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

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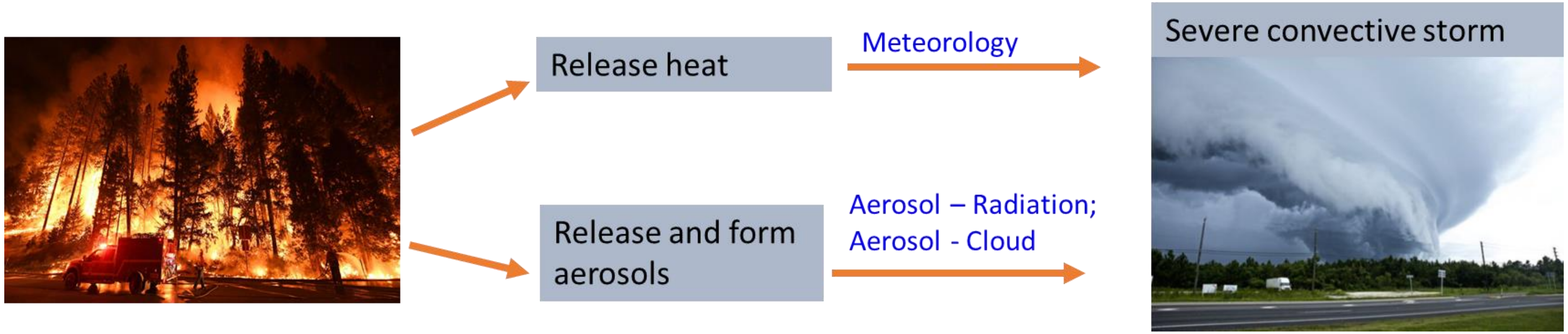
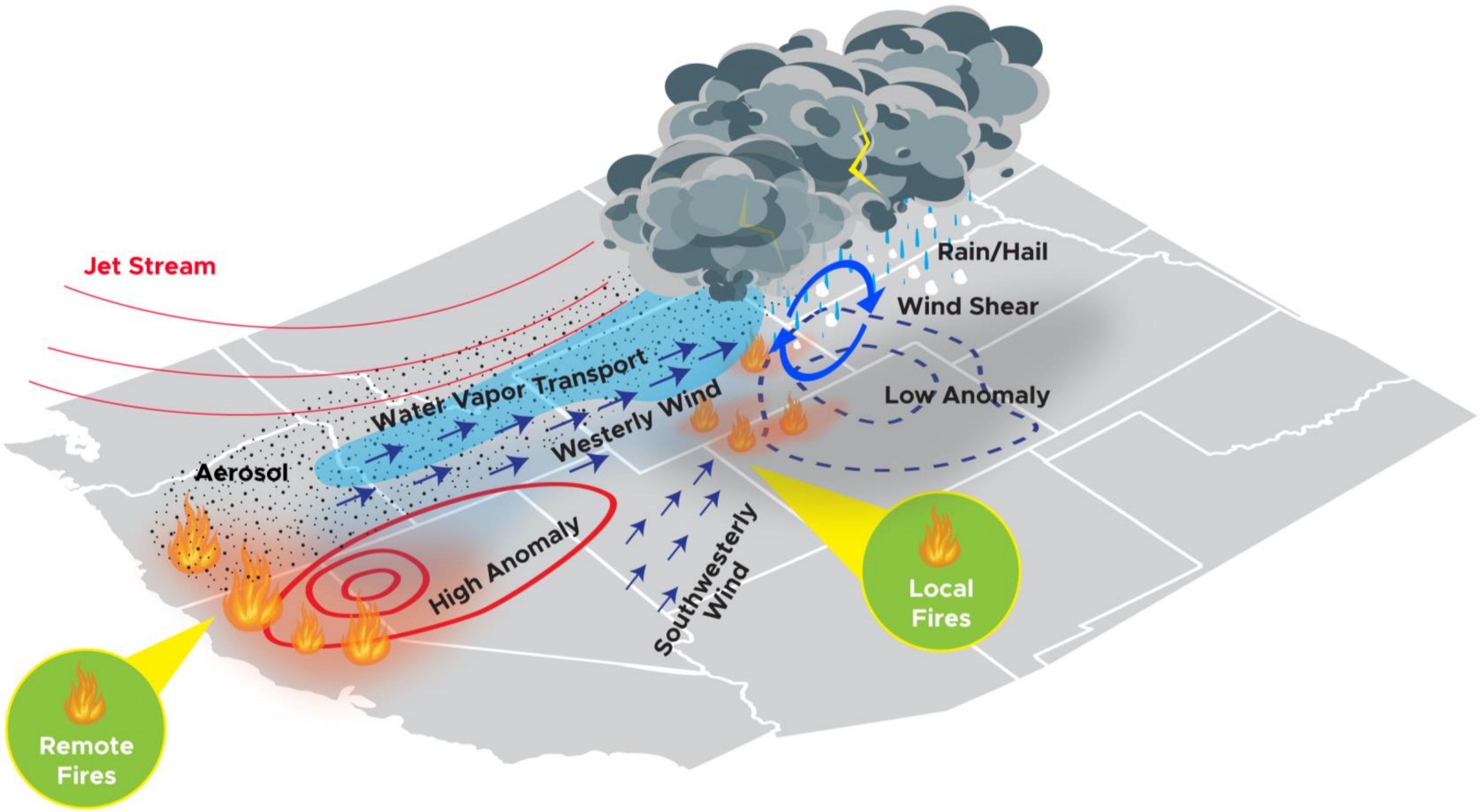
Mechanisms

- Wildfires and severe convective storms and their associated hazards (e.g., flash flood, hail, tornado, and straight-line winds) **cause 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.
  - Sensible heat released from wildfires can potentially perturb synoptic-scale meteorology, modify the environmental thermodynamics and can induce pyrocumulonimbus (pyroCb) cloud formation;
  - Aerosol particles released from wildfires affect storm intensity and weather hazards through aerosol-cloud interactions



Mechanisms



- Wildfires enhance surface high pressure in the WUS and the surface low pressure in the CUS and increase westerly and southwesterly winds
- Stronger moisture and aerosol transport to the CUS
- **Enhanced westerly winds, leading to a meteorological condition** more conducive to severe convective storms
- **Increased aerosols:** aerosol-cloud interactions enhance storm intensity and hail size

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

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

Objective

- Following on the case 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).

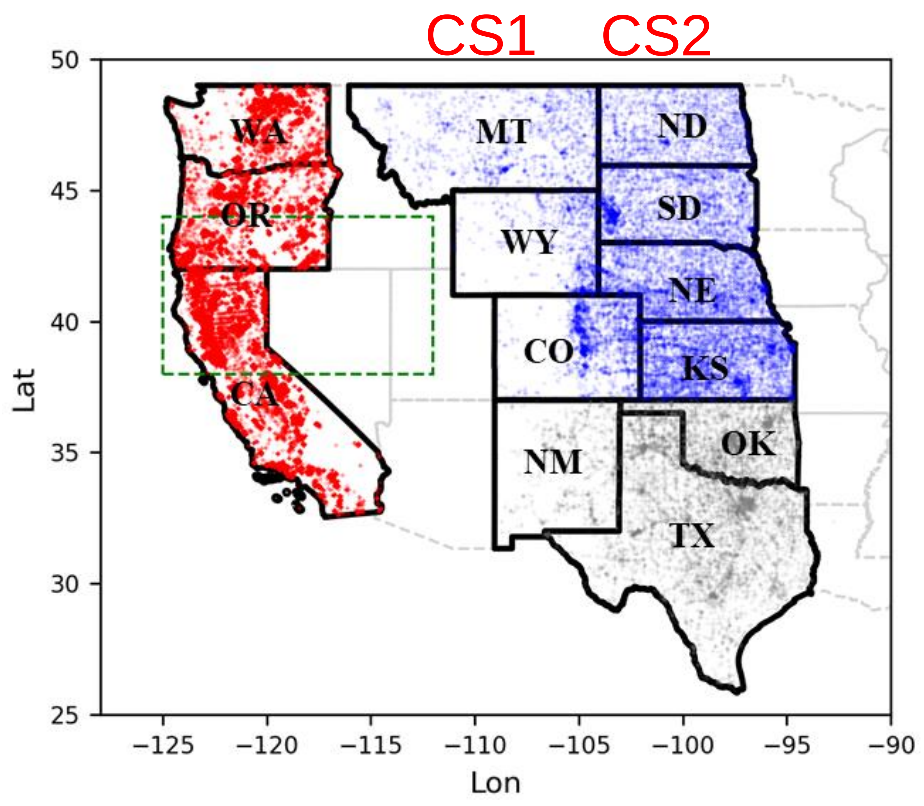
Approach

- 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 only wildfires considered over a 10-year period the cases were only a few).
- 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

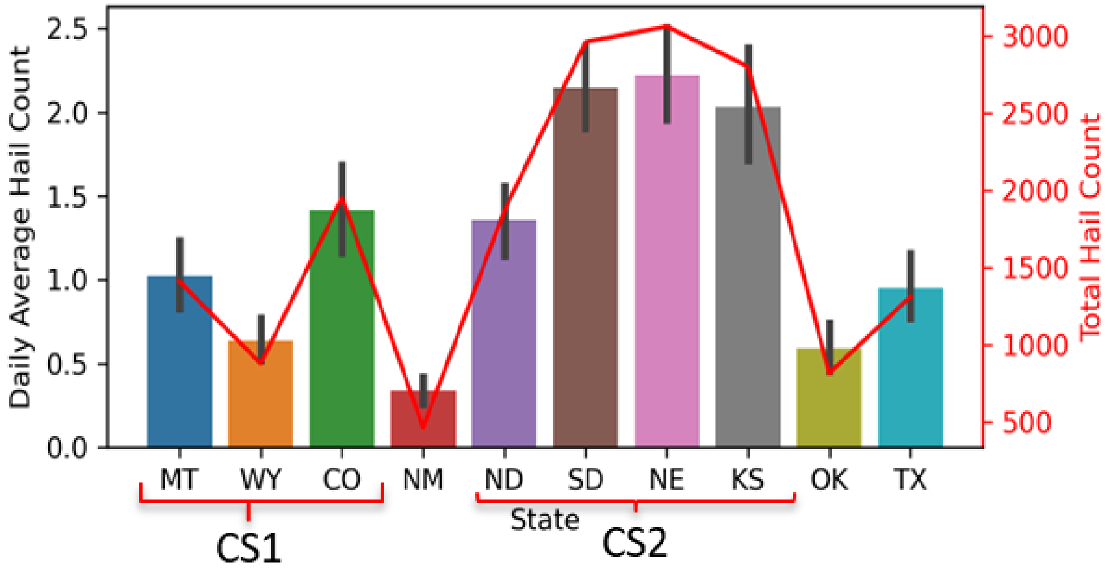
Lin, Fan, et al., submitted to AAS

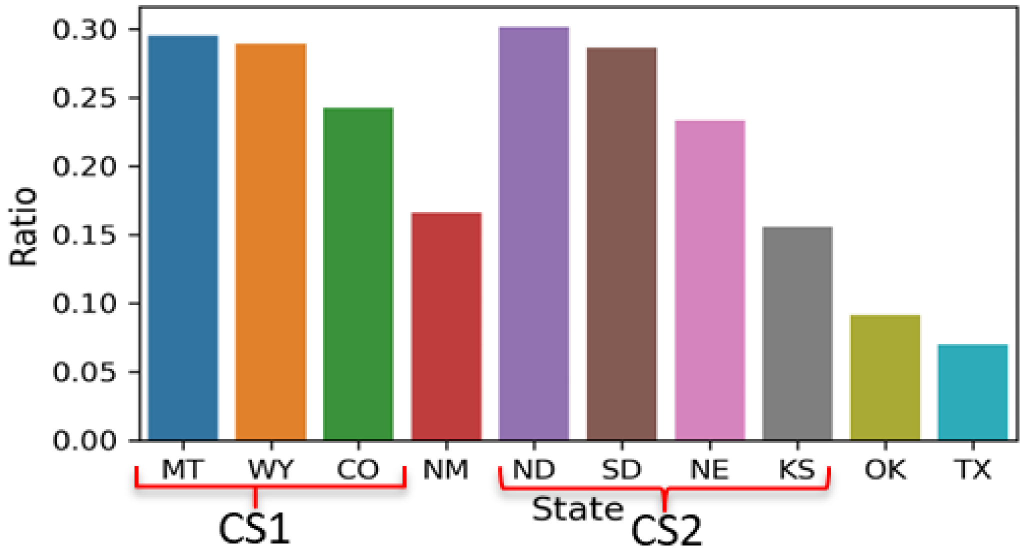
Predictor variables (91):
Fire related properties: fire power, burned area, and smoke aerosols (BC+OC)
Meteorology: air temperature (T), relative humidity (RH), etc. in the WUS fire region and U wind over the plume transport

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

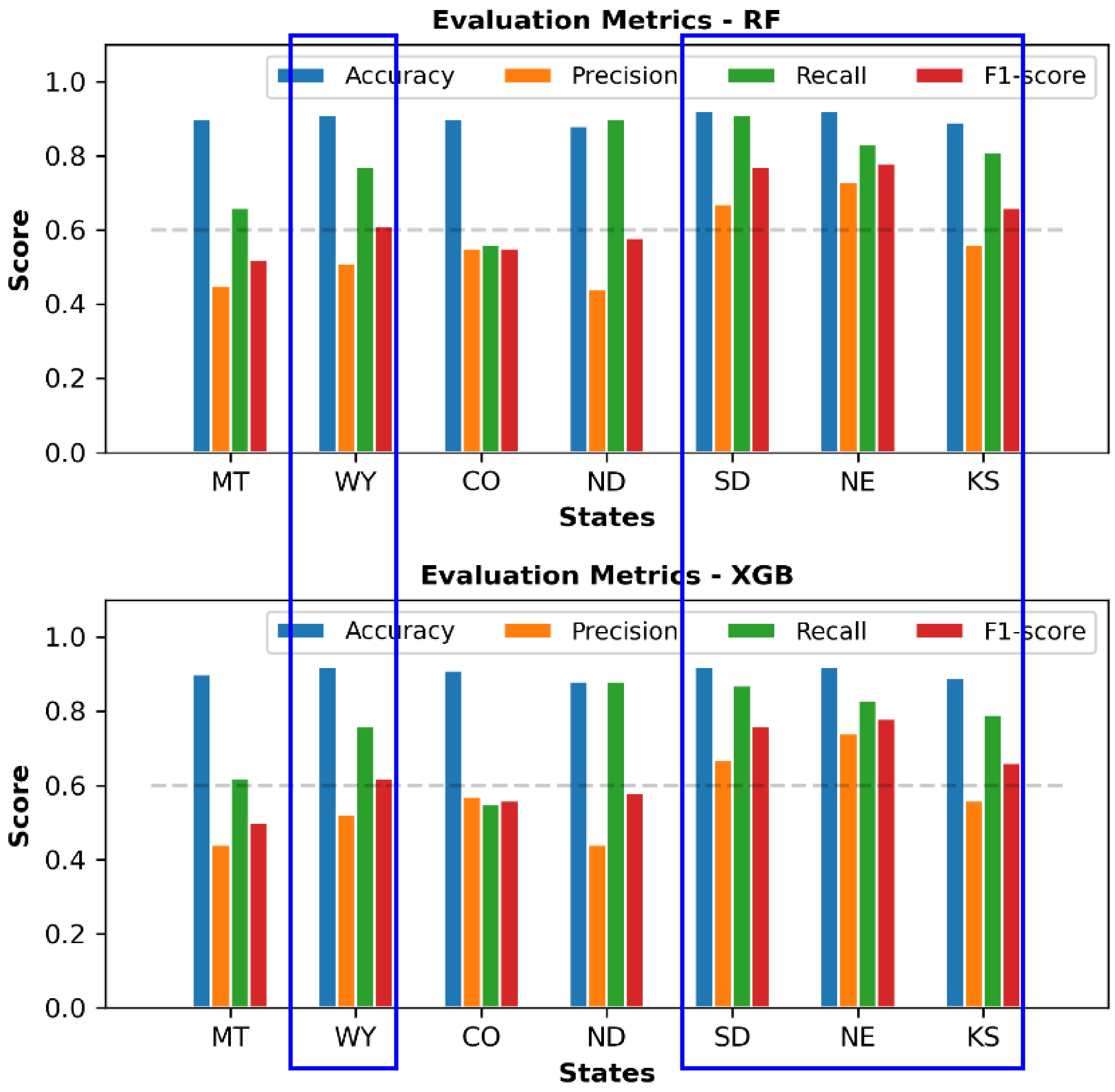
The number of large hail events co-occurring with WUS fires in each state

- 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

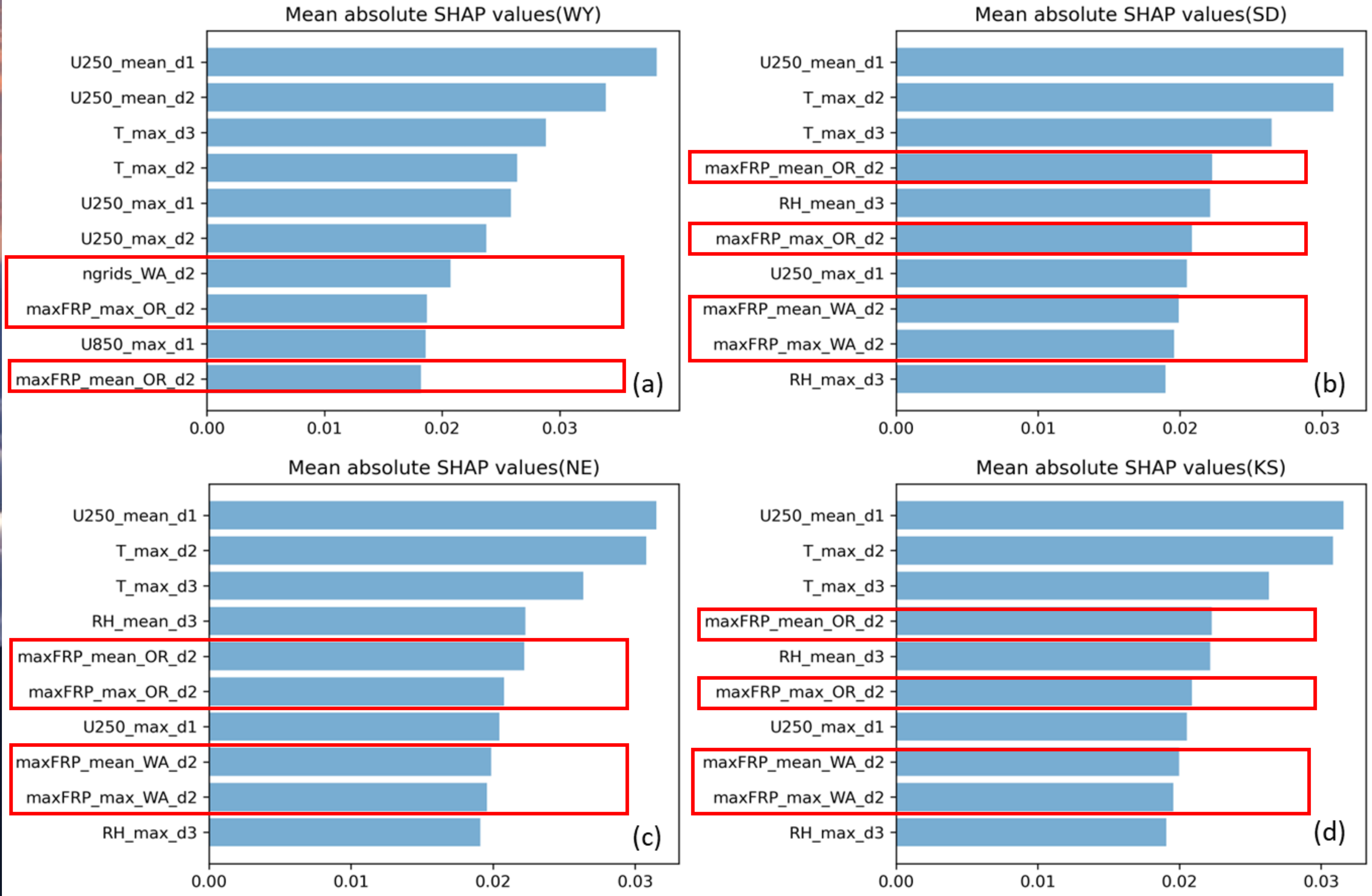
- CS1 and CS2 are of similar ratio

ML models performance



- 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.

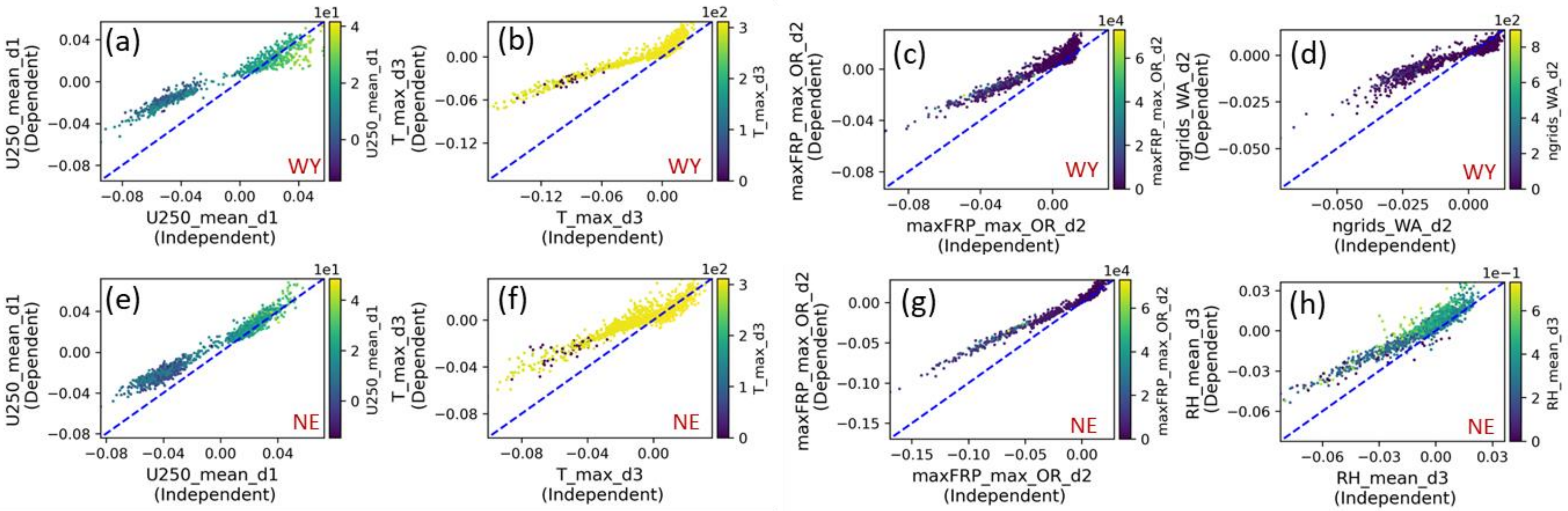
Variable importance (SHAP) shows both meteorological variables and fire properties can be important

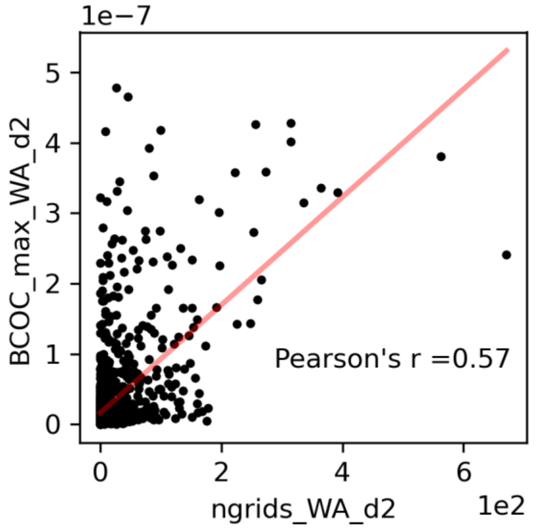


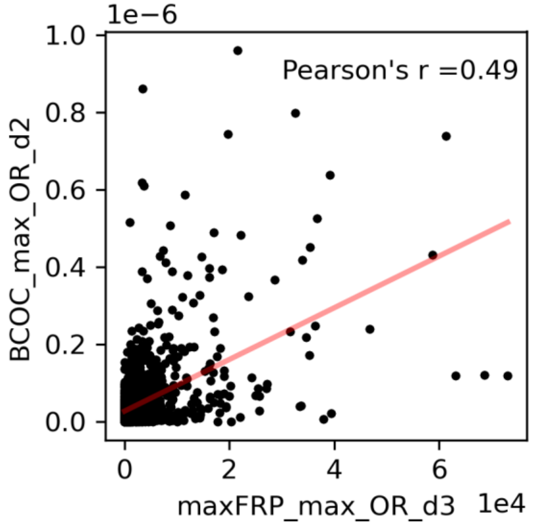
Red: Fire property variable

- U-wind at the high levels over the path of fire plumes, the max. T (T_max), and RH at the low levels in the wildfire region are identified as the most important variables.
- Fire related features such as max. fire radiative power and burned area are 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 dash 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/burned area and BC+OC.(0.3~0.6). Thus, the fire aerosol effects could be taken into account through these variables

Summary

- **ML analysis of fire and hail data over the 20-year time period (2001-2020) 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 radiative power and burned area
  - Smoke aerosols show up in top 20 only in the XGB models. Correlations with fire power and westerly winds could make the aerosol effects taken into account through these variables
- **Corroborate the western wildfire effect and the mechanism revealed from modeled case study in Zhang et al. (2022).**

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Thank you