# Wildfire Smoke Composition and Evolution


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UNIVERSITY of WASHINGTON

The University of Montana

UNIVERSITY of WYOMING

Colorado State University

University of Colorado Boulder

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

# Understanding wildfire smoke composition is critical to predict air quality, nutrient cycles, climate and weather.

| WE-CAN focused on 3 topics: | Why are these important? |
| --- | --- |
|  fixed nitrogen emissions and evolution | Nitrogen is central to within-plume chemical evolution, and nitrogen deposited to ecosystems. |
|  evolution of aerosol optical properties | Rivers of smoke are present over North America in summer and they change light availability. |
|  cloud activation and chemistry in wildfire plumes | Clouds chemically process smoke. Smoke particles serve as condensation nuclei (can form cloud droplets) and ice nuclei. |

https://www.eol.ucar.edu/field_projects/we-can

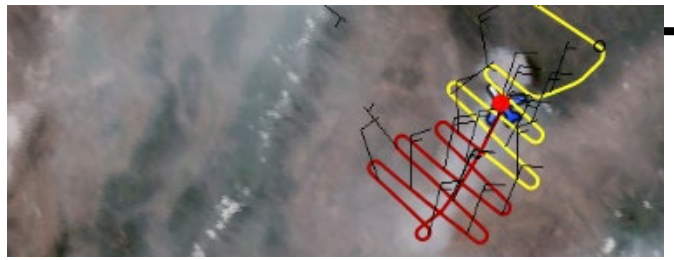
# WE-CAN had an extensive in situ measurement payload and a lidar which was used primarily for navigation.

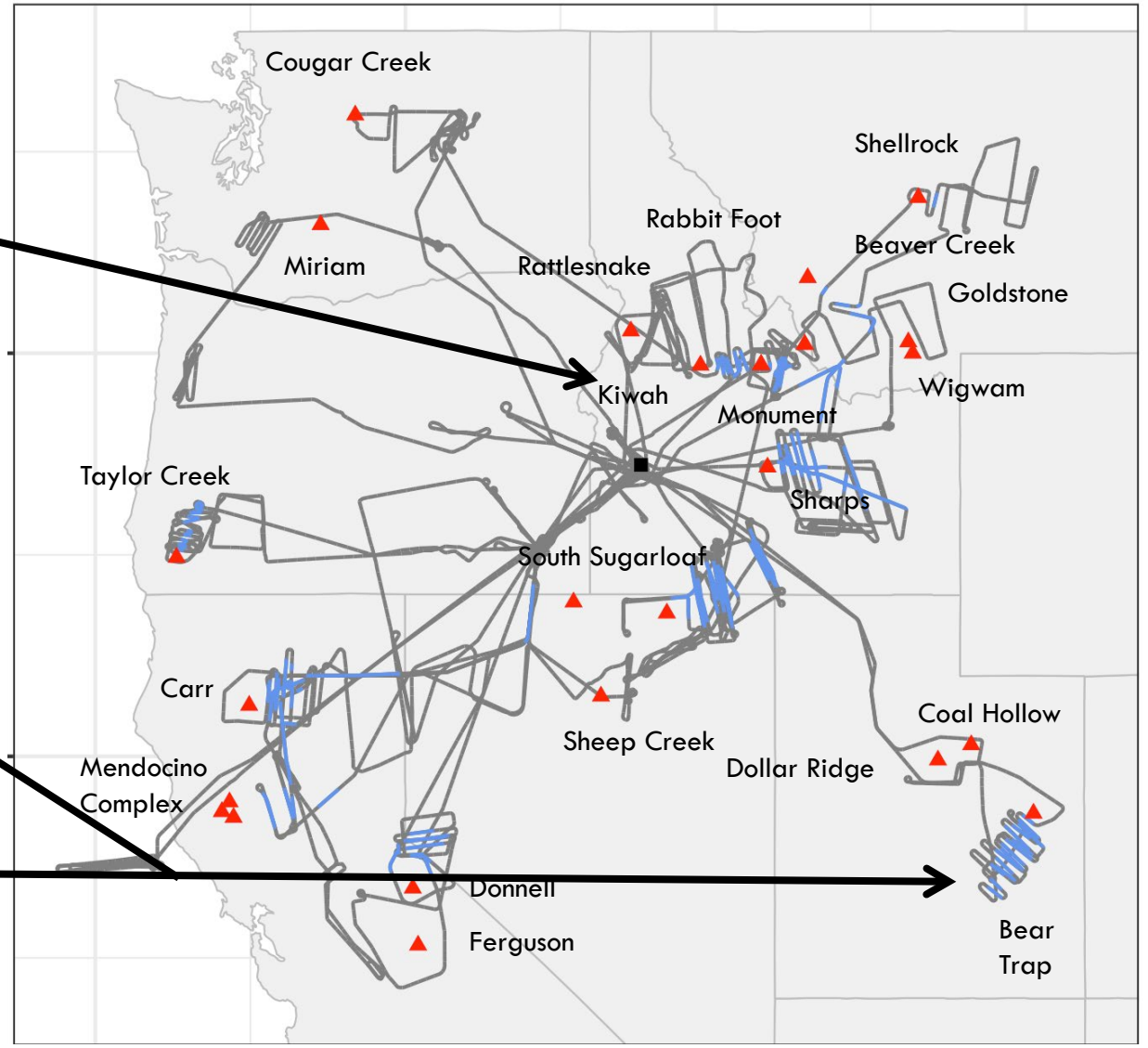
| 3 topics: | Corresponding measurements: |
| --- | --- |
|  fixed nitrogen emissions and evolution | $NO_X$, $NH_3$, PANs, $HNO_3$, HONO, HNCO, HCN, $CH_3CN$, aerosol composition and extensive VOCs |
|  evolution of aerosol optical properties | Absorption with Thermal Denuder, Extinction, Scattering and Absorption and Aerosol Composition |
|  cloud activation and chemistry in wildfire plumes | Cloud-active particles (CCN, INPs), Microphysics in Smoke- Impacted Clouds, Cloud water for Chemical Analysis |

https://www.eol.ucar.edu/field_projects/we-can

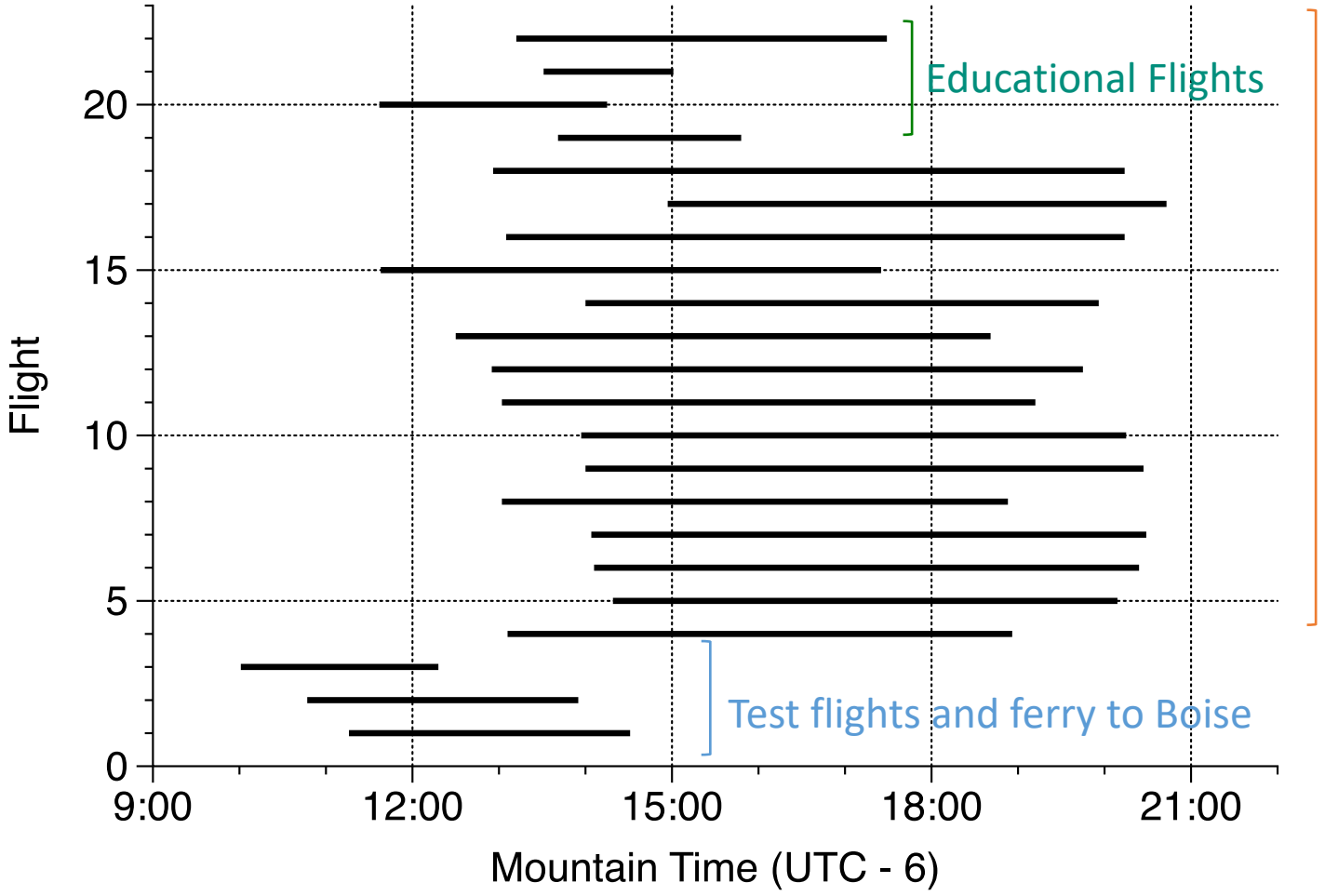
# In 2018, WE-CAN used the NSF/NCAR C-130 to sample fresh smoke (30 min – 4 hours) from>20 large fires.

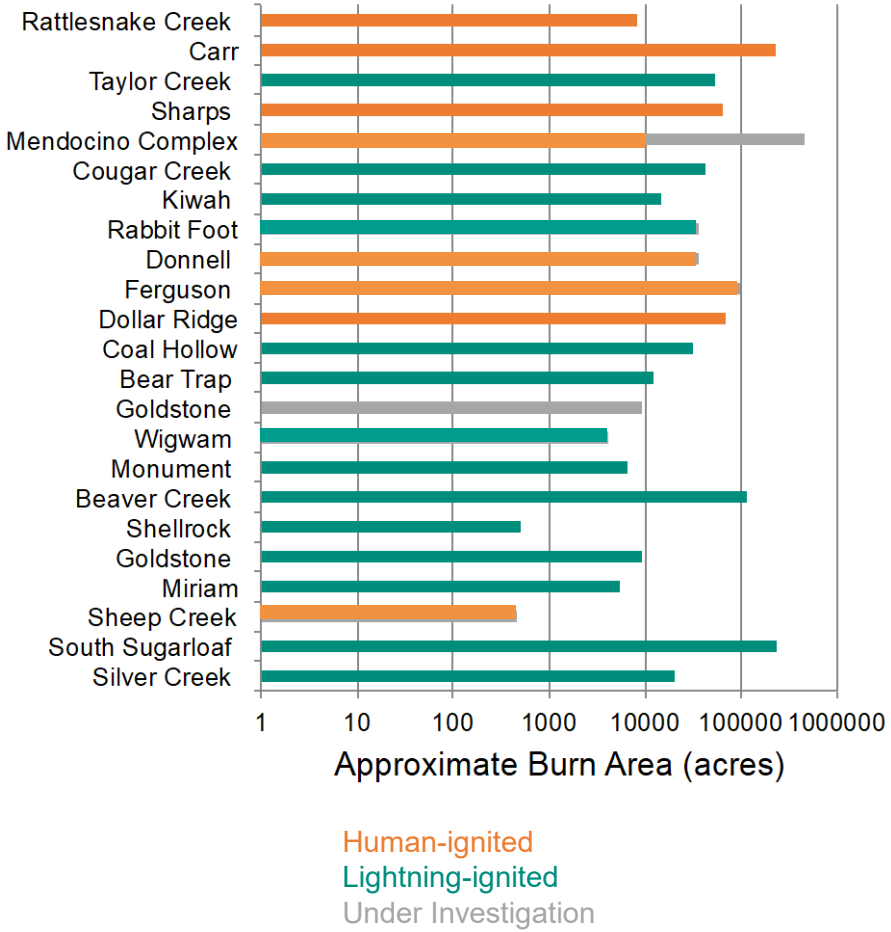




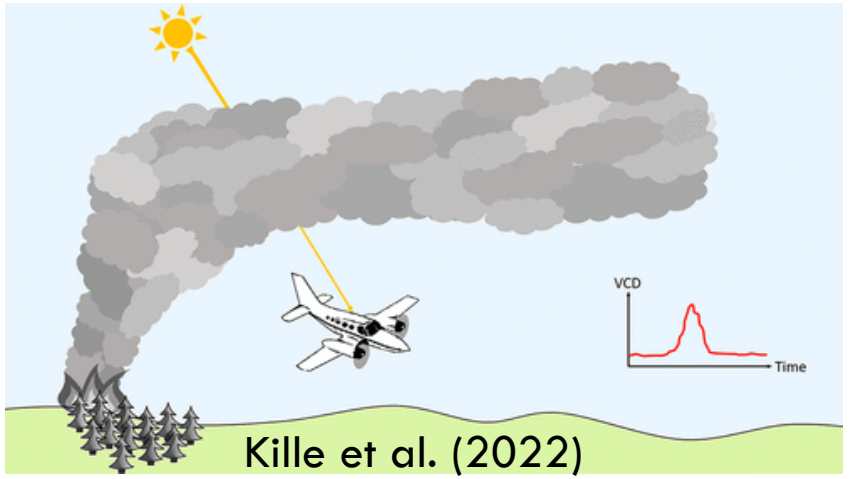


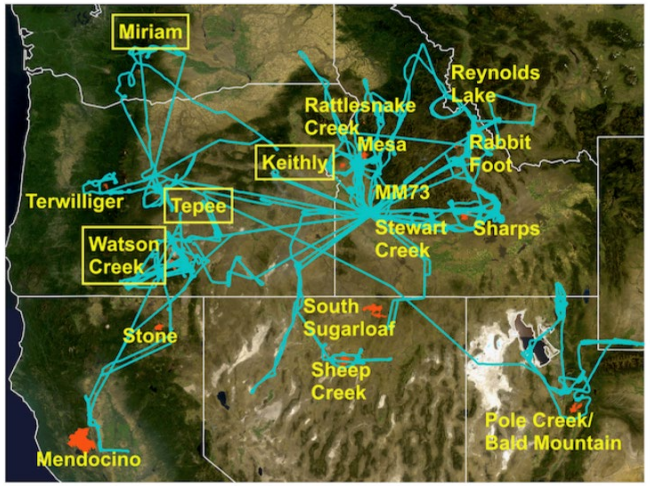
# WE-CAN flights focused on large fires in the afternoon afternoons with relatively high smoke injection heights.



# NSF-C130 coordinated with the UW King Air to sample smoke from in situ and remote-sensing approaches.



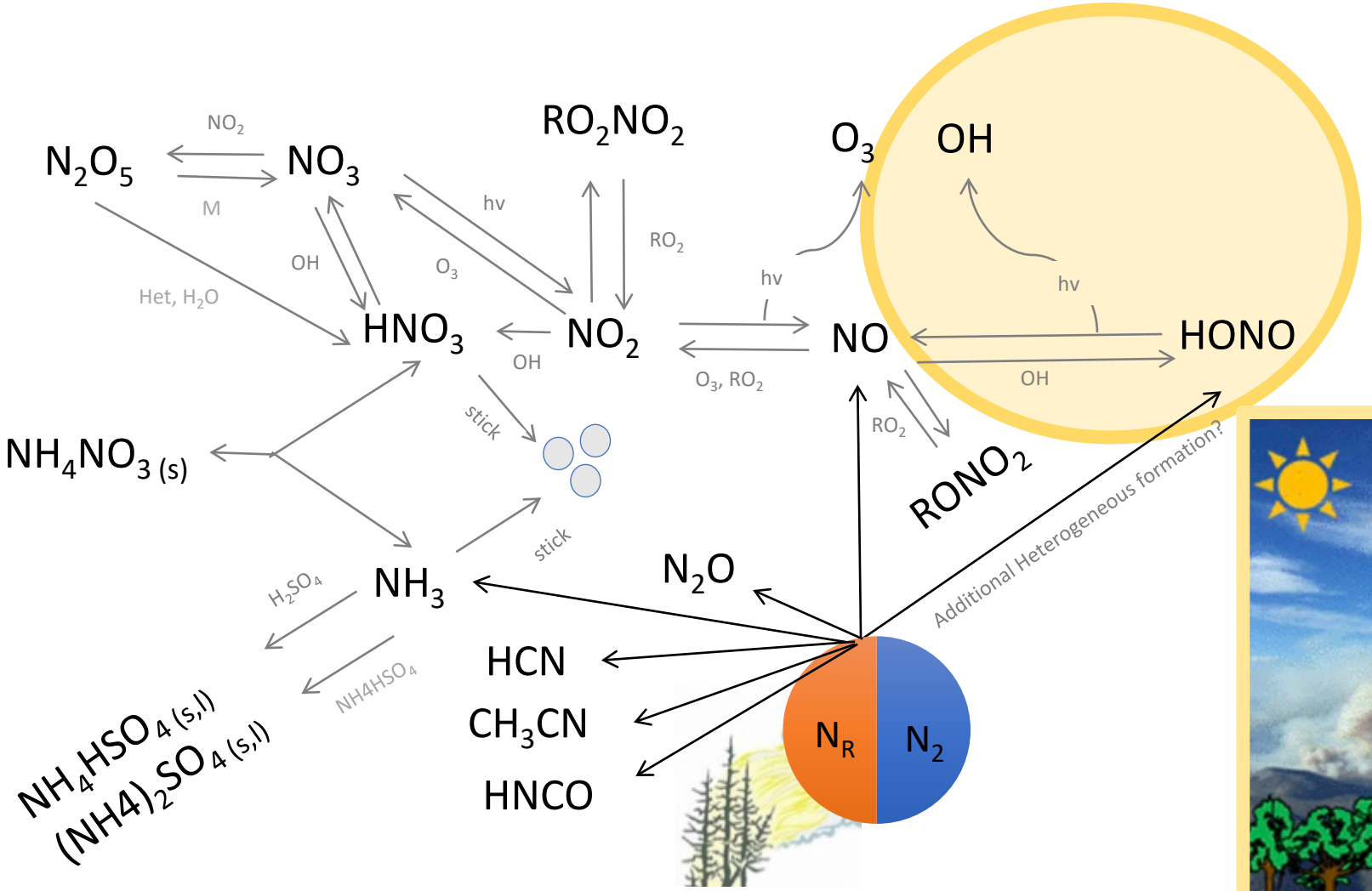

Key: BB-Flux Goals:

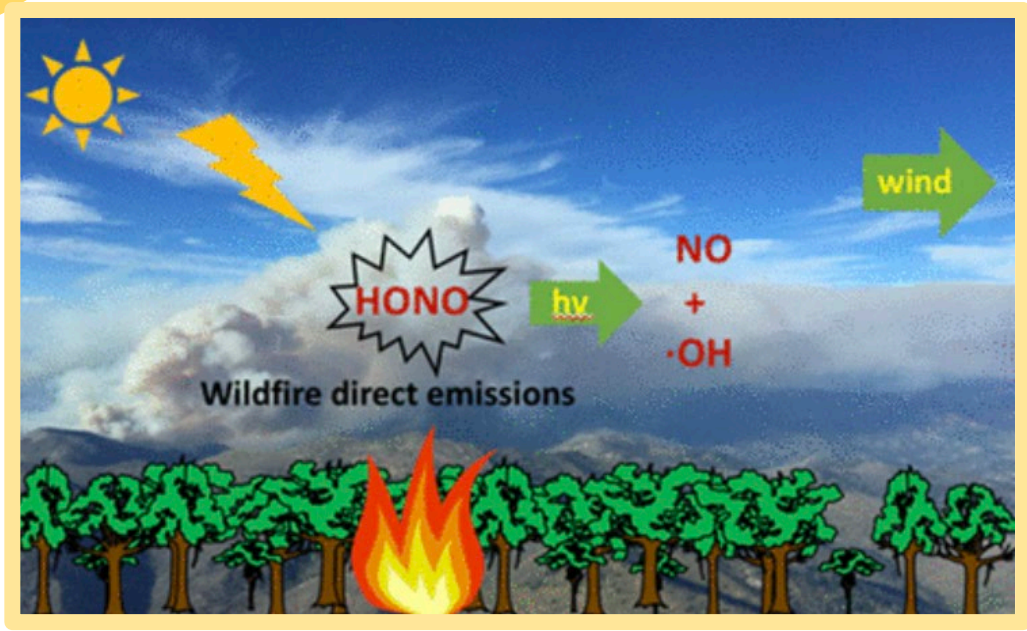
1) Quantify emission fluxes of CO, $CO_2$, other gases, and particle volume;
2) Characterize plume injection height;
3) Remote sensing and in-situ observational comparisons.

Photos and more information: https://volkamergroup.colorado.edu/timeline/field/bb-flux

# Wildfire smoke is chemically complex, and it changes rapidly.

*WE-CAN filled knowledge gaps enabling us to predict plume evolution.*

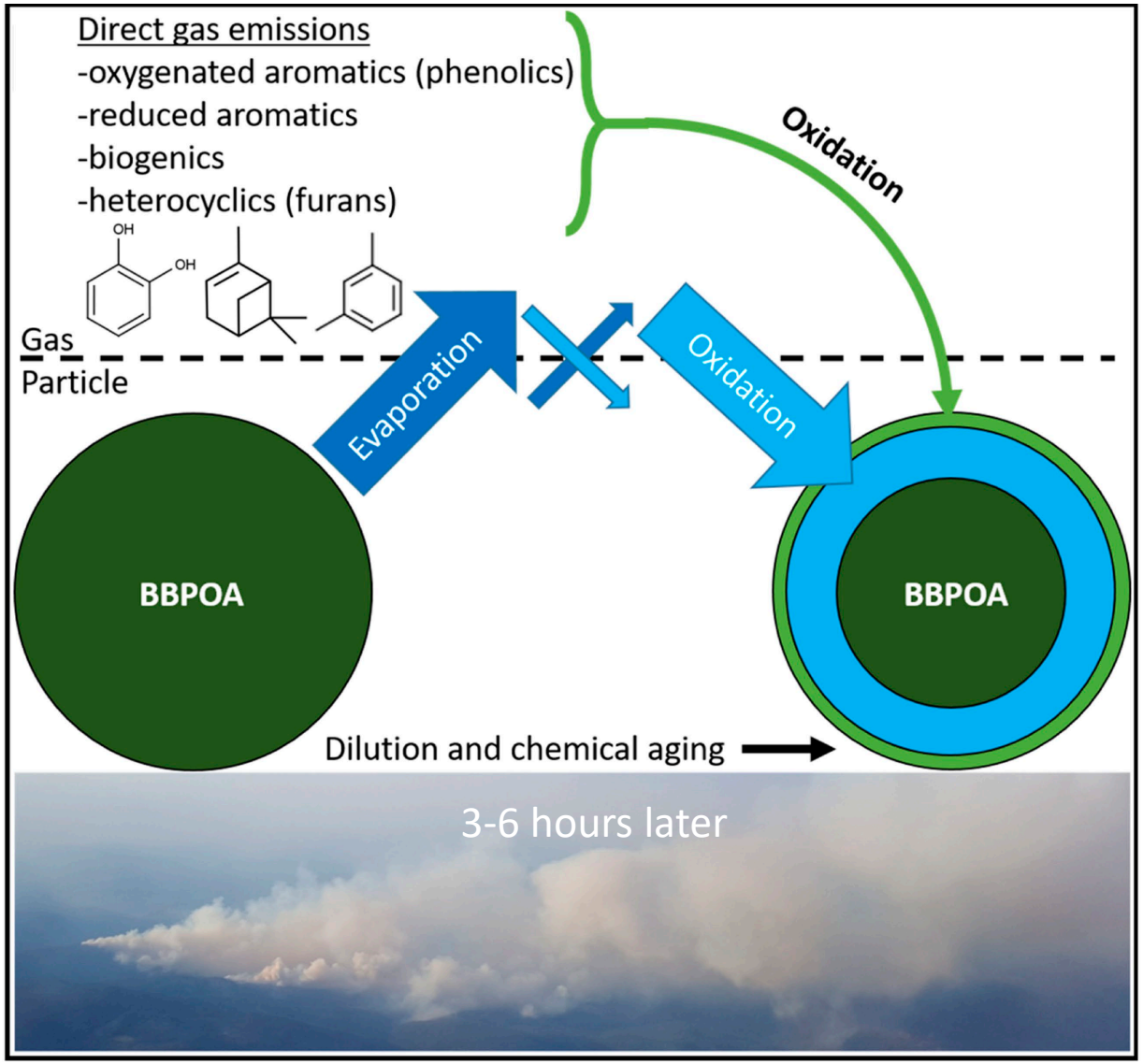



Peng et al. (2020)

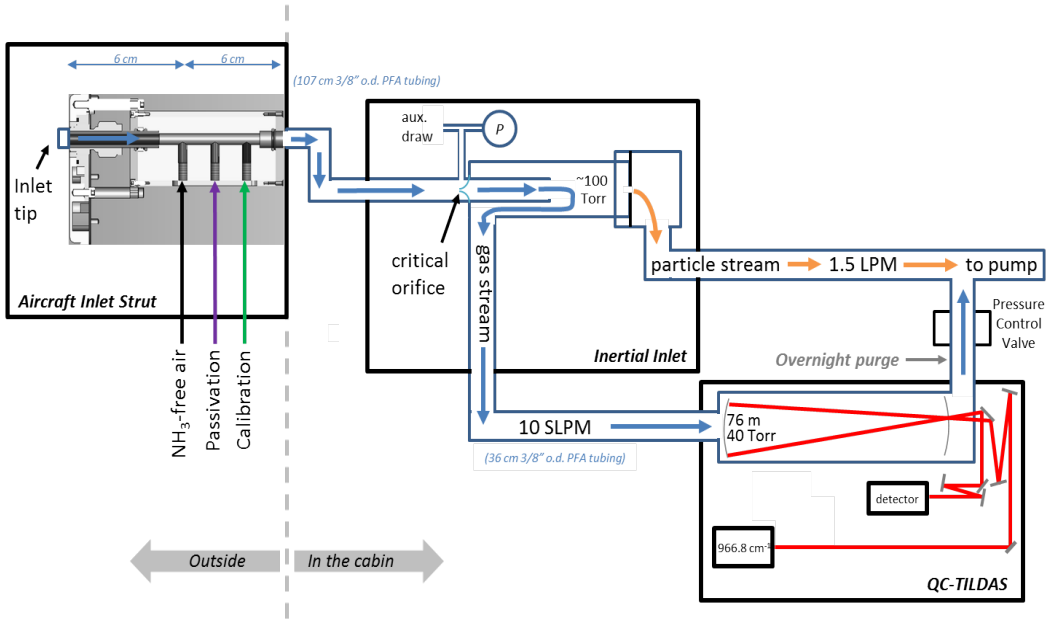
# Fine particulate matter (PM) is the part of smoke you see.

*WE-CAN illuminated ways PM mass and light absorption evolve in smoke.*




Palm et al. (2020)
see also Sullivan et al. (2022)

# Non-traditional air pollutants are important and under-constrained.
## *WE-CAN instrument development benefits other air quality research.*




**2017 - 2018**

**Ex: $NH_3$ Instrumentation Optimized for Smoke**

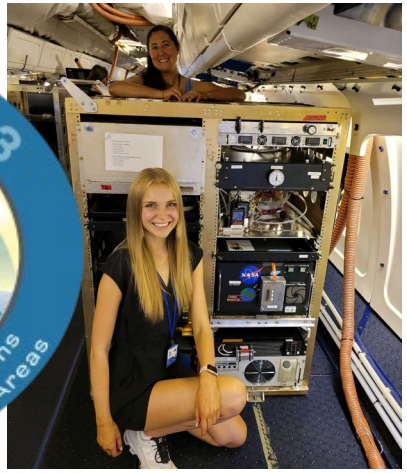
Pollack et al. (2019); Lindaas et al. (2020)

**2019 -2022: Applied to Agriculture**

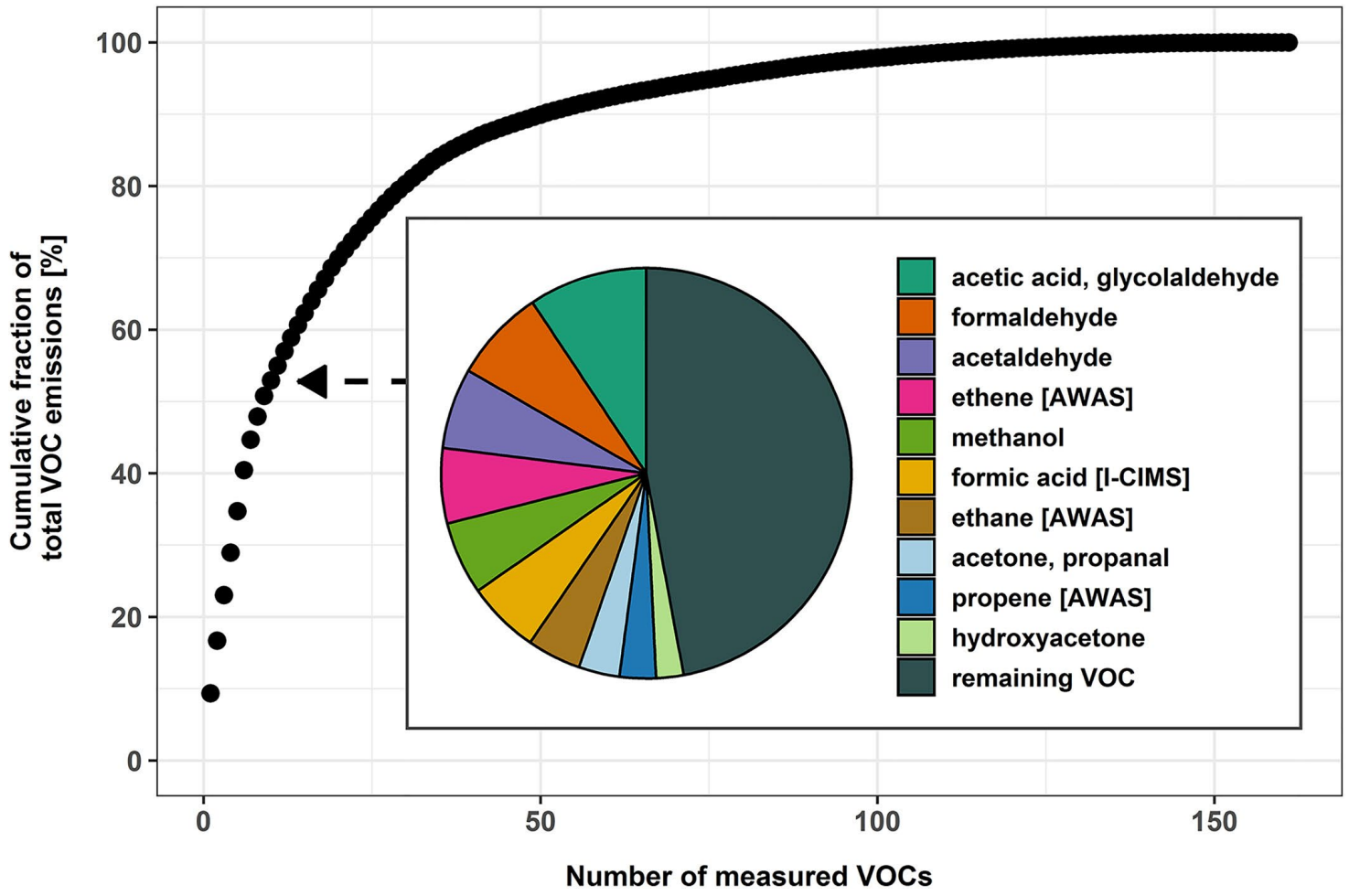

TRANS$^2$AM: Pollack et al. (2021)
Juncosa Calahorrano et al. (under revision)

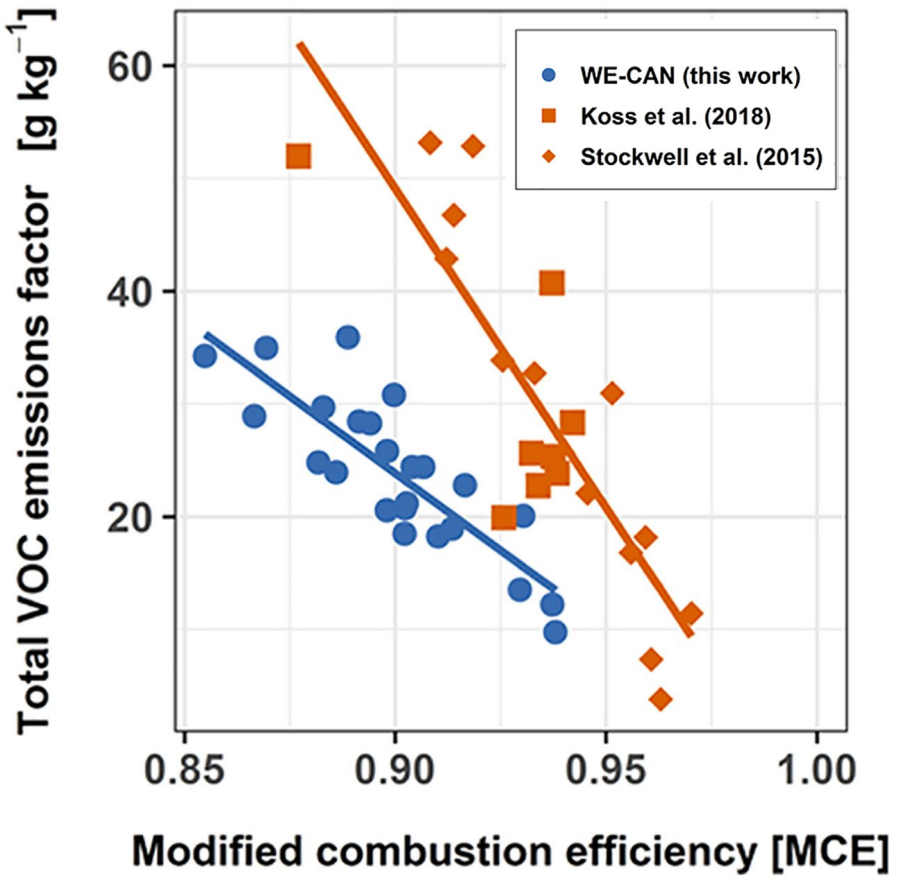
**2023: Applied to Megacities and Marine Regions**

NOAA 2023 AEROMMA Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas



# WE-CAN provides a robust understanding of VOC emissions and their direct AQ impacts.



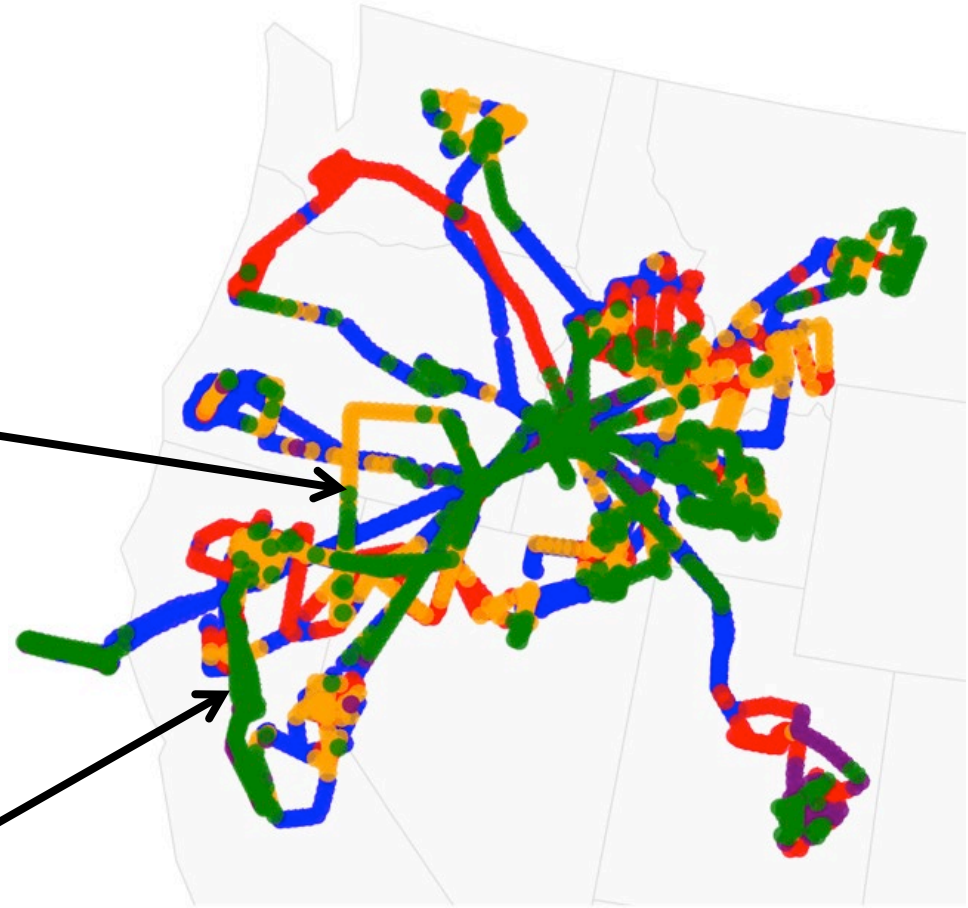




Permar et al. (2021)

# Smoke travels and its approximate age can be chemically fingerprinted.

## *WE-CAN surveyed mixed-age smoke covering large regions.*





Not in Smoke

Young Smoke (< 7 hrs)

Medium Age Smoke (7-17 hrs)

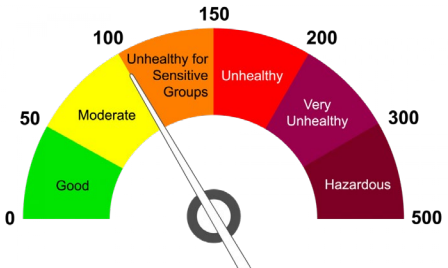
Older Smoke (< week)

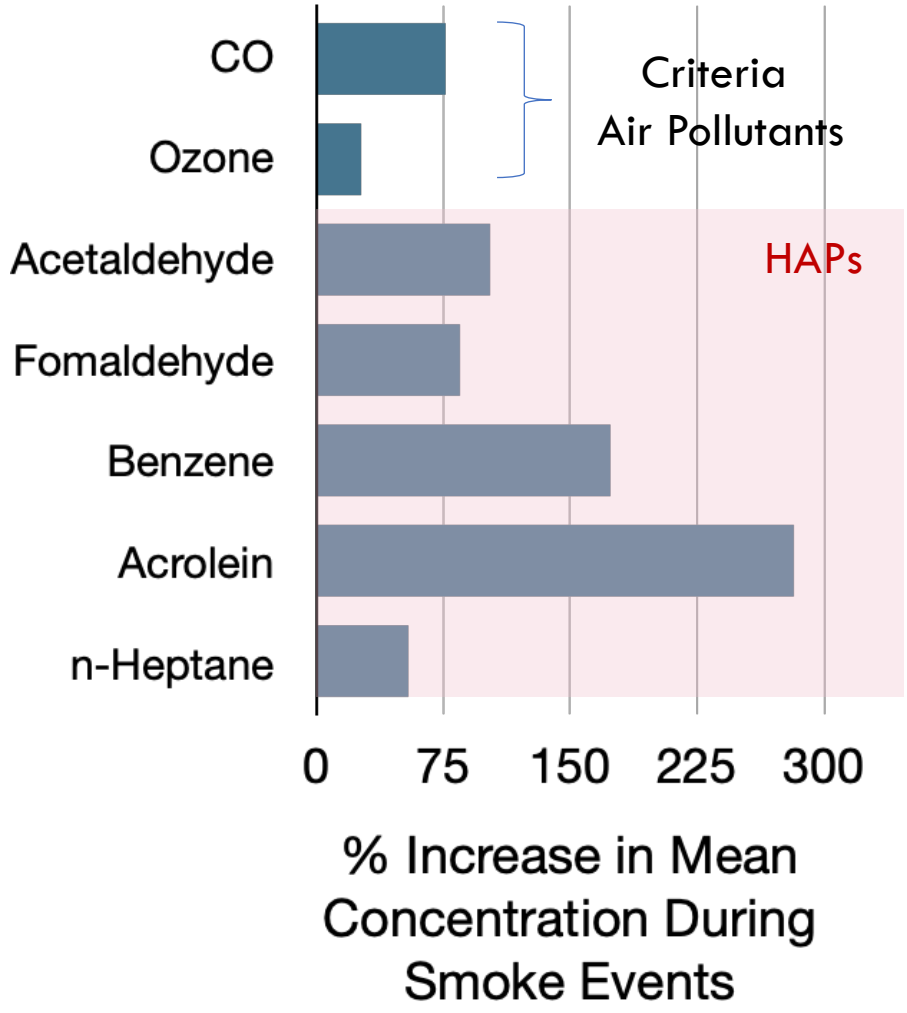
Oldest Smoke (> week)

O'Dell et al. (2020); Permar et al. (2021)

# You cannot see (or smell) all the air quality impacts of smoke.
## *WE-CAN provides a robust understanding of emissions and AQ impacts.*

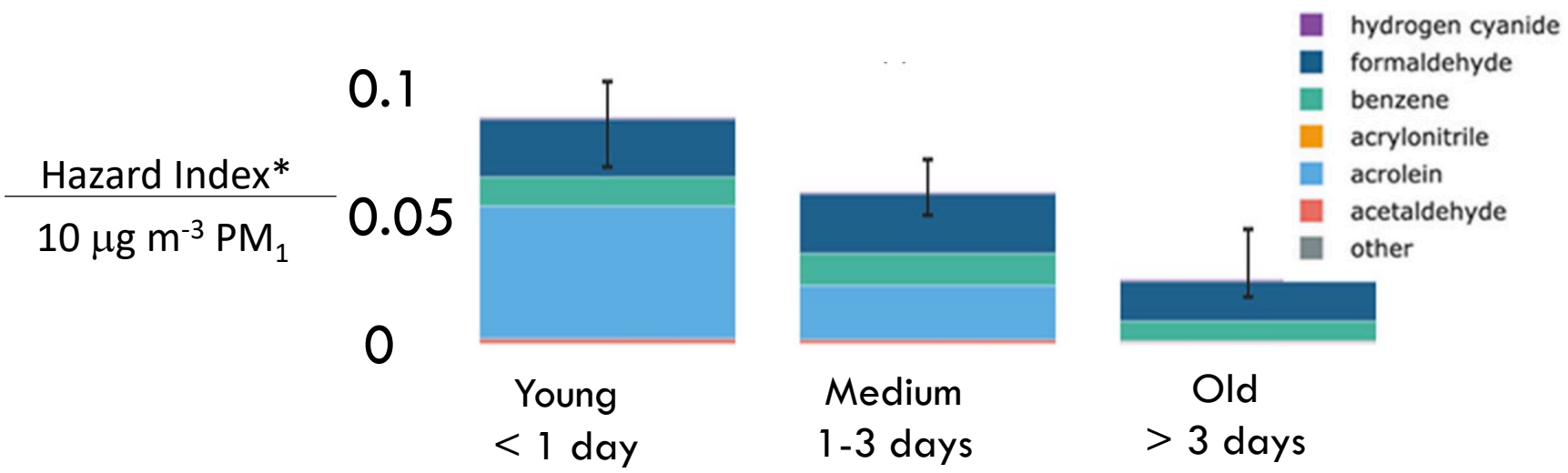

AQI based on particulate matter (PM)

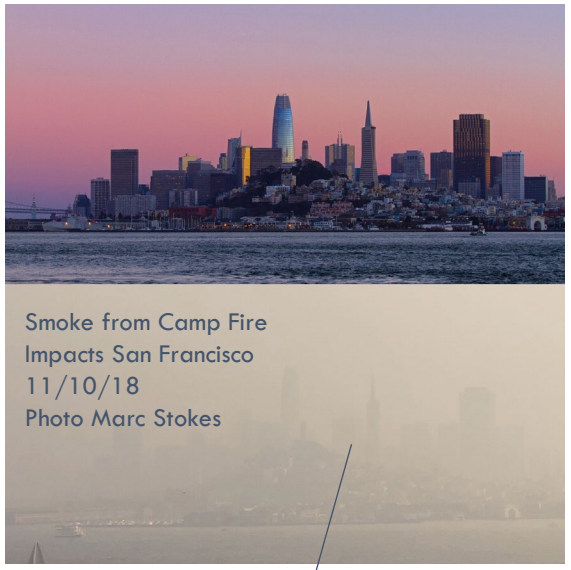



Lill et al. (2021)

# You cannot see (or smell) all the air quality impacts of smoke.
# *WE-CAN provides a robust understanding of emissions and AQ impacts.*



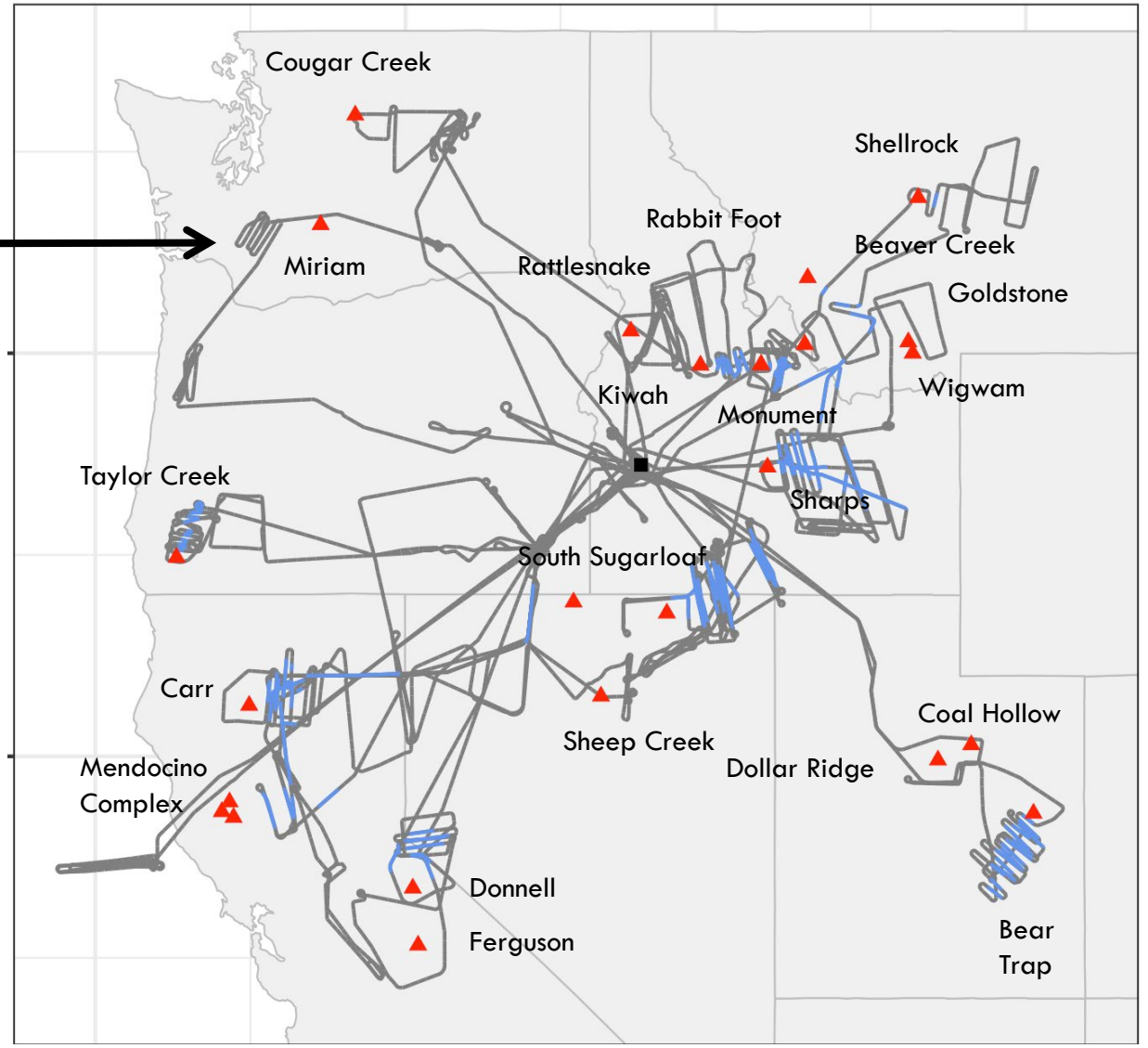




* A Hazard Index is a tool to understand health risks of chemical mixtures. Potential for adverse effects exists when this value > 1.

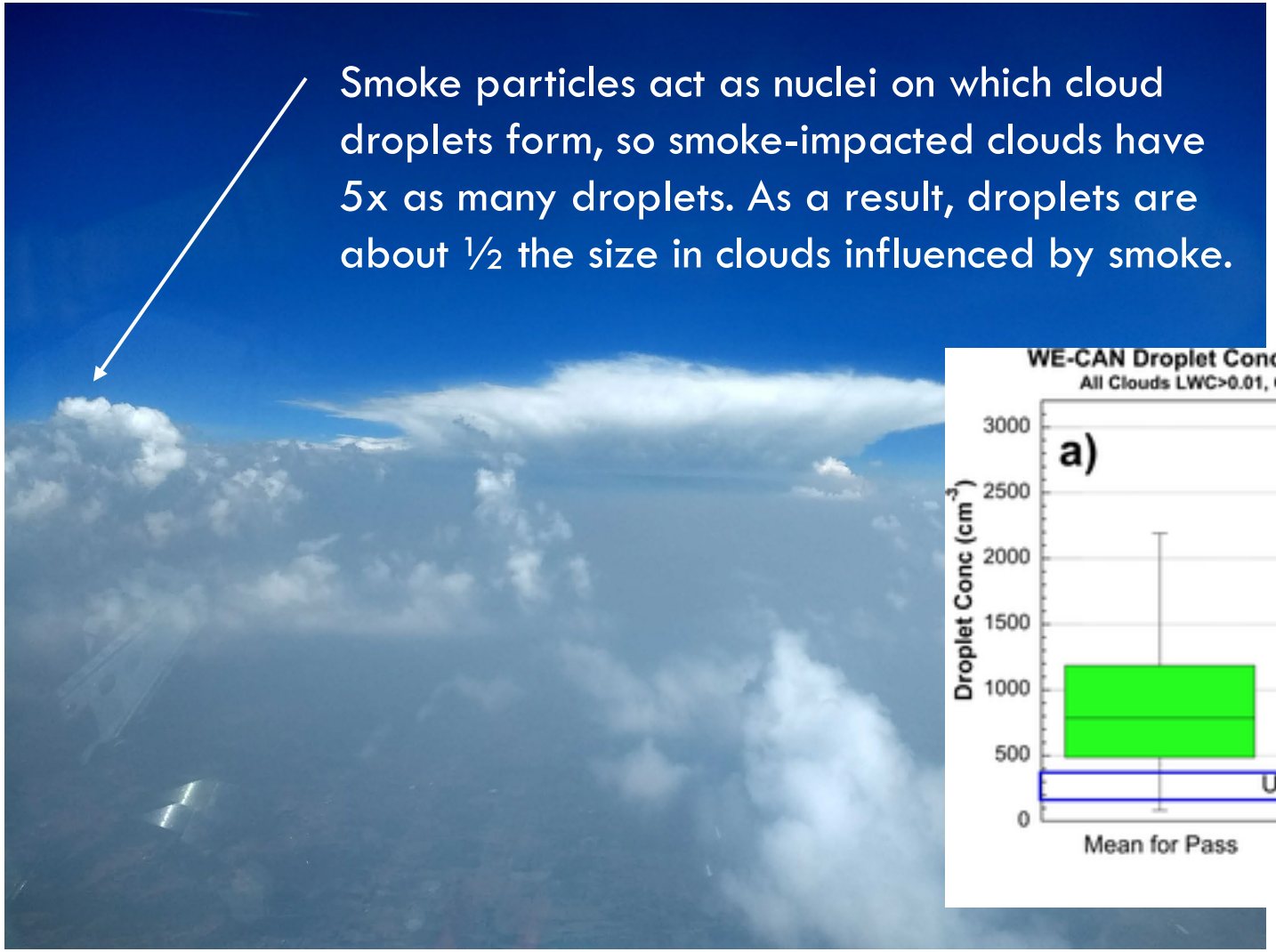
Young - Medium Age Smoke
200 μg $m^{-3}$ $PM_{2.5}$
Acute Hazard Index > 1
Benzene was 5-6 μg $m^{-3}$
Local weather impacts too.

O'Dell et al. (2020)

# WE-CAN sampled 5 different instances of smoke-cloud mixtures.

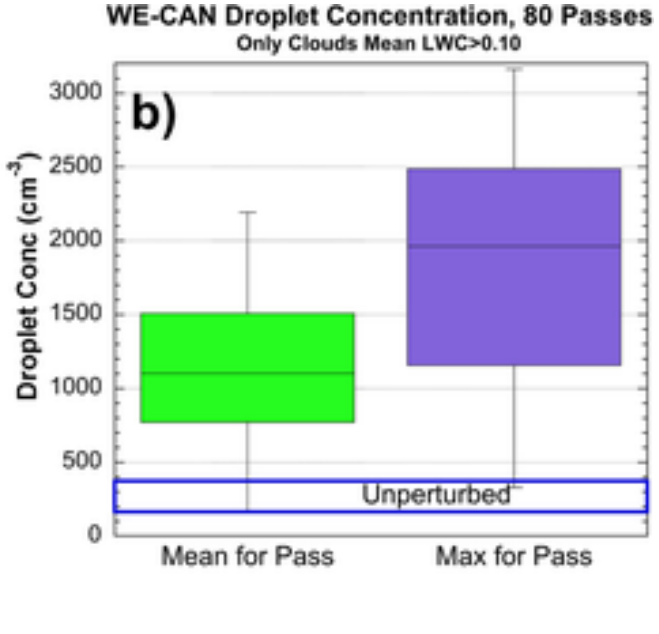



# Smoke impacts climate and weather. *WE-CAN showed that smoke-impacted clouds reflect more light and could produce less rain.*










Twohy et al. (2021); see also Barry et al. (2021) for INPs

# In situ observations, like those collected during WE-CAN, are critical for improving models and interpreting satellite observations.

Smoke changes rapidly

*Near-fire chemistry matters.*

Smoke impacts clouds

*Cloud particles are smaller.*

Smoke elevates criteria air pollutants and HAPs.

*Impact is national.*

Necessitated analytical development.

*Rapidly leveraged*

*for other needs.*

Photo from Frank Flocke

# NSF support of WE-CAN also built capacity.

- NOAA/NASA FIREX-AQ
  - Flight patterns
  - Safety protocols with USFS
- NWS Weather Forecasts
  - Development of aerosol parameterizations within cloud / mesoscale models
- Chemical transport models
  - Understanding of missing chemical processes


Safer Field Programs

Best practices in **preventing sexual harassment**

Public Education

Videos and lesson plans

Better Impact Assessments

Health effects

Communication strategies

NSF EPSCoR: prescribed fire (MT)

## Immediate opportunities:

- Build a consolidated system for recording U.S. prescribed fire activity
- Document spectrum of intensities & conditions for prescribed and wildfires
- Challenge models with the wildfires sampled during WE-CAN and BB-Flux

## Challenges:

- Statistics require large sample sizes (more fires)
- Wide scale ranges [time (seconds -> month) and length (m - continental)]
- Disciplinary boundaries require time and effort to overcome
- Decreases in days meteorologically favorable for prescribed fire (Swain et al., 2023)
- Increases in smoke-trapping low-level stagnation days (Swain et al., 2023)
- Coursework is currently lacking for training next generation of scientists