A PLAIN-LANGUAGE RESEARCH STORY

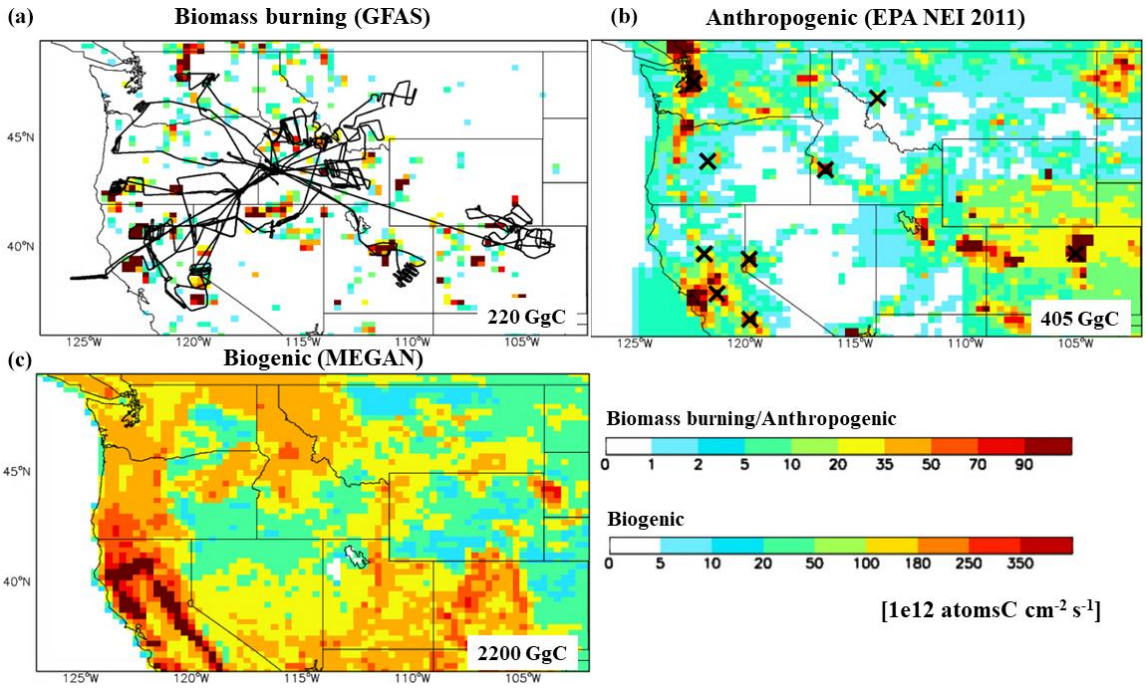
Aircraft Measurements Reveal Missing Wildfire CO and VOC Emissions

The fires were detected but their modeled CO and VOC emissions were too low

Jin et al. (2023) | Atmospheric Chemistry and Physics

Wildfire-smoke modeling often begins with satellite observations. Satellites can show where fires are burning, but a fire-emission inventory must still estimate how much fuel burned and how much of each gas entered the atmosphere. We tested those estimates using measurements from two major aircraft campaigns and a network of ground monitors across the western United States.

The inventories generally detected the large fires behind the smoke plumes sampled during WE-CAN. Yet the modeled increases in CO and many VOCs were too small, and the model represented only part of the measured VOC mixture.



Aircraft and ground measurements provided complementary tests of GEOS-Chem simulations driven by three satellite-based fire inventories.

How we tested the model: We compared GEOS-Chem simulations driven by three satellite-based fire inventories with carbon monoxide (CO) and volatile organic compound (VOC) measurements from WE-CAN 2018 and FIREX-AQ 2019. We also compared daily modeled and observed CO at nine western US ground sites.

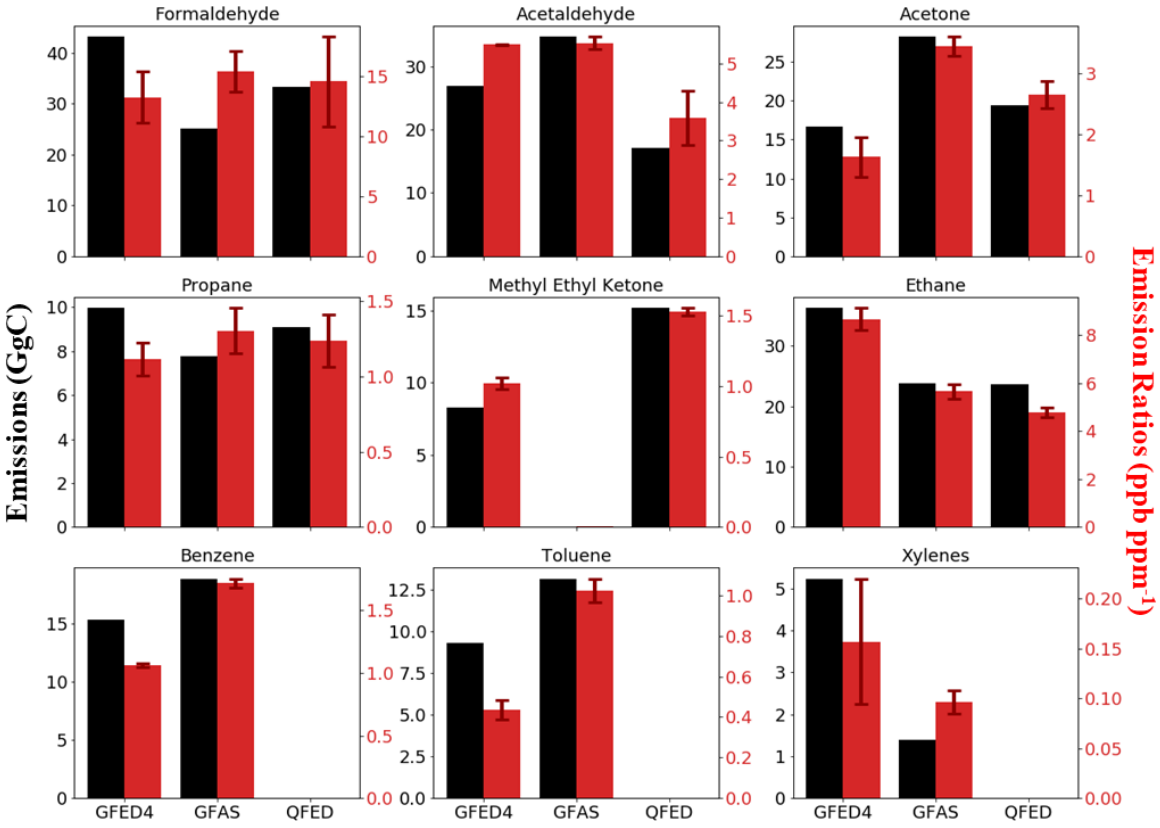
SIMILAR TOTALS HIDE DIFFERENT VOC MIXES

Total VOC Emissions Look Similar but Individual Estimates Differ by Up to Fivefold

A similar total did not mean a similar mix of VOCs.

For the 14 VOC groups represented in GEOS-Chem, total 2018 western US fire-season emissions differed by about 30%–40% across GFED4s, GFAS, and QFED. Estimates for individual compounds, however, differed by as much as fivefold.

The main reason was that each inventory assumed a different mix of VOCs would be released from the vegetation that burned. This was a different issue from finding the fires or estimating the overall strength of their emissions. Because VOCs react at different rates, changing the mix changes how the model predicts ozone and other pollutants that form downwind.



Black bars show 2018 western US fire-season emissions for each compound. Red bars show how much of that compound was emitted relative to CO. Similar totals can still hide large differences among individual VOCs.

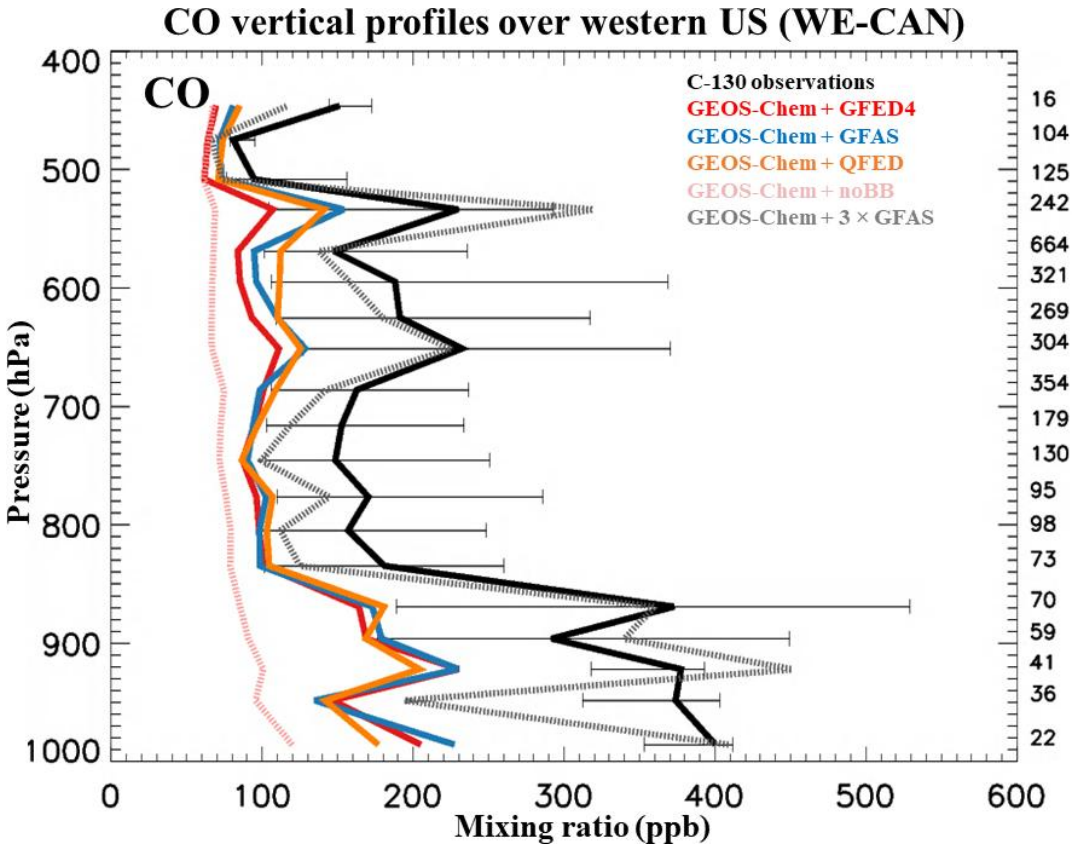
Jin et al. (2023), Fig. 2, CC BY 4.0.

Aircraft measurements then tested a separate question: Did the model produce enough CO and VOCs from the fires it had already detected?

THE MODELED SMOKE SIGNAL WAS TOO WEAK

The Fires Were Detected but Their CO and Primary VOC Emissions Were Too Low

The simulations generally placed the smoke at the right time and location but produced much smaller gas increases than the aircraft measured.



Aircraft measured much more CO than any of the three standard simulations. Tripling GFAS fire emissions closed much of the gap.
Jin et al. (2023), Fig. 3, CC BY 4.0.

The three inventories generally detected the large fires sampled during WE-CAN, and the simulations often placed the smoke at the right time and location. Even so, the modeled fire-related increases in CO, propane, benzene, and toluene were only about one-third to one-seventh as large as the corresponding increases measured by aircraft.

Each GEOS-Chem grid cell covered an area much wider than many smoke plumes, so the model could not fully resolve their narrow peaks. To limit this mismatch, we compared campaign-wide averages and smoke-related increases instead of individual plume peaks. We then used daily ground-level CO and a second aircraft campaign to test whether the low bias extended beyond the WE-CAN plume crossings.

We then tripled the modeled fire emissions to see which gases moved closer to the aircraft measurements.

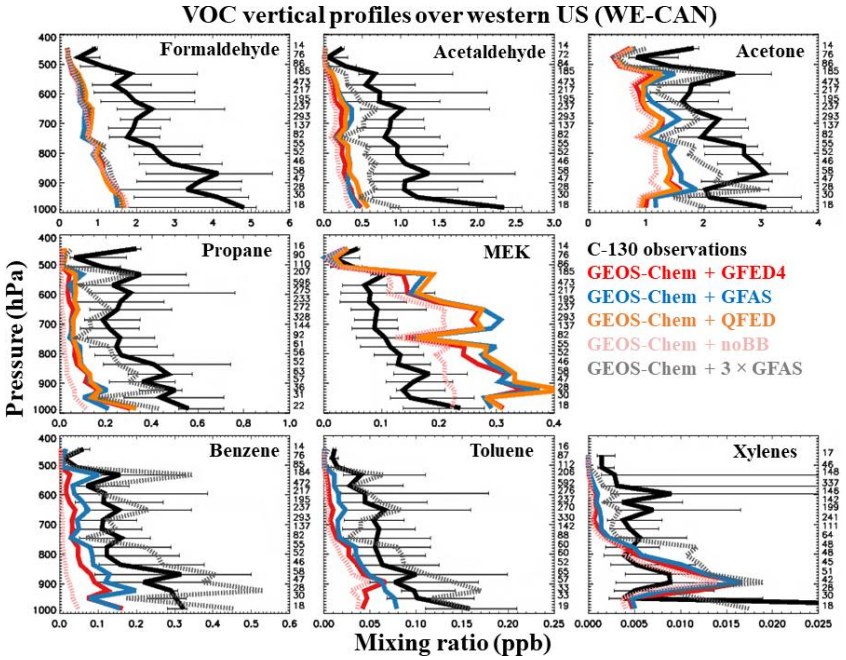
ONE CHANGE PRODUCED TWO DIFFERENT RESULTS

Tripling Fire Emissions Improved Primary Gases but Not Every Oxygenated VOC

More fire emissions brought much of the primary-gas signal closer to observations but left several oxygenated VOCs too low.

Tripling GFAS fire emissions brought CO, propane, benzene, and toluene much closer to the aircraft observations. Taken together, checks of fire detection, smoke height, emission ratios, fuel consumption, and ground CO supported one leading explanation: even where fires were detected, the inventories effectively assumed that too little vegetation had burned.

Several oxygenated VOCs behaved differently. Acetaldehyde and acetone improved, but formaldehyde remained too low. Formic acid, acetic acid, and larger aldehydes also changed little. This pattern suggests that the model missed an important source of oxygenated VOCs: secondary production as smoke reacted in the atmosphere. The gap could reflect missing precursor emissions, incomplete chemistry, or both.



Tripling emissions brought primary VOCs closer to observations but left formaldehyde too low. The different response points to a separate gap in the chemistry that forms oxygenated VOCs downwind.

Jin et al. (2023), Fig. 4, CC BY 4.0.

How to read the threefold test: The threefold experiment provides an upper-limit estimate of how much fire emissions may have been underestimated in these western US cases. Narrow plumes unresolved by the model could explain part of the gap, so this is not a universal correction.

A second aircraft campaign and daily ground-level CO provided an independent check.

INDEPENDENT OBSERVATIONS TOLD THE SAME STORY

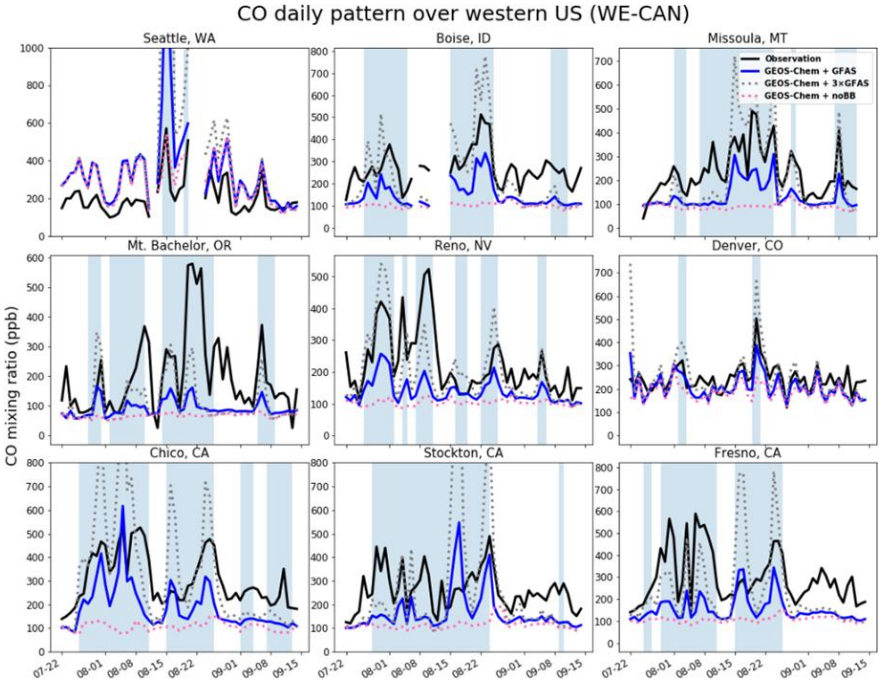
Aircraft and Ground Measurements Showed That Modeled Fire Emissions Were Too Low

At seven fire-influenced sites, ground-level CO showed a similar model shortfall.

We evaluated daily CO at nine western US sites. At the seven sites with stronger fire influence, the base simulation was 95–140 ppb lower than the observations on average over the full 2018 analysis period, with larger shortfalls on smoke-affected days. Tripling fire emissions reduced the bias. The FIREX-AQ 2019 aircraft comparison also showed a weak modeled fire signal.

Emission strength was only one of the two problems. When we added up VOC emissions relative to CO, the 14 biomass-burning VOC groups represented in GEOS-Chem accounted for only about half of the total measured across 161 compounds. This comparison concerns the VOC-to-CO ratio, not VOC mass, toxicity, or reactivity. It shows that the model represented only part of the measured VOC mixture.

After accounting for both the weak modeled fire signal and the VOCs missing from the model, we estimated that wildfires supplied about 45% of primary VOC emissions in the western United States during the intense 2018 fire season and about 10% in 2019. The standard GEOS-Chem simulation put the wildfire contribution at only 1%–10%.



Across nine western US sites, the standard simulation often produced too little CO. Tripling fire emissions usually moved the model closer to the observations during smoke periods.

Jin et al. (2023), Fig. 8, CC BY 4.0.

The inventories generally detected the sampled fires, and the simulations often placed the smoke at the right time and location. The model still underestimated CO and primary VOC emissions, represented only part of the measured VOC mixture, and likely missed some precursor emissions or chemistry that forms oxygenated VOCs.

Explore the study: ACP article · Supplement · Post-publication data · Post-publication code