Air Quality Modeling for wildfires in Alaska

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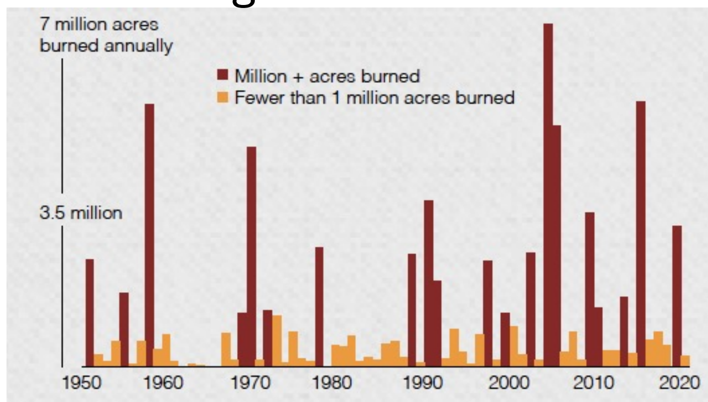
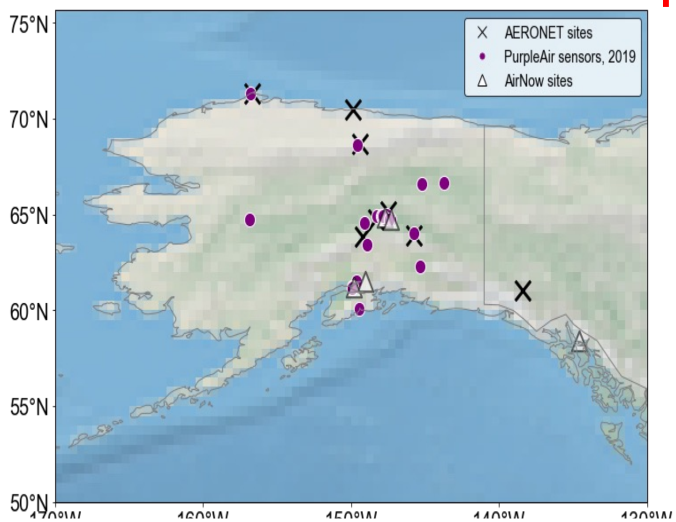
Wildfire accounts for majority of PM2.5 pollution in Alaska summer, and it will get a lot worse…

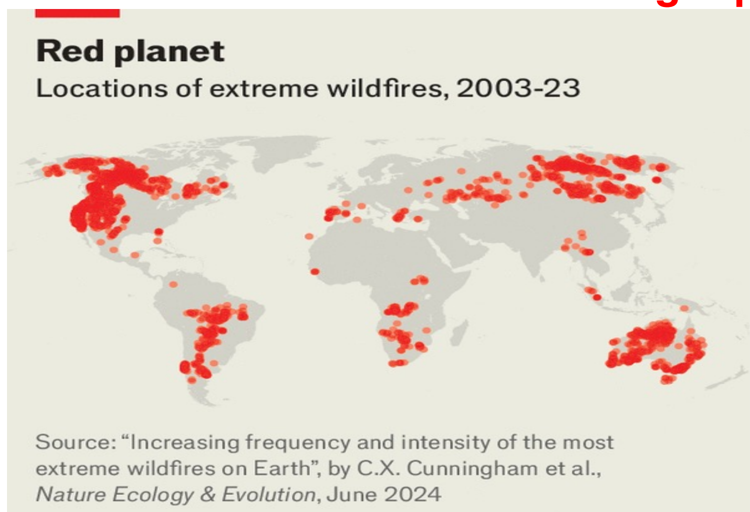
Burning area in Alaska



Ground-based measurements are sparse in Alaska



Extreme wildfires are increasing rapidly



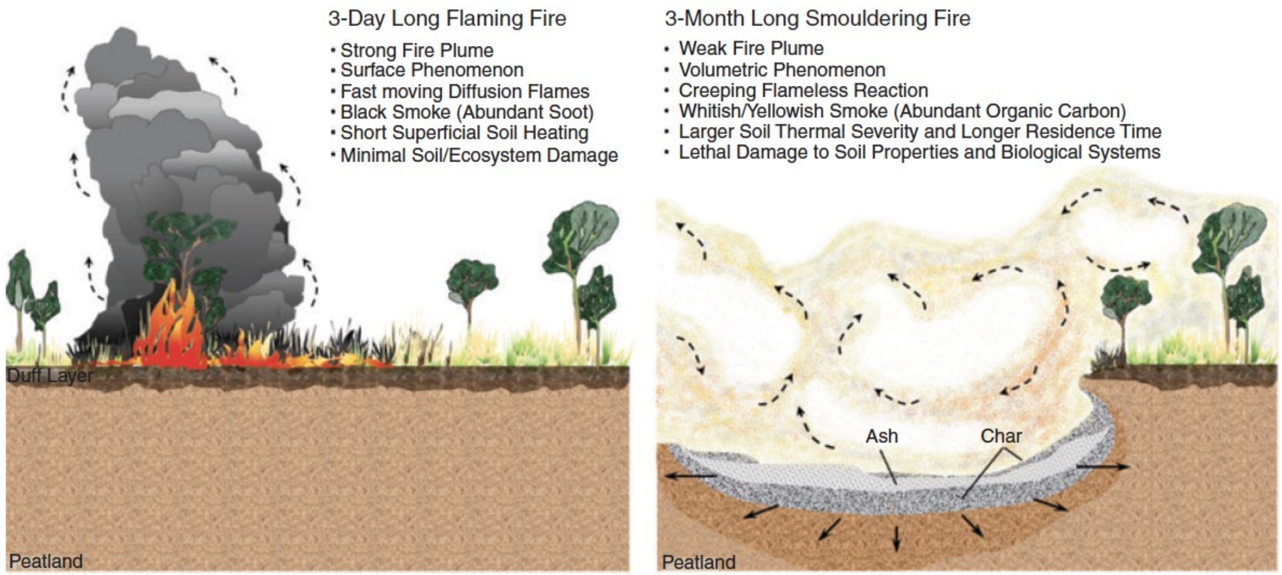
Boreal wildfires are very unique (1)

- Boreal forest fires are mainly set by lightning, not people.

(Veraverbeke et al., 2017, Nature Climate Change)

Boreal wildfires are very unique (2)

Boreal forest fires last longer



- 60-90% of fuel consumption comes from carbon in boreal soils (Peat, duff burning).
- Fires burning in the lower 48 U.S. states are often put out as quickly as possible, to avoid damage to property and human lives.
- In the Arctic, where the population is sparser, fires are often allowed to burn and often grow massive.

Boreal wildfires are very unique (3)

Arctic wildfires are often fueled by duff layer smoldering

The duff layer is the organic material layer between the A-horizon (or uppermost soil mineral horizon) and the litter layer.

It is actually the primary carrier of fire in black spruce forest and often supports smoldering combustion.

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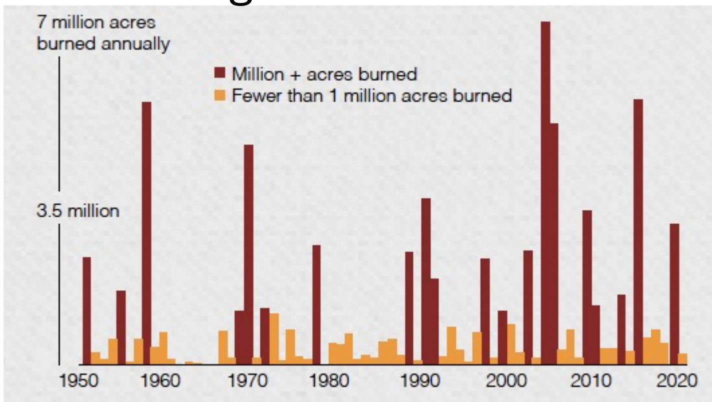
Burning area in Alaska



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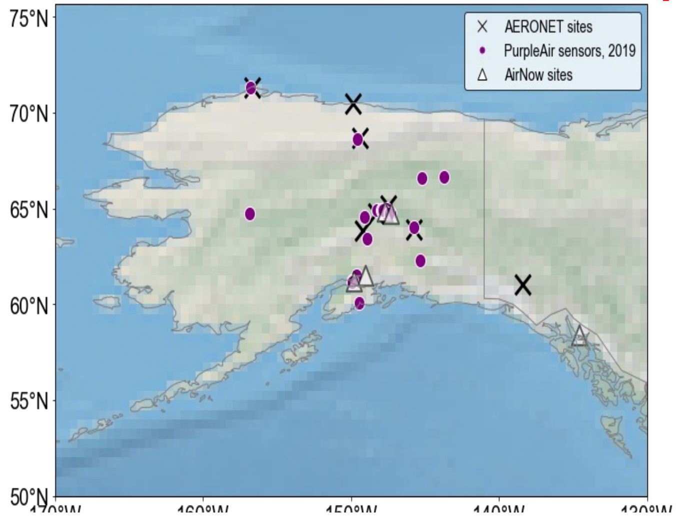

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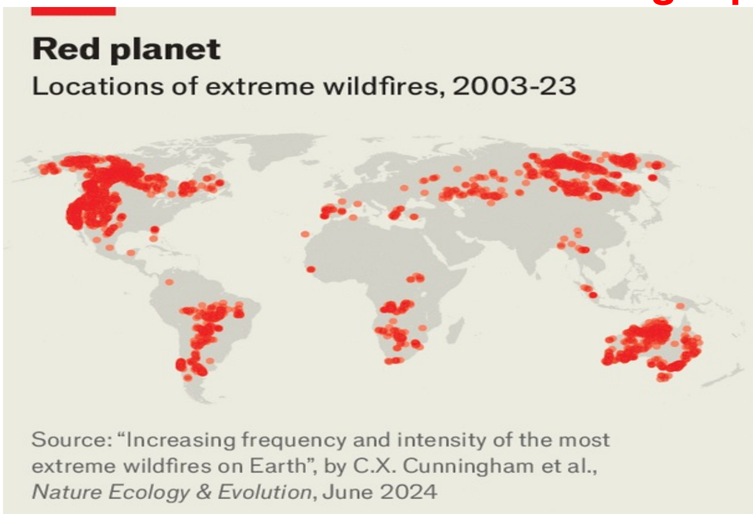
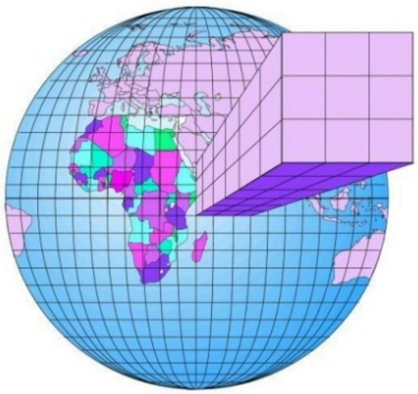
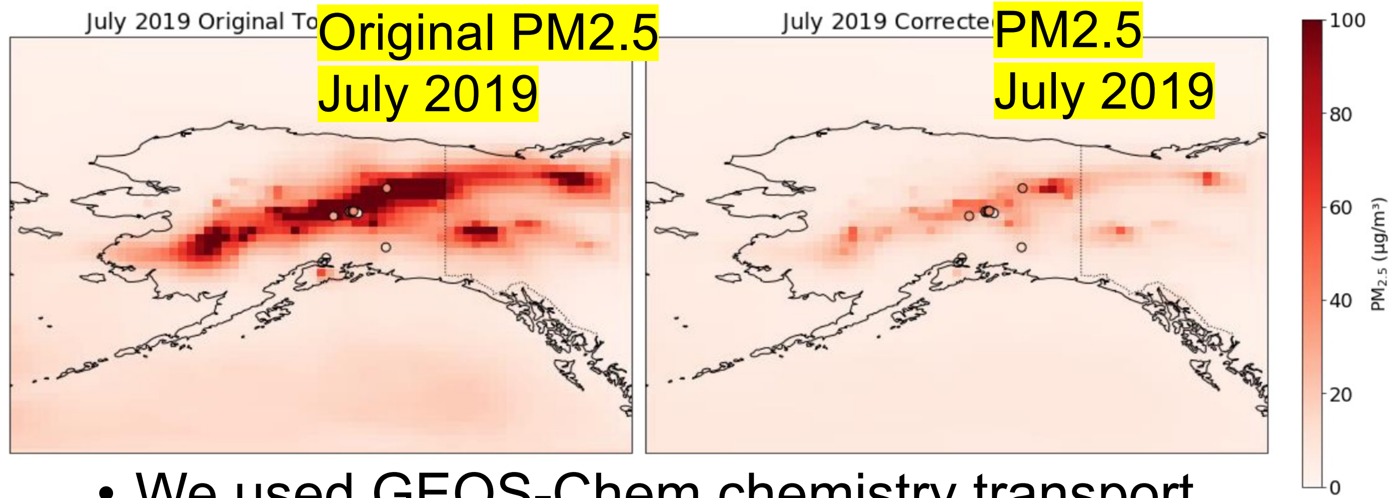


What are the wildfire Impacts on Alaska air quality in the past two decades?

GEOS-Chem simulation





- We used GEOS-Chem chemistry transport model to simulate the PM2.5 concentrations in Alaska from 2003 to 2020, May-September.
- We then used DEC and Purple Air measurements to re-pencentile the GEOS-Chem simulations and remove model bias.

(Hahn et al., Environ. Res. Lett, 2025)

Purple Air

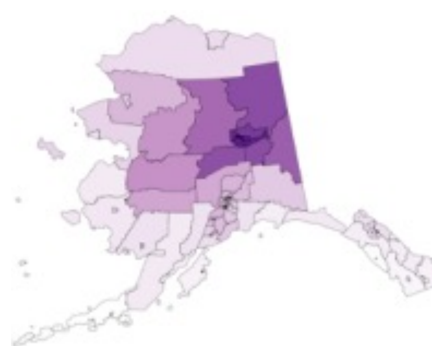
DEC/BAM

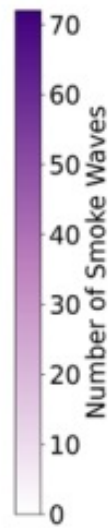
Develop Wildfire Smoke Metrics using GEOS-Chem and Purple Air data

- We then built several wildfire smoke metrics to assess the wildfire impacts on Alaskan communities in the past two decades.
- Annually Alaskans experienced **~3.5 million person-days** of moderate smoke and **~0.8 million person-days** of dense smoke
- **Smoke exposure ≠ area burned**: 2019 had record person-days despite only the 5th-largest burned area, showing that population exposure depends on fire location and transport, not just acres burned
- New metrics ("number of smoke waves", "longest smoke wave", "person-days of smoke exposure") better capture cumulative, population-weighted risk than acres burned or AQI.

Number of Smoke Waves

2003-2020



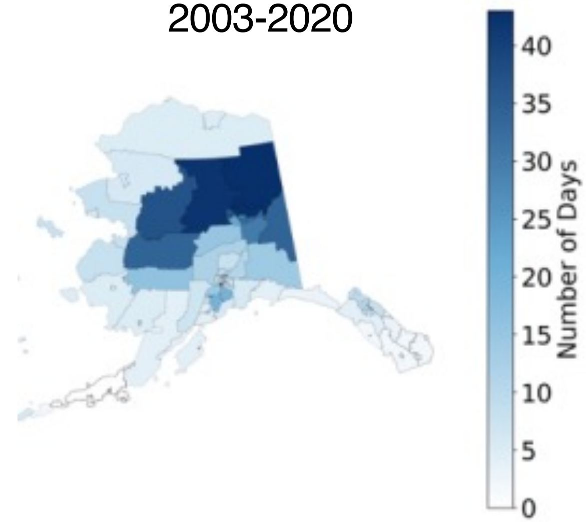


(Hahn et al.,
Environ. Res. Lett, 2025)

Smoke wave
Two or more consecutive days with WFS $PM_{2.5}$ over 9 μg/m^3 (Moderate or worse air quality)

Length of Longest Smoke Wave

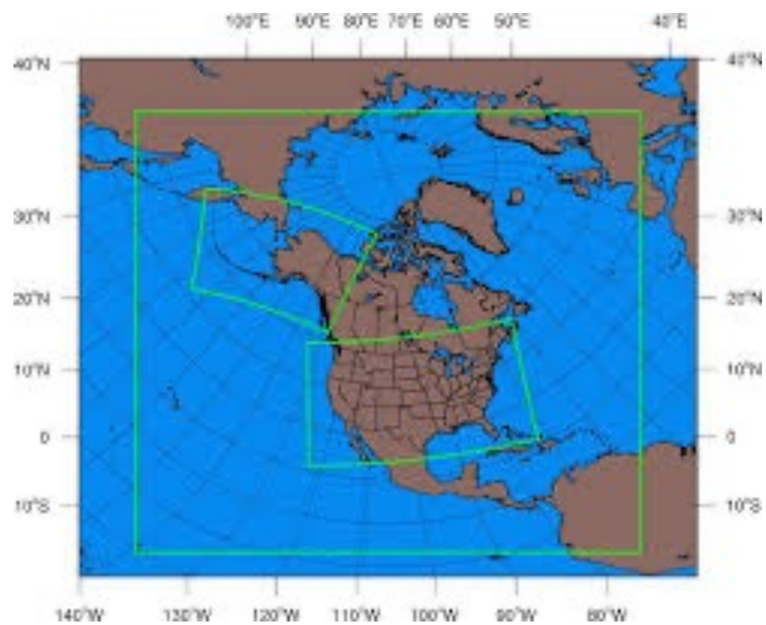
2003-2020



Hahn group (UAA)

Zhiwei Dong

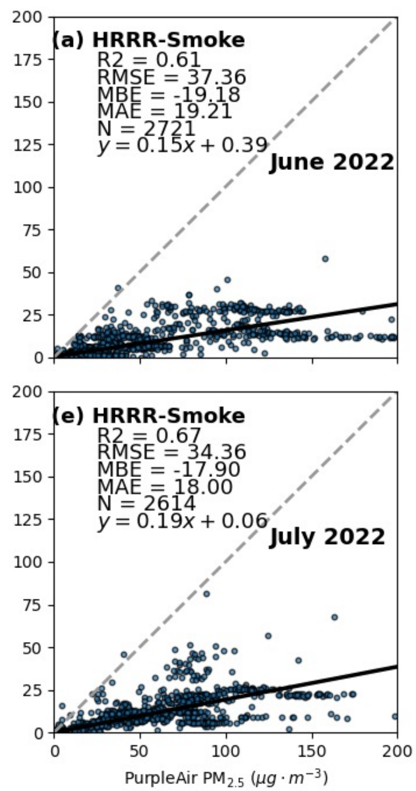
Can we achieve better air quality forecast during wildfire season in Alaska?



HRRR-Smoke provides high resolution (3km x 3km) surface smoke forecast in Alaska since 2020.

High-resolution air quality forecast tends to be too low by a lot…

HRRR smoke model

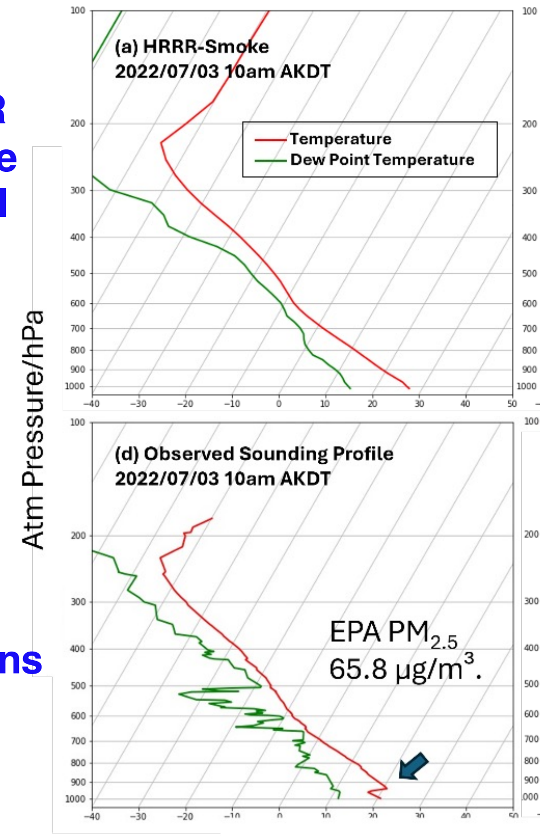


Purple Air

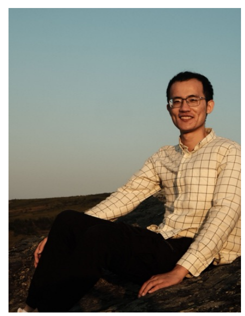
Temperature profile in Fairbanks on a smoky day

HRRR smoke model

Observations

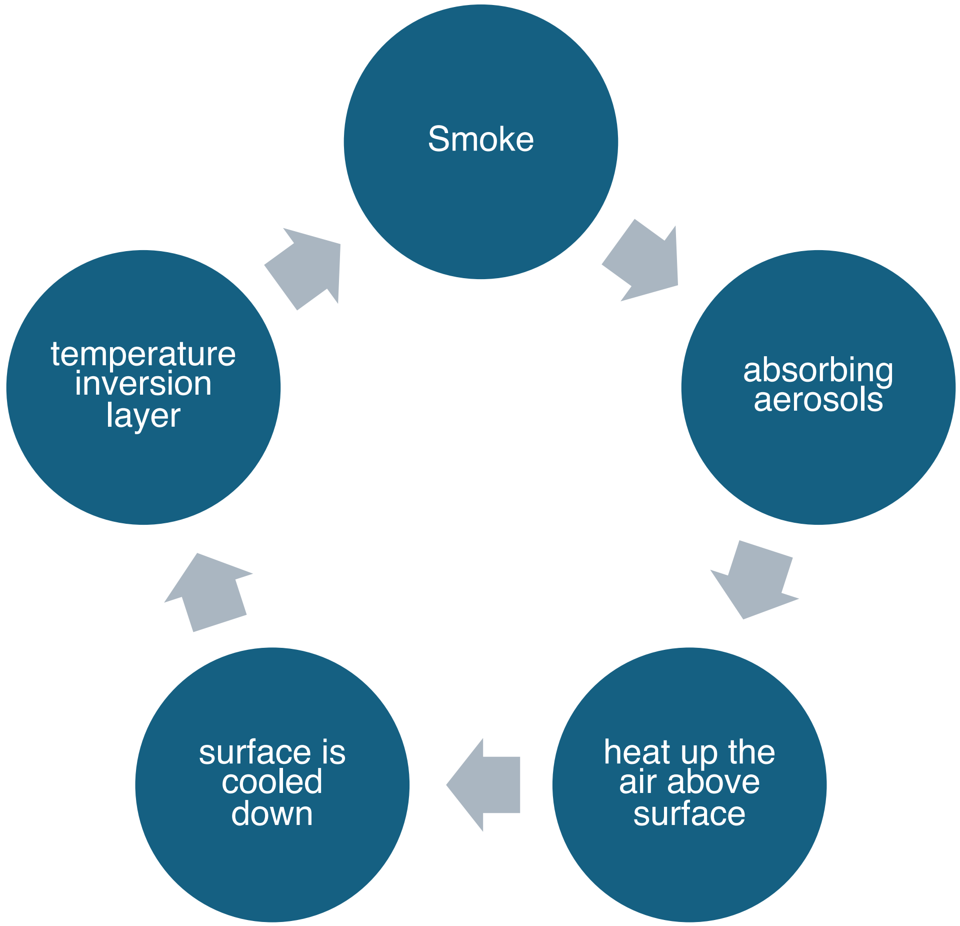


Zhiwei Dong



(Dong et al., submitted)

A positive feedback on smoke-weather interaction…likely underrepresented in most models



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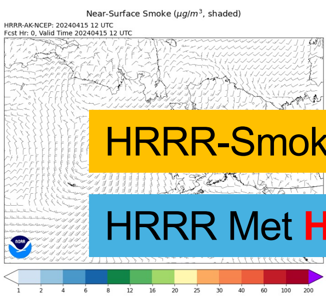
(Dong et al., submitted)

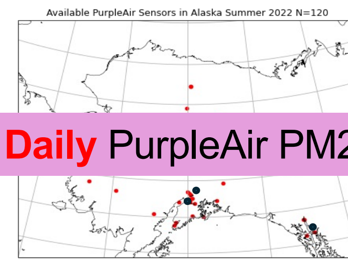
Develop Machine Learning approach to improve air quality forecast to …bypass the complexity of physics!



HRRR-Smoke **Hourly** Forecasts

HRRR Met **Hourly** Forecasts

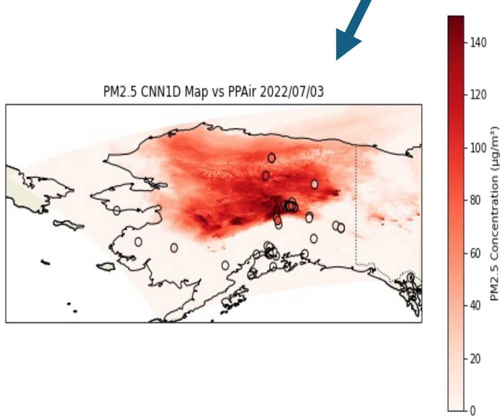
Step1: Use machine learning to build relationship/model between collocated HRRR variables and PurpleAir PM2.5



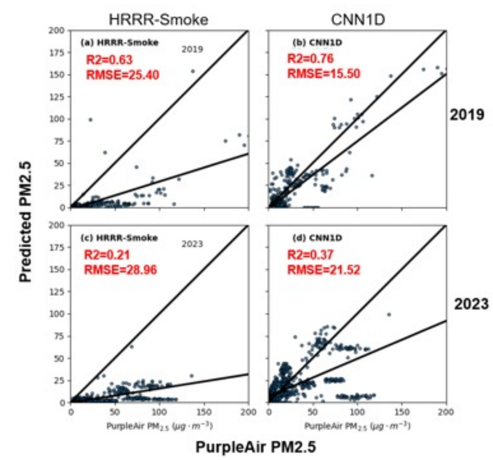
Calibrated **Daily** PurpleAir PM2.5

Step2: Apply the trained Machine Learning model to the entire domain to generate the PM2.5 map

Popular Machine Learning Models:
Random Forest (RF)
Convolutional Neural Network (CNN)



Step3: Post-process with Satellite **Daily** AOD



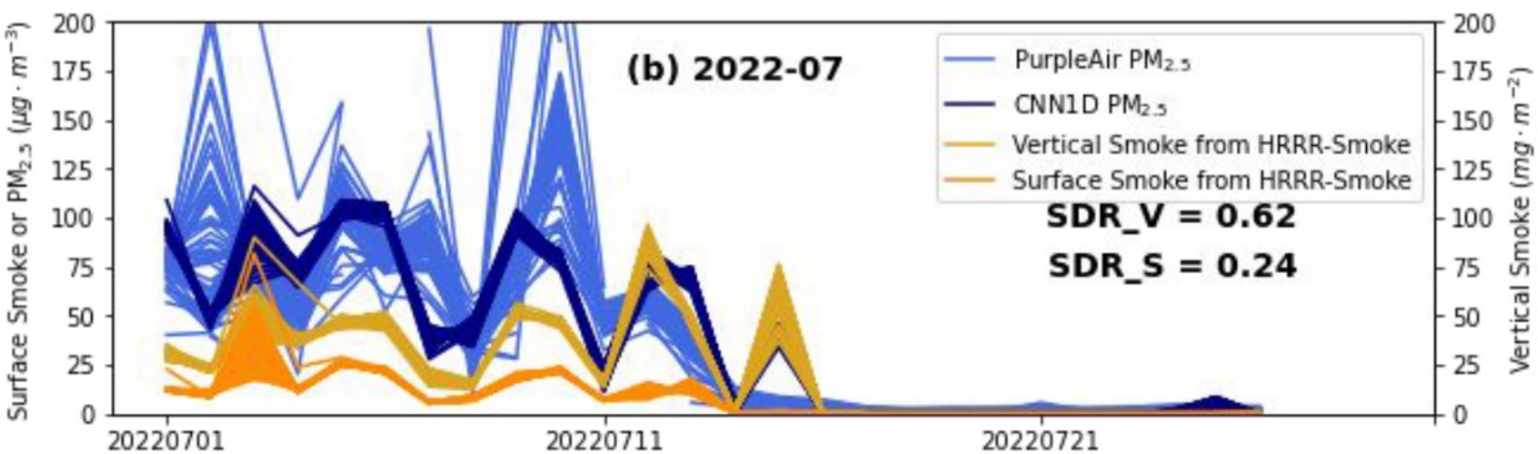
HRRR-Smoke bias is more likely due to vertical distribution rather than emission strength

Table 3 Average Increase of RMSE after 10 times of permutation of each predictor.

	Average RMSE	Increase RMSE
Surface smoke	134	119
Vertical Smoke	126	111
CAPE	17.8	2.3
TEMP	17.7	2.2
WIND-80m	17	1.52
WIND-10m	16.8	1.27
PBL	16.7	1.17
Precipitation	16.2	0.68
RH	15.9	0.4
Pressure	15.9	0.37
Visibility	15.5	0

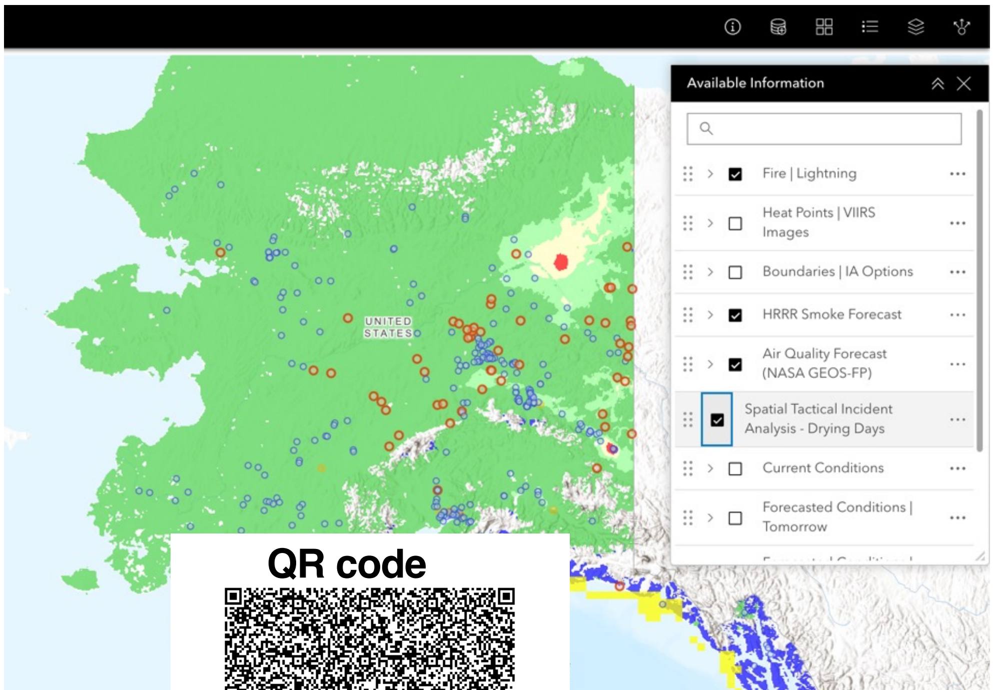
Surface Smoke and **Vertical Column Smoke variables** are the major contributors to our machine learning model. While **Visibility** has no contribution at all!

PurpleAir PM2.5 has higher changing trend correlation with Vertical Column Smoke, **indicating more smoke were put at higher layers instead of at surface in HRRR-Smoke model.**



(Dong et al., 2025, submitted)

An integrated ArcGIS system for wildfire management



QR code

Air quality website: http://fireaq.alaska.edu

QR code

GINA www.gina.alaska.edu

Quinn McHenry