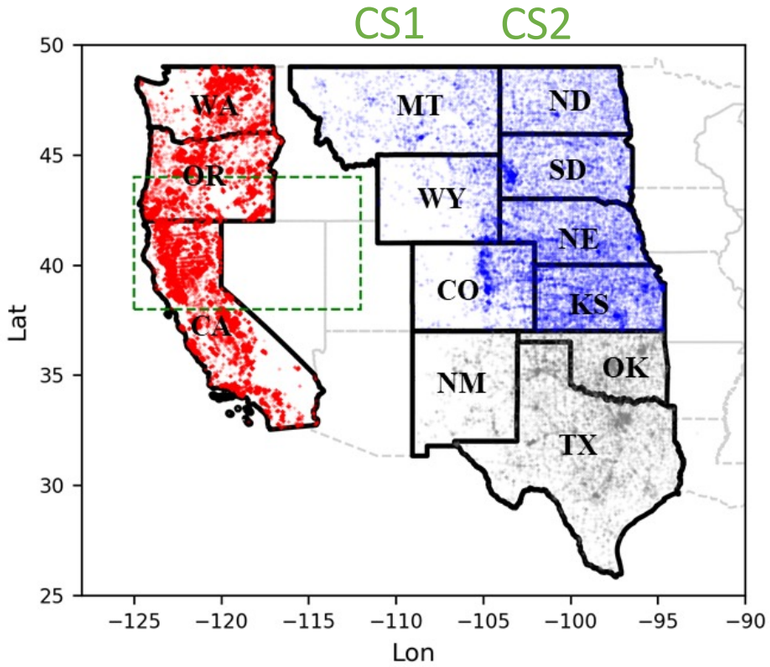
Approach

- Employ MODIS fire dataset (1 km) which includes **all fires** like prescribed and agriculture fires **to increase case numbers** (different from Zhang et al. 2022 where considering wildfires also only over a 10-year period).
- Built RF and XGB models to predict occurrence of large hails with size of 1 inch or larger (0 or 1) in the CUS considering meteorological and fire variables
- Evaluate the built ML models for different states and identified the most important variables

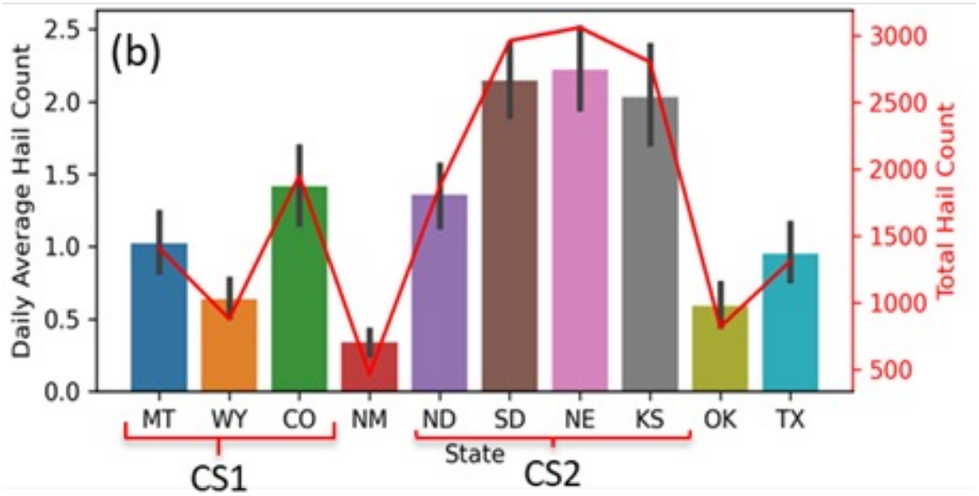
Lin, Fan, et al., to be submitted

- **Predictor variables (91):**
  Fire related properties: fire power, burned area, and smoke aerosols (BC+OC)
  Meteorology: air temperature (T), relative humidity (RH), etc. in the WUS fire region and U wind over the plume transport

- **Target:** Occurrence of large hail >= 1 in (0 or 1)



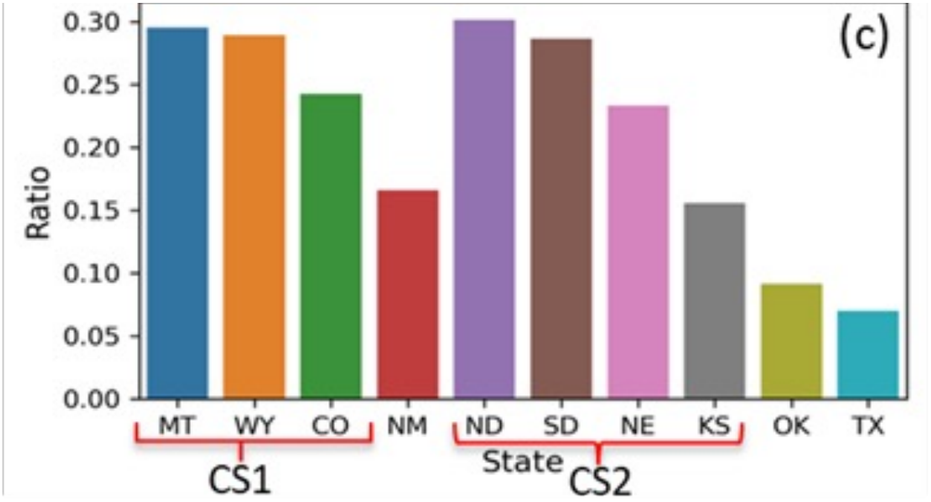
Co-occurrences of the CUS large hail and WUS fires



Consider fires with burned area > 20 km^2 and large hail reports ≥ 20 summed over all the studied CUS states

# of large hail events co-occurring with WUS fires in each state

- NM, OK, and TX are excluded due to low co-occurrences
- CS2 states have more co-occurrence then CS1 states

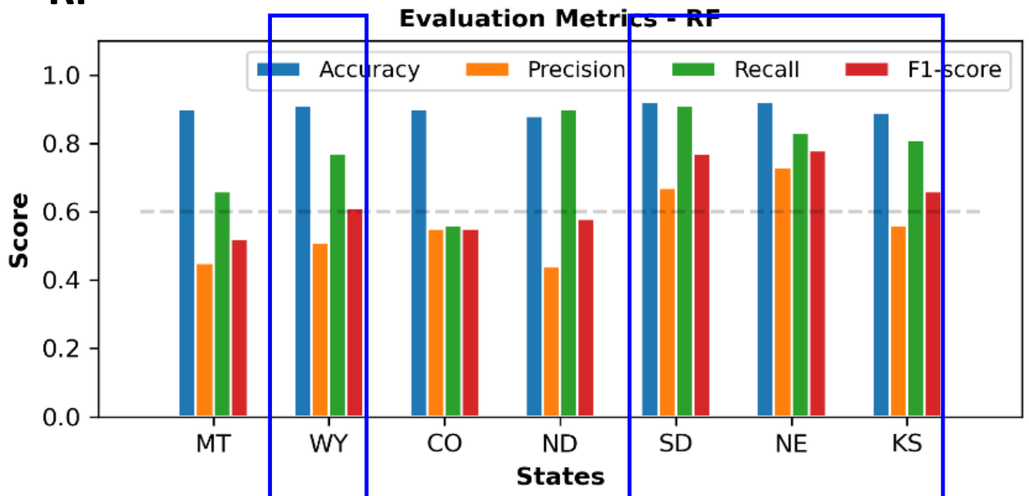


The ratio of co-occurrence to the total hail occurrence

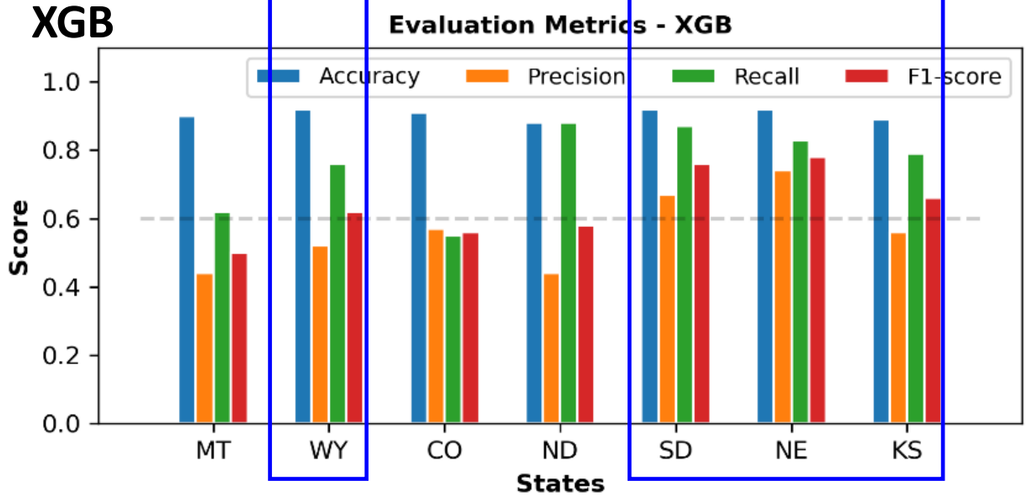
- CS1 and CS2 are of similar ratio

ML models perform well overall

RF

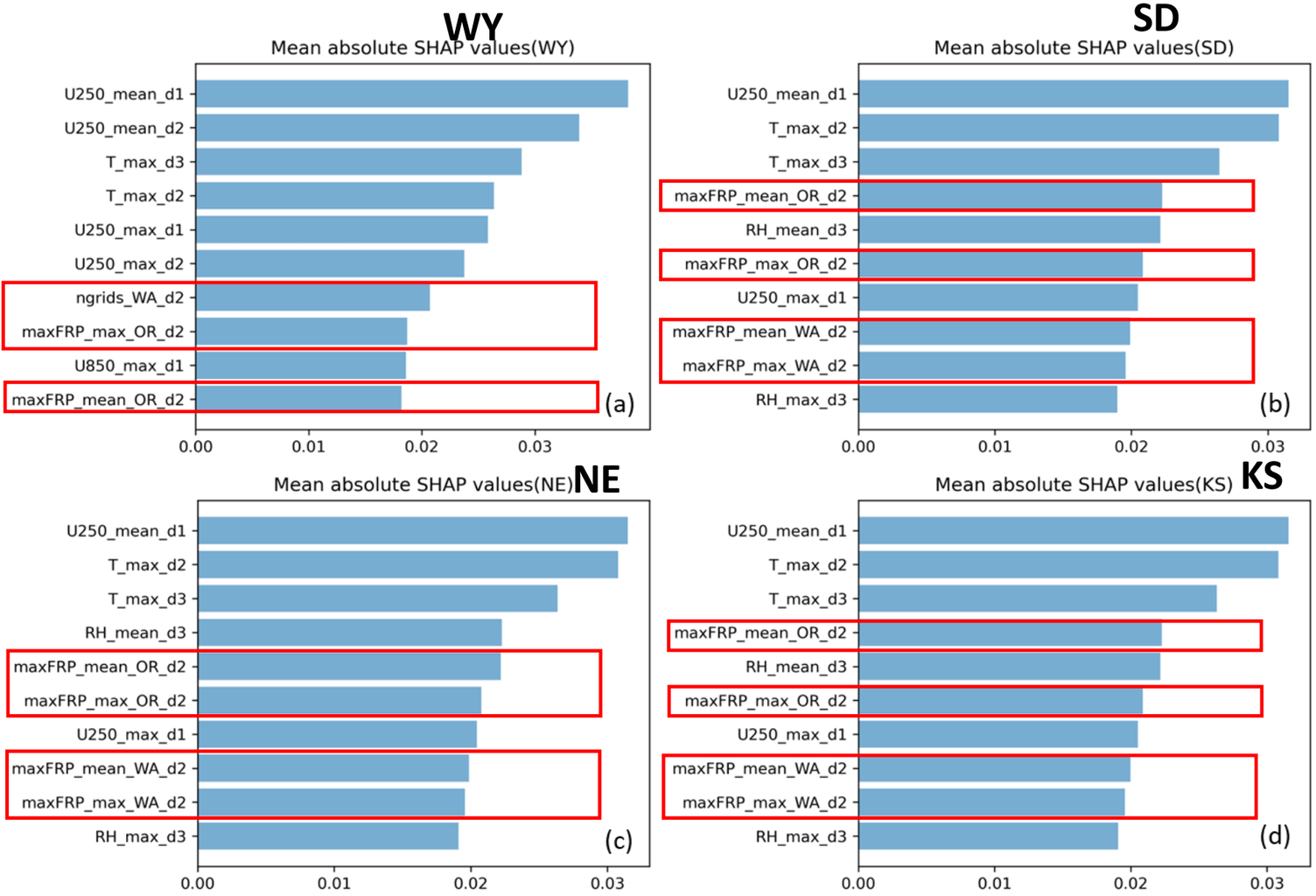


XGB



- Overall, RF and XGB models do a good job for 3 CS1 and 4 CS2 states
- Particularly better at predicting the large hail occurrence in WY, SD, NE and KS: F1 score 0.61-0.78 and accuracy 89% - 92%. Perform the best in NE.

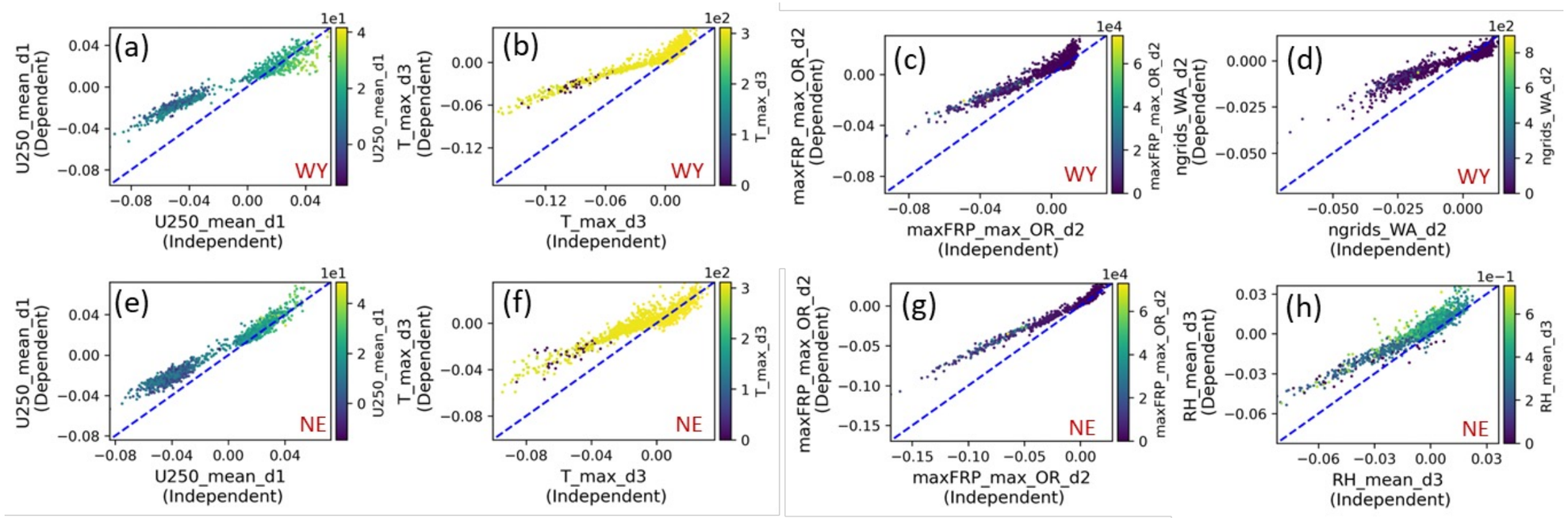
Variable importance (SHAP) shows both meteorological variables and fire properties can be important



Red: Fire property variable

- First, meteorology stands out: U-wind at the high levels over the path of fire plumes, the max. T, and RH at the low levels are identified as the most important variables.
- Fire related features such as max. fire power and burned area (red box) are also identified as important predictors, indicating a strong linkage between fire and hail occurrences
- Agree with the mechanism (1) proposed in Zhang2022

SHAP dependence and independence tests show interactions of these important variables



- Westerly wind, max. T, max. fire power, fire area, and RH are off the diagonal line at a certain value range, suggesting those important variables **may interact with other variables (not independent)**

- **Smoke aerosols (BC+OC) only show up in the top 20 rankings for XGB models only.** We see a collinearity between maxFRP and BC+OC.(0.3~0.5). Thus, the fire aerosol effects could be taken into account through correlated variables

Summary

- **ML analysis of fire and hail data over the 20 year time period shows there is a strong linkage between western fires and occurrence of large hail in 7 central US states (WY, CO, MT, ND, SD, NE, and KS)**
- **SHAP analysis shows the important contributing variables are**
  - Temperature (maximum) in the fire region
  - RH at 850 hPa in the fire region
  - Westerly winds over the plume transport
  - Fire power and burned area
  - Smoke aerosols show up in top 20 only in the XGB models. They correlate with other variables.
- **Corroborate the western wildfire effect and the mechanism revealed from modeled case study in Zhang et al. (2022).**