An Evaluation of Biomass Burning Plumes on the Vertical Distribution of Tropospheric Ozone Over the Midwestern United States

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Many thanks to collaborators

NASA HAQAST; U.S. Forest Service; U.S. EPA

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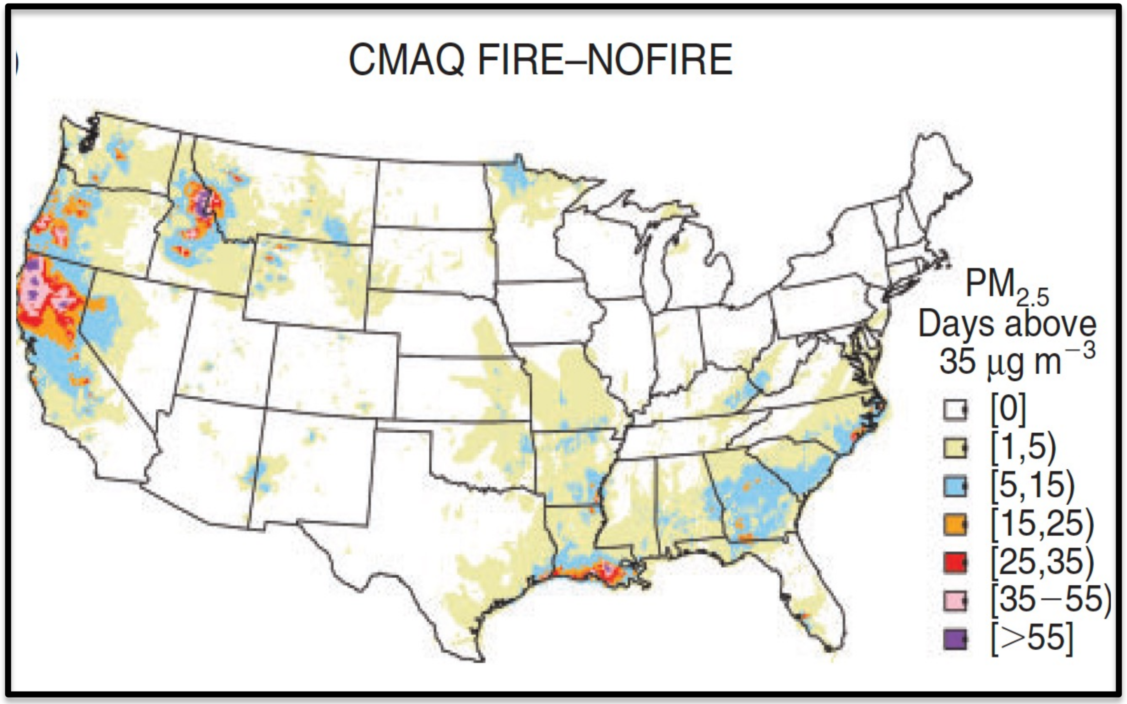
Recent advances

Looking at the larger U.S. with focus on the Midwest

- Study Period 2008-2012, CMAQ: 5.0.1-5.2
- Analysis revealed that BB:
  - Increased $PM_{2.5}$ by a factor of 4
  - Increased O_3 by 14%
  - Health exposure is location based
- These findings have been critical to regulatory work and health studies.
  - National Ambient Air Quality Standards (NAAQS) evaluations
  - Exceptional events demonstrations
  - Source apportionment



- A Recent study revealed BB can lead to a 10 to 80 ppbv enhancement of surface ozone in the Midwest.

Wilkins *et al.* 2018, *Int. J. Wildland Fire; Wilkins et al. 2020, JGR*

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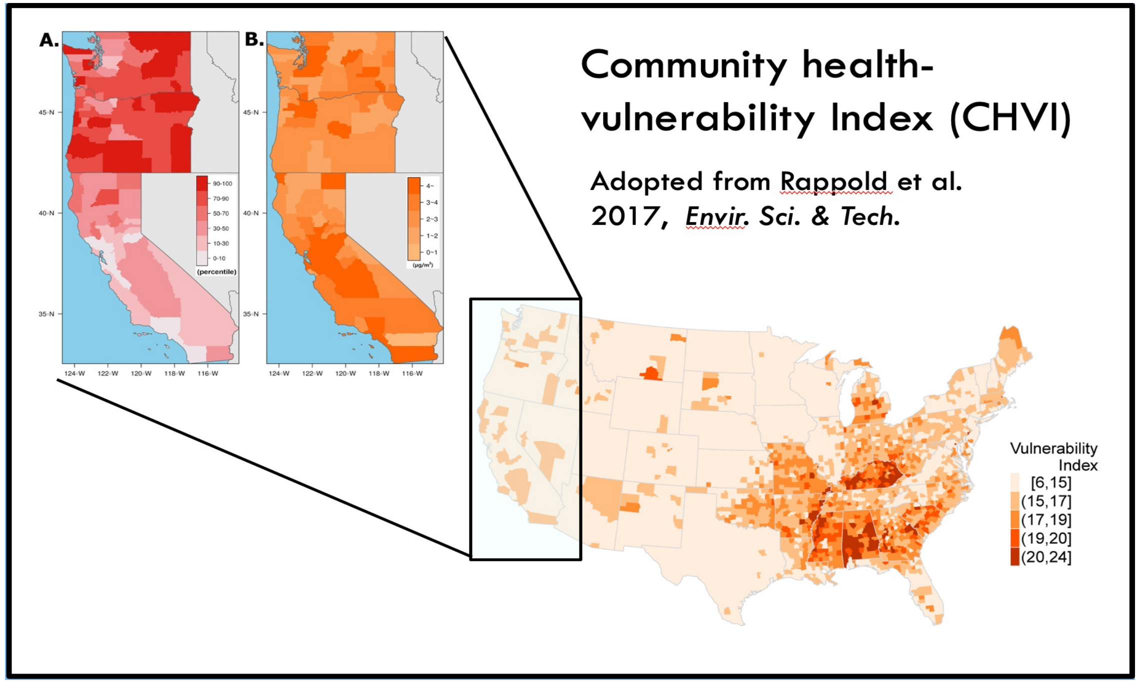
Recent advances

Looking at the larger U.S. with focus on the Midwest

- Study extended 2008-2018, CMAQ: 5.0.1-5.2

- Contiguous U.S.
  - 10% of the population (30.5 million persons) exposed to unhealthy AQ
- Western U.S.
  - 30% of the population (2.5 million persons) live in “at-risk” areas inside the wildland fire interface (WUI)
- Midwest U.S.
  - Currently unclear; can be difficult to quantify. How best to define the WUI
    in Rx or transported smoke context???



D’Evelyn, Wilkins *et al.*, in review, *Sci. Adv.*

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Historical Midwestern city trends for Health and AQ

Clean air getting dirtier; Dirtier air getting cleaner

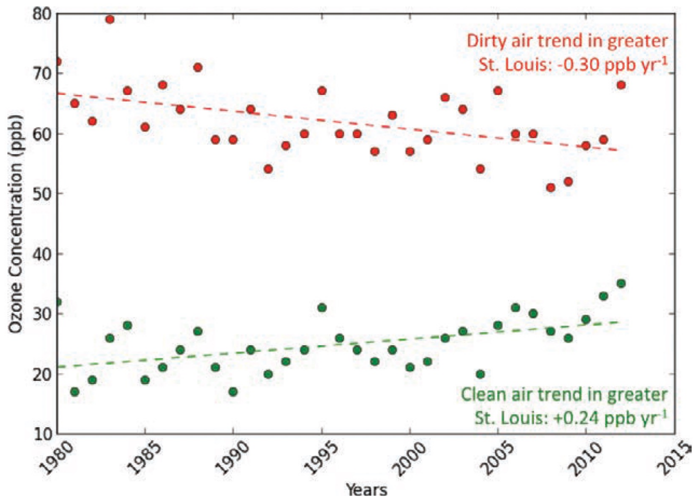
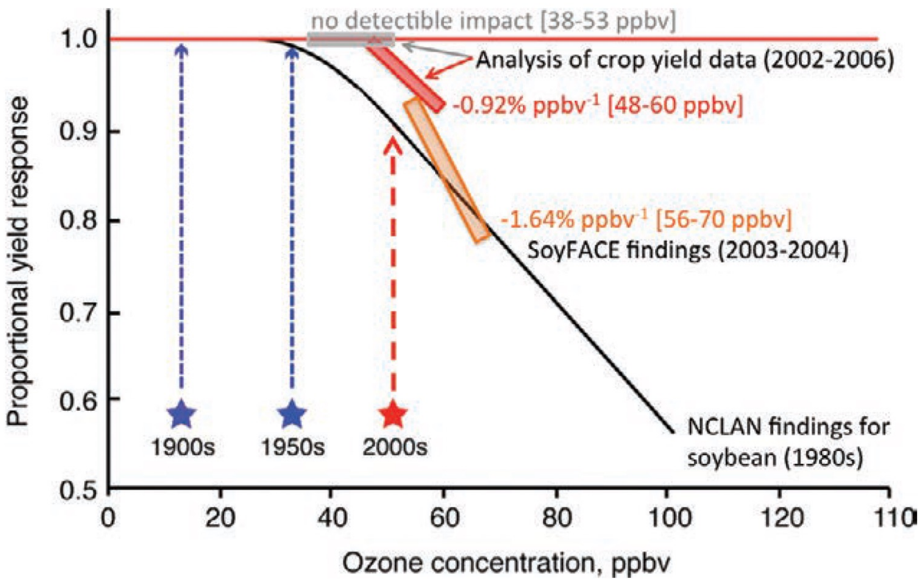


FIG. 2. Ozone trends between 1980 and 2012 in St. Louis for "dirty air" (red, influenced by local emissions) and "clean air" (green, representative of air entering the metropolitan area).



Amongst smoke-exposed communities, Black, Latinx, and Native American communities may experience 50% greater risk of adverse health effects based on systemic and structural inequities (Moser et al. 2019, Clim. Change.)

Fishman *et al.* 2014, *BAMS*

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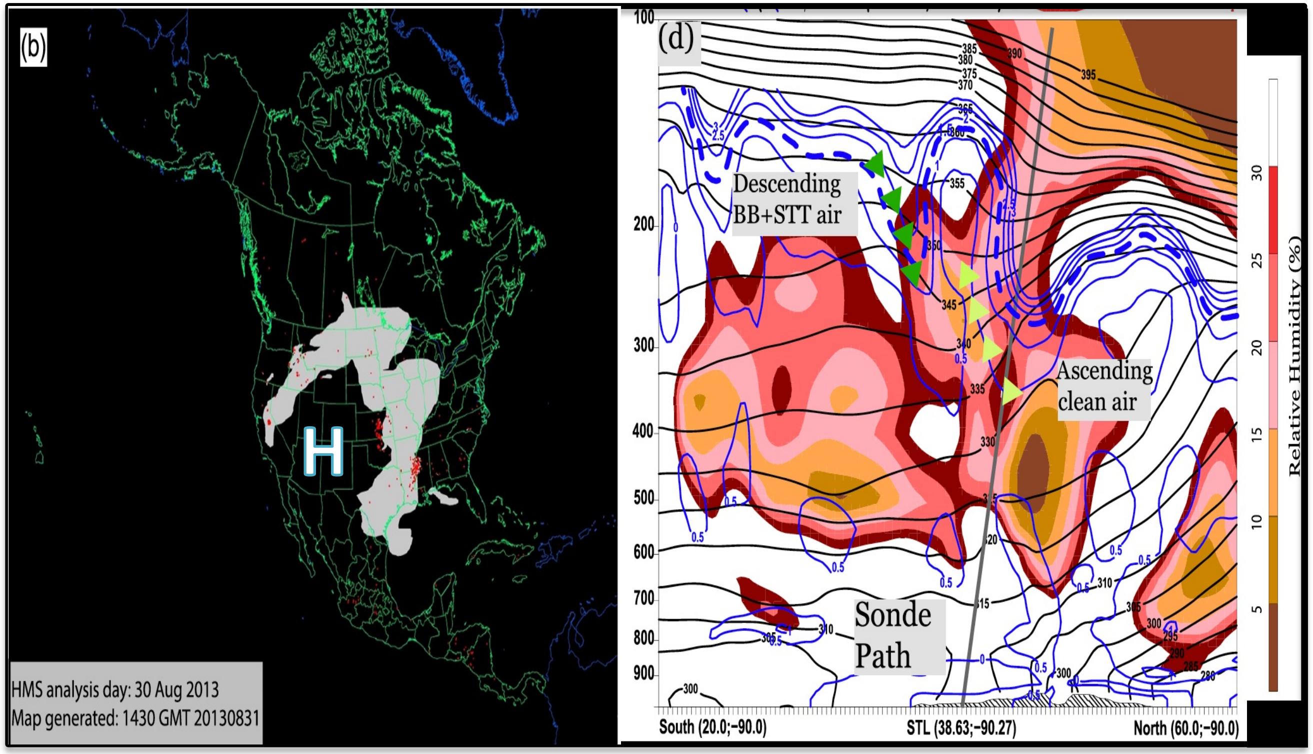
Midwest U.S. extreme weather and air quality

Weather pattern impacts on pollution:

- Studied midwestern pollution patterns
  - Identified common pollution transport patterns (cut-off low, blocking high)
  - Evaluated model inputs/output
- Measured non-controllable O_3 sources (NCOS) contributions
  - Biomass burning (BB)
  - Stratospheric-Tropospheric Transport (STT)

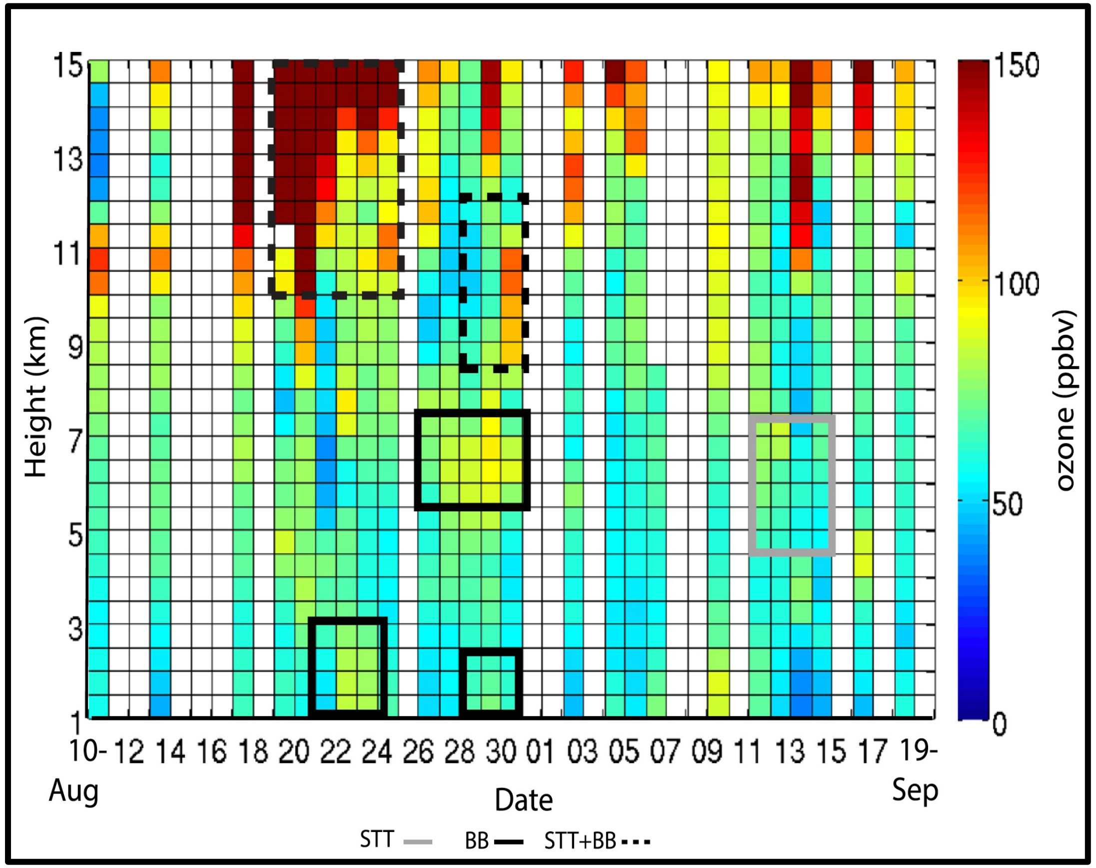


Wilkins et al. 2020, JGR

Using remote sensing to observe the Atmosphere

Key findings with remote sensing:

- Investigated O3 for St. Louis, MO summer 2013
  - 55 ppbv background ozone
    - Note: 40 ppbv is unhealthy for plants
    - Note: 70 ppbv is unhealthy for people
- Quantified Non-controllable O3 sources (NCOS)
  - BB can contribute ~10-80 ppbv
  - STT can contribute ~10-15 ppbv
- NCOS source daily contribution
  - 10-15% of O3 from stratosphere
  - 15-30% of O3 from BB
  - BB plumes 70% Int. West / 3% Midwest/ 10% SE
  - Demonstrated the need for improved plumerise



Wilkins et al. 2020, JGR

Data assimilated into CMAQ – Tracking origin of air.

Settings	No Fires	Baseline	GTP (GOES Temporal profile)
Period	Oct 2-20, 2017	Oct 2-20, 2017	Oct 2-20, 2017
Resolution	Horizontal: 4-km Vertical: 37 layers	Horizontal: 4-km Vertical: 37 layers	Horizontal: 4-km Vertical: 37 layers
Meteorology	WRF v3.7	WRF v3.7	WRF v3.7
Chemistry	CMAQv5.2, SAPRC07, AERO6	CMAQv5.2, SAPRC07, AERO6	CMAQv5.2, SAPRC07, AERO6
Fire Emissions	--	BlueSky v3.5.1	BlueSky v3.5.1
Fire Activity	--	Five Wine Country Fires: GOES-16 Other Fires: MODIS/VIIRS	Five Wine Country Fires: GOES-16 Other Fires: MODIS/VIIRS
Fire Diurnal Profile	--	Five Wine Country Fires: CMAQ (default) Other Fires: CMAQ (default)	Five Wine Country Fires: GOES-16 Other Fires: CMAQ (default)
Non-Fire Emissions	CARB area and non-road, EMFAC2017 on-road, BAAQMD facility-level point source emissions, BEIS3.61	CARB area and non-road, EMFAC2017 on-road, BAAQMD facility-level point source emissions, BEIS3.61	CARB area and non-road, EMFAC2017 on-road, BAAQMD facility-level point source emissions, BEIS3.61

In the absence of better data, the best way to improve plume rise is updating the temporal profile.

- WF: satellite based, e.g., GOES TEMPORAL PROFILE
- RX: 3 to 6 hr not 12 hr
- Improves MB by 20% and RMSE by 1000 m

(Wilkins et al. 2021, IJWF)

O'Neill, Wilkins, et al., 2021, *J. Air Waste Manage. Assoc.*

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Evaluating and Assessing Models

Models demonstrate skill in panels of visible satellite imagery and WRF-CMAQ runs at 11:00 am PDT October 9, 2017.

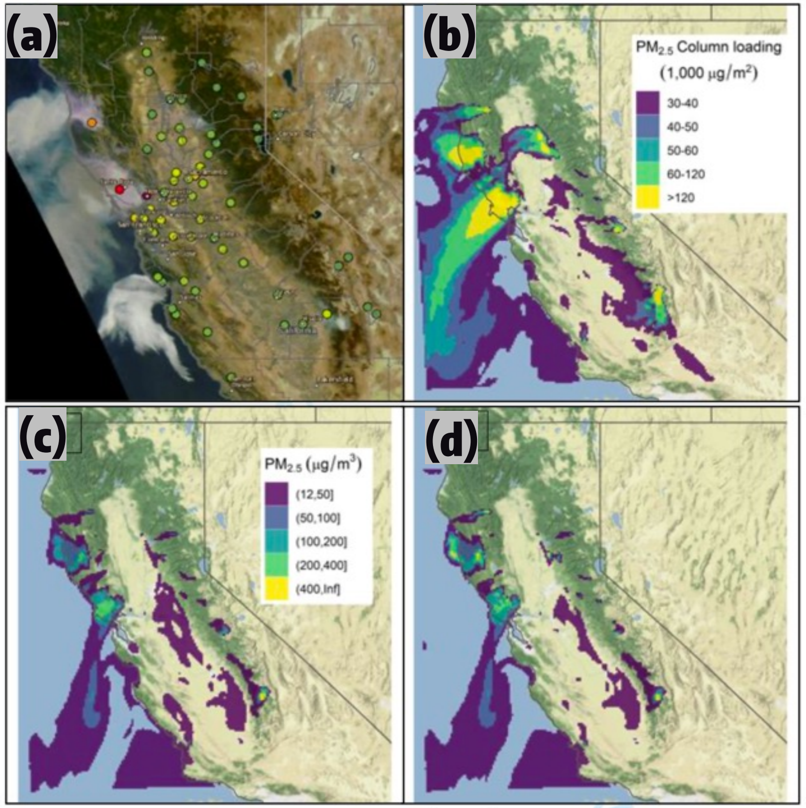
a) Visible GOES-16 satellite imagery and surface 1-hr average PM2.5 concentrations (circles) from EPA AirNowTech color-coded by air quality index (Figure: NOAA AerosolWatch)

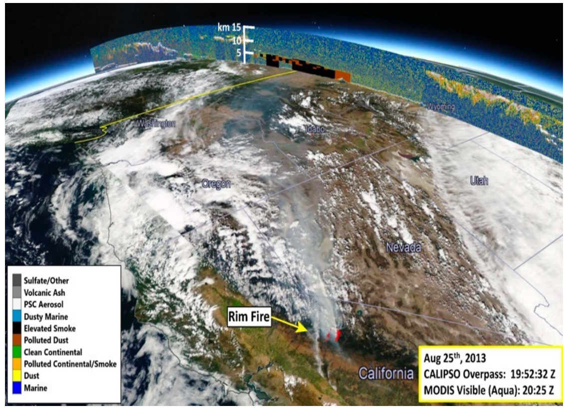
b) the Baseline total column PM2.5,

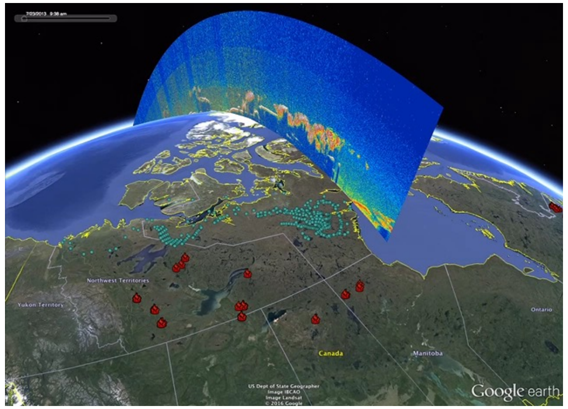
c) the Baseline surface 1-hr average PM2.5 concentration, and

d) the GTP surface 1-hr average PM2.5 concentrations (same scale of PM2.5 concentrations as in 5c).

*For large WF, Briggs placed >60% of the plume above the boundary layer, compared with 83% from OBS and 30–55% from alternatives.







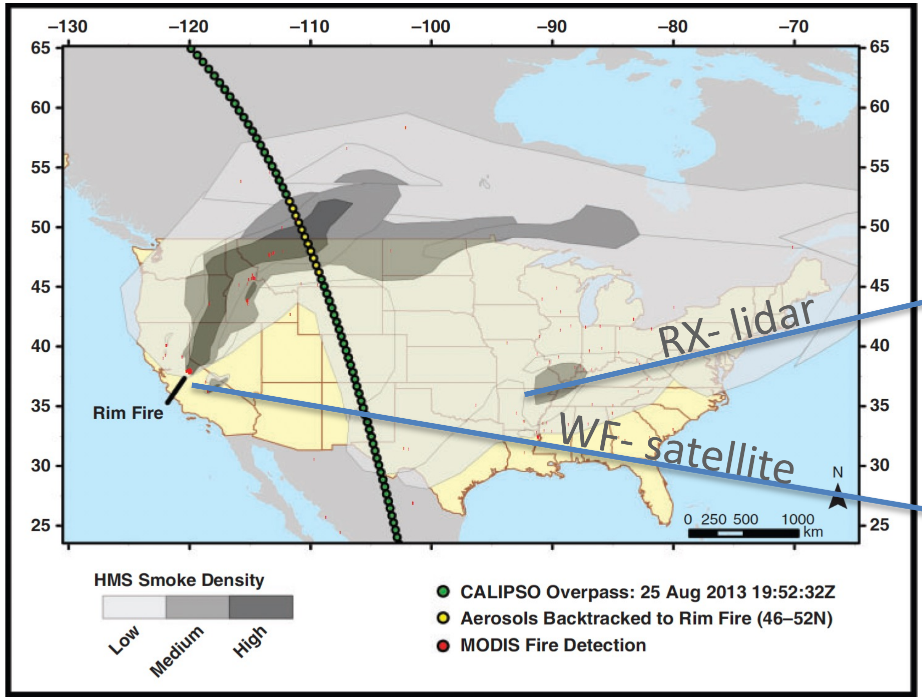
O'Neill, Wilkins, et al., 2021, *J. Air Waste Manage. Assoc.*

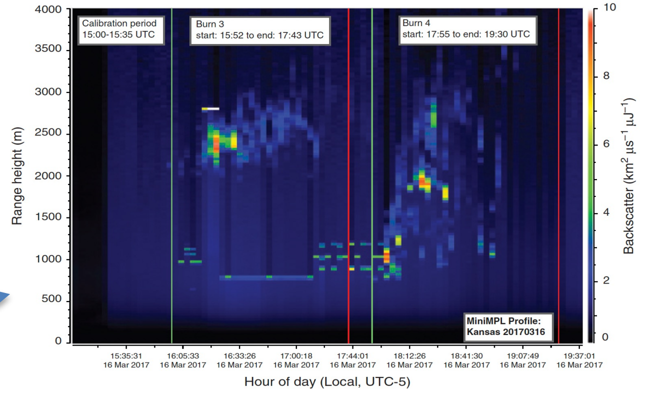
Impacts of plume rise on AQ – Where is the smoke-plume??

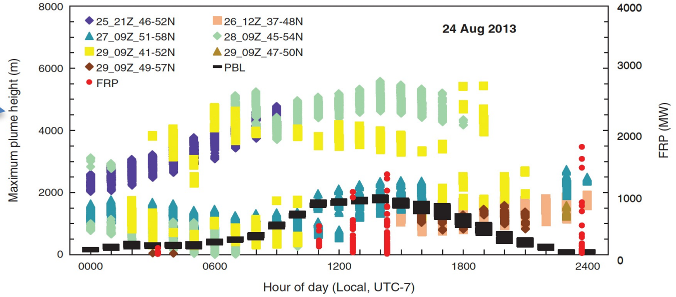
Up to 60% of the smoke plume lies above 3.5 km, and this needs to be simulated as it can later be mixed down to the surface and lead to ozone exceedances days later.

Caption: CALIPSO track overpass path on 25 August 2013 (green dots: see Fig. 3) overlaid on a Hazard Mapping System Fire and Smoke (HMS) product with MODIS Terra and Aqua fire detection data (red dots). Map shows the site of the 2013 California Rim Fire. The aerosols backtracked to the Rim Fire were transported across California, Nevada, Oregon and Idaho before intersecting with the CALIPSO track over Montana and Canada (yellow dots).

Data source	Air parcels	Max. plume height		Min. plume height	
	Number	% < PBL	% > PBL	% < PBL	% > PBL
Rim, 21 August	53 859	8	92	10	90
Rim, 24 August	96 965	8	92	28	72
Rim, total	601 291	17	83	36	64
MISR		88–96	4–12		





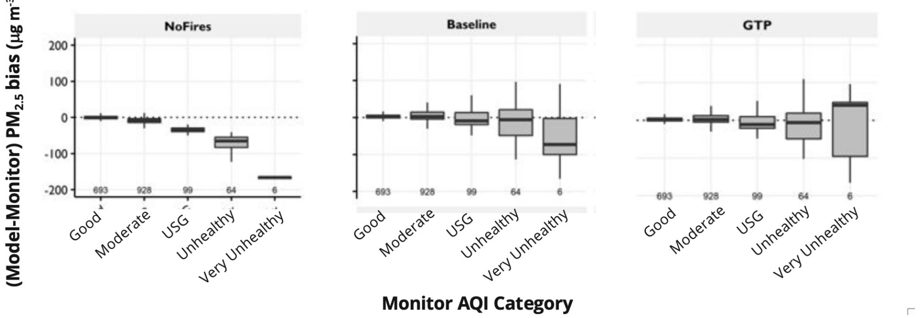


Wilkins *et al.* 2021, *Int. J. Wildland Fire*

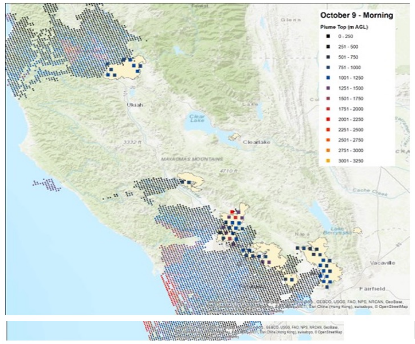
Plume heights can lead to changes in end user results

With improved air quality data, the mortality rates found increased by 47% due to fires.

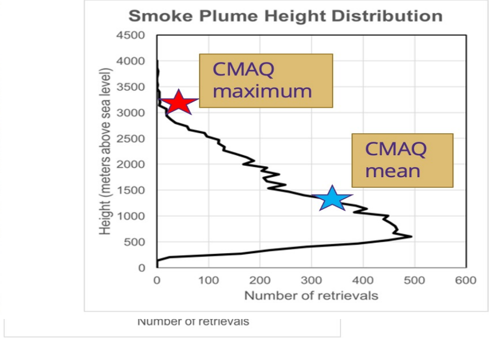
GTP bias > zero for the very unhealthy category
**critical result for forecasters looking for AQ events.



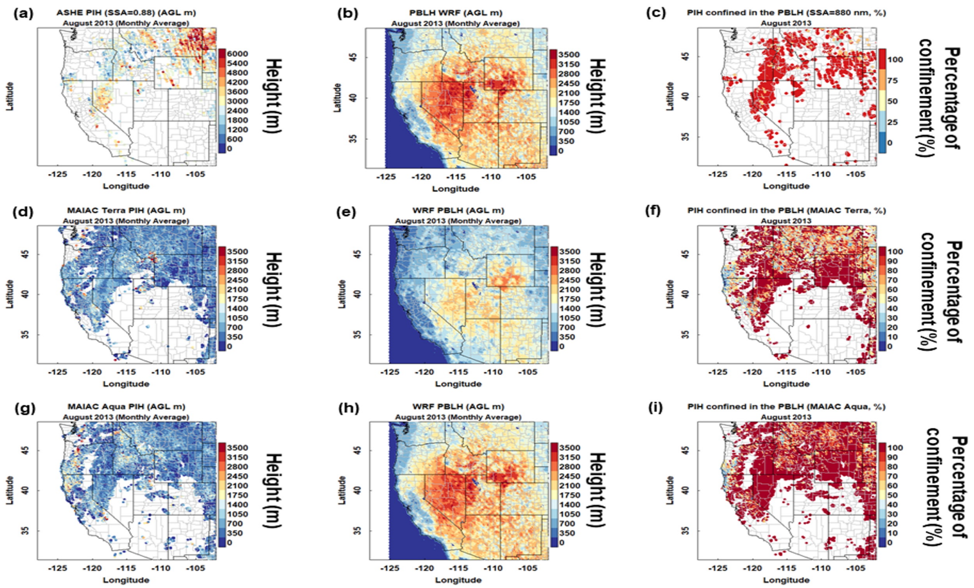
MAIAC and CMAQ-baseline



MISR and CMAQ-baseline



Possible solutions: 1. Data fusion and machine learning. 2. Create a smoke height boundary layer product (smoke>PBL) and inventories for high altitude injection smoke (e.g., pyrocb)



O'Neill, Wilkins, et al., 2021, *JAWMA;* Loria-Salazar, Wilkins et al., 2021, *JGR-atmos; Wilkins et al., in prep*

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We suggest the following modifications to the current air quality modelling systems:

Situation	HAQAST Team Task
Fires are continuing to grow and intensify	Take systematic approaches to investigate impacts to health and air quality
Numerous data sources available and more is soon to come	Combine data sources and streamline for inter-comparisons
Variety of model set ups and predictions	Use models to drive observations and observations to drive model development
Accurate plume rise and transport	Combine novel approaches and ground- and satellite-based observations

https://sites.google.com/firenet.gov/wfaqrp-airfire/projects/haqast/2017NorthernCAWildfiresTT

- **Compute plume rise for small fires (<500 ha).**
  - Many current models simply inject smoke from small fires into the boundary layer or the lowest model layer.
- **Assume a temporal profile matching flaming period Rx.**
  - Many models currently assume 12 or 24 h, but this tends to dilute the emissions and heat intensity of these fires.
- **Assume a fire-specific temporal profile, and if information is not available, apply one of two selectable options:**
  - Take the detection time and generate a temporal profile (e.g. if fire is detected by MODIS or GOES-16/17 at 1100 UTC, time profile applied if using 4 h will be 0900–1300 UTC for the burn).
  - Use the burn rate or the regional average estimate of area burned (e.g. 35 ha hr 1 for the Konza Prairie prescribed burn).

Wilkins *et al.* 2021, *Int. J. Wildland Fire*

Thank you for listening

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CMAQ setup for 2008-2018

Year	NEI year	CMAQ version	BEIS version	EGU CEM data	Gas phase chemistry	PM chemistry	Boundary inflow	WRF version
2008	2008 NEI	v5.0.1	3.14	2008	CB05	AERO6	GEOS-CHEM	v3.4
2009	2008 NEI	v5.0.1	3.14	2009	CB05	AERO6	GEOS-CHEM	v3.4
2010	2008 NEI	v5.0.1	3.14	2010	CB05	AERO6	GEOS-CHEM	v3.4
2011	2011 NEI	v5.0.1	3.14	2011	CB05	AERO6	GEOS-CHEM	v3.4
2012	2011 NEI	v5.0.2	3.14	2012	CB05	AERO6	GEOS-CHEM	v3.4
2013	2011NEIv2	v5.2	3.6.1	2013	CB6r3	AERO6	GEOS-CHEM	v3.8
2014	2014NEIv1	v5.2	3.6.1	2014	CB6r3	AERO6	GEOS-CHEM	v3.8.1
2015	2014NEIv2	v5.2.1	3.6.1	2015	CB6r3	AERO6	Hemispheric CMAQ	v3.8.1
2016	2014NEIv2	v5.2.1	3.6.1	2016	CB6r3	AERO7	Hemispheric CMAQ	v3.8.1
2017	2014NEIv2	v5.2.1	3.6.1	2017	CB6r3	AERO7	Hemispheric CMAQ	v3.8.1
2018	2014NEIv2	v5.3	3.6.1	2018	CB6r3	AERO7	Hemispheric CMAQ	v3.8.1