



National Laboratory  
of the Rockies

# Data-Driven Analysis of Wildfire Weather Drivers Across Past and Future Conditions

Grant Buster, Data Scientist  
Strategic Energy Analysis Center, NLR  
ESIG Summer Workshop 2026

# Surface Wind Modelling

---

Challenges for wildfire risk

# Challenges in Modelling Surface Winds

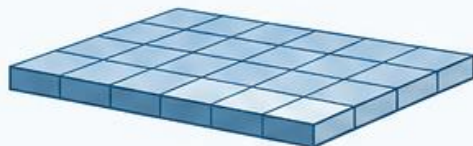
## NWP SURFACE MODEL (SIMPLIFIED REPRESENTATION)

VS.

## REAL EARTH SURFACE (COMPLEX REALITY)



REPRESENTATION  
OF THE SURFACE



Coarse grid cells (1–10+ km)  
with homogeneous surface  
properties per grid box.



Highly heterogeneous: mix of land uses, vegetation,  
topography, water, urban areas at meters to km scales.



SURFACE  
ROUGHNESS



Single roughness length ( $z_0$ )  
per grid cell.



Sub-grid variability in roughness from smooth water  
to tall buildings and hills.



TOPOGRAPHY

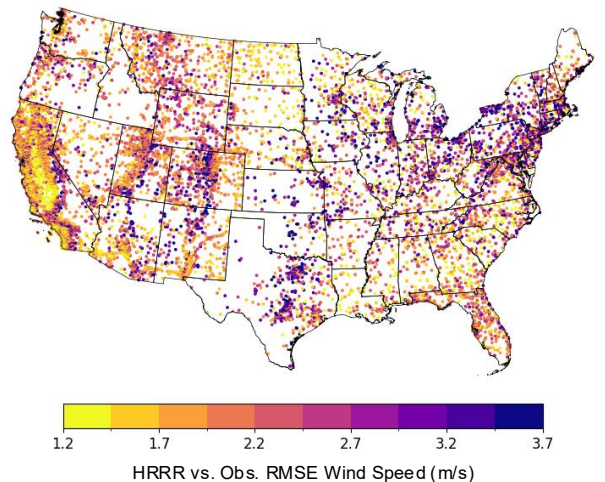
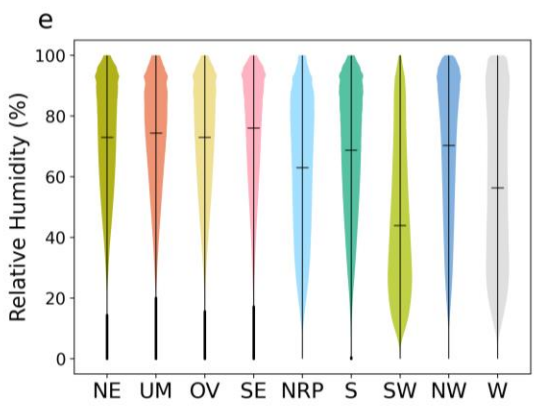
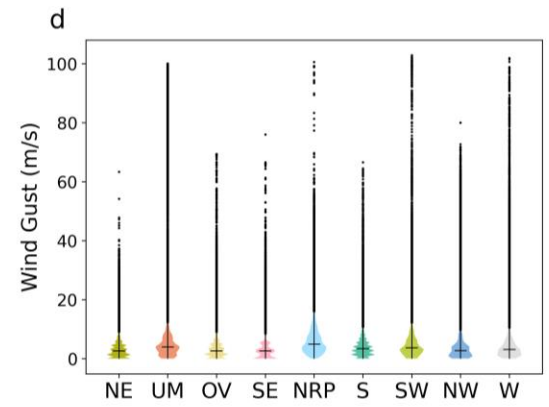
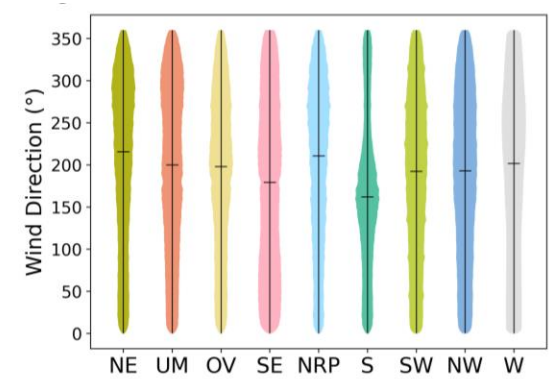
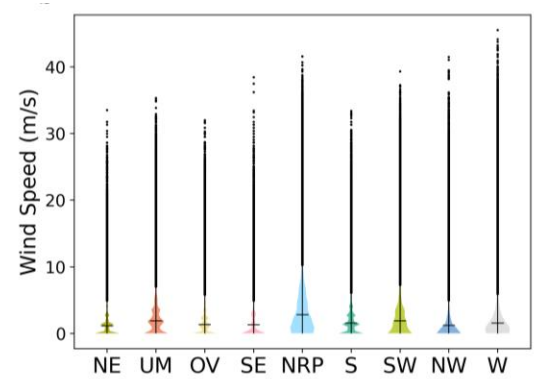
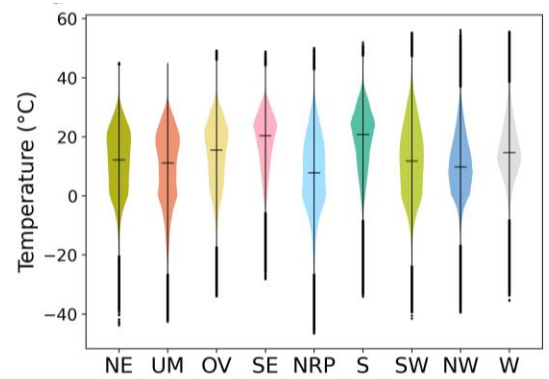


Smoothed terrain; small-scale  
hills and valleys are muted.

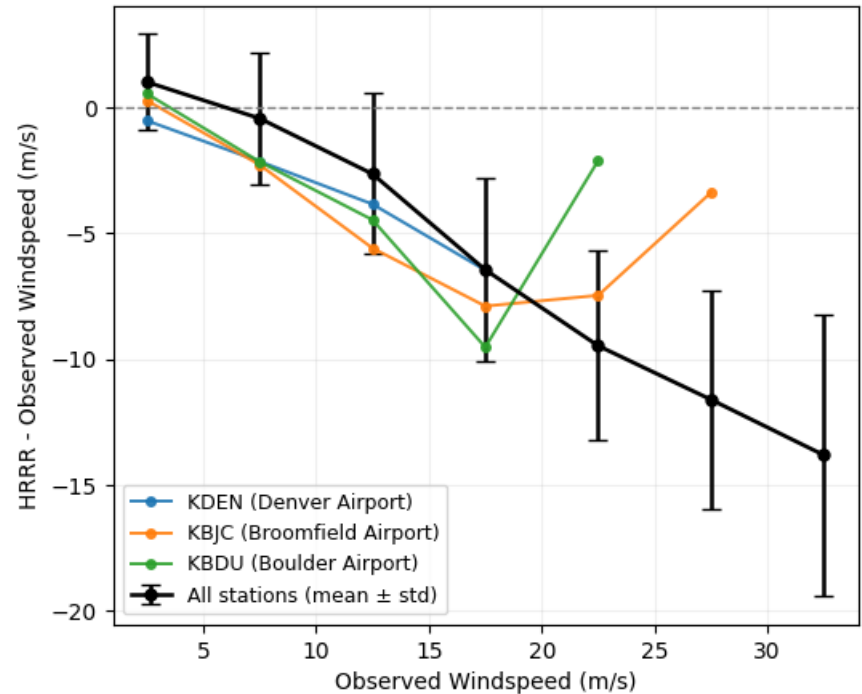
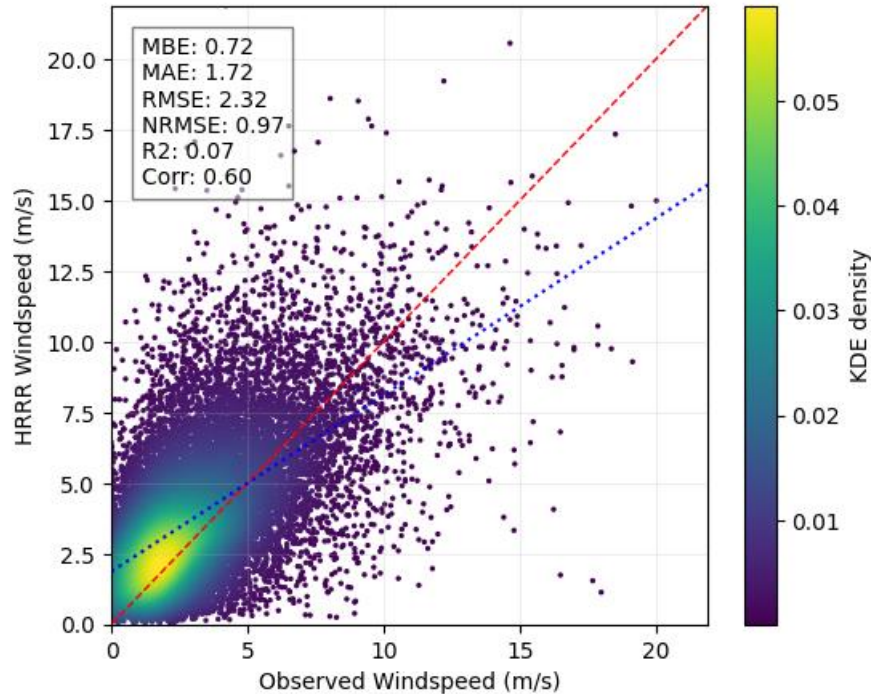


Complex terrain with ridges, valleys, slopes and  
channeling effects.

# A Benchmark Dataset for Near-Surface Observed Wind Speed Across the Conterminous United States (Bazlen et al., *in prep*)



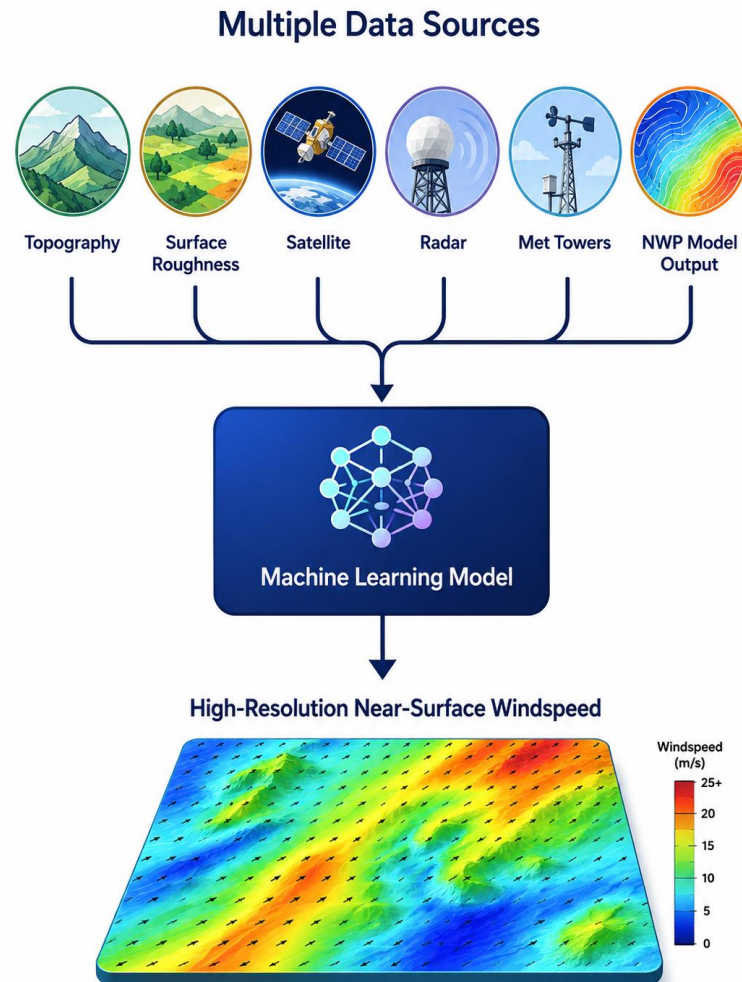
# Modelled Wind vs. Ground Measurements



- Model data taken from HRRR f02 modelled windspeed at 10m
- Based on quality-controlled data from 193 Colorado RAWS and METAR stations in 2021
- Similar results documented by [Collins et al., 2024](#)

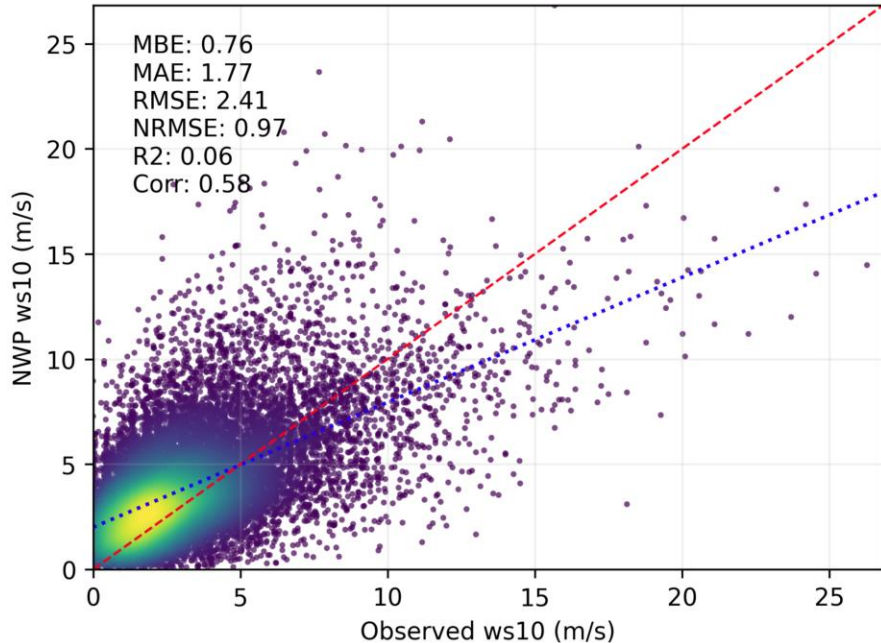
# Towards a Multi-Modal Downscaling Model for Surface Winds and Gusts

- Goal is to use all inputs available:
  - Topography
  - Surface roughness
  - Satellite
  - Radar
  - Met. towers
  - NWP
- Working on building unique features:
  - Sub-1km resolution
  - Conditional inference
  - Uncertainty quantification

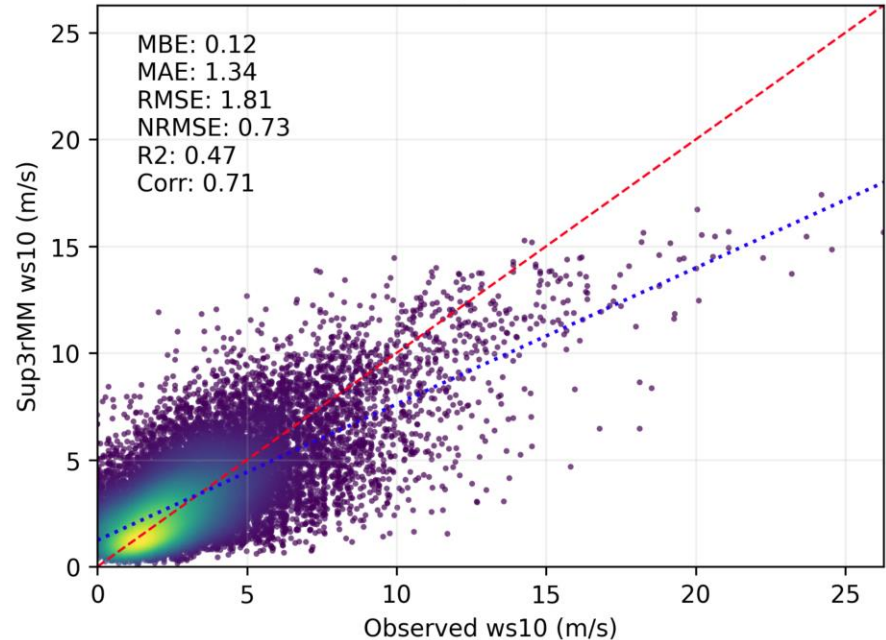


# Preliminary Results: Colorado Front Range

## HRRR



## ML Downscaling



- Substantial skill improvement with ML multi-modal downscaling
- Improved surface characterization leads to better predictions
- We still see regression to the mean and negative bias at high windspeeds

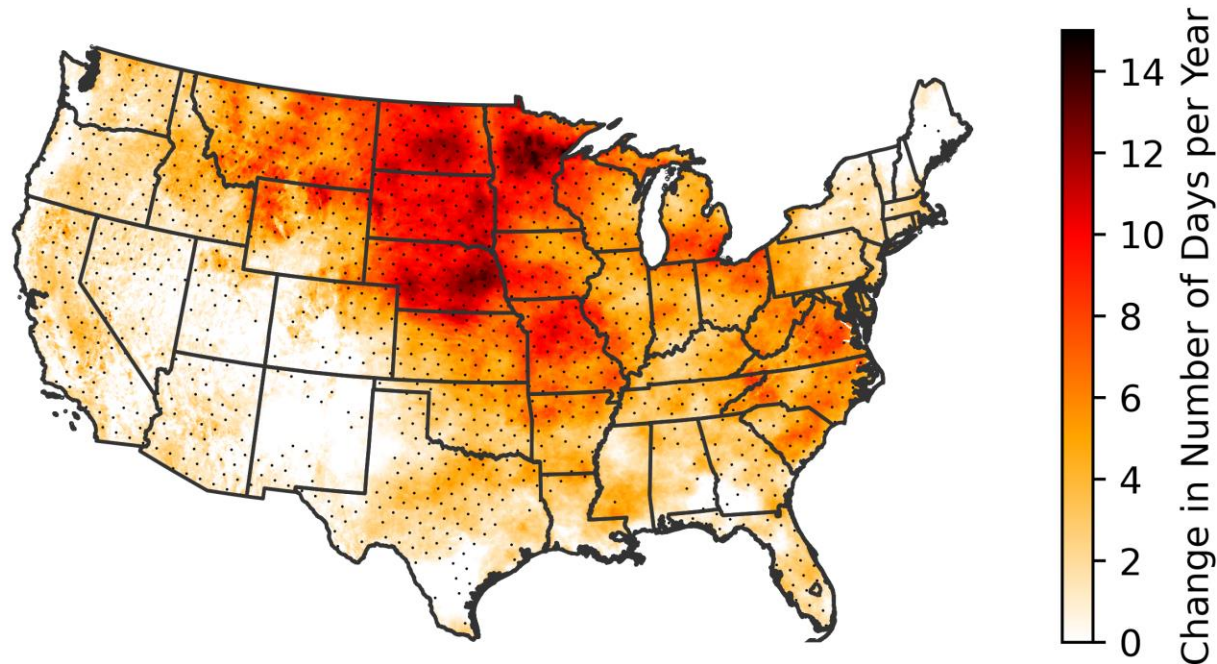
# Long Term Trends in Fire Weather

---

Surprisingly dry

# Model-Projected Changes (2020-2039) in Extreme Fire Weather Days

- Many large parts of the United States see modelled increases in extreme fire weather days by mid-century
- Based on the Canadian Fire Weather Index (FWI) averaged from 5x SSP2-4.5 scenarios from Sup3rCC<sup>1,2</sup>
- Stippling indicates 3/5 model agreement and statistical significance ( $p < 0.05$ )



*Extreme fire weather days are defined as greater than the 95<sup>th</sup> percentile FWI from 2000-2019 (18 extreme days per year in historical period)*

# Model-Projected Changes (2020-2039) in Extreme Fire Weather Days

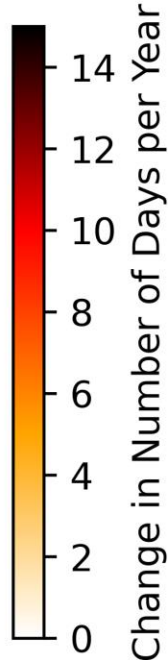
- Many large parts of the United States see modelled increases in extreme fire weather days by mid-century
- Based on the Canadian Fire Weather Index (FWI) averaged from 5x SSP2-4.5 scenarios from Sup3rCC<sup>1,2</sup>
- Stippling indicates 3/5 model agreement and statistical significance ( $p < 0.05$ )



No substantial Changes in the West?

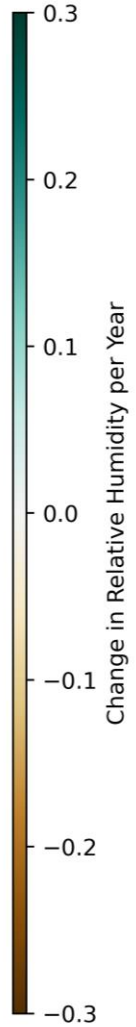
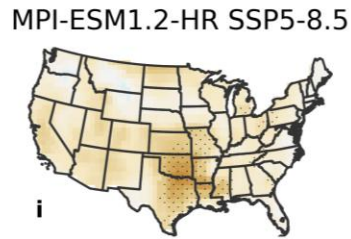
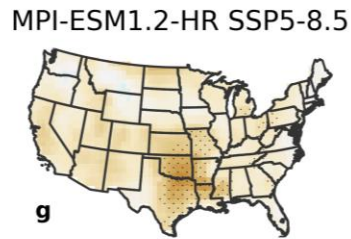
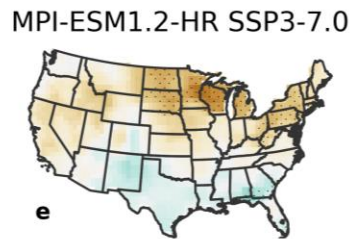
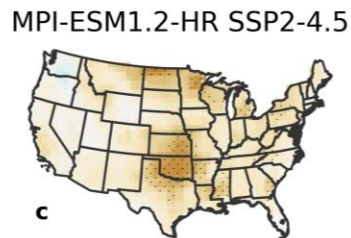
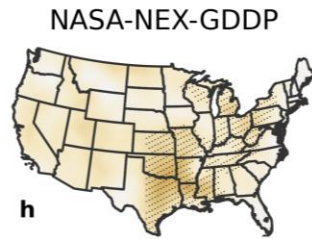
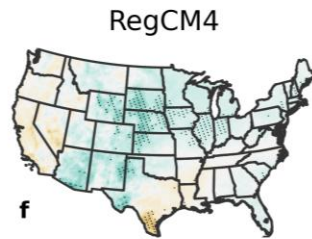
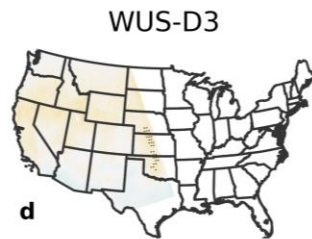
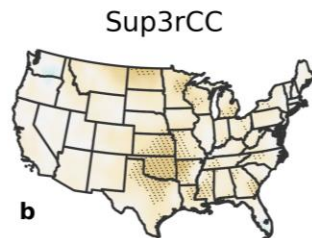
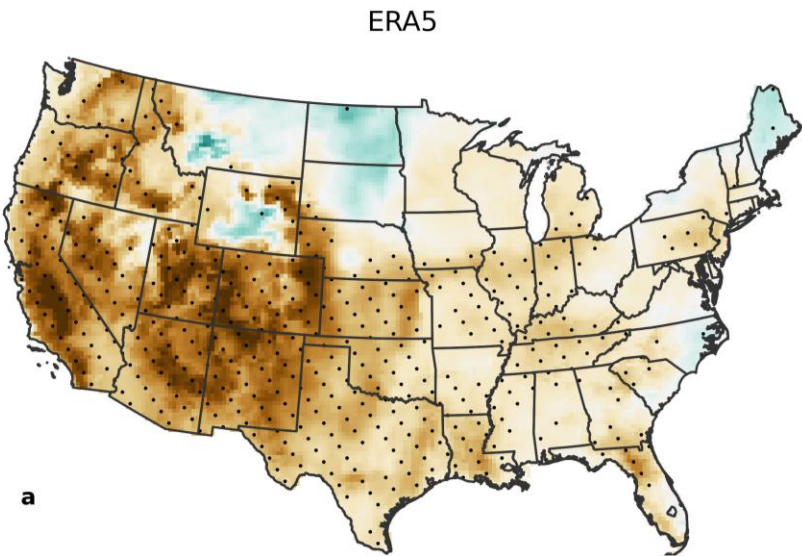
“An Unexpected Decline in Spring Atmospheric Humidity...” Jacobson et al., [Journal of Hydrometeorology](#), 2024

“Observed humidity trends in dry regions contradict climate models” Simpson et al., [PNAS](#), 2023

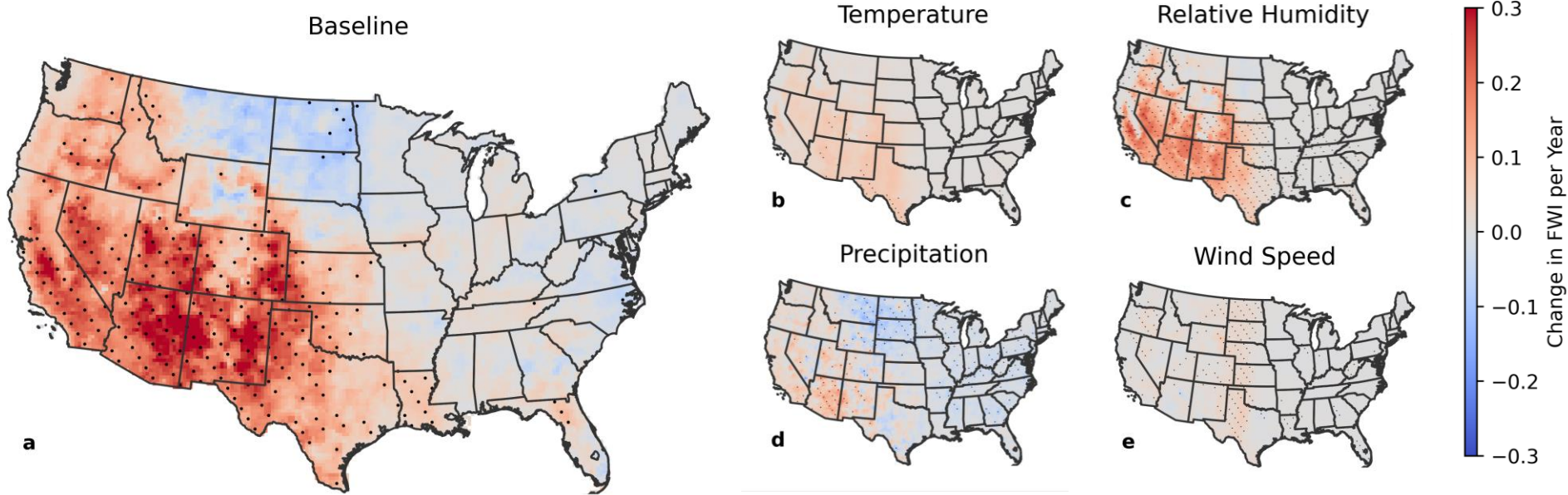


# Are We Underestimating Trends in Fuel Drying?

- We can see that in many locations in the American West, **declining trends in humidity are not reflected in ESMs or their downscaled counterpart**



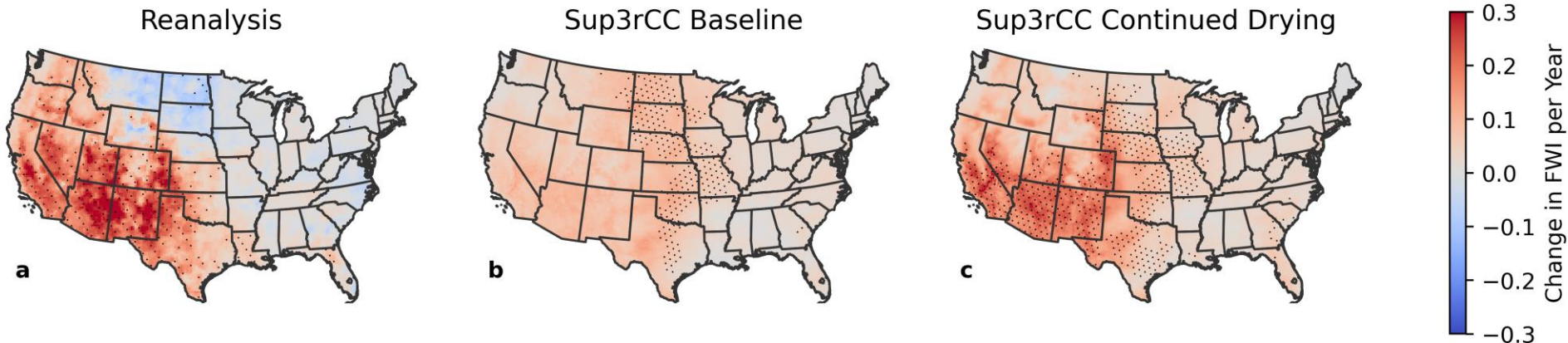
# What is the Role of Relative Humidity in Fire Weather?



- Over the last 40 years in the American West (1980-2019), **declining relative humidity has been the leading contributor to increased fire weather**, as measured by the Canadian Fire Weather Index (FWI)

# What if Drying Trends Continue?

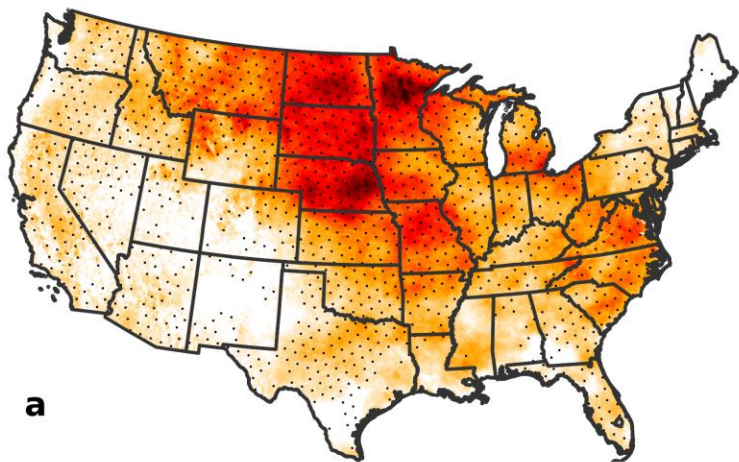
- Linear trends of FWI based on downscaled projections show little spatial variability and lower magnitude changes than we have observed in the historical record
- Correcting the relative humidity trend in the downscaled projections more closely matches our observed trends in FWI



# Future Fire Weather Projections (2020-2039) with a Continued Drying Scenario

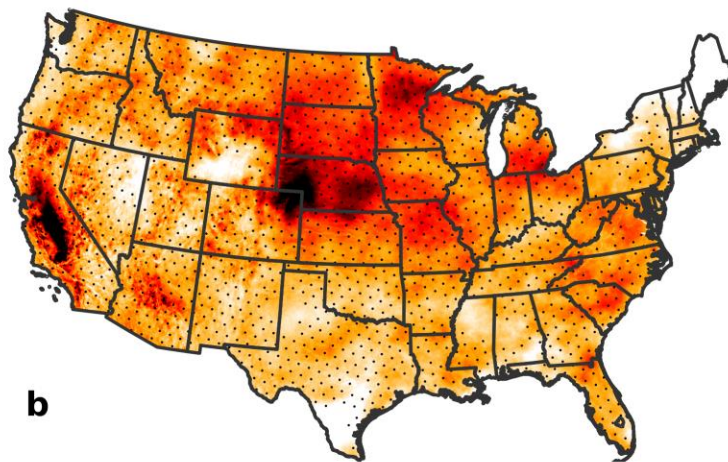
- Trend correction of relative humidity reveals western regions where ESMs have substantially underestimated drying trends

Sup3rCC Baseline

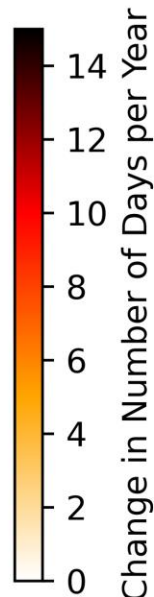


a

Sup3rCC Continued Drying



b



*Extreme fire weather days are defined as greater than the 95<sup>th</sup> percentile FWI from 2000-2019 (18 extreme days per year in historical period)*

This work was authored in part by the National Laboratory of the Rockies for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. Funding provided by the DOE Office of Energy Efficiency and Renewable Energy (EERE), the DOE Office of Electricity (OE), and the DOE Office of Cybersecurity, Energy Security, and Emergency Response (CESER), the NSF CO-WY ASCEND, grant NSF-2315760, and the Laboratory Directed Research and Development (LDRD) program at the National Renewable Energy Laboratory. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

## Q&A

Preprint on fire weather trends available at  
<https://doi.org/10.31223/X54F4N> (in review)

Contact: [Grant.Buster@NLR.gov](mailto:Grant.Buster@NLR.gov)



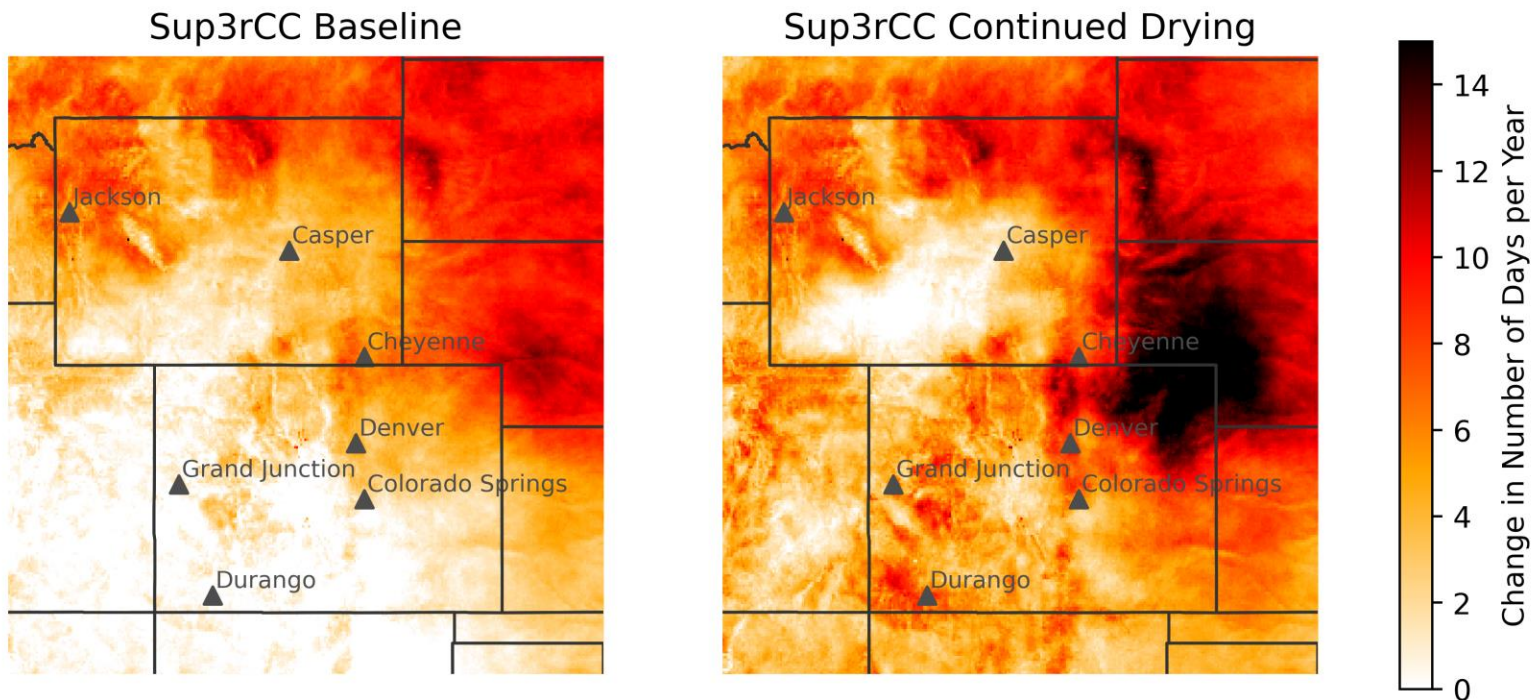
**National Laboratory  
of the Rockies**

# Appendix

---

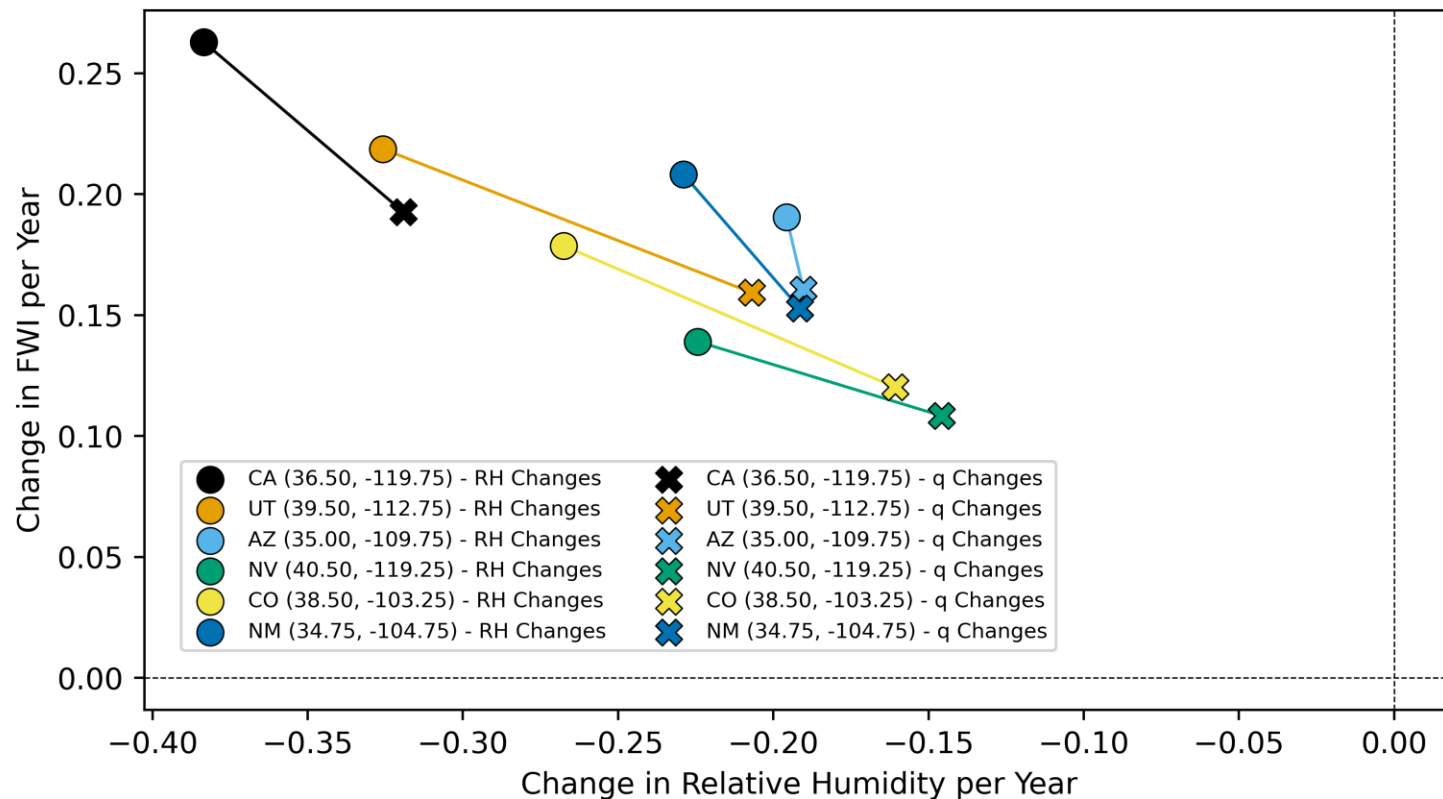
# Future Fire Weather Projections (2020-2039) with a Continued Drying Scenario

- Regions in Colorado and Wyoming are drying faster than estimated by ESMs



*Extreme fire weather days are defined as greater than the 95<sup>th</sup> percentile FWI from 2000-2019 (18 extreme days per year in historical period)*

# Specific Humidity (q) Changes Dominate Temperature-RH Effects



# Simplistic Linear RH Trend Correction Based on Reanalysis

