Underestimated Fire Emissions in Inventories: Evidence from Model Simulations and Aircraft Observations

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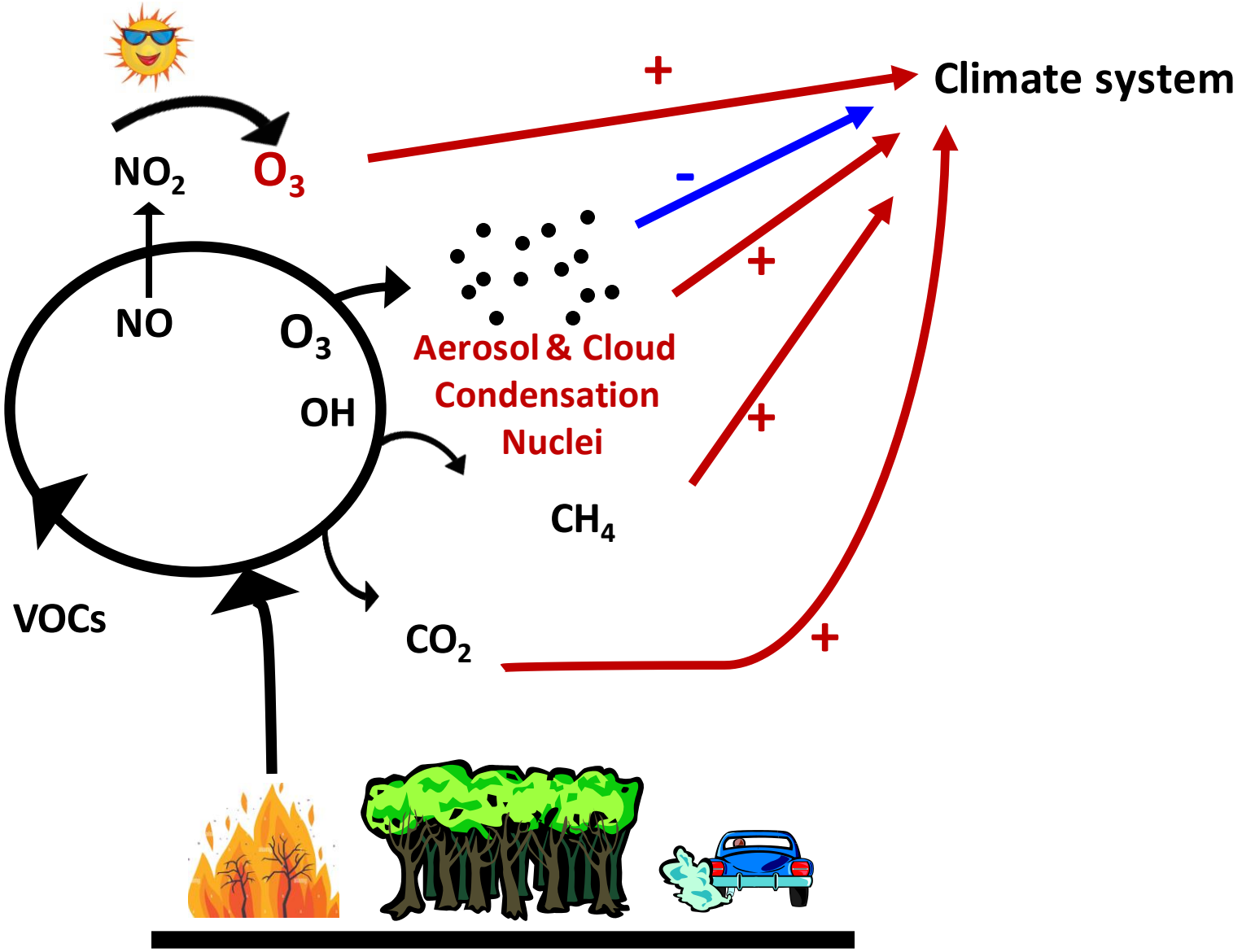
Volatile organic compounds (VOCs) play a key role in tropospheric chemistry

NO_x + VOC -> O3 + aerosols



Adapted from Penuelas and Staudt, 2009

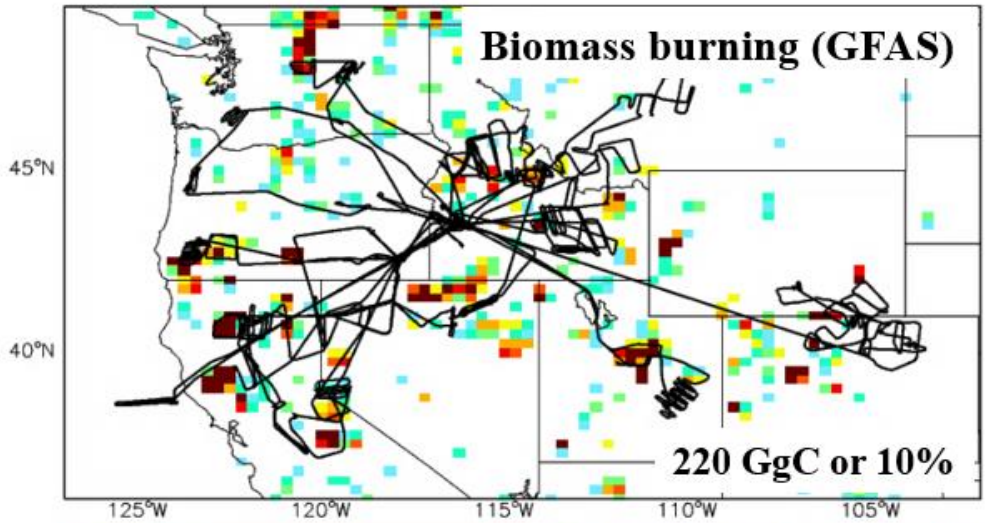
Current knowledge gaps in predicting air quality impacts from wildfires

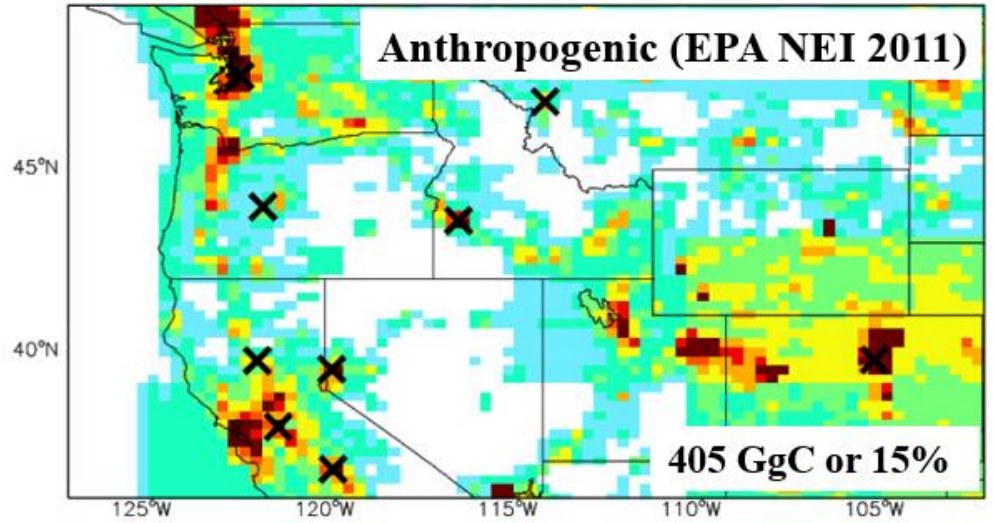
- Amount of biomass burning (BB) **emissions** for precursors (**e.g., emission factor, dry matter burned, and fire detection**)
- Unclear **chemistry** or chemical mechanism (**VOC representatives**, aerosol impacts, etc.)
- **Plume transport** (plume rise and spatial transport)
- …

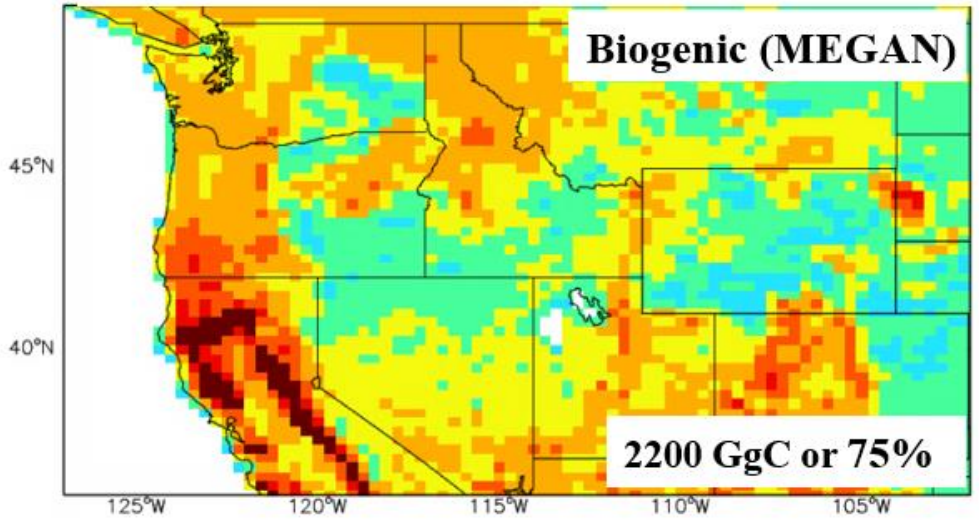
Objective: Constraining current VOC emissions from recent plume-targeting field campaigns

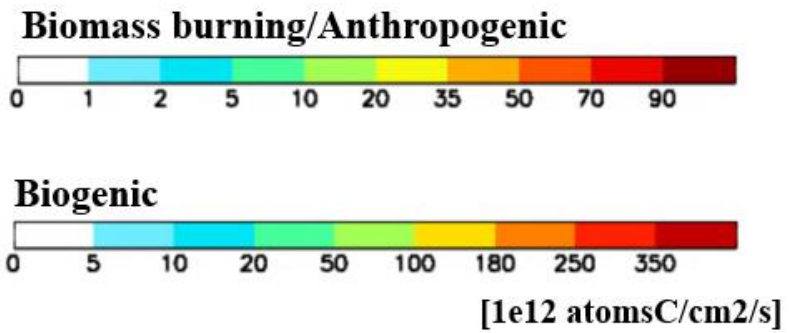
Emission(g) = emission factor (g/kg) × biomass burned (kg)

Current understanding of VOC emissions in the western US (2018 summer)









According to emission inventories, fire is thought to account for 10% of the total VOCs in the western US.

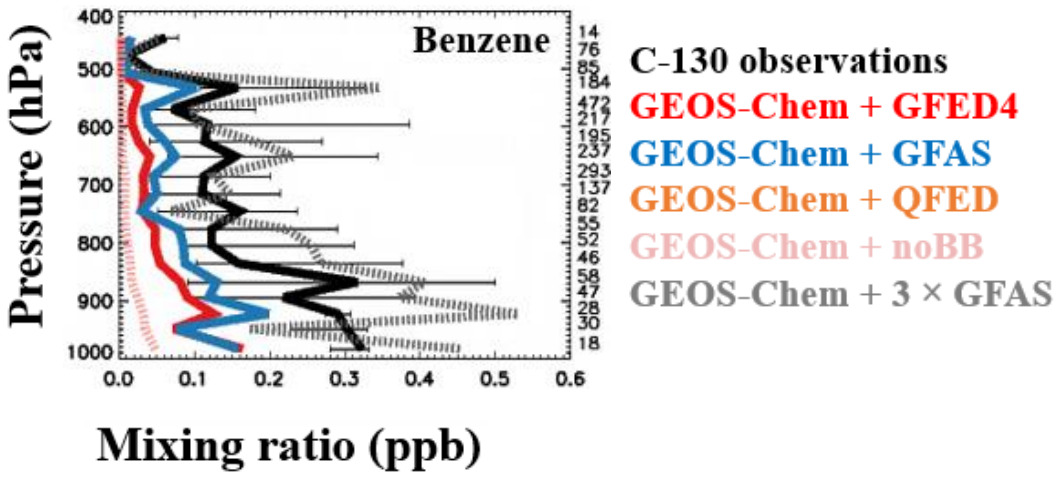
Emission(g) = emission factor (g/kg) × biomass burned (kg)

Air quality models underestimate wildfire emission by a factor of 3-7

Plume-targeting aircraft data is used to evaluate current understanding of fire emissions in AQ models…

- **Wildfire emissions are biased low by a factor of 3-7 in the AQ model.**

VOC vertical profiles over western US (WE-CAN)



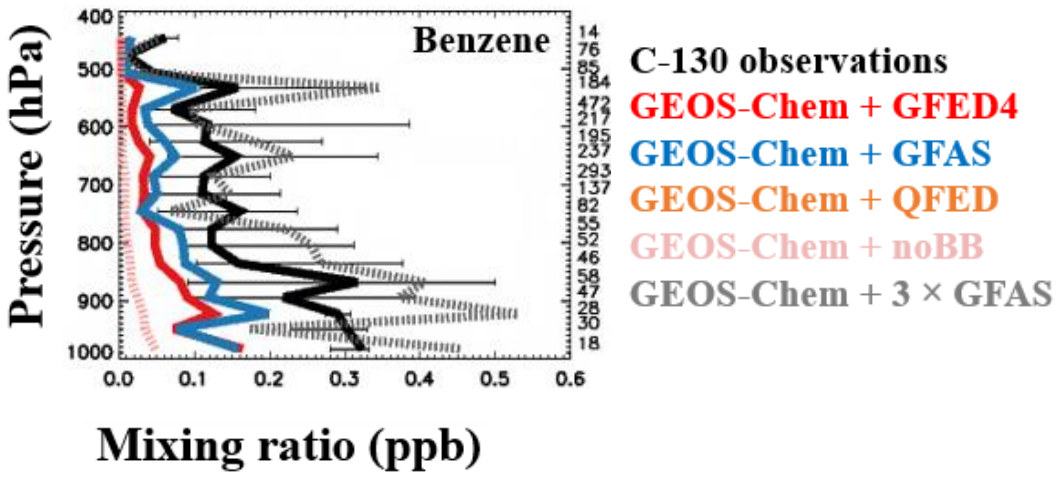
Emission (g) = emission factor (g/kg) × **biomass burned (kg)**

The low bias of biomass burning emission is likely due to the underpredicted biomass burned

Plume-targeting aircraft data is used to evaluate current understanding of fire emissions in AQ models…

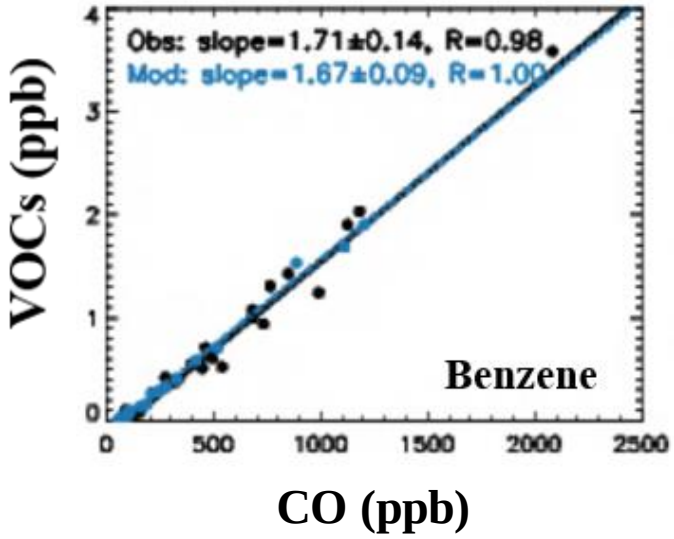
- Wildfire emissions are biased low by a factor of 3-7 in the AQ model.
- Tripling wildfire emissions does help for primary VOCs (but not for oxygenated VOCs).

VOC vertical profiles over western US (WE-CAN)



- Modeled emission factors satisfactorily agree with the observation.

Benzene vs CO

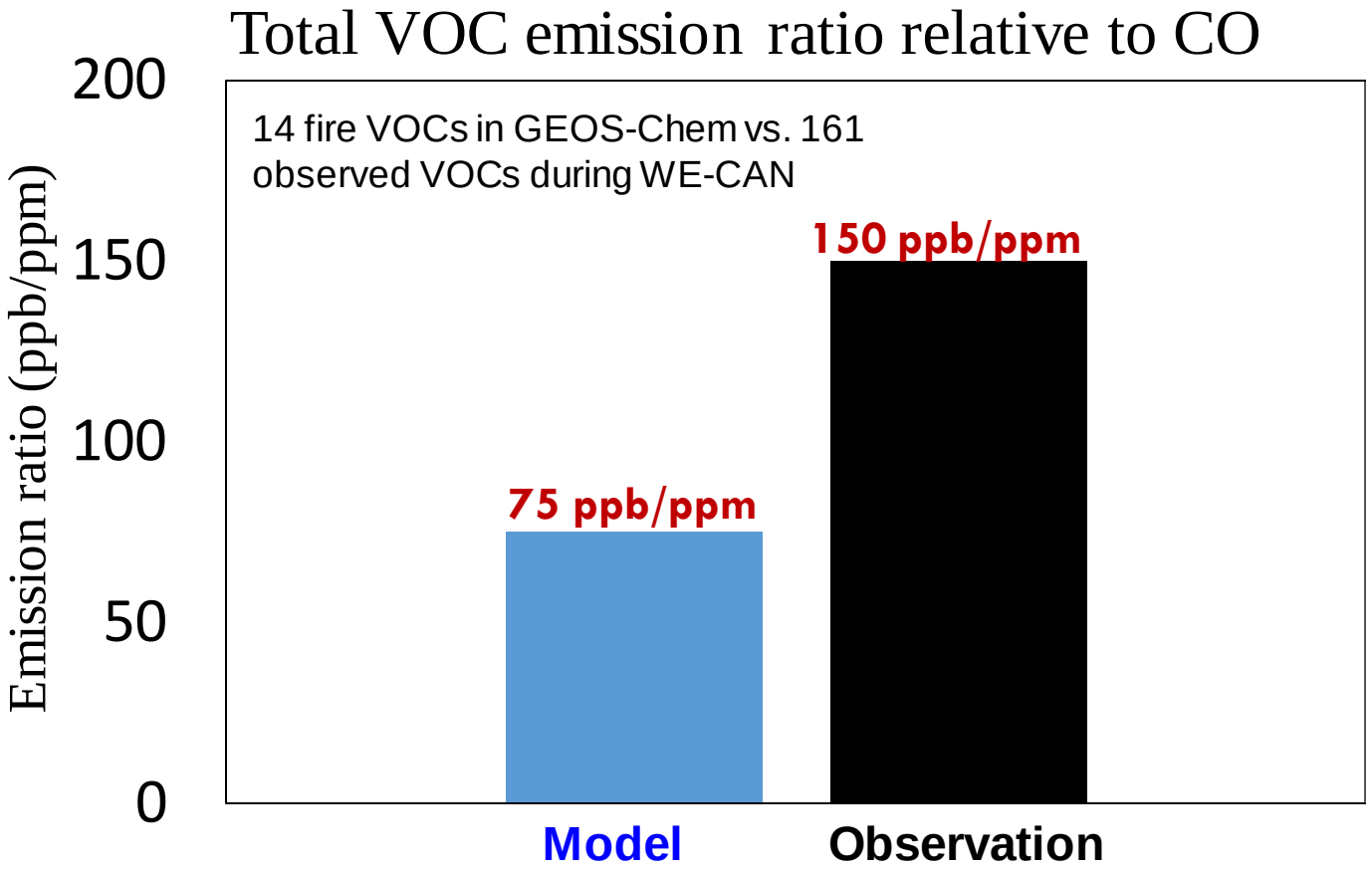


The potential errors from injection height, fire detection, and relatively coarse CTM resolution are also excluded…

Emission (g) = emission factor (g/kg) × **biomass burned (kg)** → **Low bias of biomass burned is likely the thing we need to blame (×3).**

The back-of-the-envelope calculation confirms that these global inventories' effective biomass burned are lower than limited field reports.

VOCs from wildfire emissions are underestimated by a factor of >= 6 in the western US during fire seasons



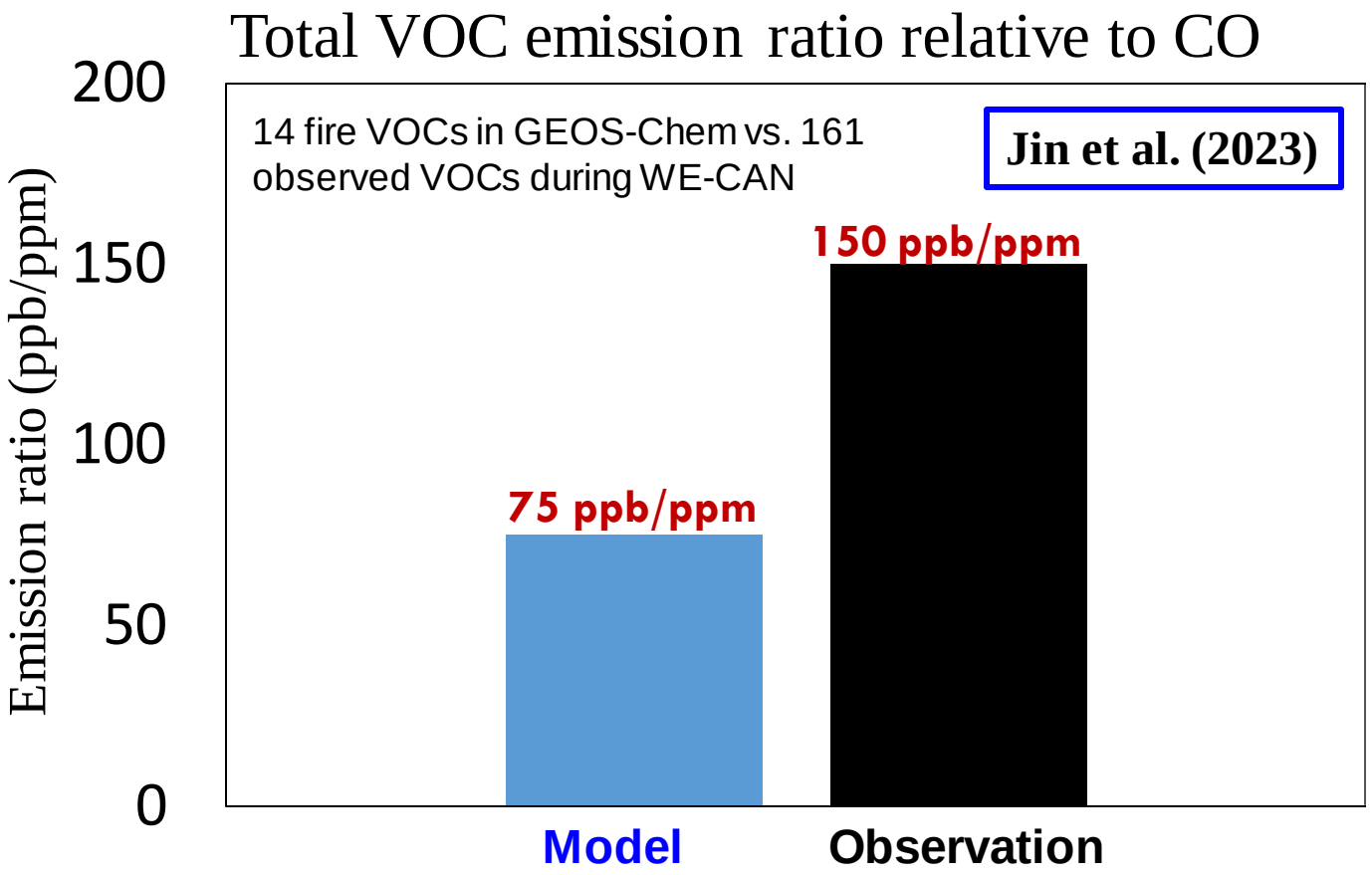
Model underpredict fire emission by a factor of ?

2 × >=3 ⟶ **>=6**

Emission (g) = **emission factor (g/kg) × biomass burned (kg)**

- **The limited number of VOCs in the model only account for half of the VOC emissions from fire smokes (14 VOCs vs 161 VOCs).**
- **Thus, the VOC emission estimates from fires can be still underestimated by a factor of 2 even we get the DM right.**
- **The combination of missing VOCs and DM error would lead to the underestimation by a factor of 6.**

VOCs from wildfire emissions could be the dominant primary source in the western US during fire seasons



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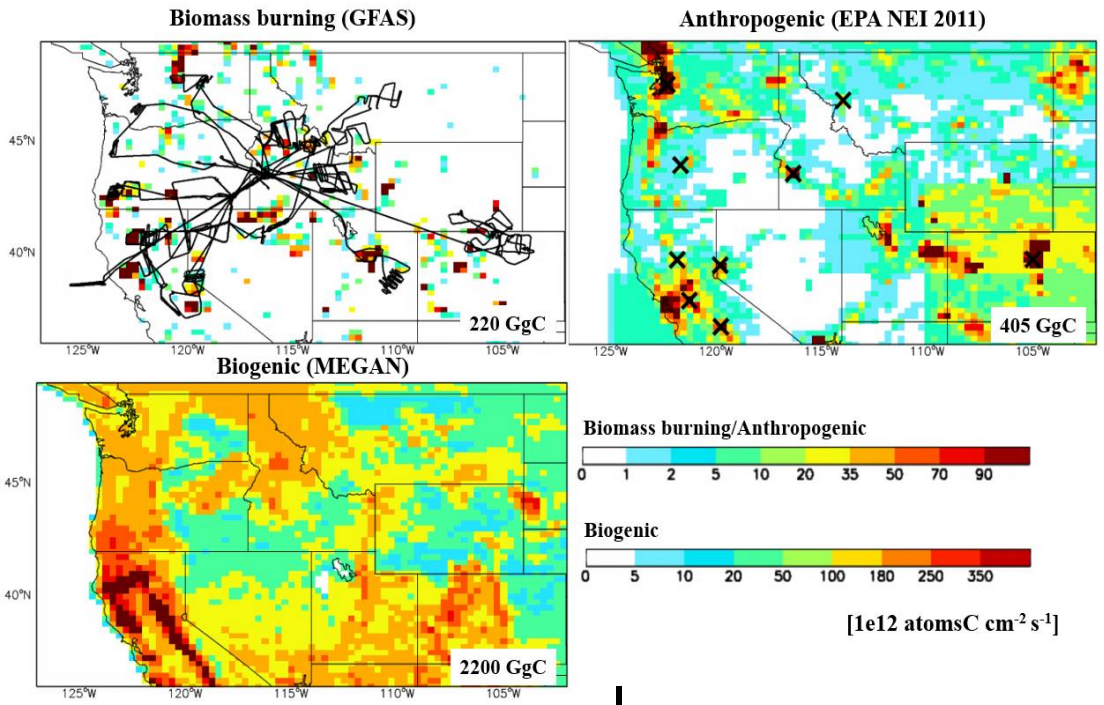
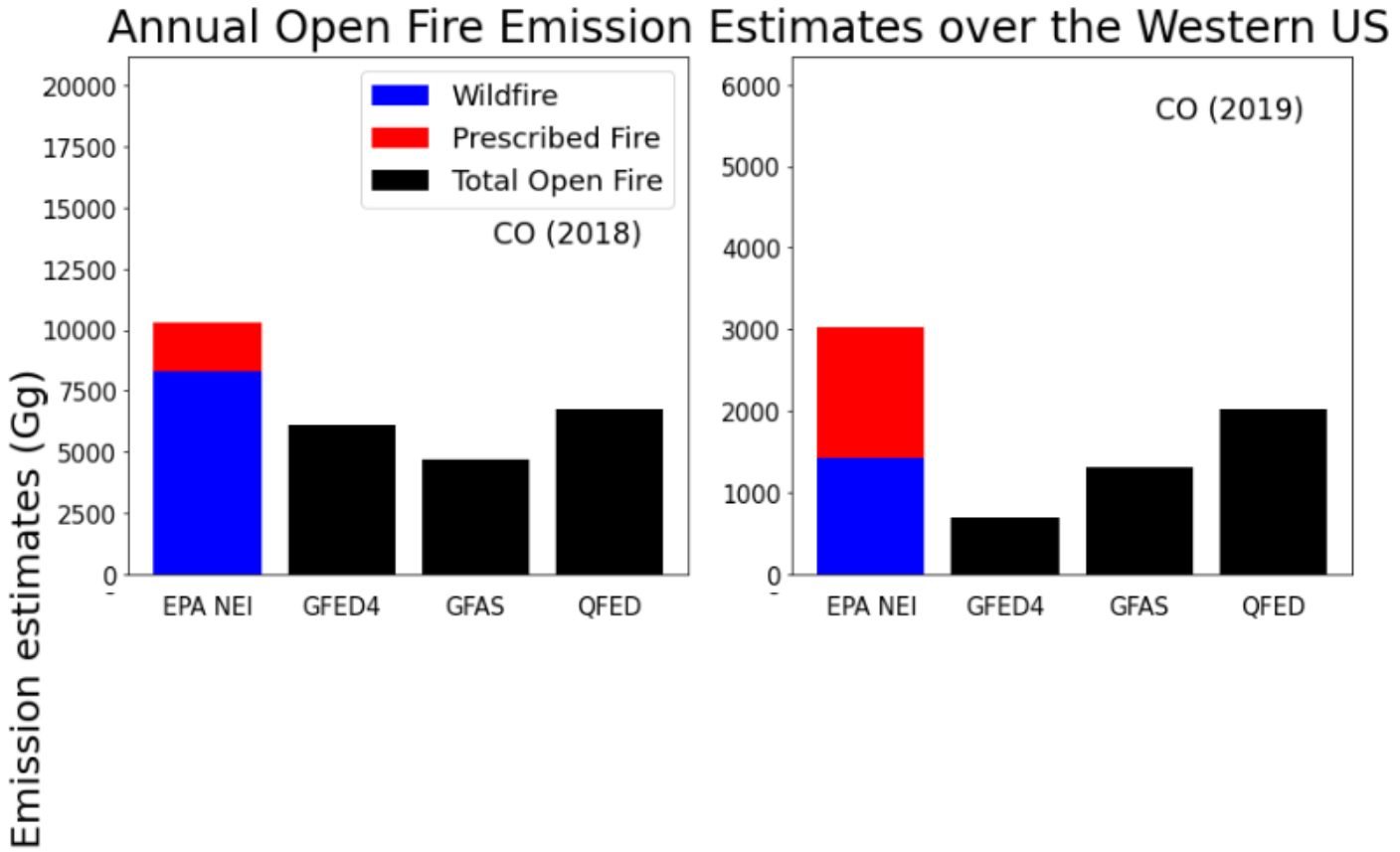


VOCs from wildfire emissions could have similar importance as biogenic emission in the western US fire seasons.

The fire emission estimates from NEI might outperform what from global emission inventories but can still be low for the west!

- **NEI CO emission estimates is higher than other three inventories by a factor of 1-4 in the west.**



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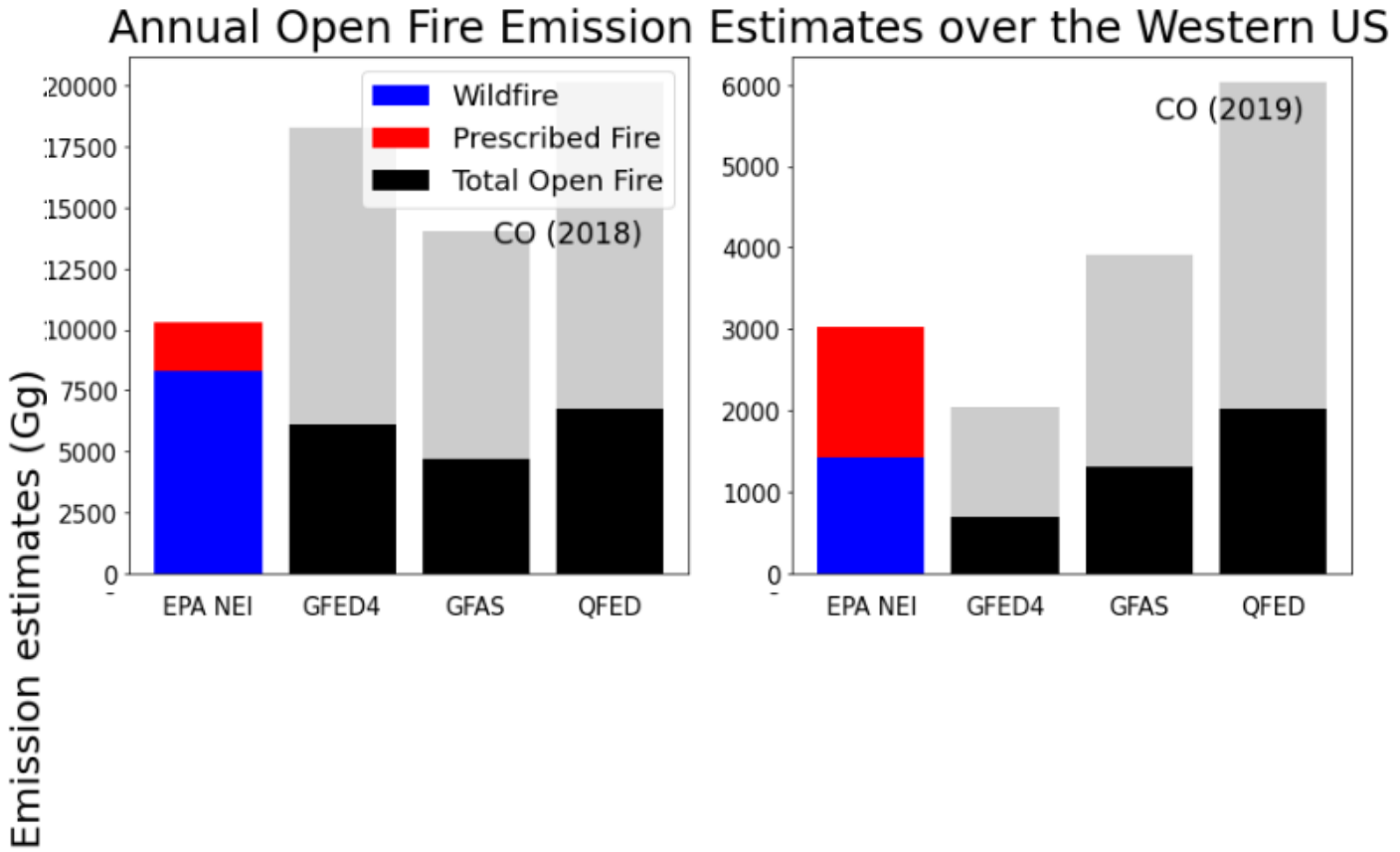
- **However, the NEI still tends to be lower than the corrected emission estimates by a factor of 1-2.**



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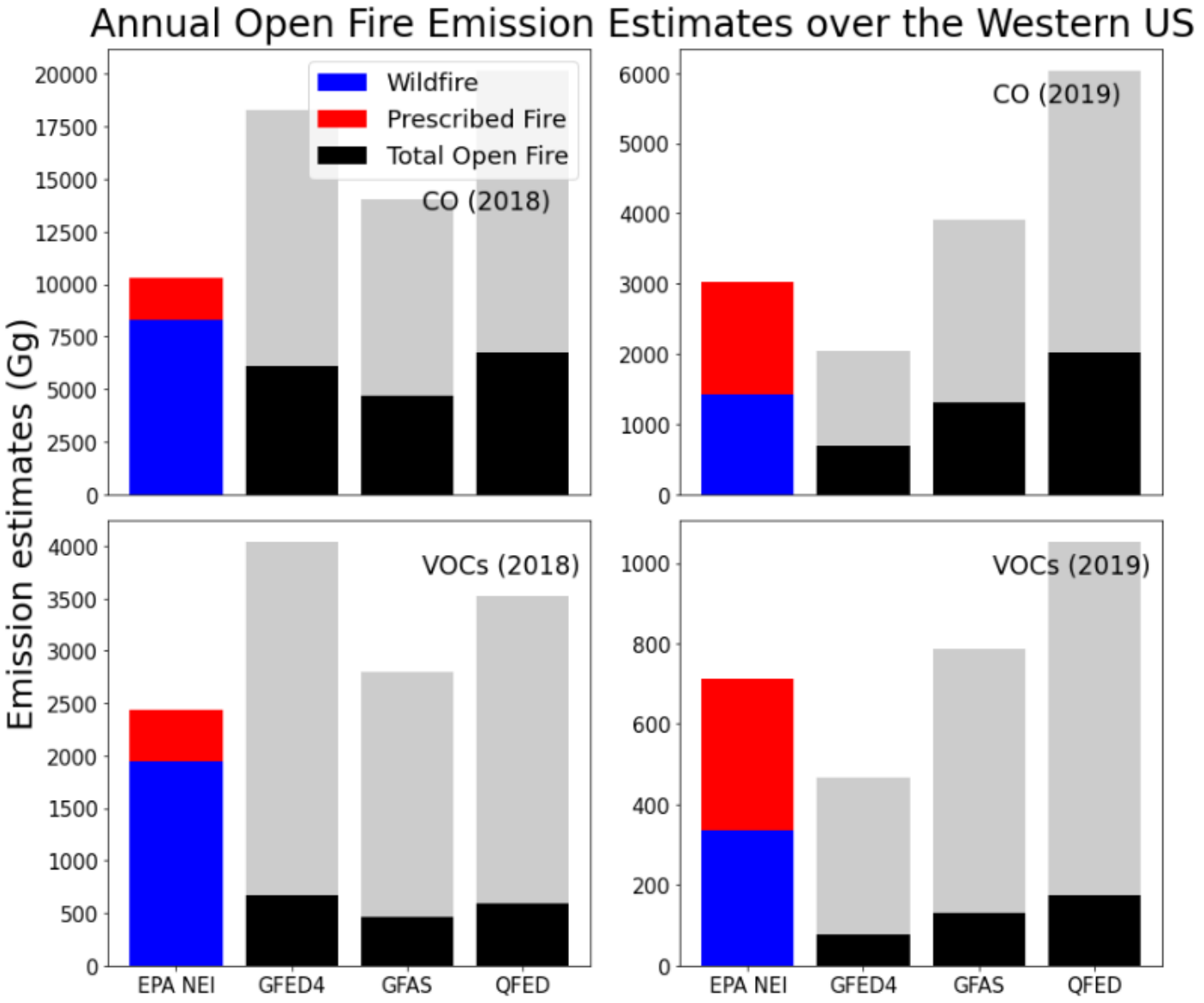
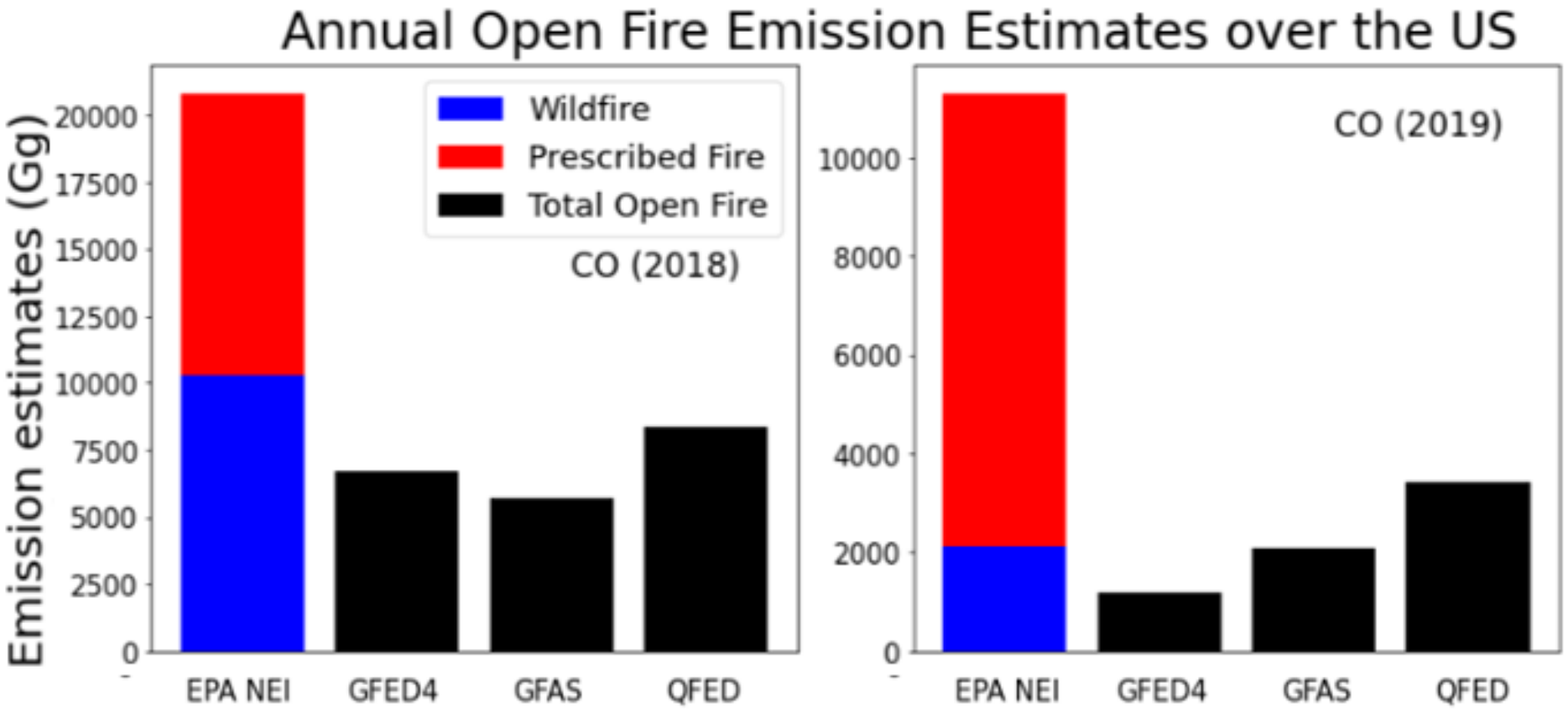
- **NEI CO emission estimates is higher than other three inventories by a factor of 1-4 in the west.**
- **However, the NEI still tends to be lower than the corrected emission estimates by a factor of 1-2.**
- **The same pattern is found in VOCs, indicating the discrepancy between NEI and global EIs is likely from systematic errors across compounds.**



What if we extend the studies into the US?

NEI CO is higher than other three global inventories by a factor of 3-10 in the lower 48



- **More than half of the open fire emissions are from prescribed fires.**
- **It would be interesting to validate the NEI with CTM in the future…**

Current knowledge gaps in predicting air quality impacts from wildfires

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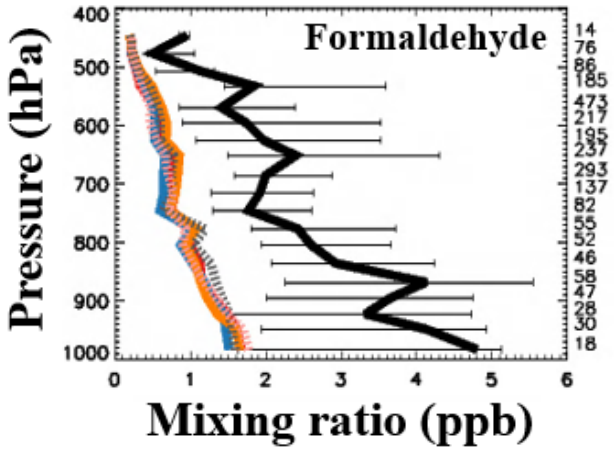
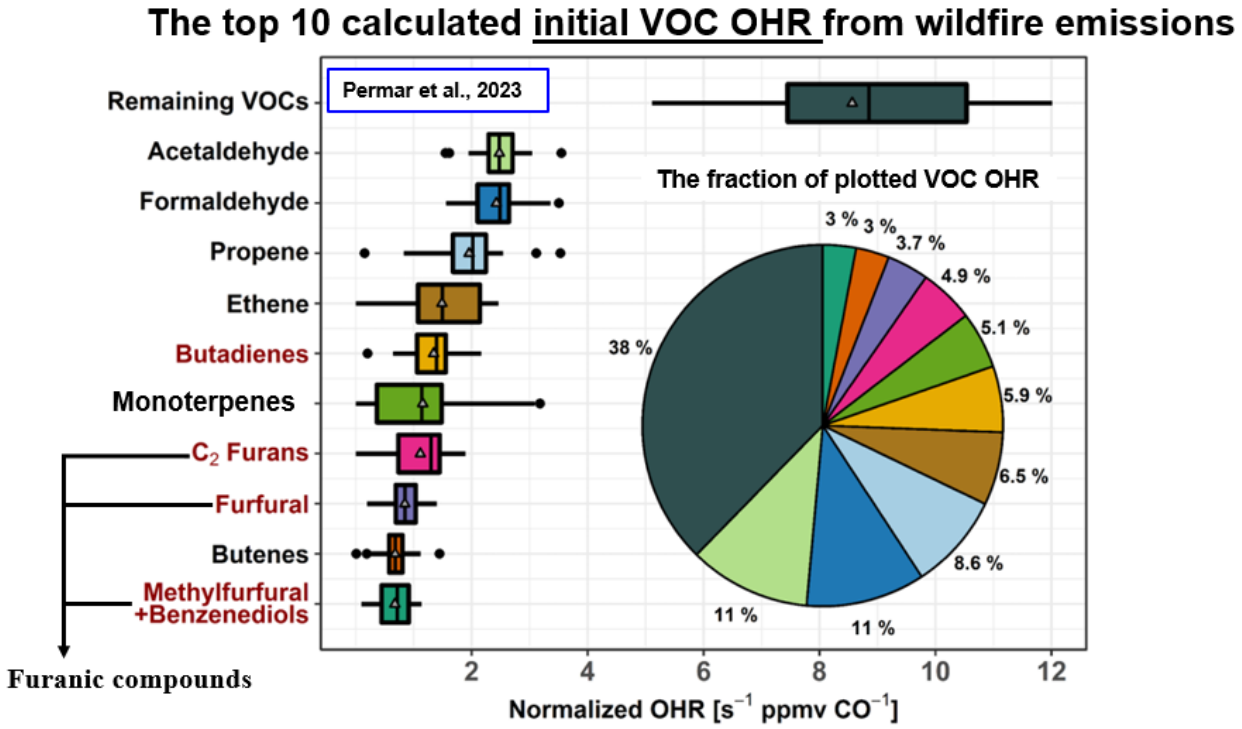
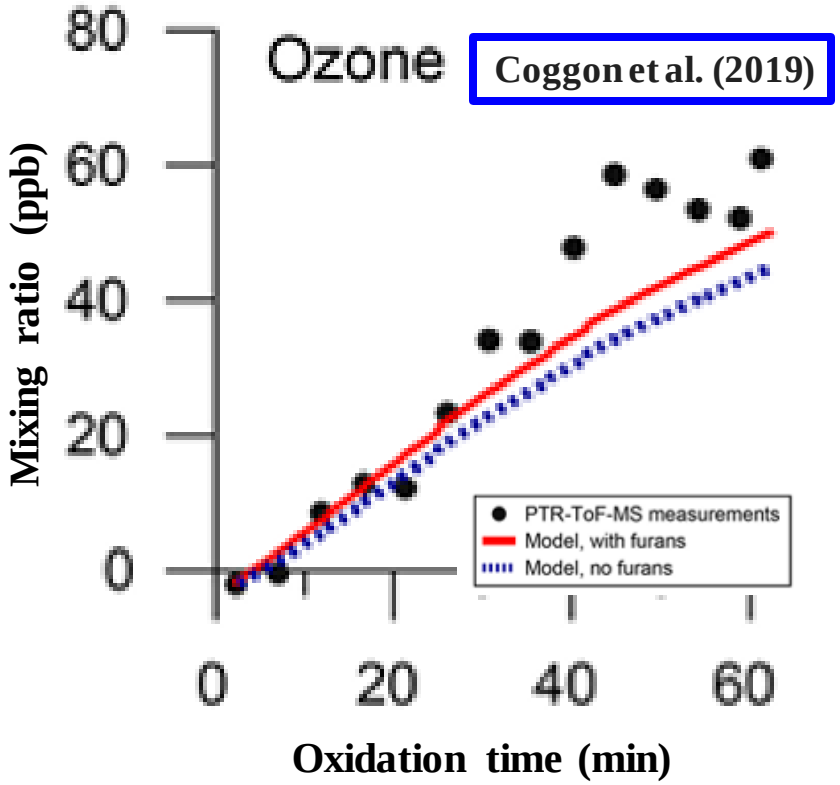


Improving VOC chemical representation in the CTM, regarding unmodeled compounds, their functionality and chemical mechanisms.

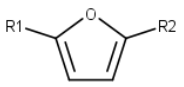
The incomplete VOCs representation is influencing the ozone prediction!

OH reactivity (OHR) is used to describe how reactive the species are, calculated by multiplication of k_{x+OH} and X concentration.

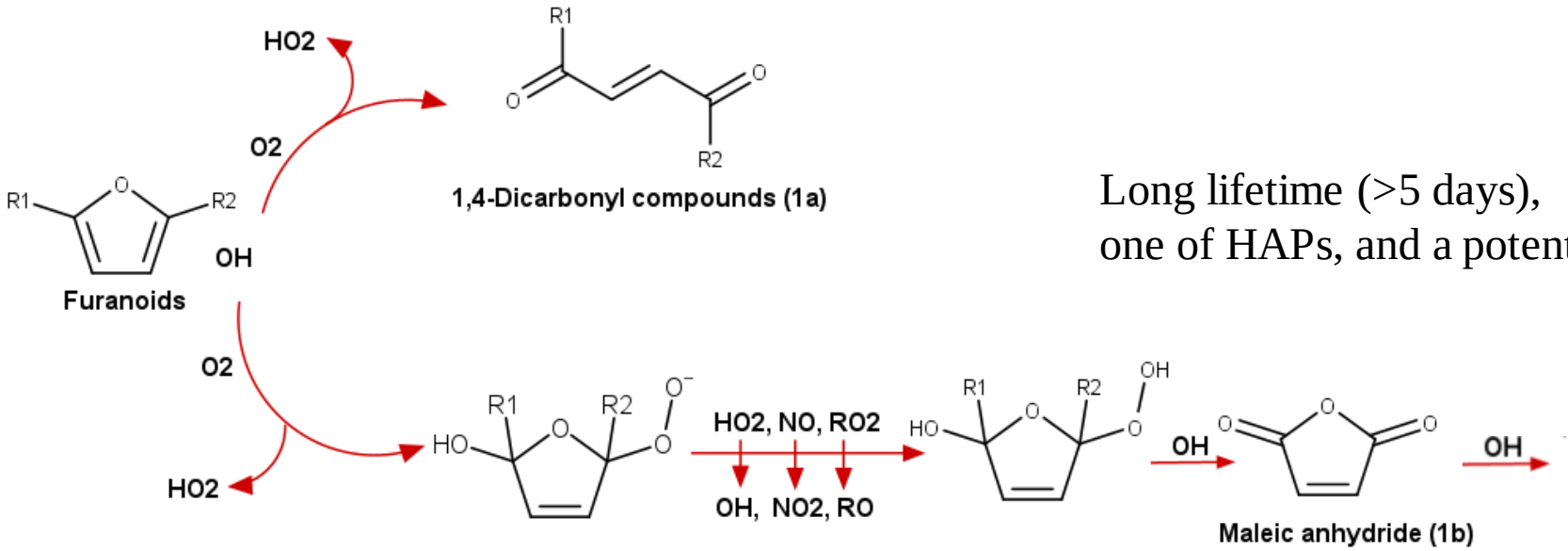




- Among the top ten reactive VOCs, three of them are furanoic compounds or furanoids.
- Adding furanoids in the MCM improve the ozone by 10% in the plume transects.

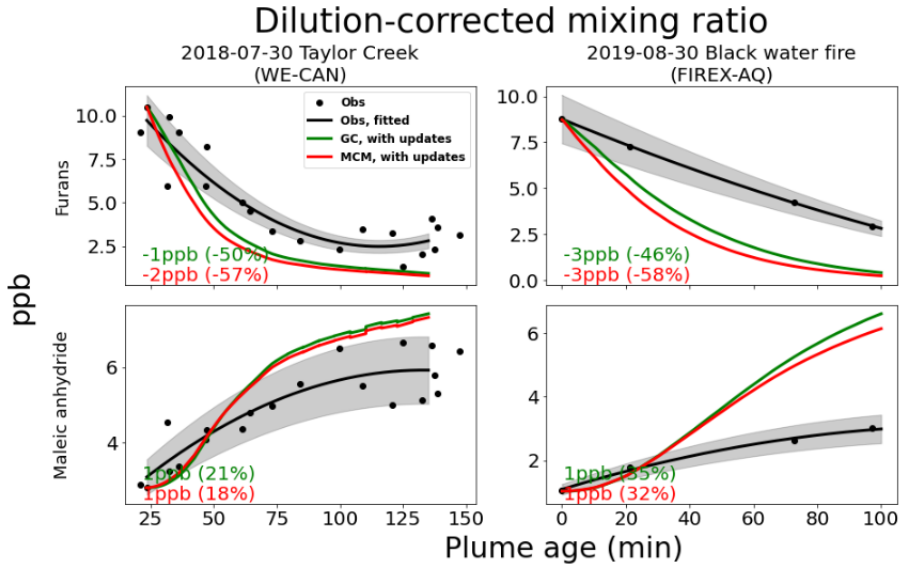


The reduced furanoids mechanism can reproduce the oxidation in the MCM



Long lifetime (>5 days),
one of HAPs, and a potential BB tracer

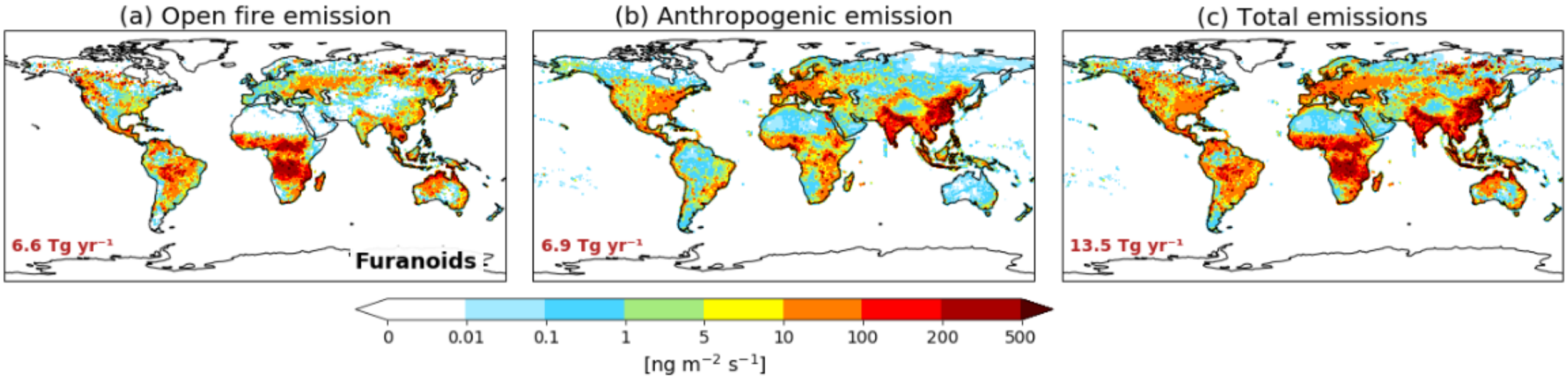
- The fire-specific MCM is a near-explicit chemical mechanism using more than 300 related reactions to describe the oxidation of five selected furanoids (Coggon et al., 2019).
- We developed a reduced furanoids mechanism using 23 unique reactions to reproduce the explicit MCM.
- Our reduced furanoids chemical mechanism can fairly reproduce the furanoids oxidation in fire smokes despite the instrument uncertainty.



Also tested in other oxidation products such as smaller OVOCs, ozone, and peroxyl nitrates!

The emission size of furanoids is comparable to other well-known aromatics

Annual emissions of selected five furanoids (2018)



- The annual global emission for furanoids (13.5 Tg per year) is comparable to aromatics such as benzene (~9 Tg per year).
- Both open fire emission and anthropogenic emissions cannot be ignored.
- The emissions suggest a significant spatial distribution for different primary sources, e.g., the US and China.

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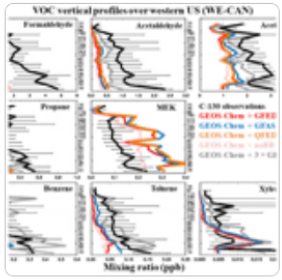
Constraining emissions of volatile organic compounds from western US wildfires with WE-CAN and FIREX-AQ airborne observations



Lixu Jin, Wade Permar, Vanessa Selimovic, Damien Ketcherside, Robert J. Yokelson, Rebecca S. Hornbrook, Eric C. Apel, I-Ting Ku, Jeffrey L. Collett Jr., Amy P. Sullivan, Daniel A. Jaffe, Jeffrey R. Pierce, Alan Fried, Matthew M. Coggon, Georgios I. Gkatzelis, Carsten Warneke, Emily V. Fischer, and Lu Hu

Conclusion:

- VOCs from open fire emissions are underestimated by a factor of >= 6 in global emission inventories over western US during fire seasons.
- The undprediction is likely due to model errors in biomass burned and incomplete representation of VOC numbers.
- The open fire emission estimates from NEI might outperform other global EIs and need to be prioritized in air quality models.
- The furanoids need to be prioritized in air quality models for either emission or chemistry.