Notable Impact of Western Wildfires on Severe Weather in the Central US

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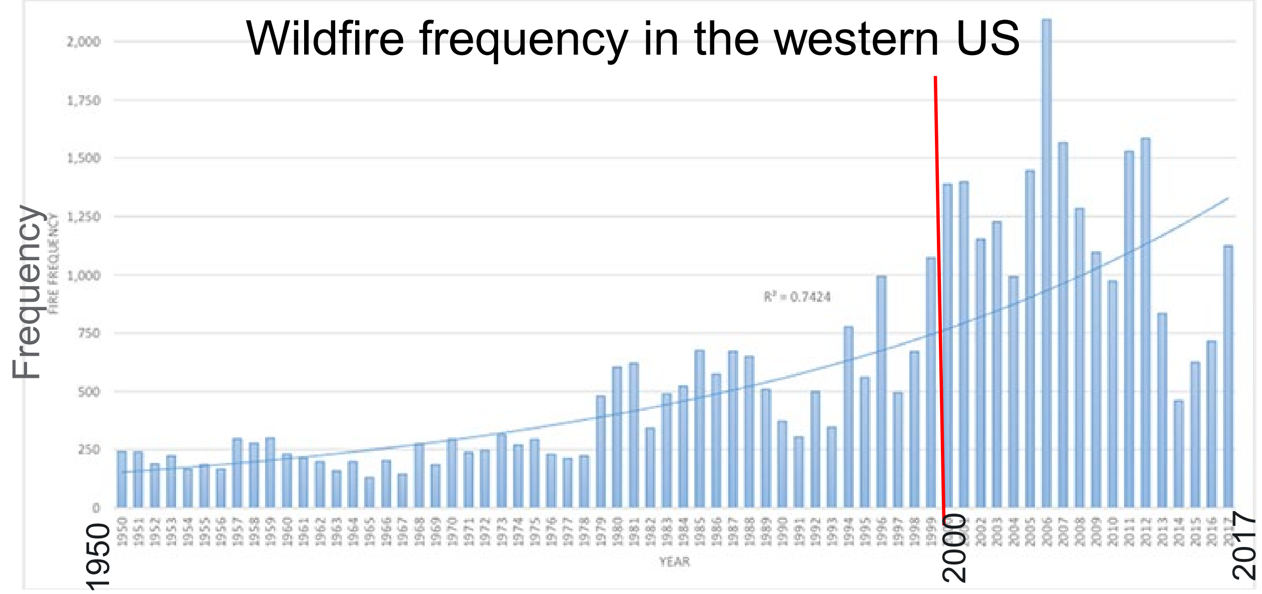
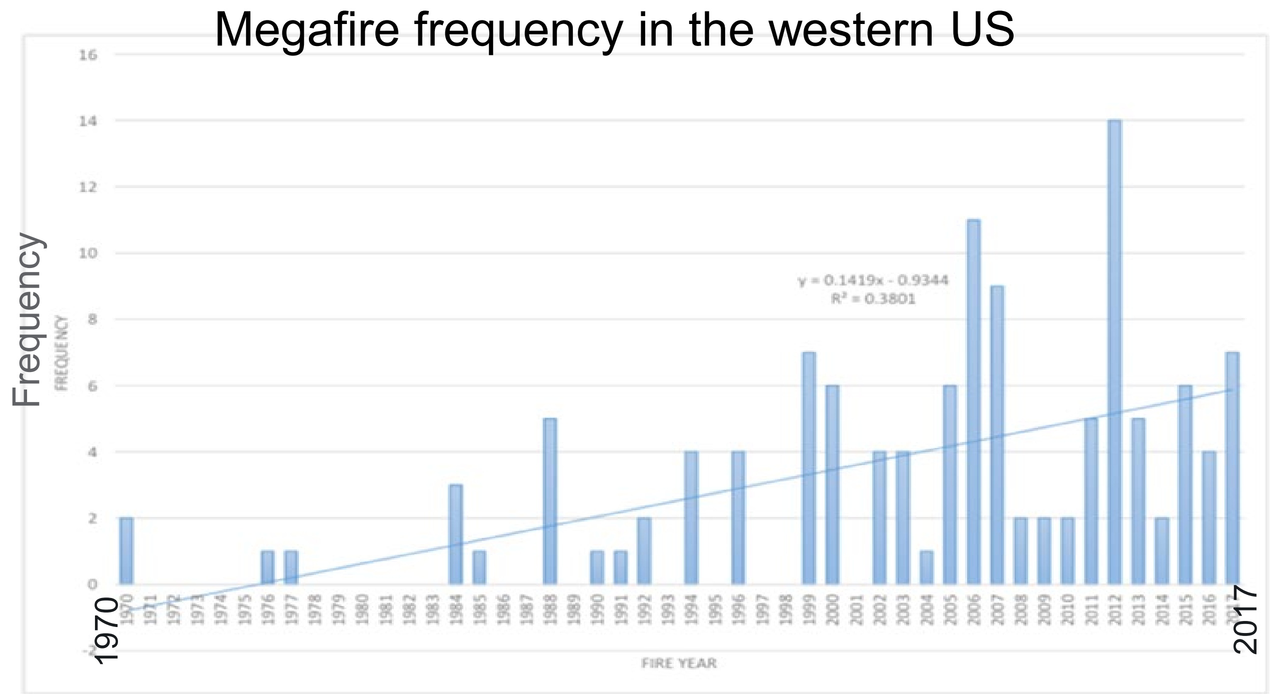
Introduction

- Wildfire frequency and burned area have been **increasing** in the US in the past decades. Wildfires in the **western US** increase in a faster rate.
- In the past six decades (since 1950), the majority of western fires—61 percent—**have occurred since 2000**
- The number of **megafires** (fires that burn more than 100,000 acres) has increased in the past two decades. No documented megafires occurred before 1970





Source: NASA RECOVER / Keith Weber

Motivation

- 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 (as much property damage and more deaths than hurricanes in U.S.)

- Wildfires can impact severe convective storms (SCSs) through **two major pathways** at the time scales of days.

Release heat → Meteorology → Severe convective storm

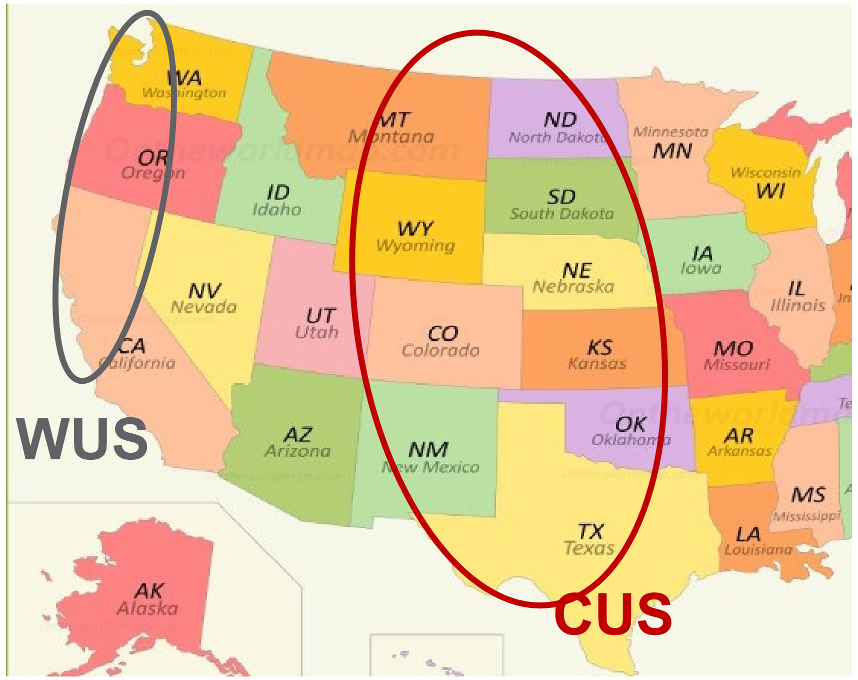
Release and form aerosols → Aerosol - Radiation, Aerosol - Cloud → Severe convective storm

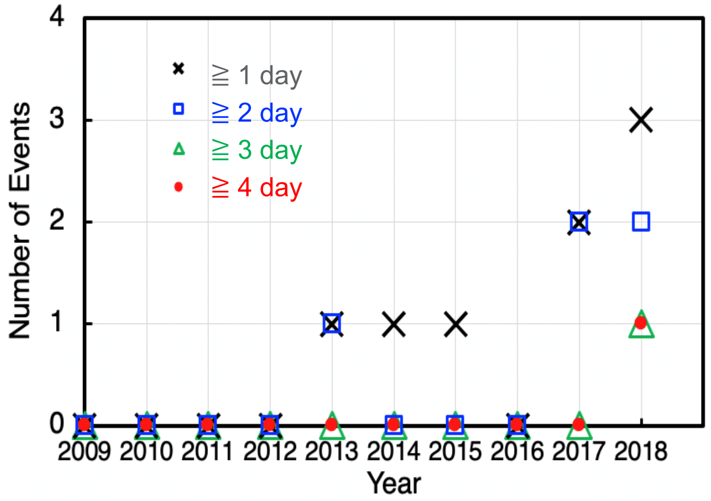
Past studies focused on pyrocb or only the smoke aerosol impact.

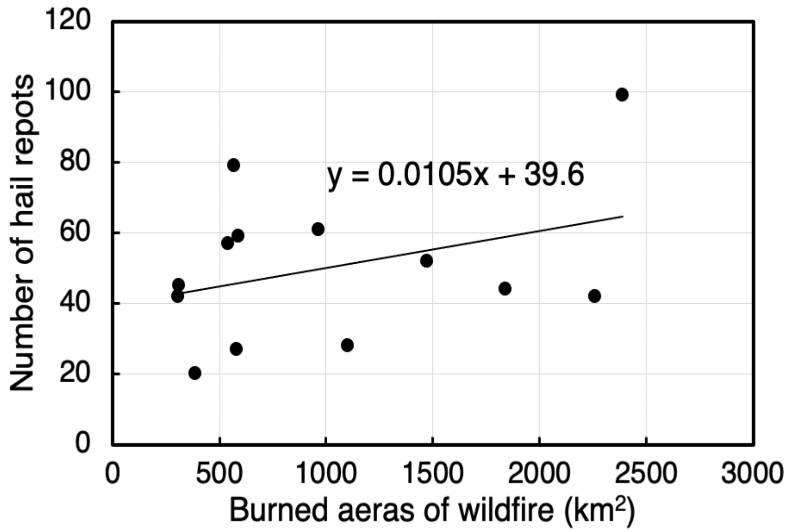
- **Studies of wildfire effects on storms in the downwind region is limited, particularly for the western US,** since western wildfire and central severe convective storms are generally **separated by seasons.**

Co-occurrence of WUS wildfires and CUS severe convective storms

- The wildfire season is starting progressively earlier in the WUS and these two extreme events can occur at the same time. Therefore, **the impact of WUS wildfires on severe weather in the central US is emerging as a new issue in the warming climate**







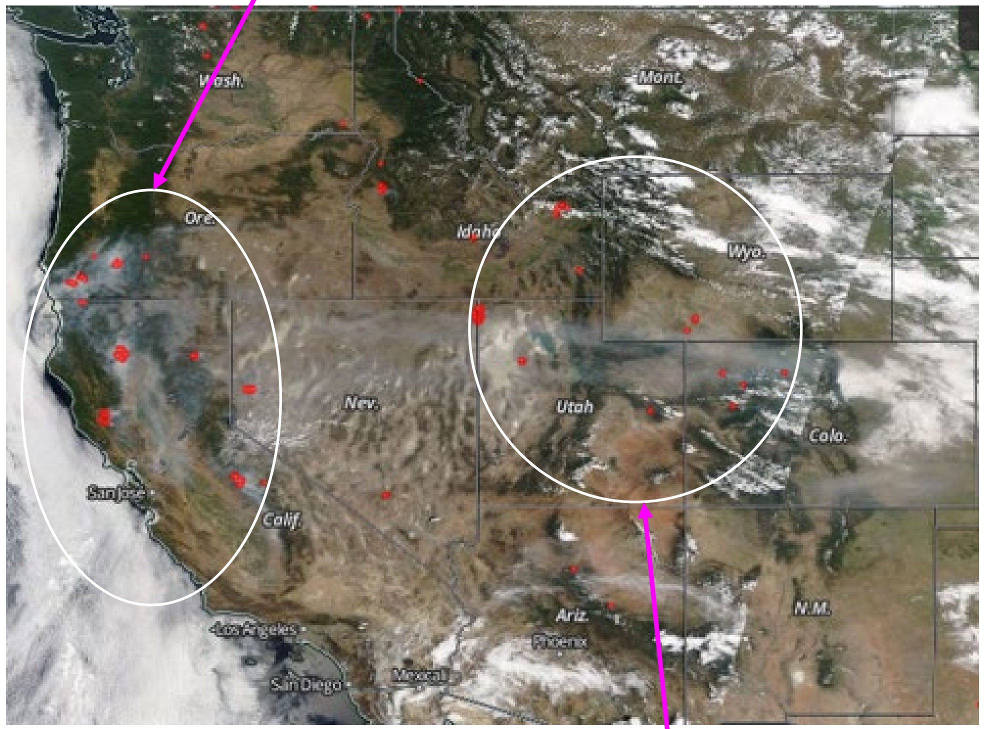
- **Co-occurrence** of WUS wildfires and CUS severe convective storms did not happen until 2013 in the past decade. The concurrence events with storms occurring on 3 or more consecutive days **did not emerge until 2018**.
- A **positive correlation** is found between the number of daily hail reports with the burned area of WUS wildfires.

Science Questions

- In addition to the potentially remote effects of WUS wildfires, storms in the CUS such as Colorado and Wyoming could be affected by **local wildfires in the Rocky Mountains**.

- What are **the joint and individual effects of remote and local wildfires** and **the major mechanisms** by which wildfires affect the CUS severe weather? Are the effects mainly contributed by the **released heat or aerosol or both**?

Remote wildfires



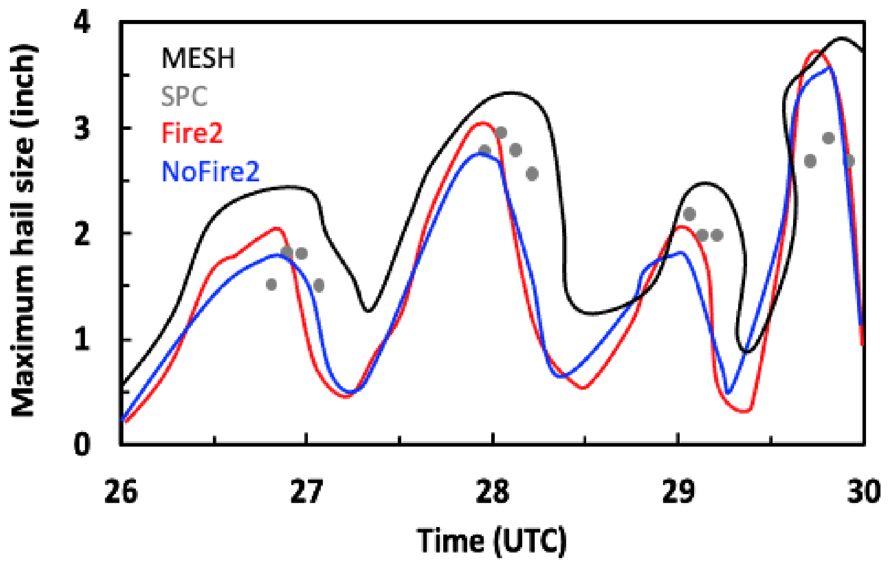
Local wildfires

Wildfires (red) from the western US and the central US (right white box) on July 29, 2018

A co-occurrence event in 20 years

- During the one week of 23-29 July 2018, four severe convective storm events occurred on each day over **26-29 July** in CO, WY, SD, NE, and KS, producing flash flooding, large hail (2.75 inches, baseball size), straight-line winds (> 90 mph), and several tornado touchdowns. Total economic losses exceeded $100 million.
- At the same time, significant wildfire events occurred in California and Oregon and before the first storm occurred.

4 severe convective storms



Carr Fire

Mendocino Complex Fire

Storm at Kit Carson, CO

Image Courtesy: Dave Ritchey

Hailstones at Flagler, CO

Image Courtesy: Crystal Smith Reeves

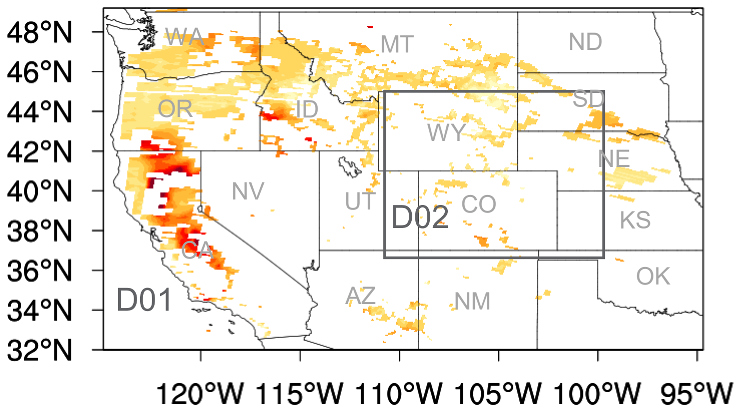
Modeling simulations

- Employed the chemistry version of the Weather Research and Forecasting model (**WRF-Chem**) coupled with a spectral-bin microphysics scheme (**SBM**) to simulate the storm events with **1 km** (D02), with accounting for **the effects of both heat and aerosols** from wildfires. Using 3-km outer domain to drive the simulations
- **Conduct model sensitivity tests to investigate the joint and respective effects, and the major mechanisms**

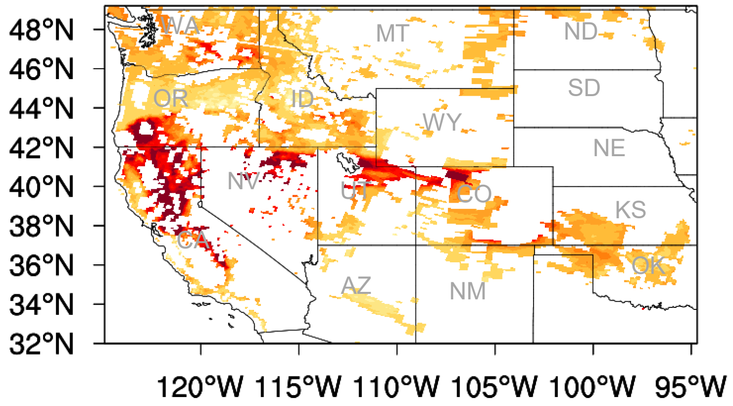
Simulation for D01 with WRF-Chem (run for a week period starting July23 00)	
Fire1	Simulation with wildfires considered.
NoFire1	Simulation without wildfire considered.
Fire1_NH	Based on Fire1, turn off the heat effect of wildfires.
Simulation for D02 with WRF-Chem-SBM (run for 4 days starting July26 12:00)	
Fire2	Simulation with both local and remote wildfire effects considered, using the initial and boundary conditions in meteorology and aerosols from Fire1.
NoFire2	Simulation without wildfires (both local and remote wildfire effects are excluded), using the initial and boundary conditions in meteorology and aerosols from NoFire1.
Fire2R	Based on Fire2, consider the remote wildfire effect only (local wildfires are turned off).
Fire2L	Based on Fire2, consider the local wildfire effect only (the effects of remote wildfires are excluded, i.e., using the initial and boundary conditions in meteorology and aerosols from NoFire1).
Fire2_NH	Based on Fire2, consider the wildfire aerosol effect only (the heat effect from both remote and local wildfires is excluded, i.e., using the initial and boundary conditions for meteorology and aerosols from Fire1_NH and turning off the heat effect from local wildfires).
Fire2_NRH	Based on Fire2, exclude the heat effect from the remote wildfires (i.e., using the initial and boundary conditions in meteorology and aerosols from Fire1_NH).

MODIS AOD

Jul 26

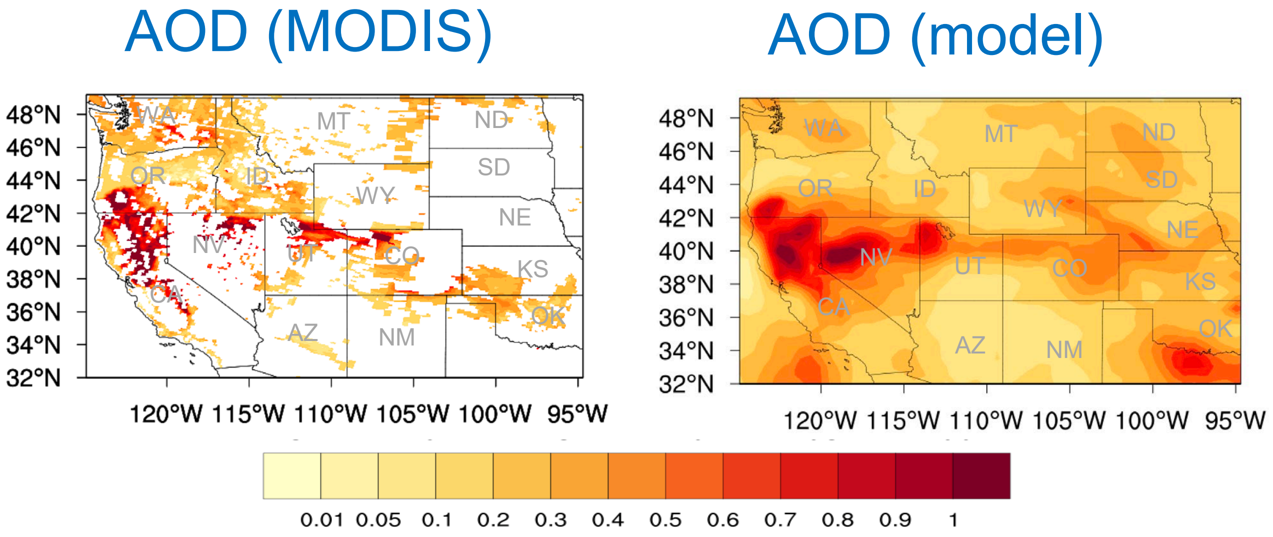


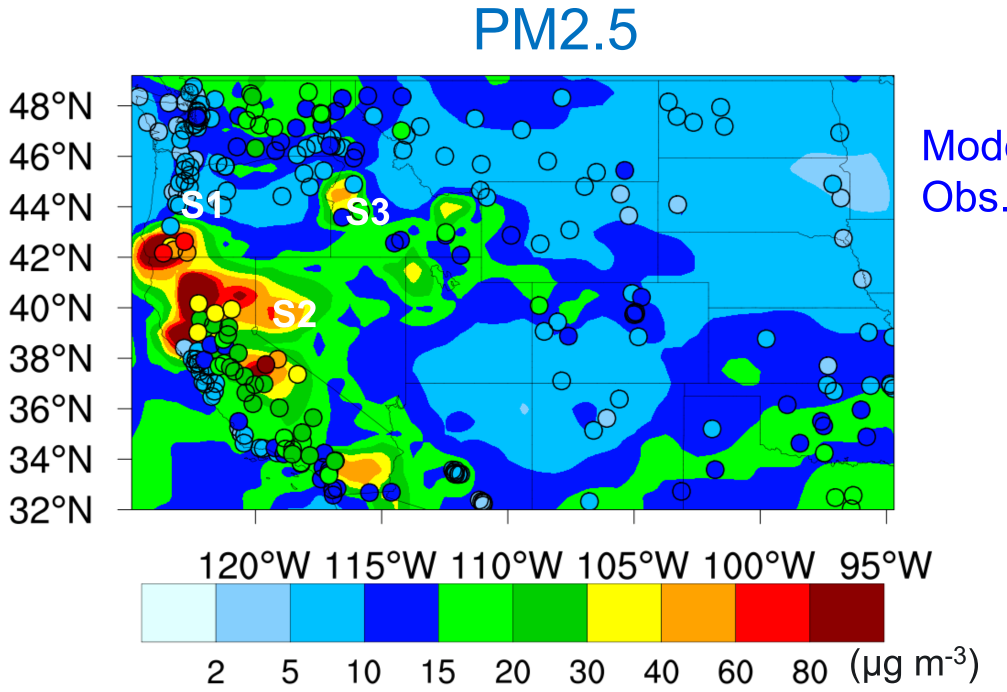
Jul 29



Comprehensive model evaluations in aerosol, meteorology, fire properties, hail, precipitation

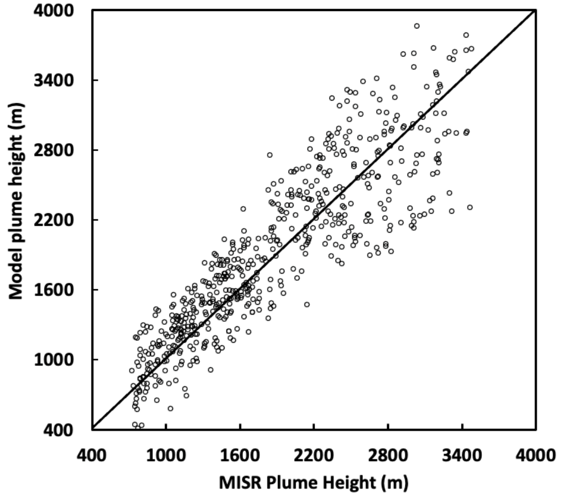
Jul 29



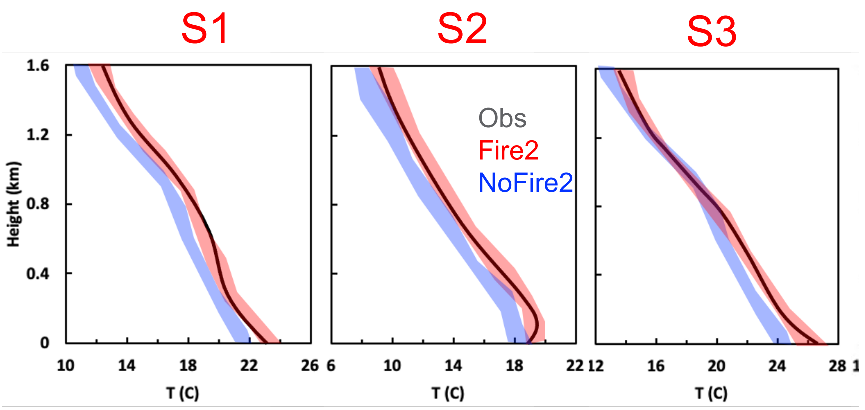


Model: contour
Obs.: circles

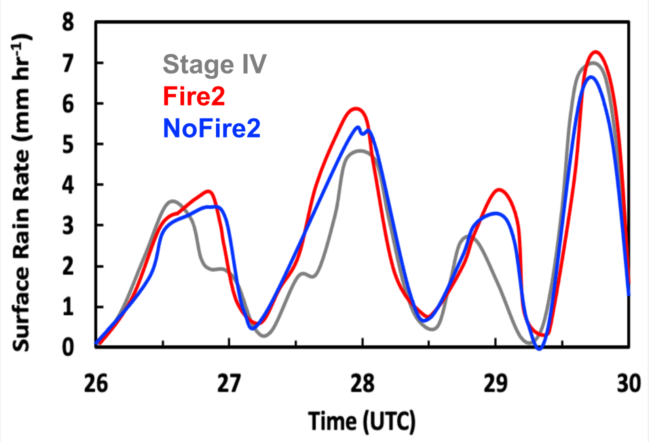
Fire plume height



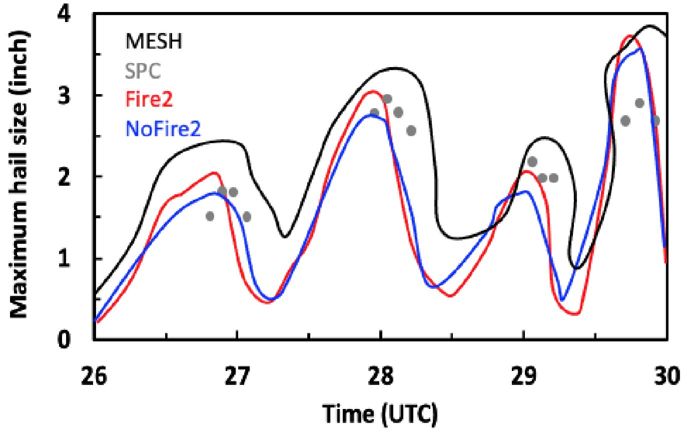
T profiles



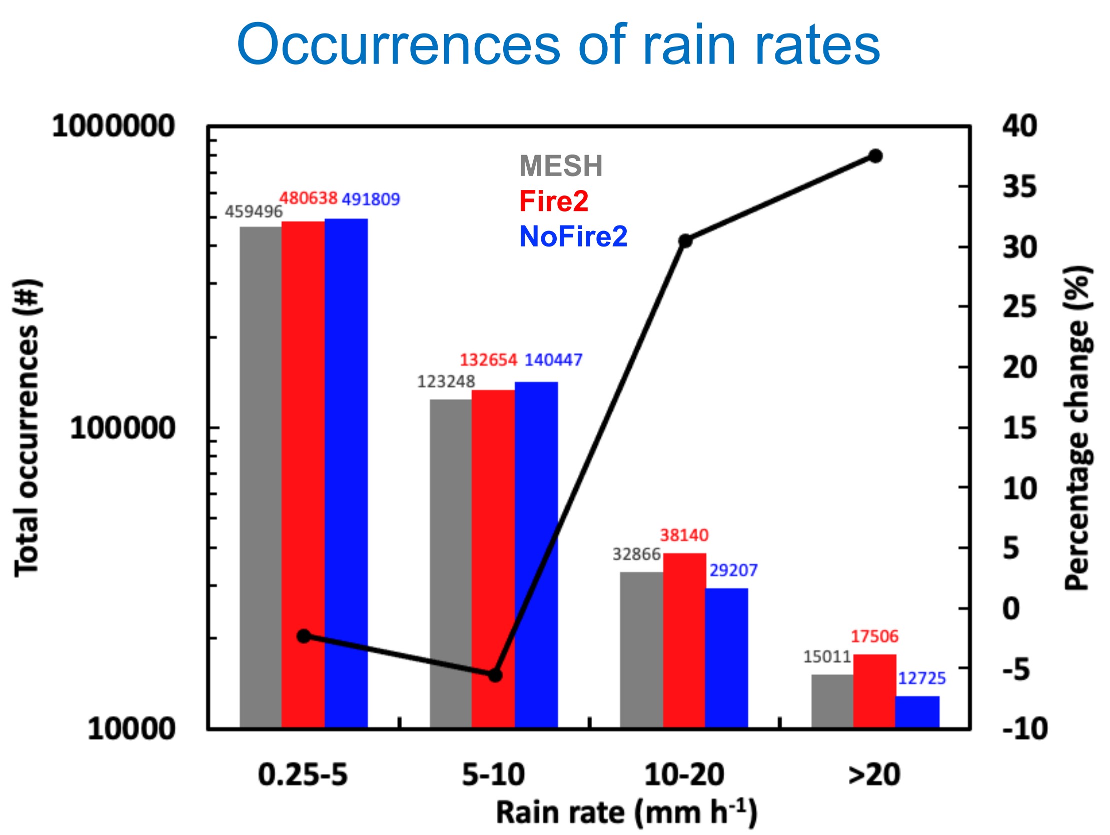
Precipitation rate

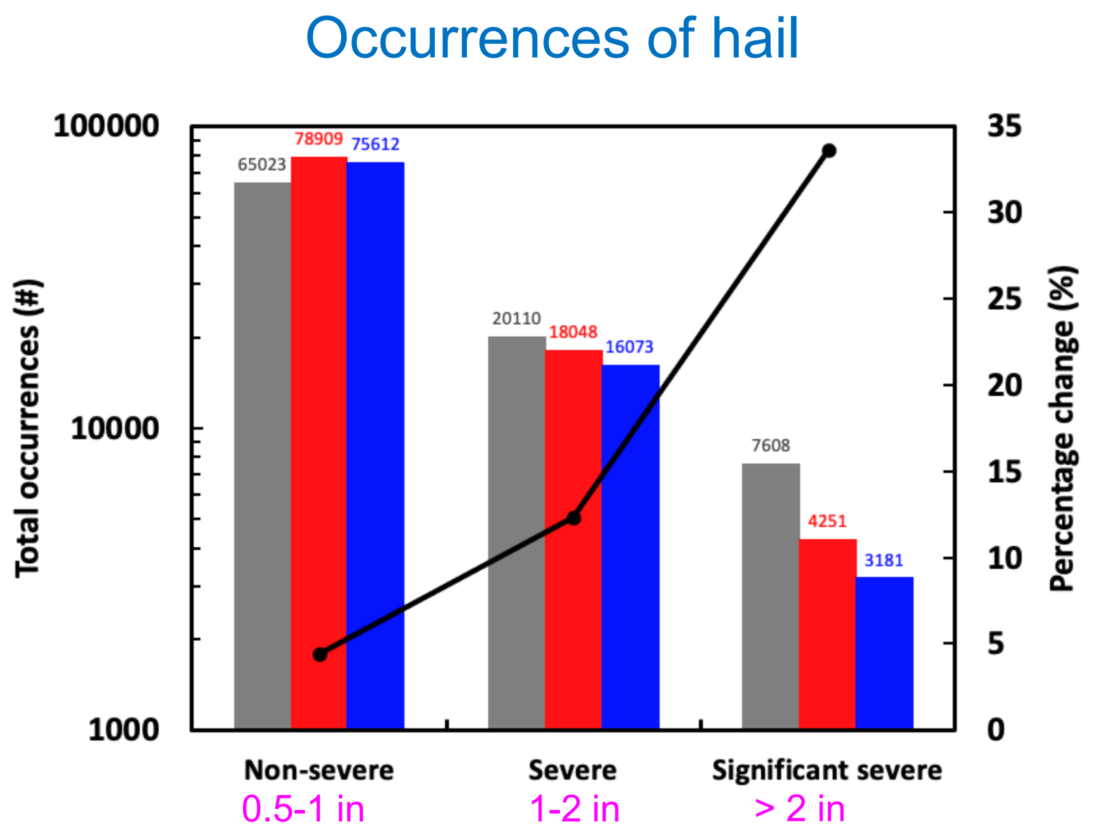


Max. hail size



Enhanced occurrences of heavy rain and large hail

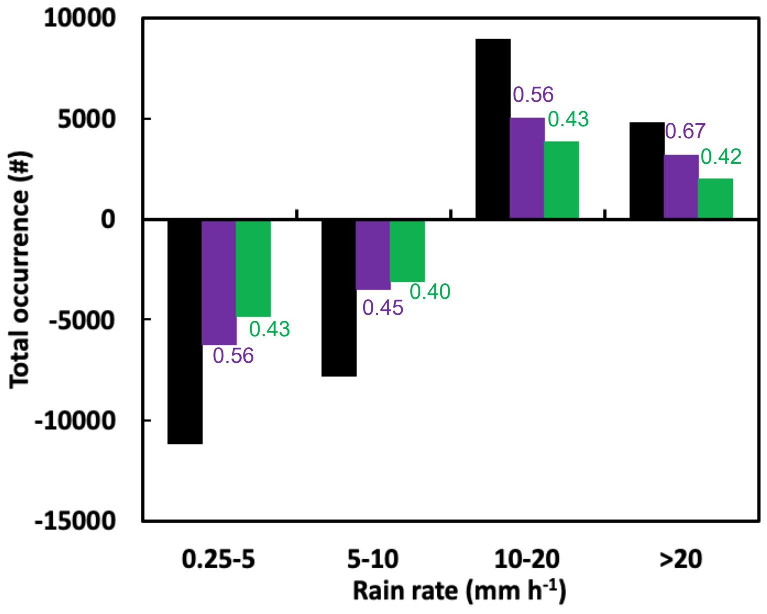




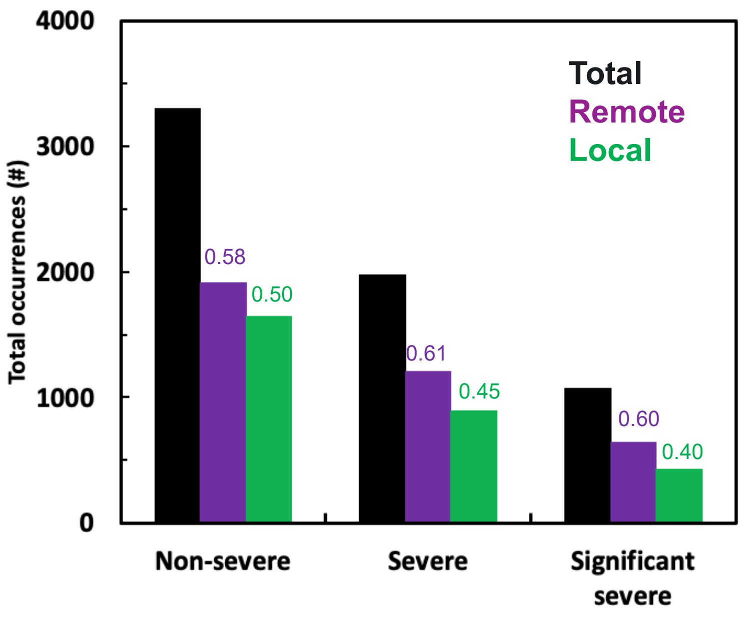
- The joint effect of both WUS and CUS wildfires increases the occurrences of heavy precipitation rates (> 20 mm h^{-1}) by 38% and significant severe hail (SSH; > 2 inches in diameter) by 34%.
- The accumulated rainfall over the 4 storms is increased by about 5.9 mm (19%).

Notable effects of the remote wildfires

Diff. in occurrences of rain rates



Diff. in occurrences of hail

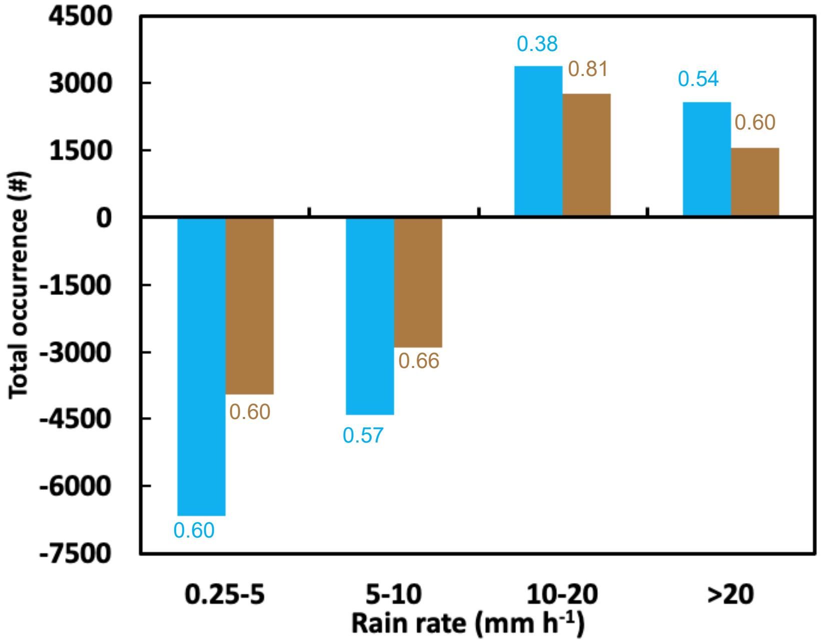


- The remote (WUS) wildfire effect contributes to 67% and 60% of the increase in the occurrences of heavy precipitation rates and SSH, respectively, (1.6 and 1.5 times greater than the local wildfire effect)
- For the accumulated rainfall, the remote wildfire effect contributes to 66% of the increase (1.6 times larger than the local wildfire effect).

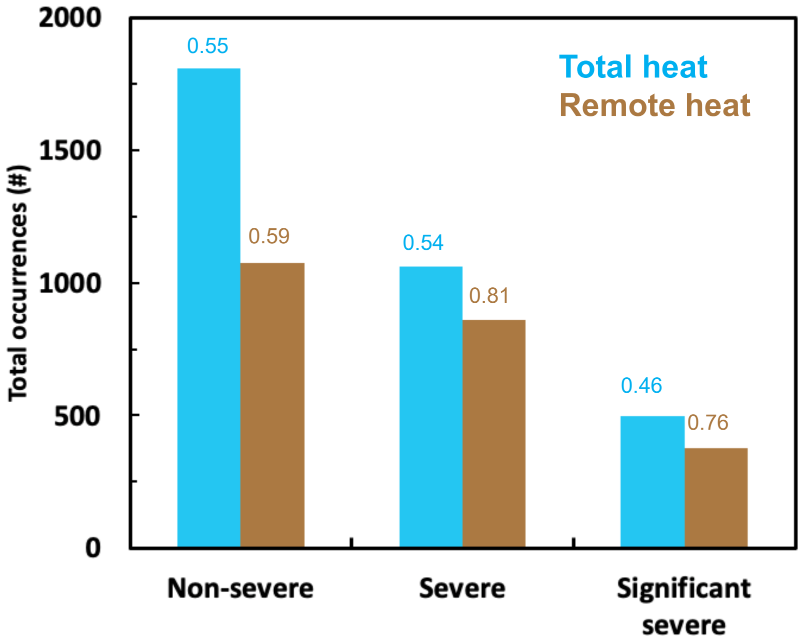
The value on the bar is the ratio of each effect to the total wildfire effect.

Both the heat and aerosol effects are significant

Diff. in occurrences of rain rates



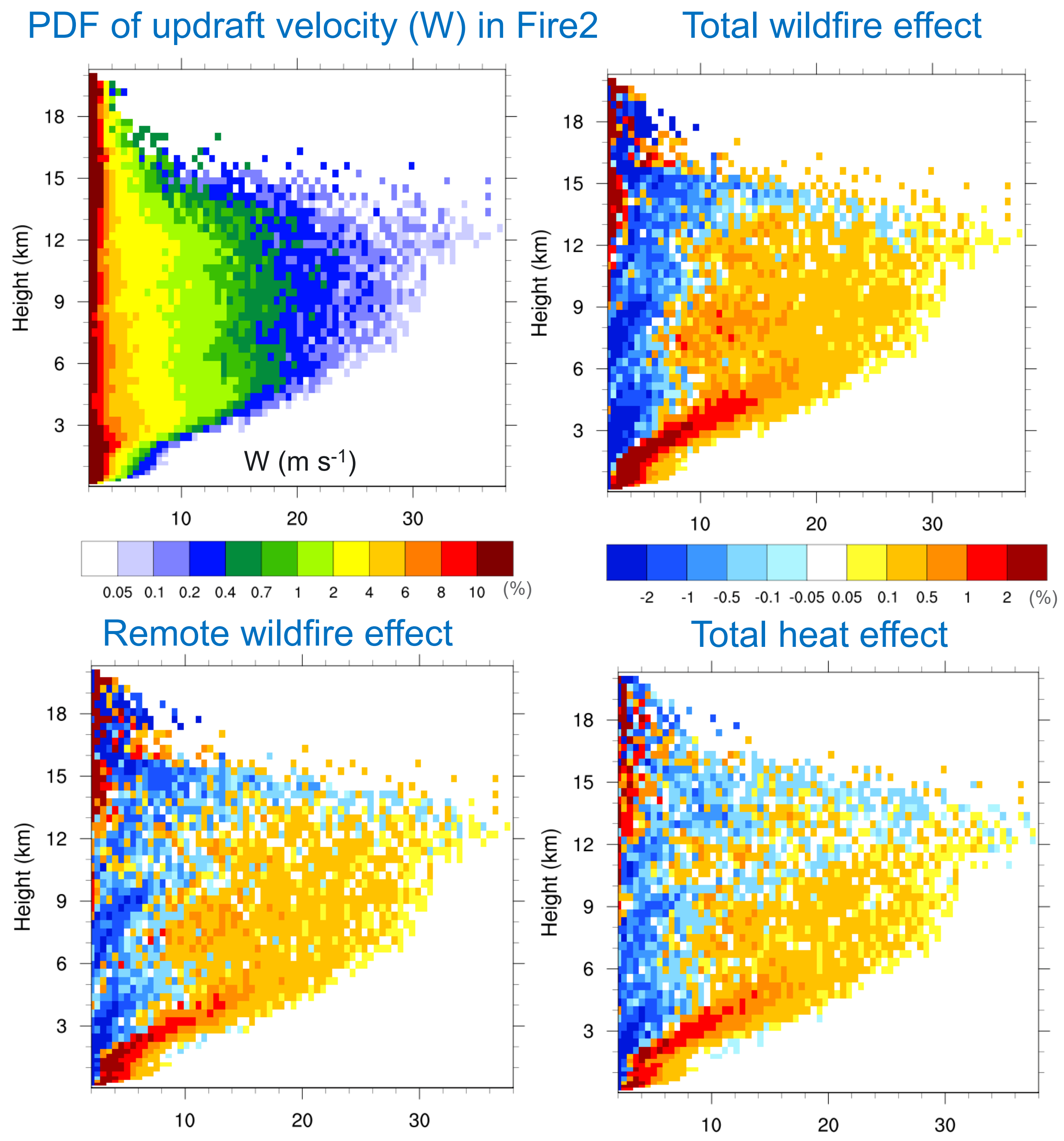
Diff. in occurrences of hail



The value on the sky-blue bar is the ratio of total heat effect to the total wildfire effect.
The value on the brown bar is the ratio of remote heat effect to the total heat effect.

- The heat effect contributes to 54% and 46% of the total wildfire effect on heavy precipitation rates and SSH, respectively, suggesting both heat and aerosol effects from wildfires are significant.
- Of the heat effect, 60% is from the remote wildfires for heavy precipitation and 76% for SSH,
- The remote heat effect contributes to 49% of the remote wildfire effect on heavy precipitation and 58% on SSH, suggesting the heat and aerosol effects from the WUS wildfires might be of a similar magnitude.

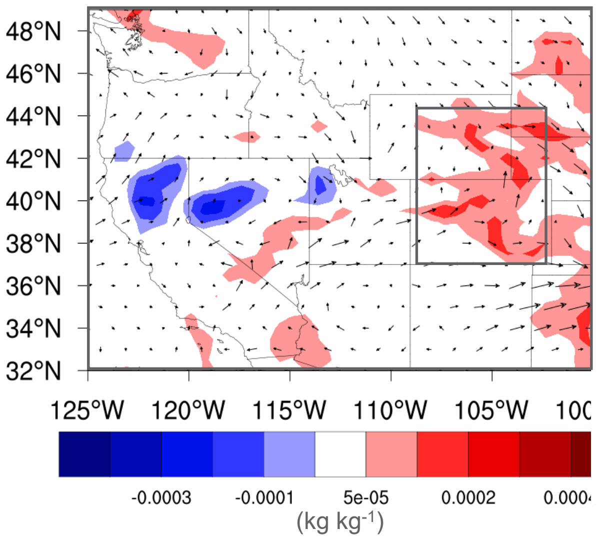
Enhanced storm updrafts



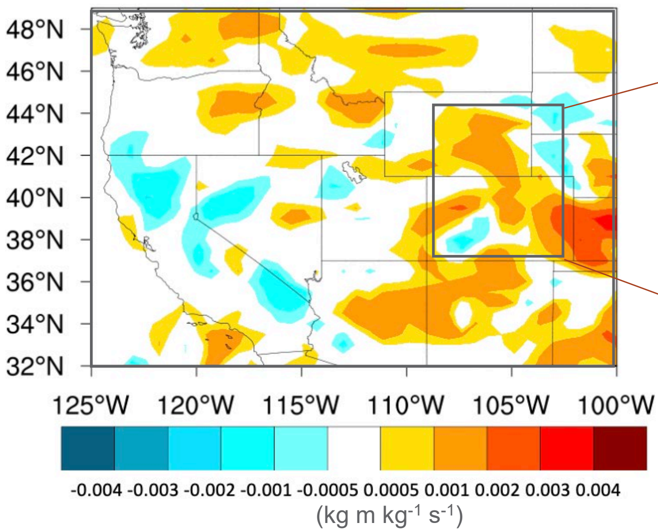
- Reduced frequencies of weak updrafts and enhanced frequencies of strong updrafts below 12 km
- Comparing total heat effect with the total wildfire effect, we can see the aerosol effect helps enhance updraft intensity a lot.

Why is storm intensity enhanced?

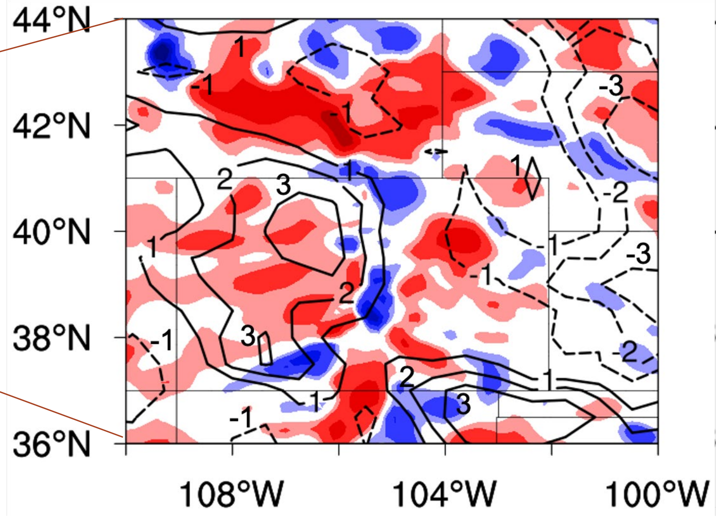
Diff. in moisture (850 hPa)



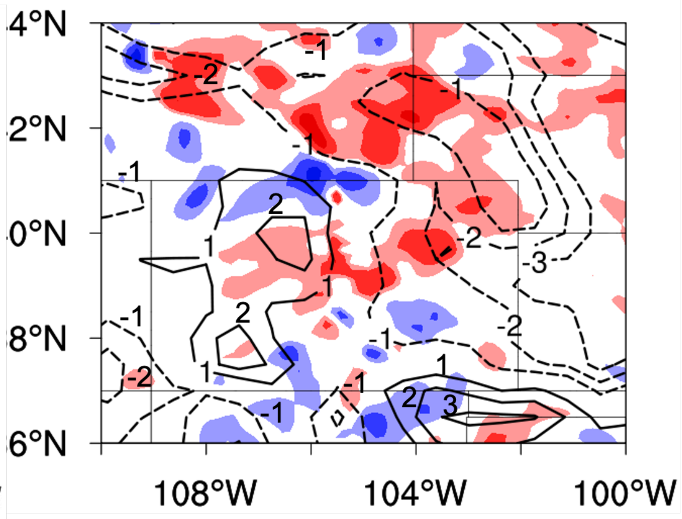
Diff. in horizontal moisture advection



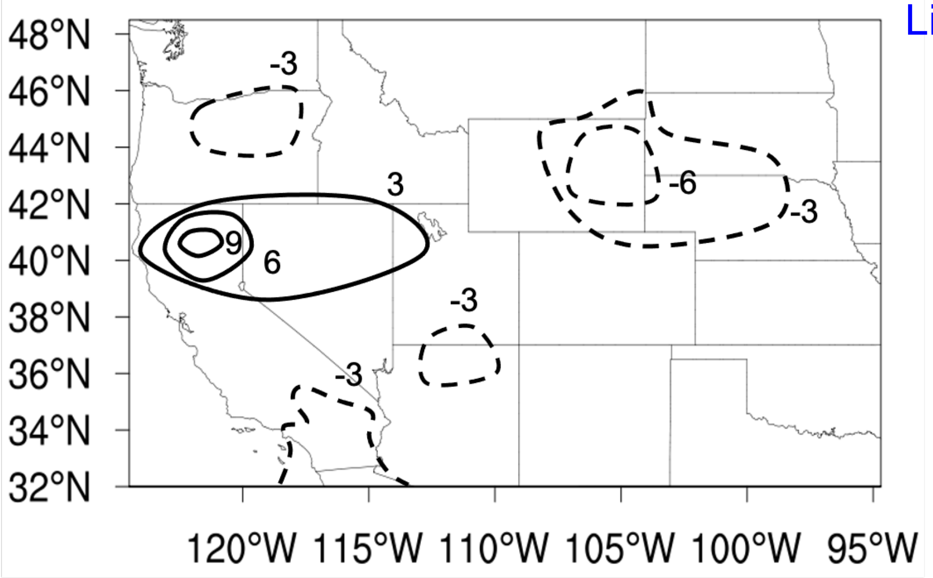
Total wildfire effect



Remote wildfire effect



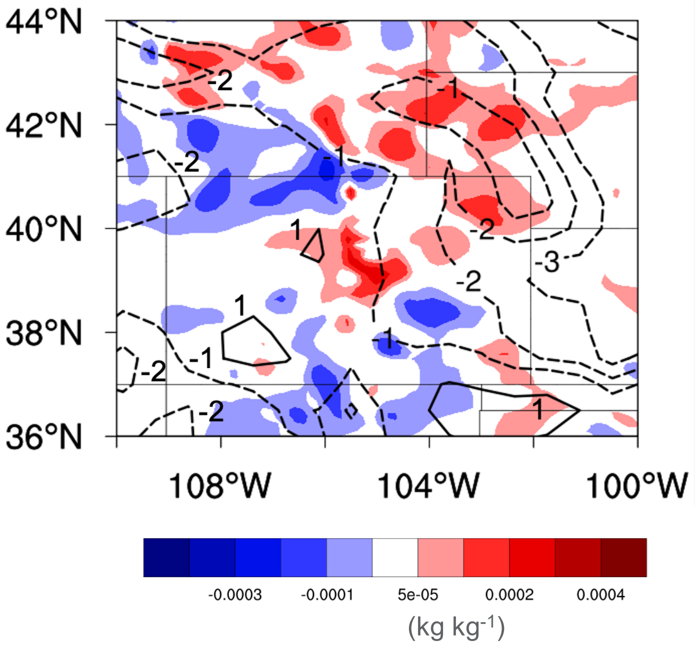
- Over the storm region (black box), the low-level moisture is enhanced due to advection, which is because of enhanced westerly and southwesterly winds.



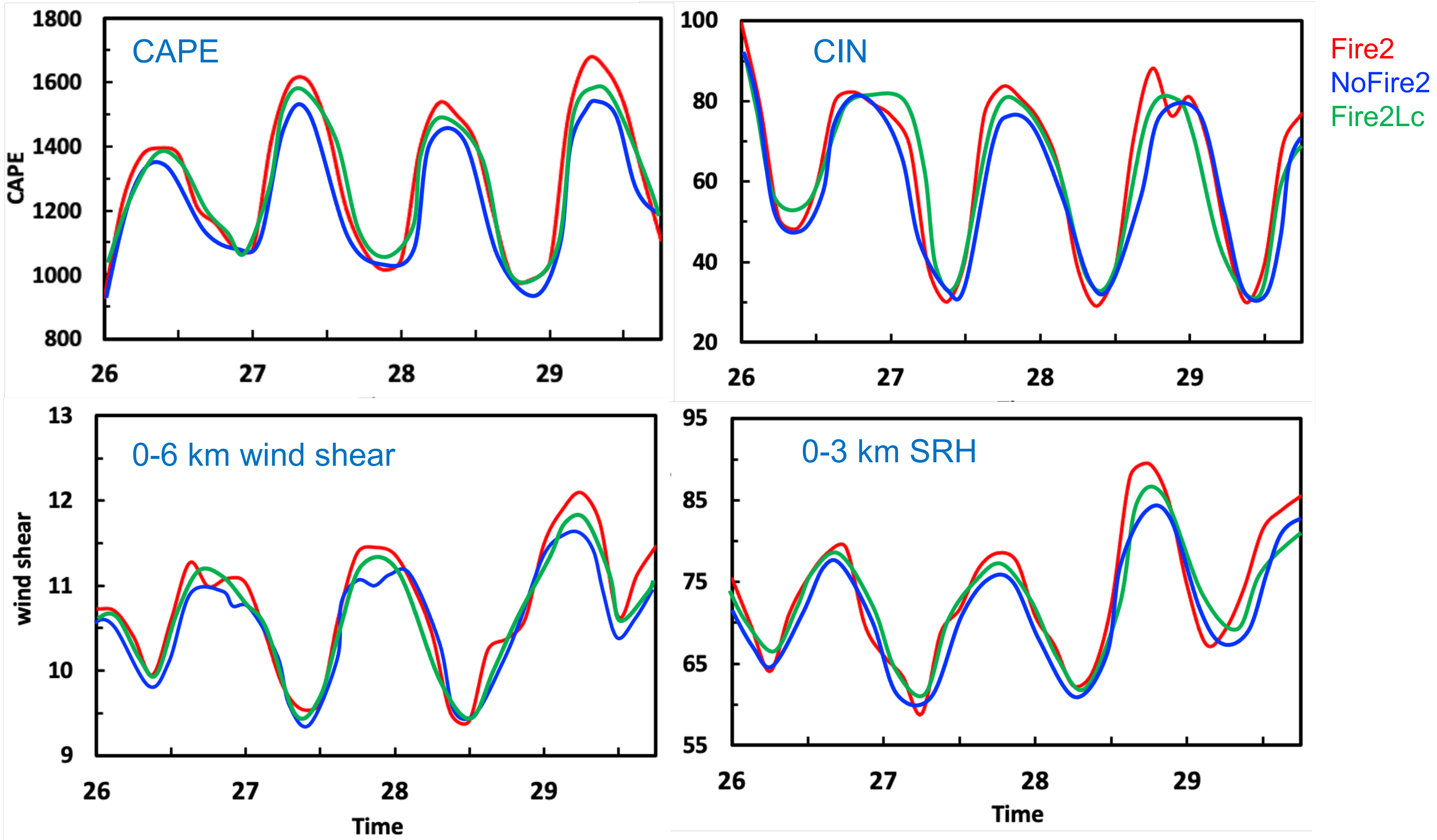
Color contours: diff. in moisture

Line contours: diff. in wind speed (solid denotes the increase and dashed denotes the decrease)

Local wildfire effect



Meteorology conducive to more severe storms

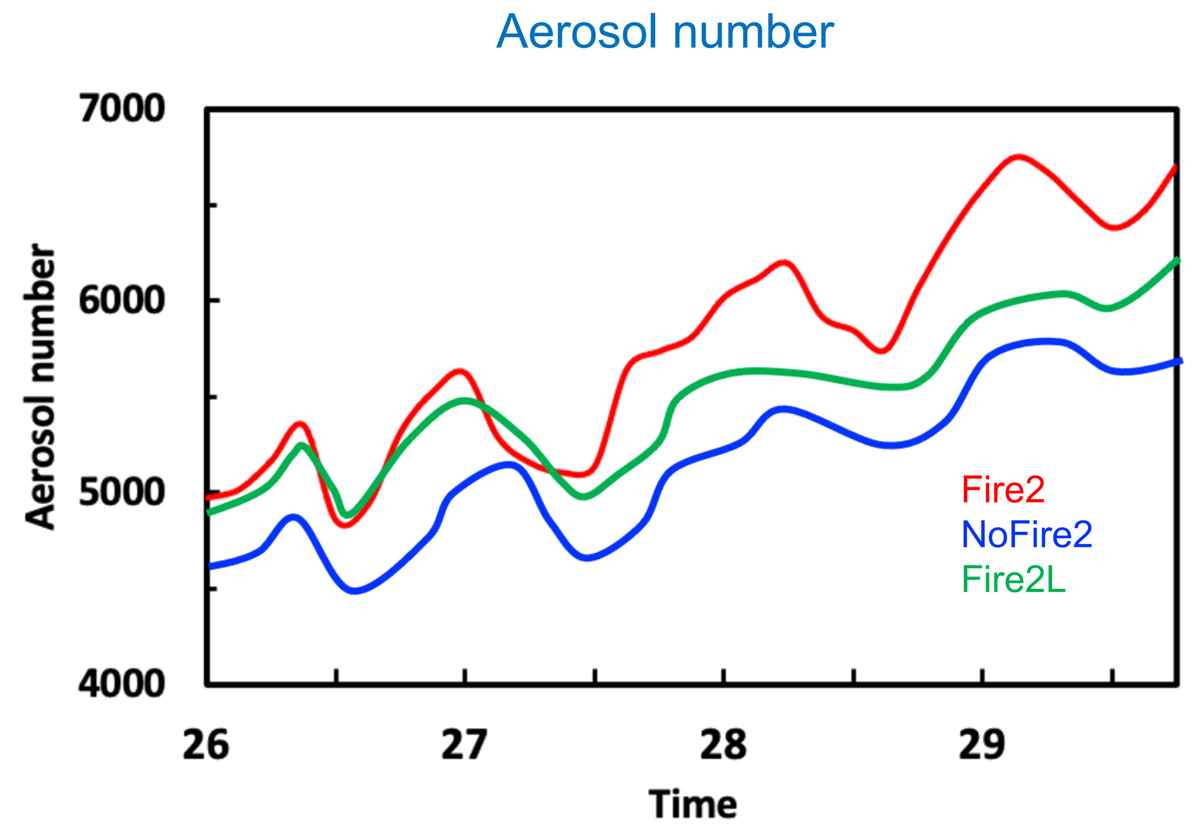


- CAPE, CIN, deep wind shear, and storm-relative helicity (SRH) all increases with wildfires, indicating meteorology conducive to more severe storms

Mean over the storm region

Difference for individual grids can be up to 420 J/kg for CAPE, 35 J/kg for CIN, 2 m/s for wind shear, and 9 m2/s2 for SRH

Aerosol effect enhances storm and hail

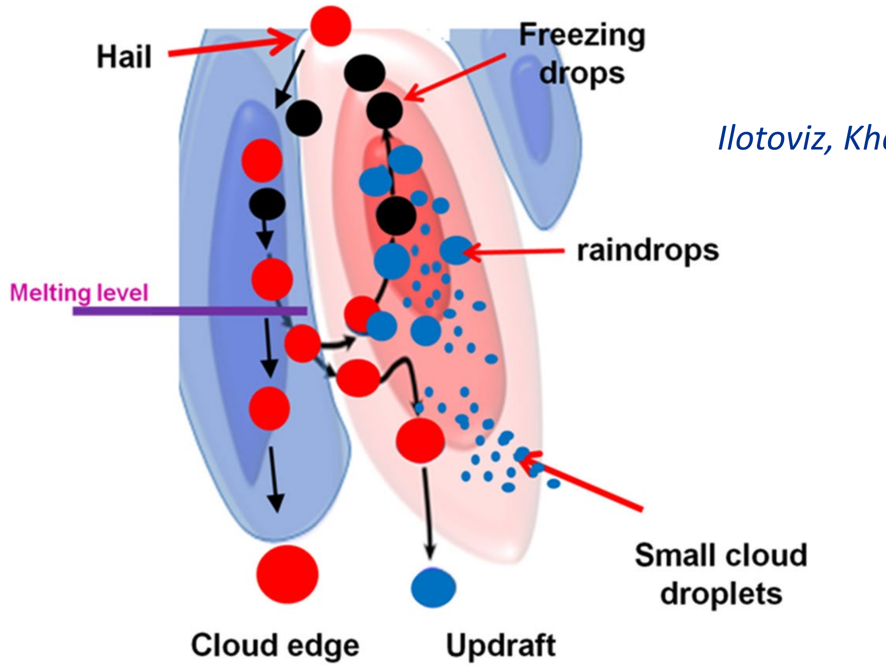


- Increase in aerosol number concentrations is mainly contributed by the remote wildfires.

- Aerosols enhance storm intensity owing to enhanced latent heat release mainly from warm phase (Fan et al., 2018; Lin et al. 2021)
- Aerosols increase large hails (Zhang et at. 2019; Lin et al. 2021; Ilotoviz et al., 2016)

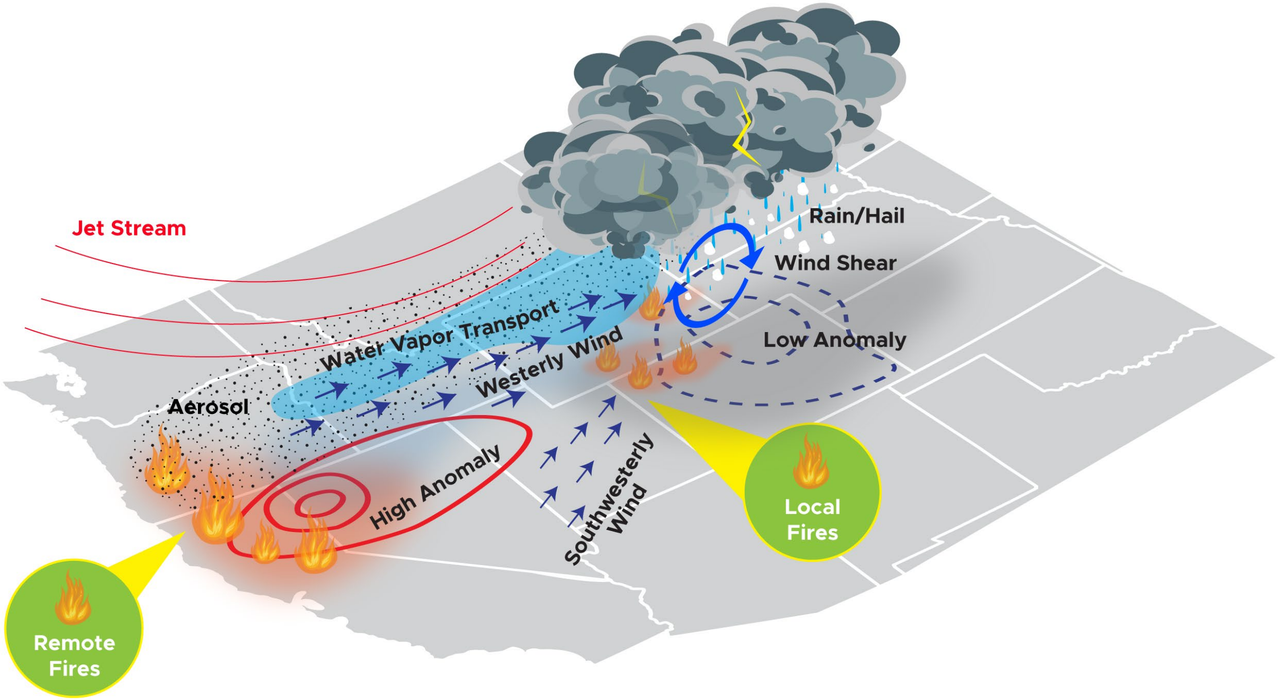
a. numerous smaller hail embryos that can reenter cloud updrafts and grow into larger hailstones

b. more supercooled droplets that allow hail embryos to reach larger sizes in the course of recycling



Ilotoviz, Khain, et al. 2016

Summary and Significance



- Our model simulations showed that WUS wildfires notably enhance the severity of storms in the CUS by increasing the occurrences of heavy precipitation rates and significant severe hail
- Both sensible heat and aerosols from the wildfires in the WUS play important roles
- Through (1) changing synoptical scale meteorology: meteorology is conducive to more severe storms; (2) increasing aerosols: aerosol-cloud interactions enhance storm intensity and hail size

Significance: This study demonstrates **a concept** that upstream wildfires can be an important factor influencing the severity of convective storms. This concept may **apply to other regions** with upstream fires. The impact of wildfires in the WUS on storm severity in the CUS may **become increasingly important in the future** as both western wildfires and central severe storms are projected to increase as climate warming continues.

This study is show of concept and hope it will spark more studies to gain more robust understanding