Constraining VOC emission from western US wildfires with WE-CAN and FIREX-AQ airborne observations

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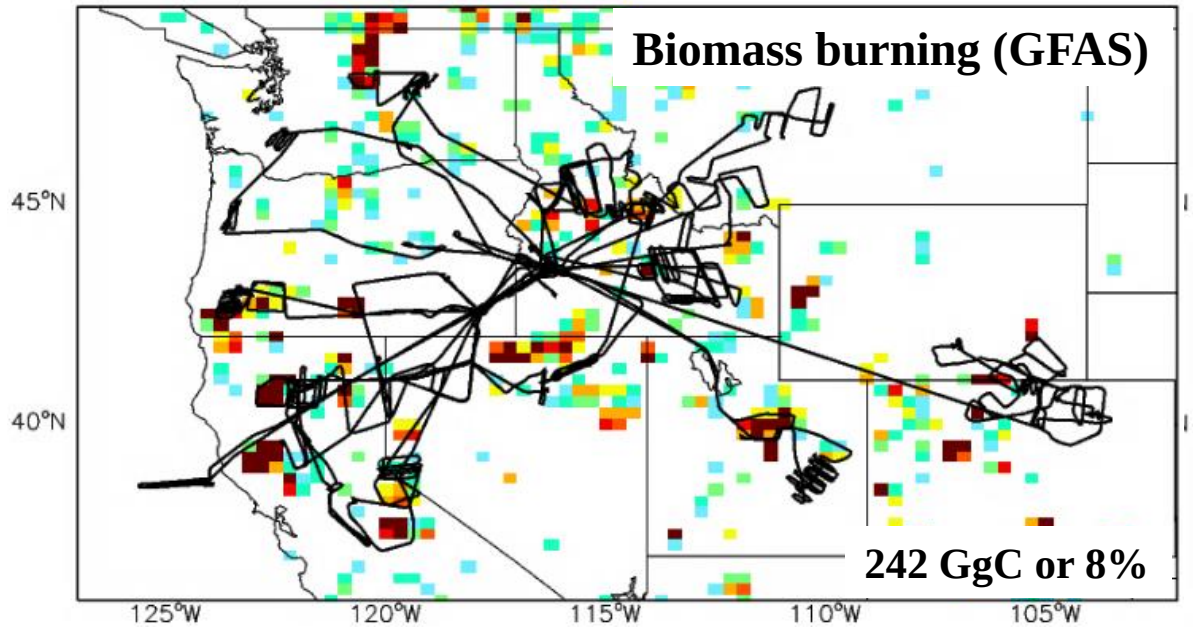
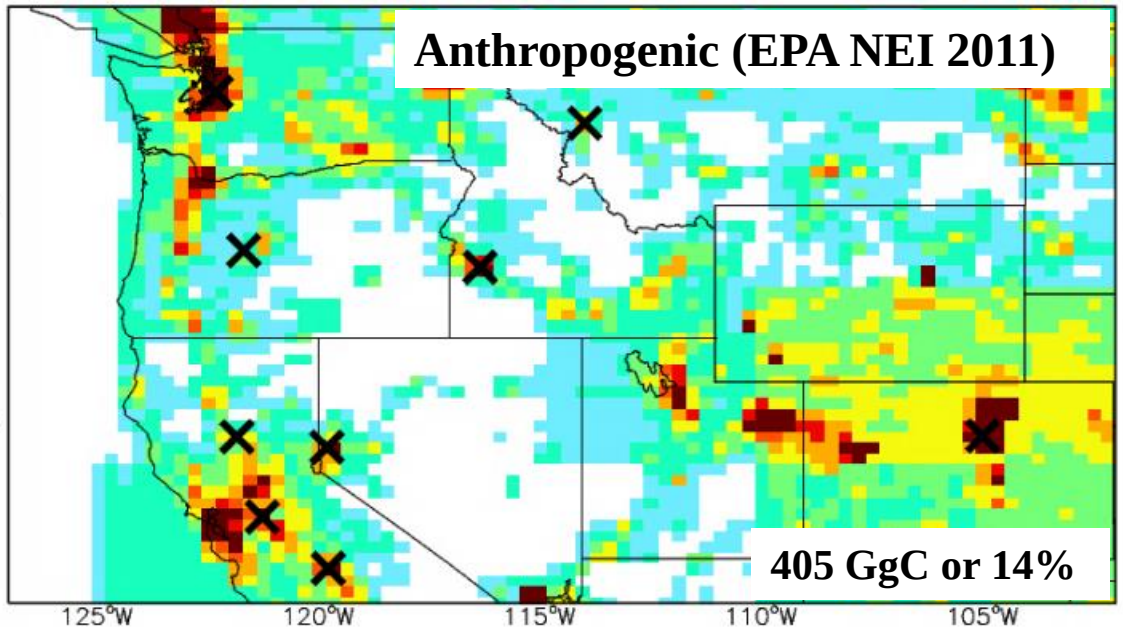
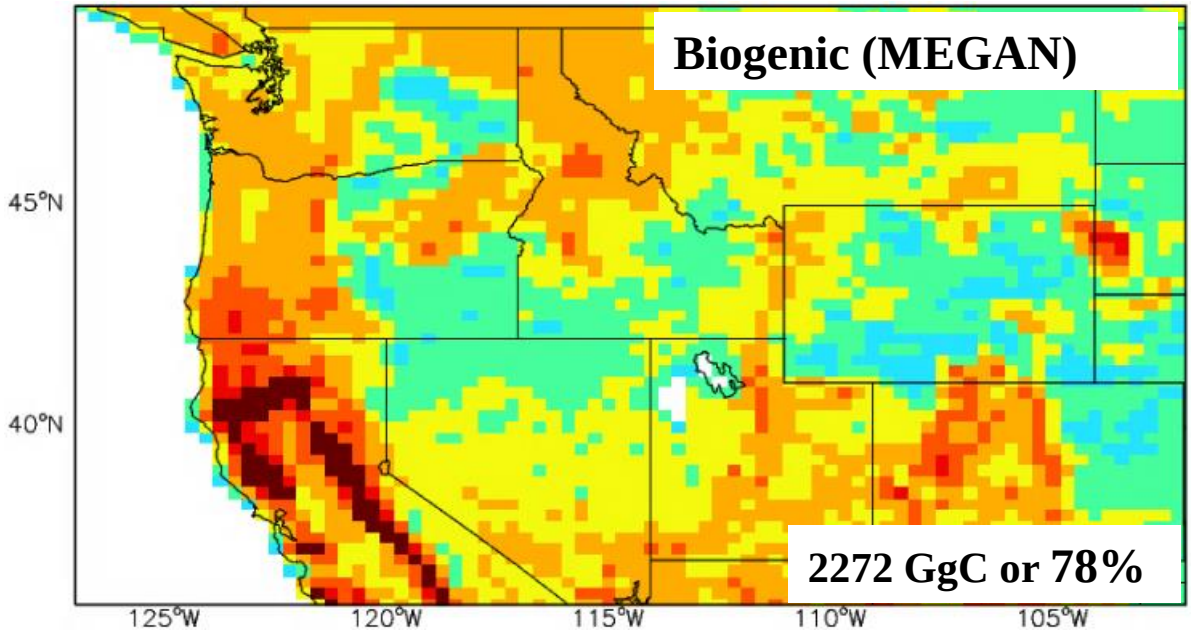
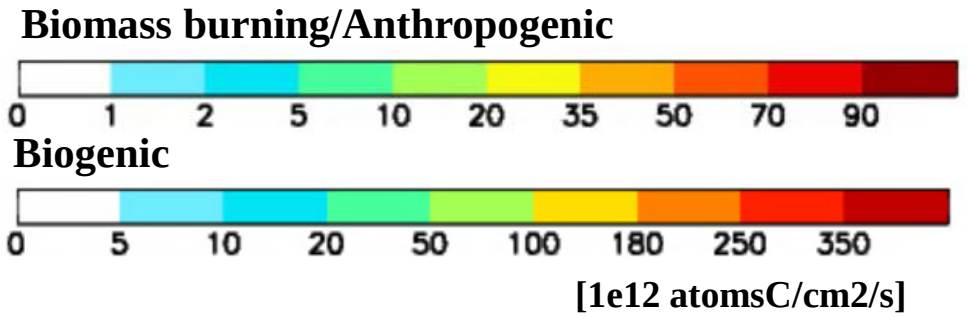
Current understanding of primary VOC emission in 2018 Summer





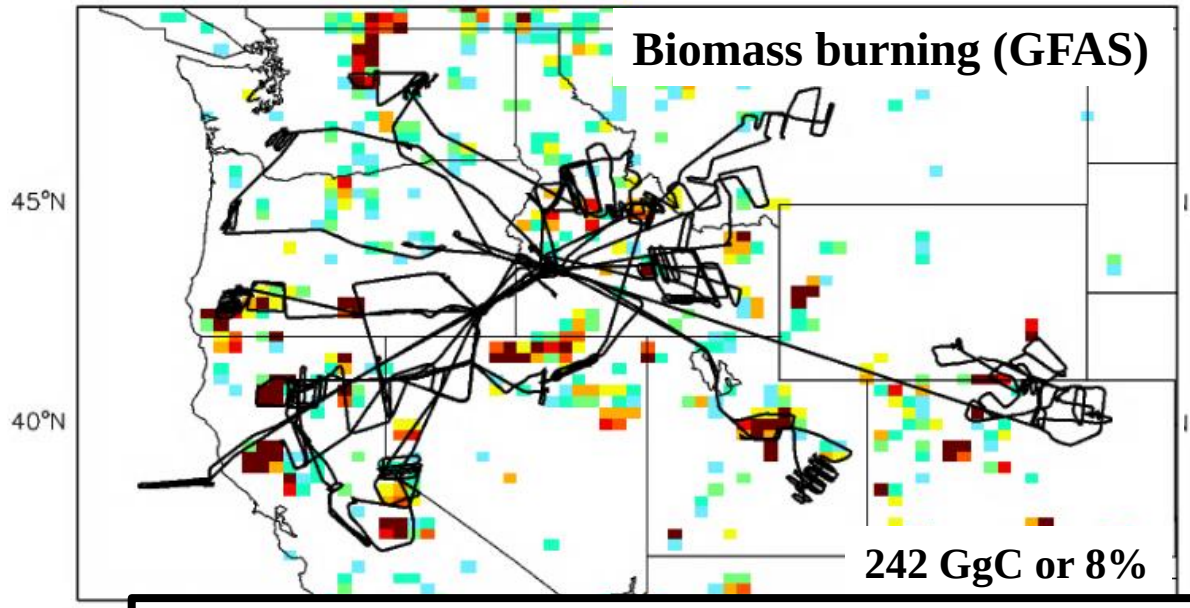


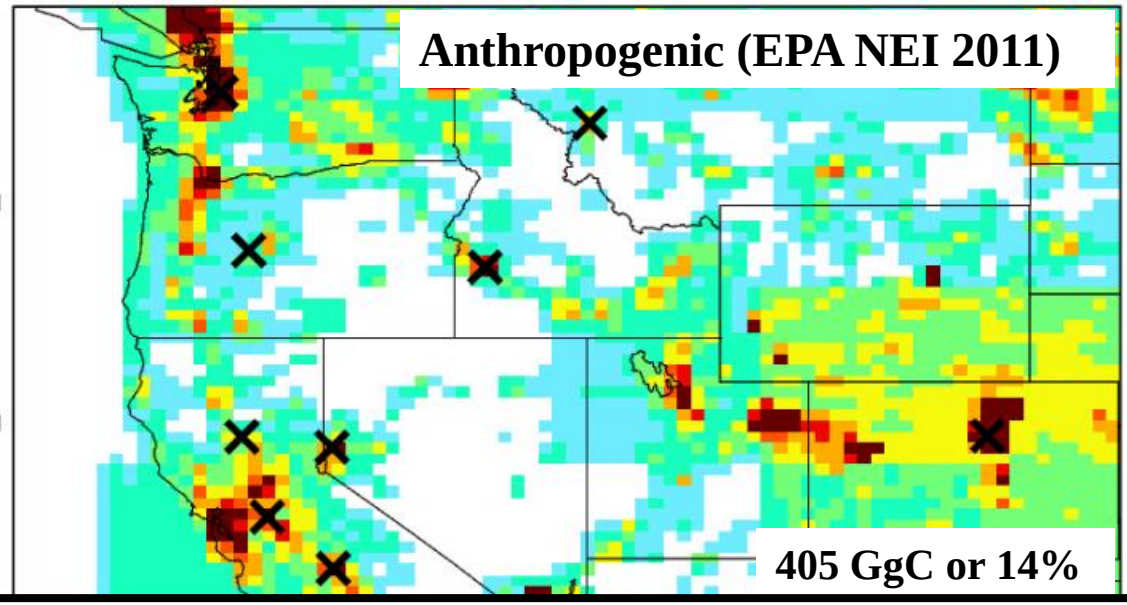


The total VOC emissions diff by 30-40% across 3 widely used BB emission inventories for this region (GFED4, QFED, and GFAS).

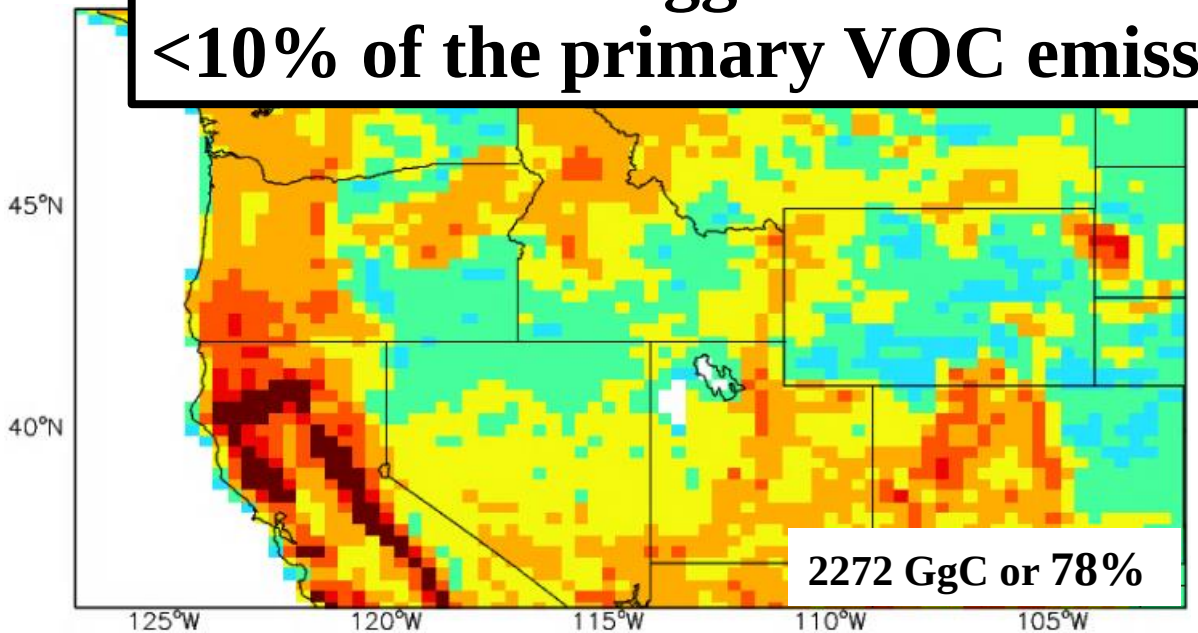
In the 2019 fire season, the VOC BB emission is only 1/6 of that in 2018 for this region.

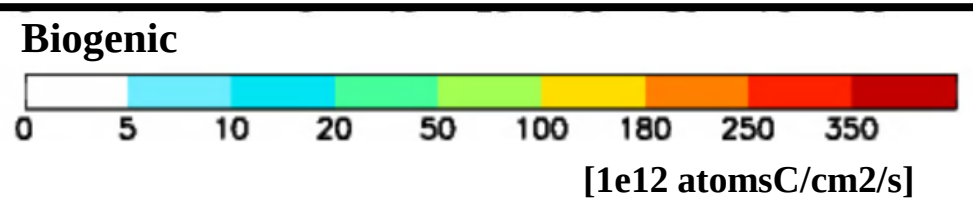
Current understanding of primary VOC emission in 2018 Summer





GEOS-Chem suggests that biomass burning (BB) only account for <10% of the primary VOC emission in the western US. Is it true?



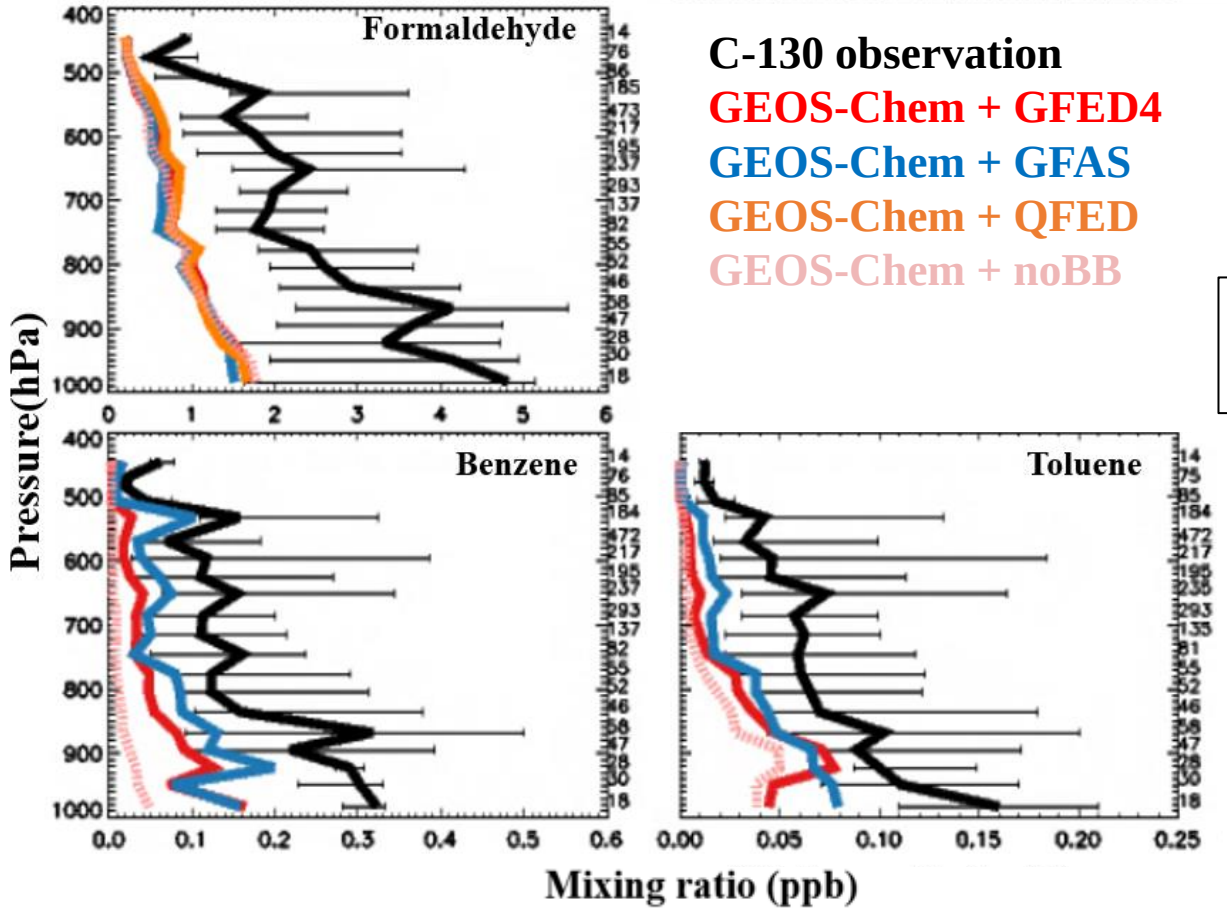


The total VOC emissions diff by 30-40% across 3 widely used BB emission inventories for this region (GFED4, QFED, and GFAS).

In the 2019 fire season, the VOC BB emission is only 1/6 of that in 2018 for this region.

- **Mod vs mod**: GEOS-Chem + GFAS tends to reproduce higher and better VOCs mixing ratios.
- **Mod vs obs**: GEOS-Chem with different inventories can reproduce the BB enhancements in the campaign averaged profiles but systematically underpredict observed VOC abundance by a factor of 2-6.

VOC vertical profiles over western US (WE-CAN)

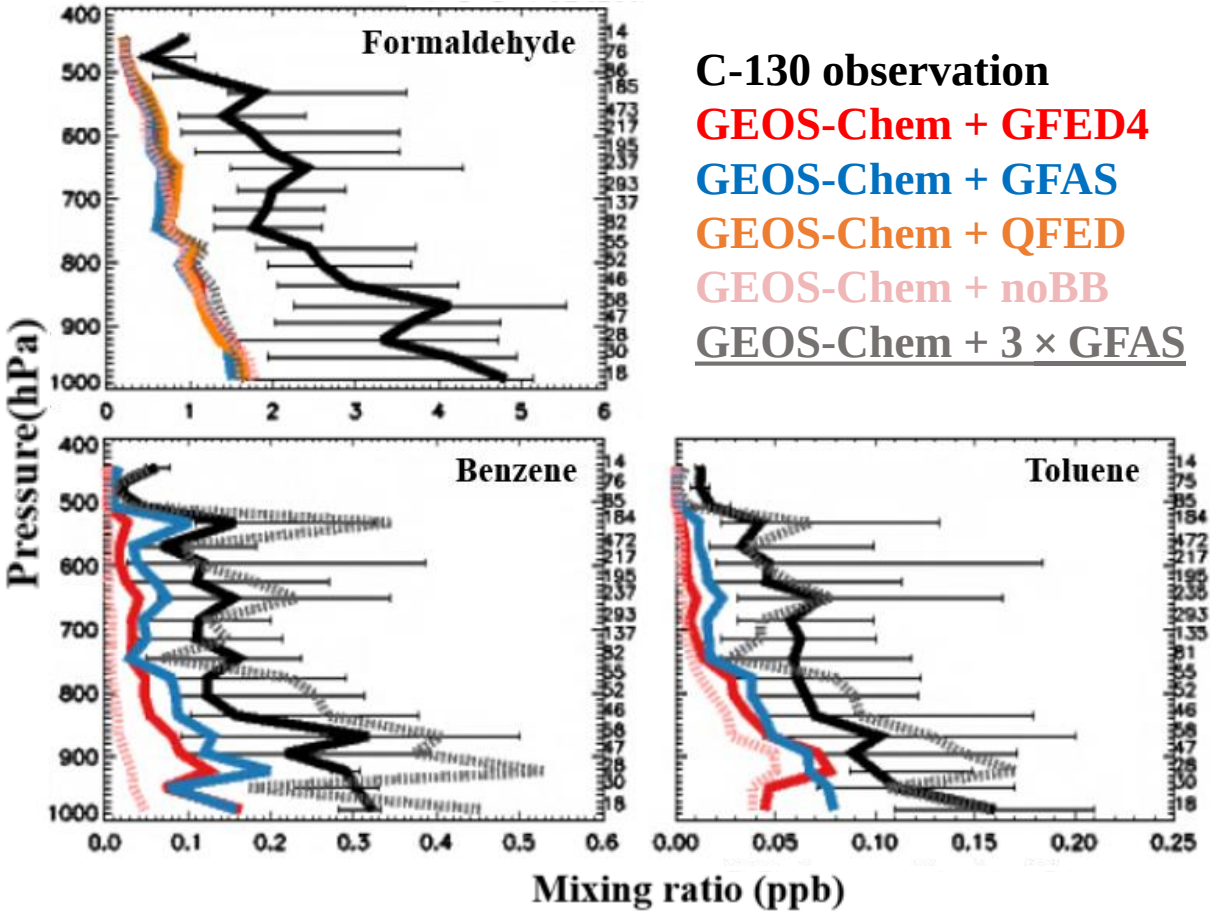


Analysis is conducted for other 11 VOCs (not shown here)

Question: Is the negative bias from BB emissions? How much and why?

- The best-case simulation (GEOS-Chem + GFAS) underestimates the BB emission by a factor of 3-5.
- For primary VOCs, tripling BB emissions agree the WE-CAN observation within measurement uncertainty; For OVOCs, there are likely missing photochemical production sources in the model.

VOC vertical profiles over western US (WE-CAN)

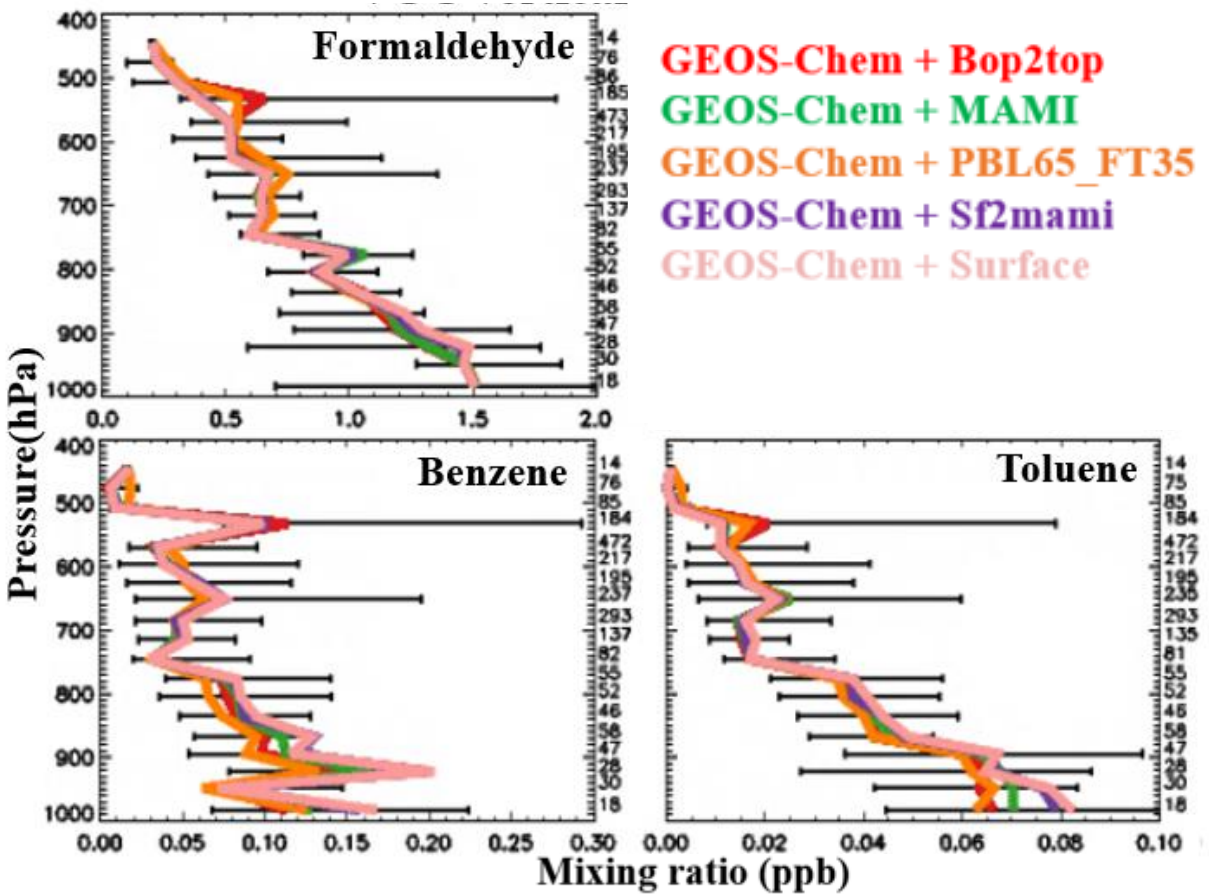


Question: Why does model underpredict BB emission?

- GFAS is selected for BB emission in this sensitivity test.

- The GEOS-Chem + Injection experiments tend to agree within 10%, suggesting that GEOS-Chem is not sensitive to those assumptions of how BB emissions are released vertically (at least for observation we used).

VOC vertical profiles over western US (WE-CAN)

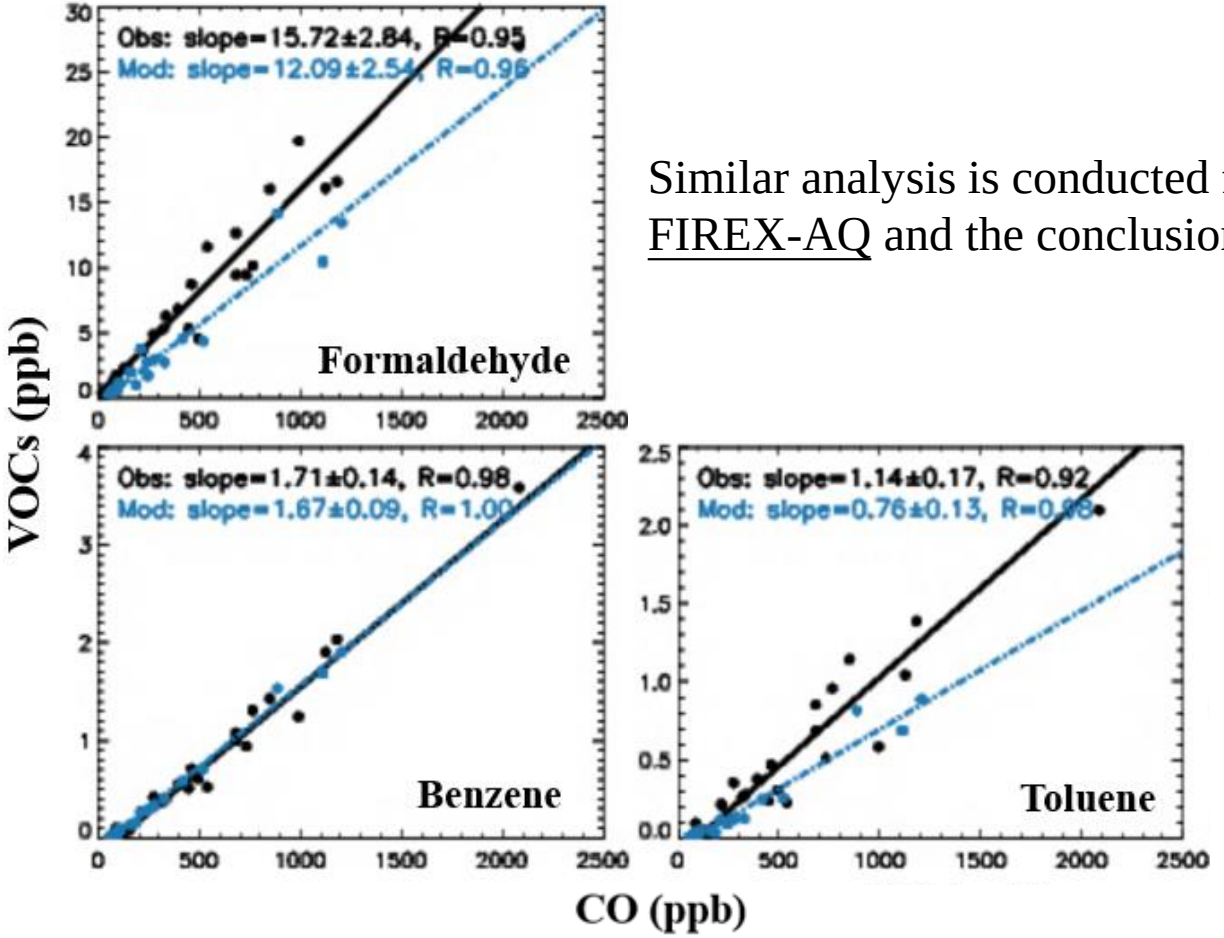


Injection height ☺

- Emission ratio test: the best representation (GFAS) tends to agree observed ER within ± 30 %.
- Fire detection experiment suggests the all 3 inventories can detect ~ 30 fires we sampled during WE-CAN.

=> VOC emission ratio and fire detection are not significant model errors in the GEOS-Chem.

VOC vs CO emission ratio (WE-CAN)



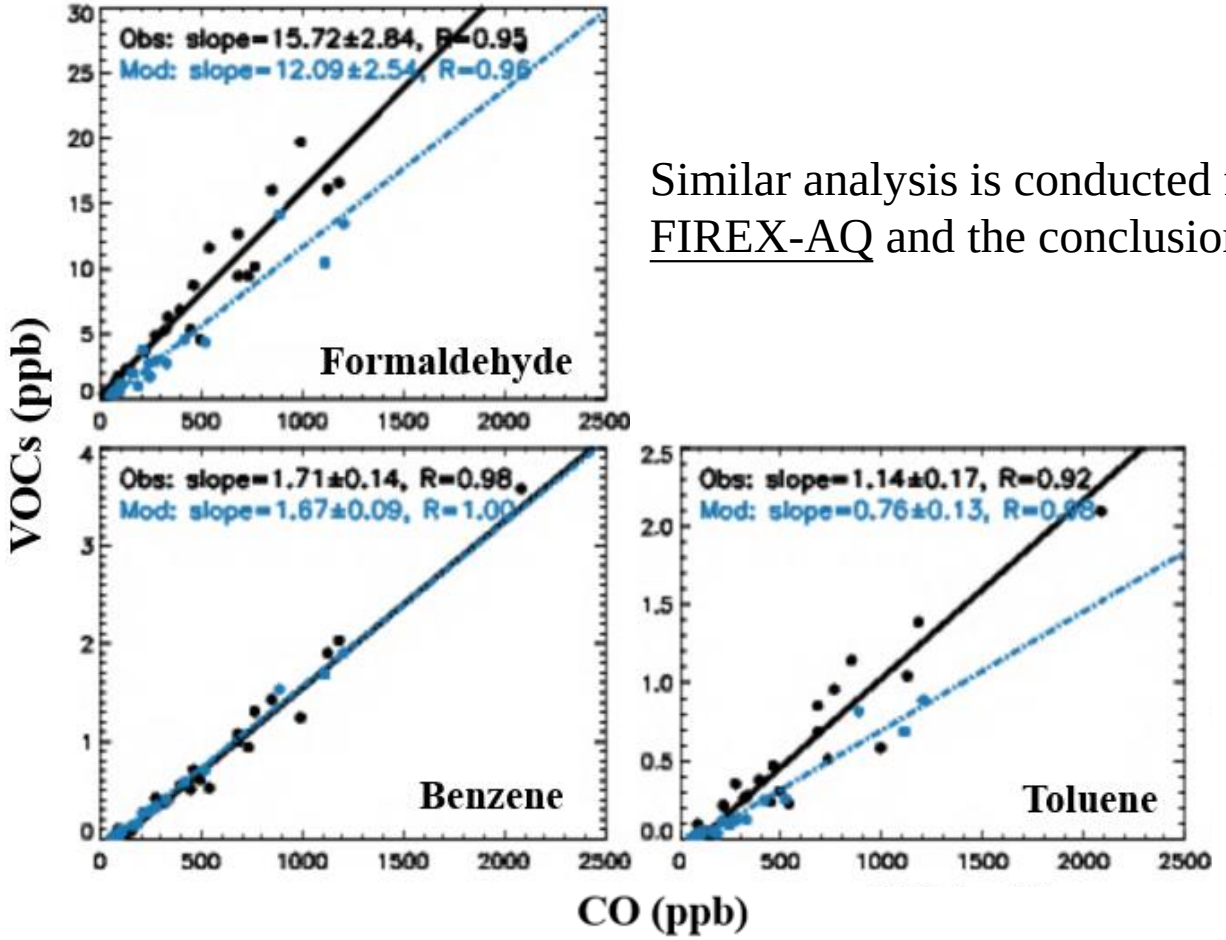
Similar analysis is conducted for FIREX-AQ and the conclusions hold.

Injection height ☺
Emission ratio ☺
Fire detection ☺

- How does BB emission inventory work?
  - ❑ Simple math: Emission estimates (g) = Emission factor (g/kg dry matter burnt) × dry matter burnt (kg)
  - ❑ Emission ratio and emission factor both suggest similar information.

=> **The BB underestimation is driven the underestimation of dry matter burnt**.

VOC vs CO emission ratio (WE-CAN)

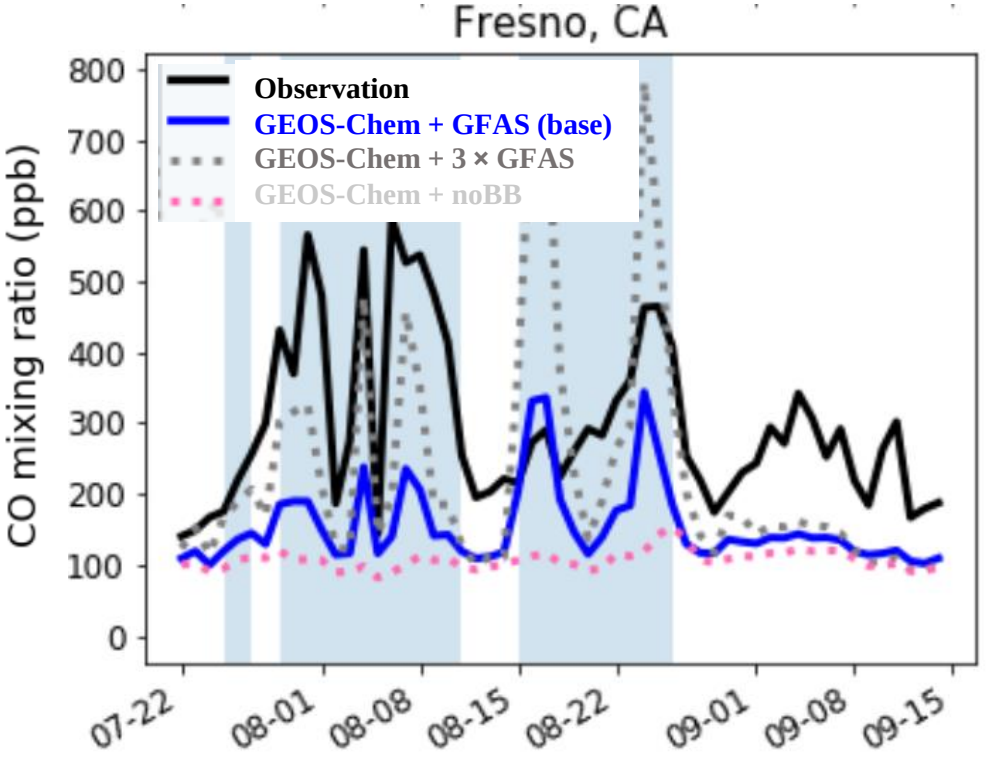


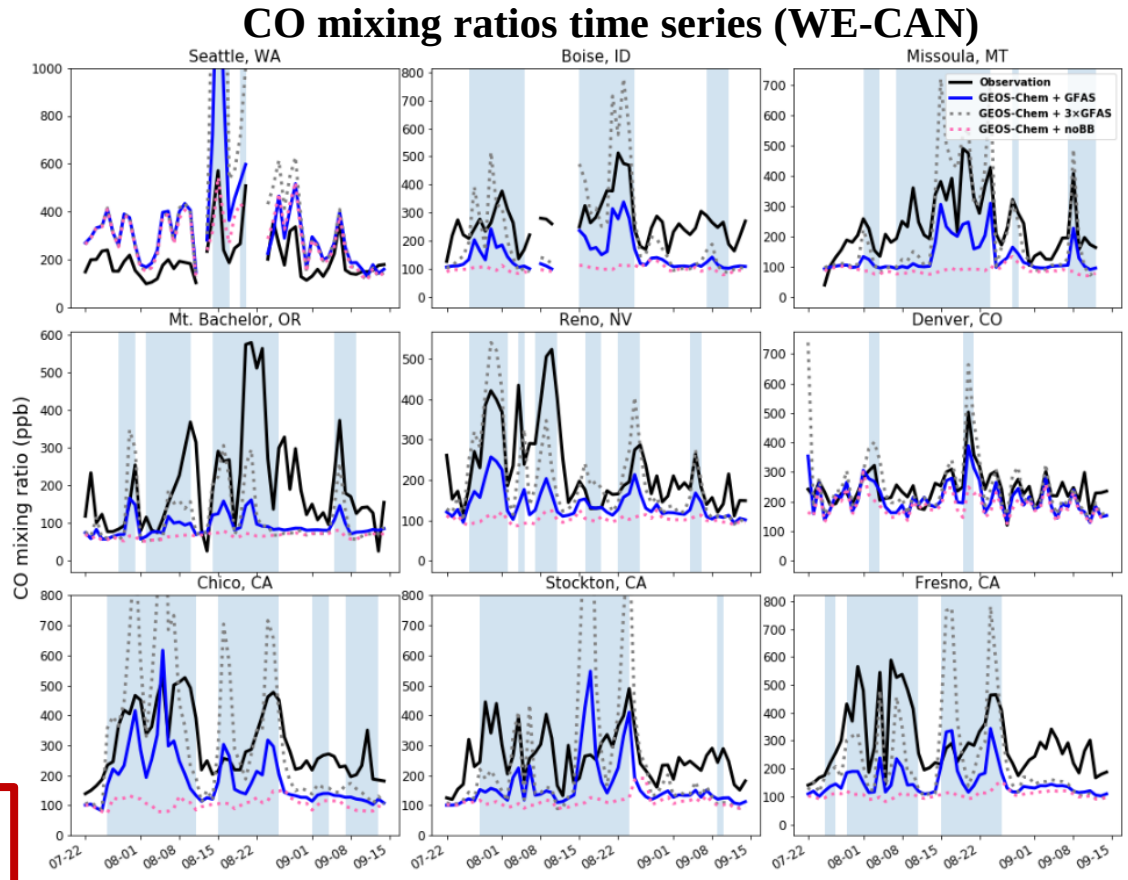
Similar analysis is conducted for FIREX-AQ and the conclusions hold.

Injection height	☺
Emission ratio	☺
Fire detection	☺
Dry matter burnt	☹

Question: Can the BB underestimation be applied to the widespread western US?

- The **base model** (GEOS-Chem + GFAS) does **underestimate** BB emissions across western US.
- The **3 × GFAS** simulation **systematically improves the model** mean bias across western US for 7 fire-influenced sites without degrading correlation coefficients with observations.





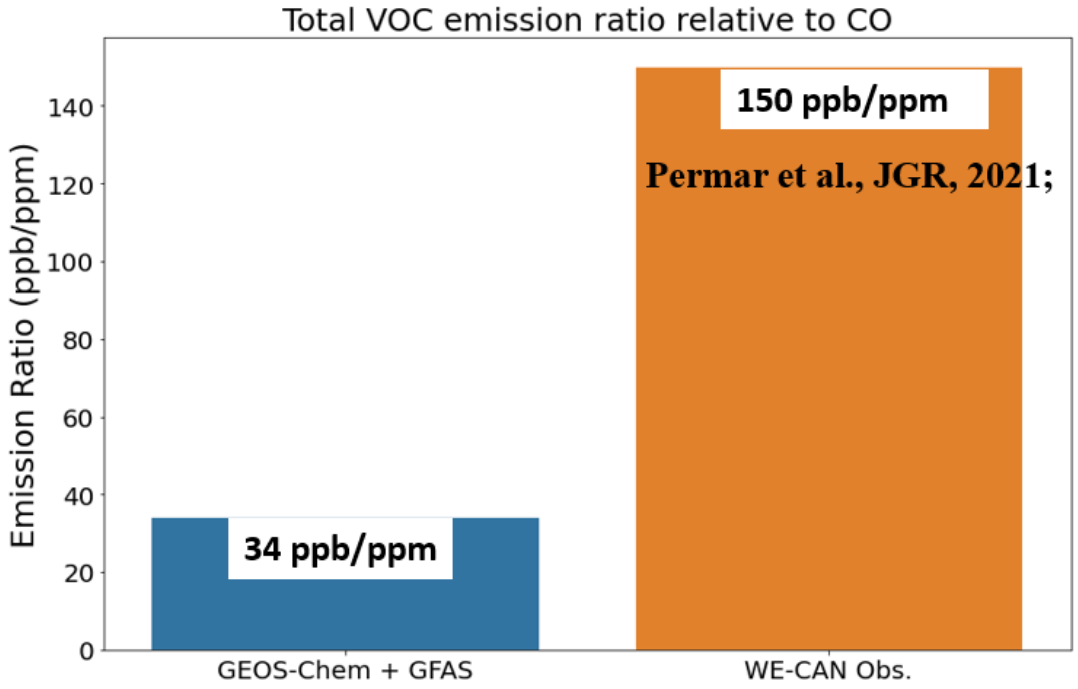
These ground measurements also point to the BB emission underestimation across western US.

Data credit:
Dan Jaffe (Mt Bachelor), Bob Yokelson and Vanessa Selimovic (Missoula), and EPA (rest)

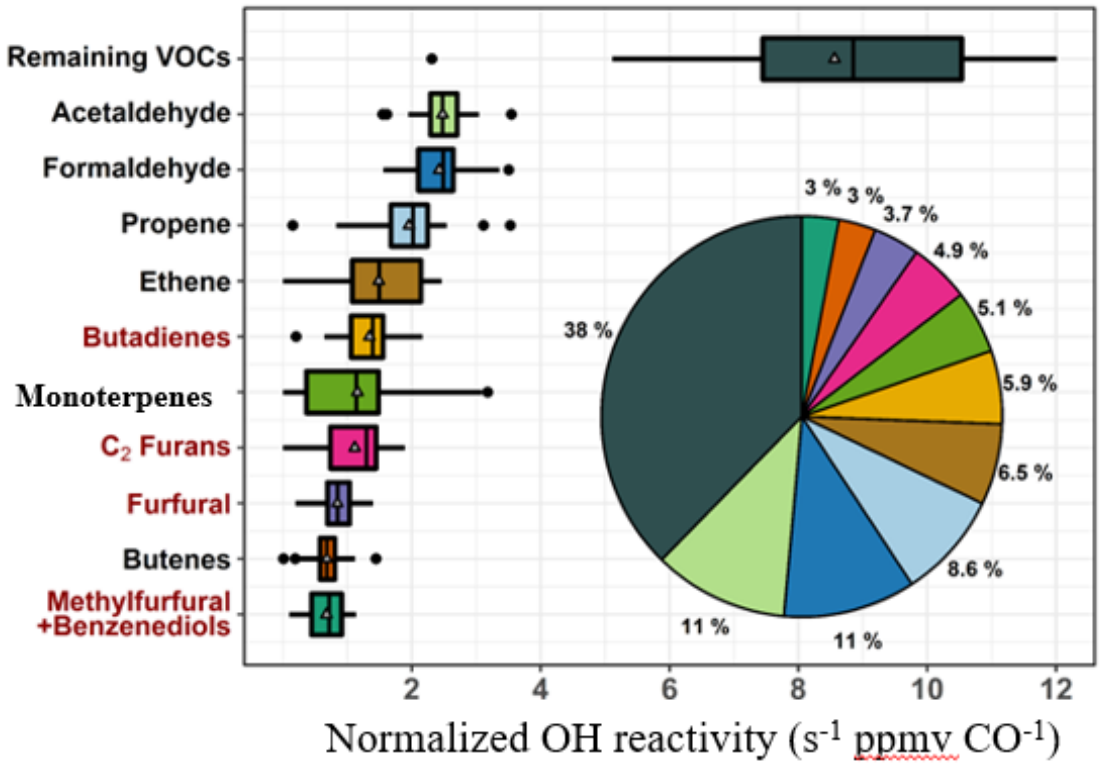
A significant amount reactive carbon from wildfire is missing in the GEOS-Chem

- Emission: VOC emission from wildfire can account for 30-60% of the total primary VOC emission (1-8% of total before), considering the dry matter burnt underestimation and unmodeled VOCs.

- Chemistry: Among top 10 OH reactivity contributor, 4 of them are not included in the GEOS-Chem: three of them are furans (furan and its derivatives) and the remaining one is butadiene.



< 20 BB VOCs **161 BB VOCs**



Permar et al. (in review)

Thanks Tess for providing a nice background about furans!

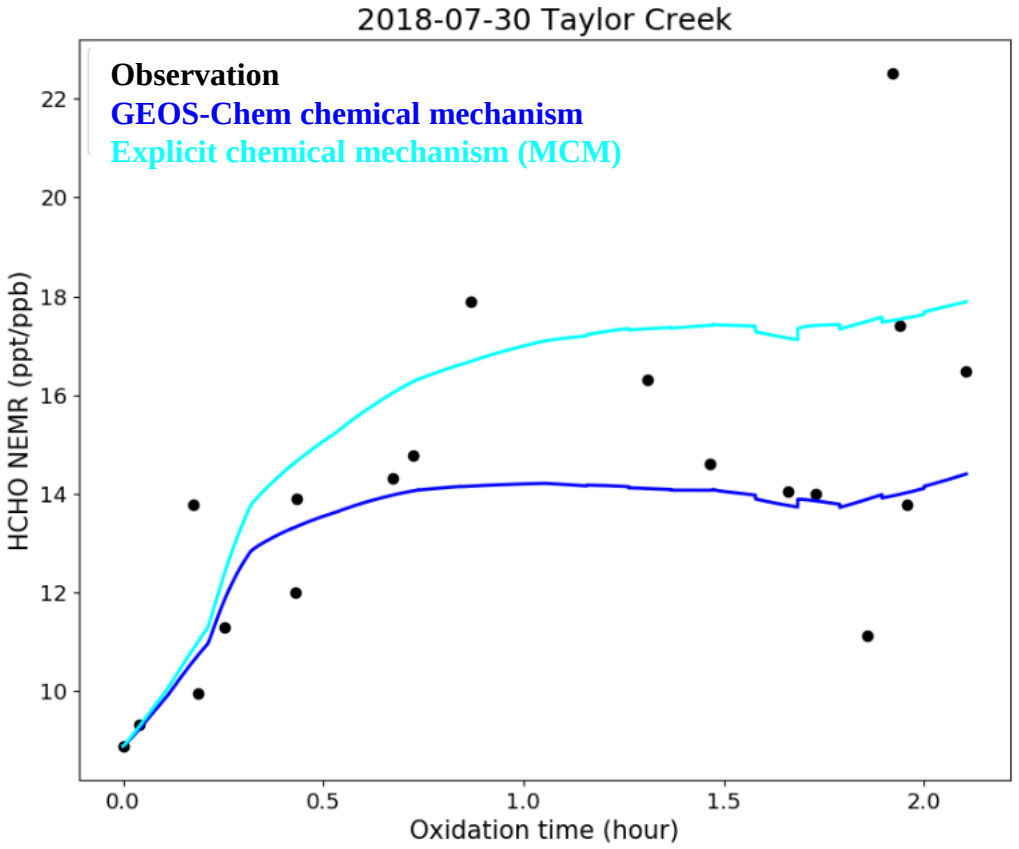
Summary

Conclusions:

- Three commonly-used BB inventories underestimate the BB emissions due to underprediction of dry matter burnt in the western US.
- Tripling the BB emission (3 × GFAS) systematically improves model: observation comparisons for primary VOCs. However, the model misses photochemical production sources for OVOCs.
- BB emissions play a far more important role than previous understanding.

Future work:

- GEOS-Chem chemistry mechanisms miss secondary HCHO production source by comparing to near-explicit chemistry (MCM).
- We need to figure out the **missing secondary source for formaldehyde.**
- **Also , we will customize chemistry of furans and other VOCs into the GEOS-Chem,** due to their significant OH reactivity contribution and corresponding chemical impacts.



To be submitted. Stay tuned!

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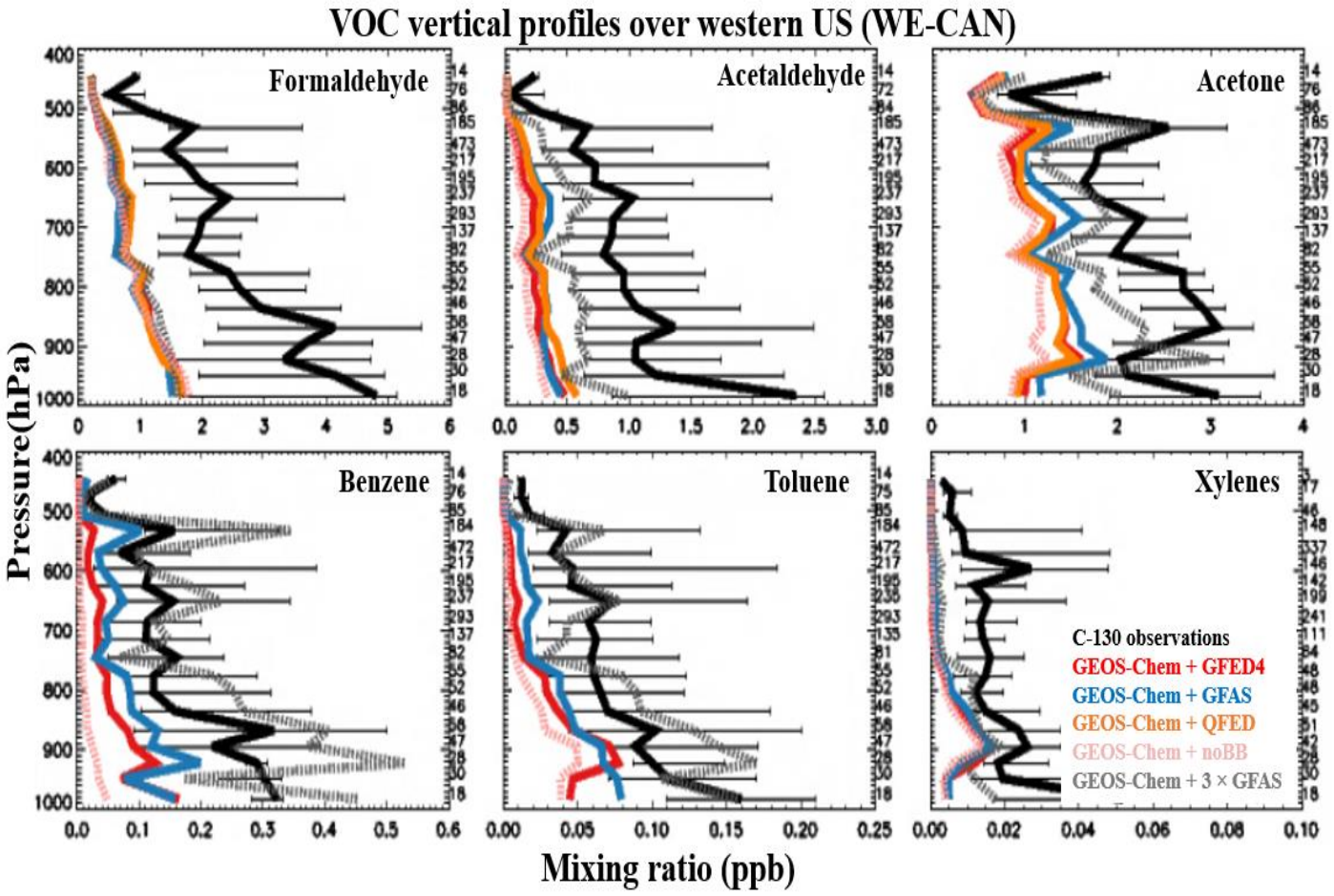
Additional materials (see following slides)

The model underpredicts the BB emissions by a factor of 3-5 (Q1 and Q2)



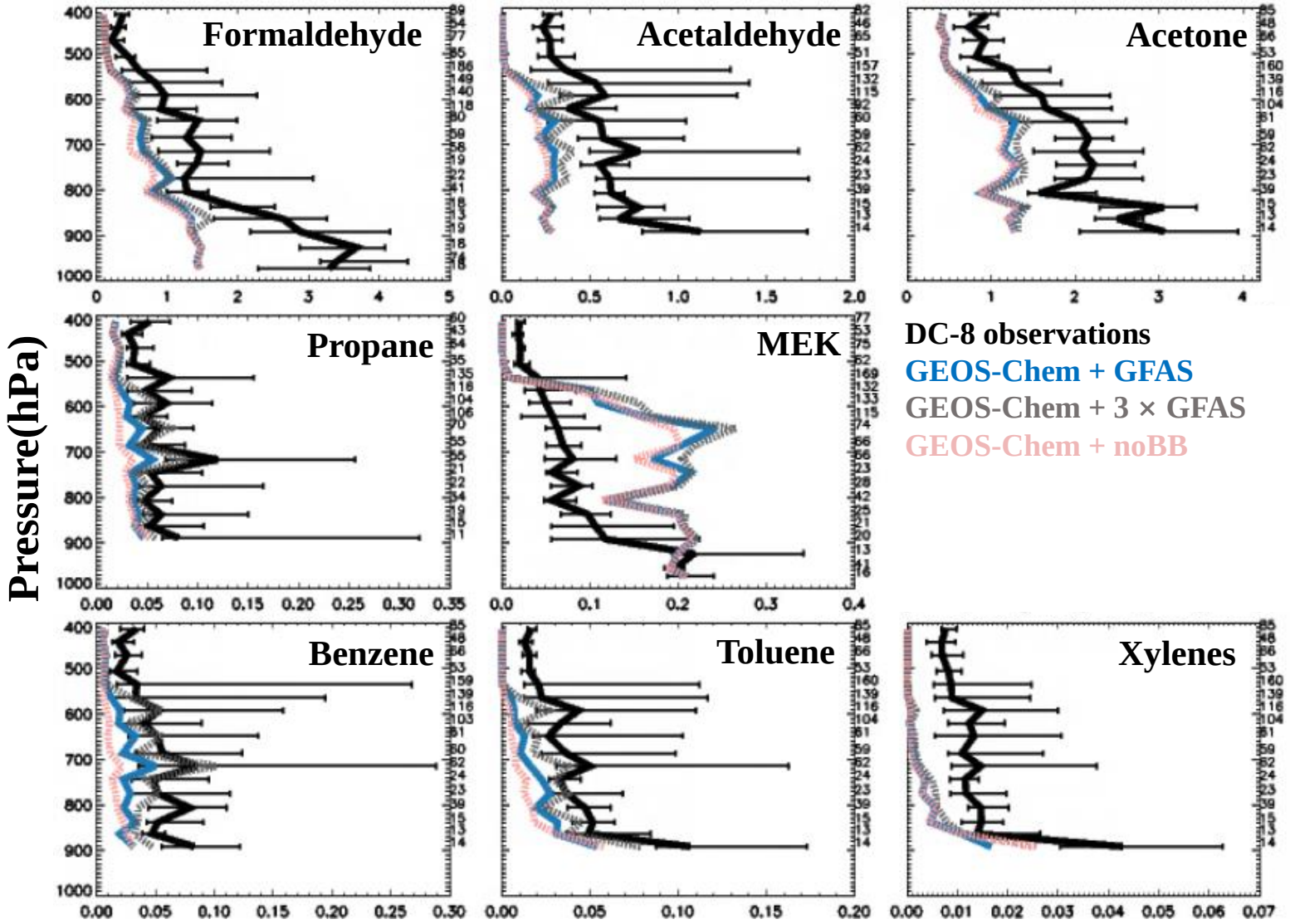
- Simple math is conducted to derive the underpredicted BB:
- BB impacts = full datasets – least fire conditions
- **Underestimated BB impacts = BB impacts from observation – from model**

⇒ **Model underestimates by a factor of 3-5 for primary trace gases (similar conclusion is gained for the 2019 FIRE-AQ)**

⇒ **Tripling the BB emissions in the model agree observed VOCs within observation uncertainty except xylenes and OVOCs (formaldehyde here).**

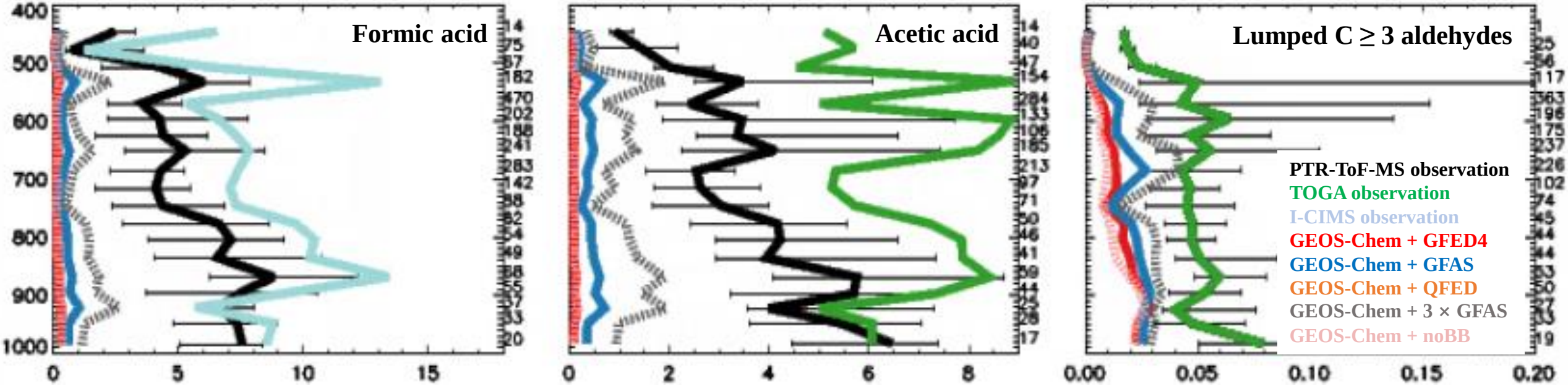
⇒ **Why are BB emissions underestimated? (e.g., emission factors, fuel burned, fire detections, and injections?)**

VOCs vertical profiles over the western US (FIREX-AQ)



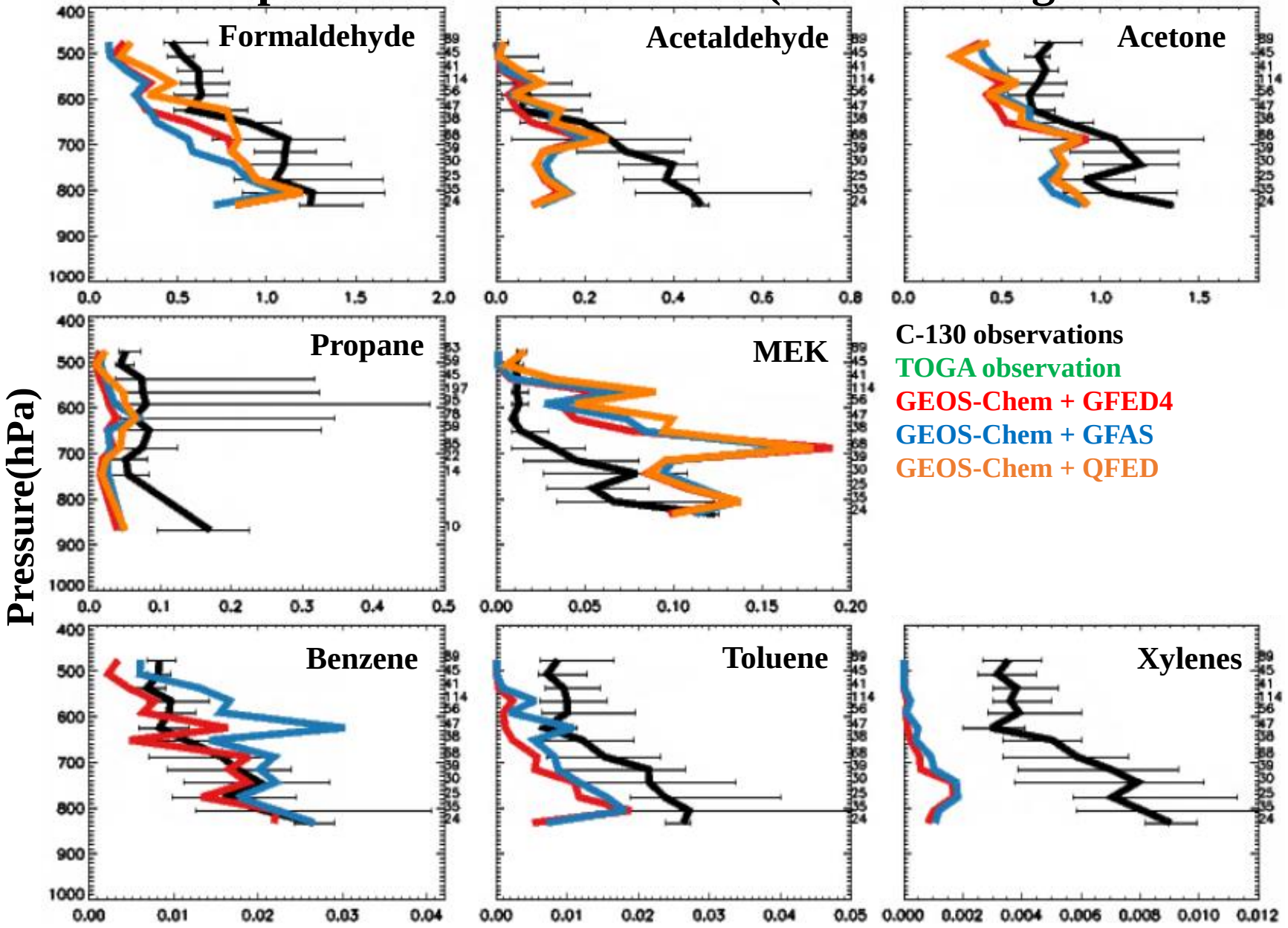
- **Similar conclusion supported by FIREX-AQ**: GEOS-Chem + GFAS can reproduce the BB enhancements in the profile but systematically underpredict BB-related source by a factor of 3-6 for primary VOCs (except MEK; a factor of 2-5 in the WE-CAN).

VOC vertical profiles over western US (WE-CAN)

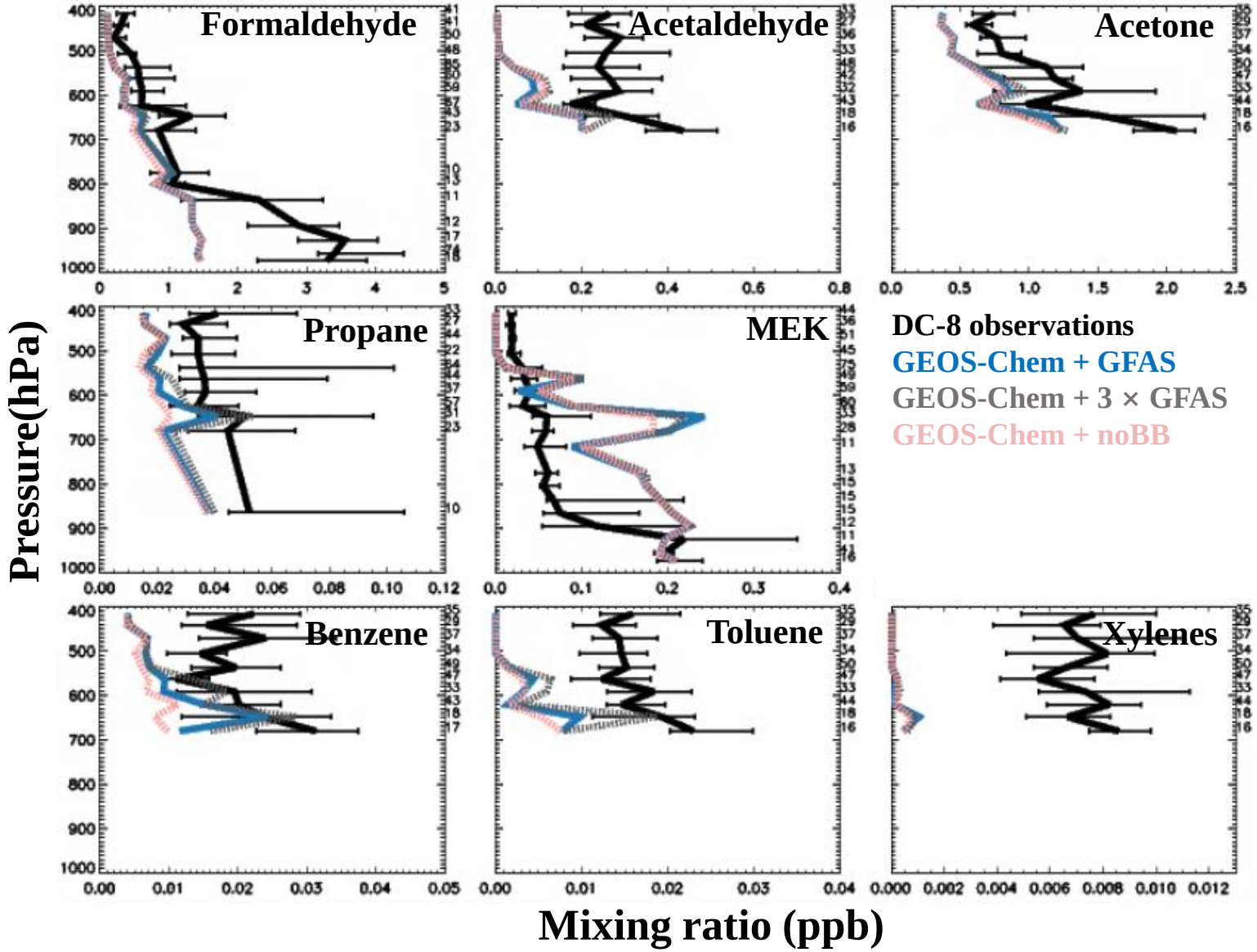


- Missing photochemical production source for formic acid, acetic acid, and lumped C ≥ 3 aldehyde

VOC vertical profiles over western US (least-fires region for WE-CAN)



VOCs vertical profiles over the western US (least BB-impacted for FIREX-AQ)



There are problems beyond BB emissions as suggested by the relatively clean environment: missing HCHO, acetaldehyde, propane, benzene, and toluene.