Observing the impacts of wildfires on ozone-NO_x-VOC-aerosol chemistry from space

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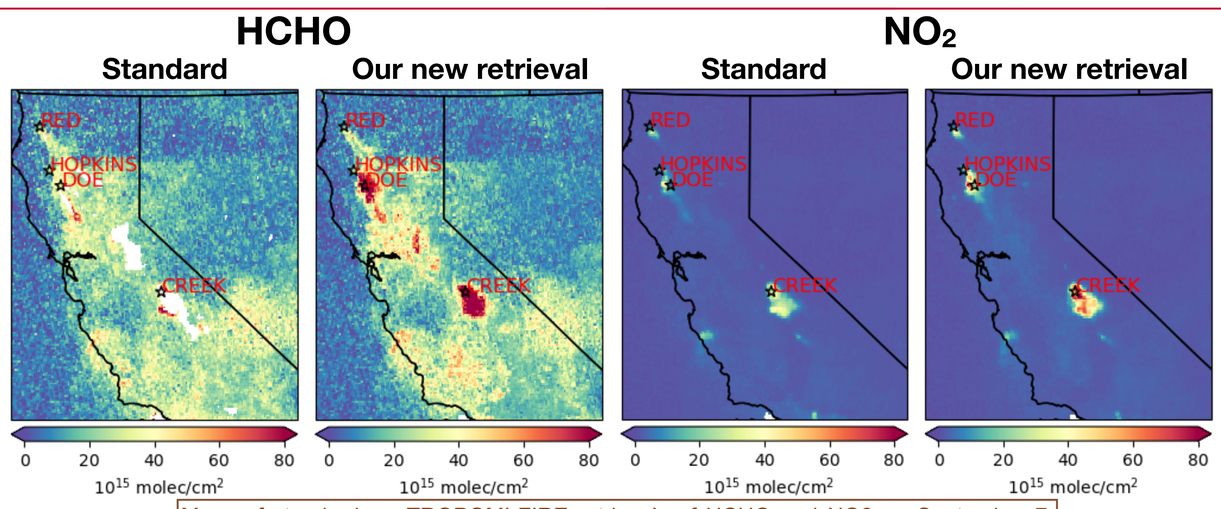
Background

The frequency of wildfires has escalated in recent decades under climate change. Here we examine the impacts of wildfires on ground-level ozone precursors and the ozone formation from source to downwind urban areas with three scientific questions:

- Can we use satellite observations to detect the influence of wildfires on trace gases?
- How do wildfire emissions of ozone precursors (NO_x and VOCs) affect ozone production?
- How do smoke aerosols affect ozone production?

New TROPOMI retrievals of NO_2 and HCHO for fire plumes



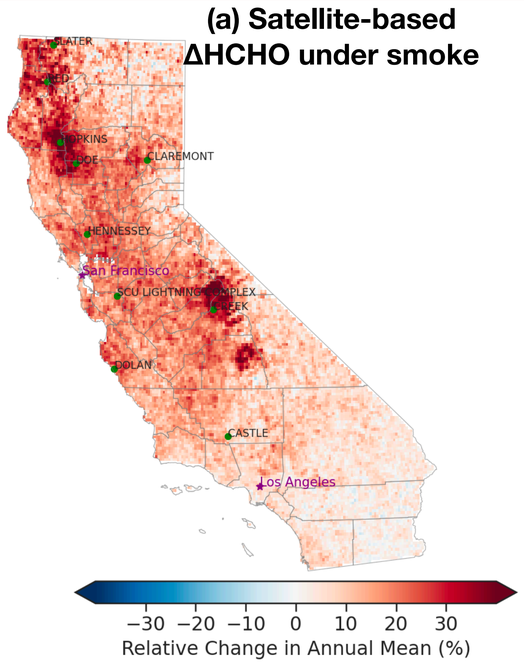
Maps of standard vs. TROPOMI-FIRE retrievals of HCHO and NO2 on September 7, 2020 over California. Four big fires occurred on this day are labelled.

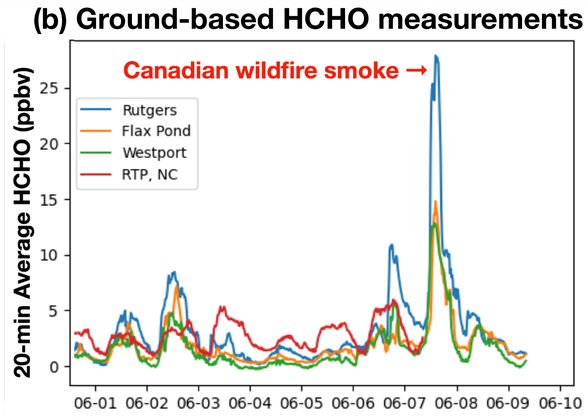
Major updates

	Standard retrieval	TROPOMI-FIRE
***A priori* vertical shape**	TM5 simulations (1° without daily fire)	**GEOS-Chem or GEOS-CF (0.25° with daily fire)**
Scattering weight	Aerosol effects implicitly accounted as cloud	**Explicitly accounting for smoke aerosol effects using LIDORT**
Availability	Global, daily, 2018 - present	**US, daily, 2018 - 2023**

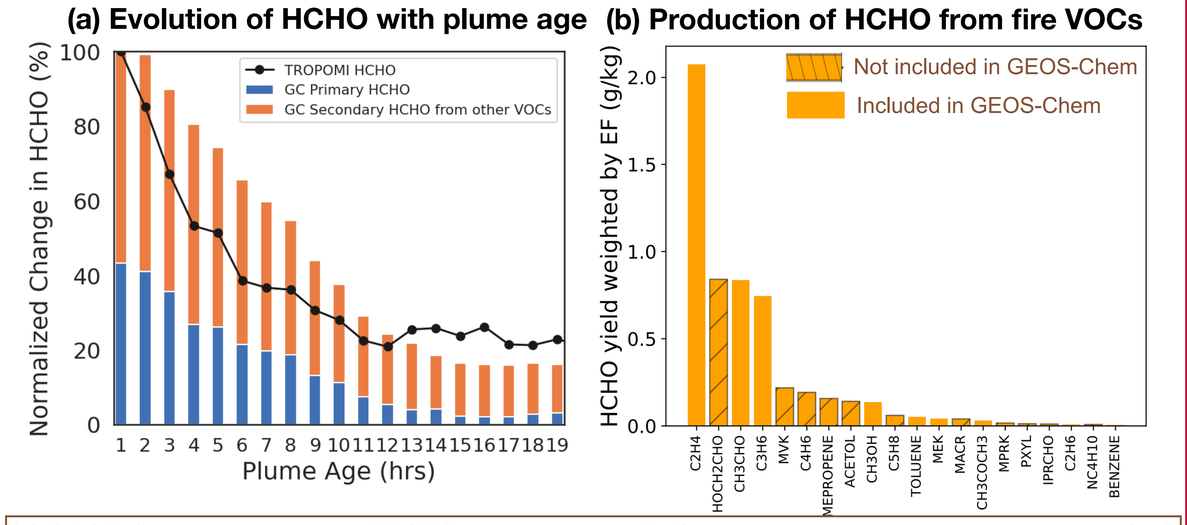
We are looking for interested data users!

Widespread increase of HCHO from wildfires



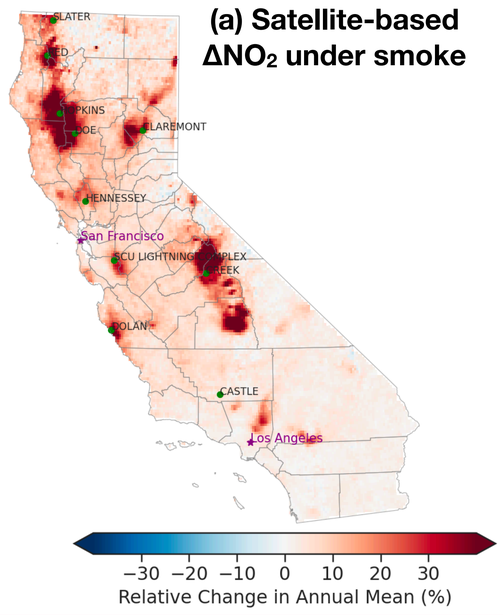


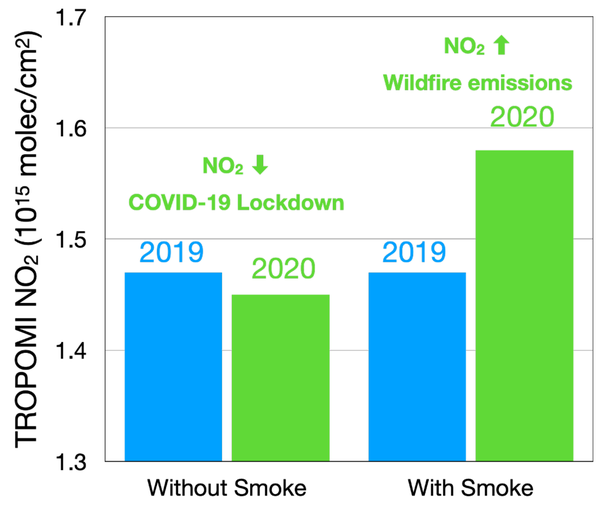
(a) Annual mean relative change of TROPOMI HCHO under smoke in 2020 over California (Figure from Jin et al. [1]). The NOAA's Hazard Mapping System (HMS) smoke product is used to identify potential areas affected by wildfire smoke plumes. (b) Surface measurements of HCHO concentrations at four sites over eastern US. Data from Luka Valin and Andrew Whitehill at US EPA.



(a) GEOS-Chem simulated and TROPOMI observed ΔHCHO with plume age normalized by the ΔHCHO at fire center. (b) HCHO yield from oxidation of VOCs weighted by the wildfire emission factors [2].

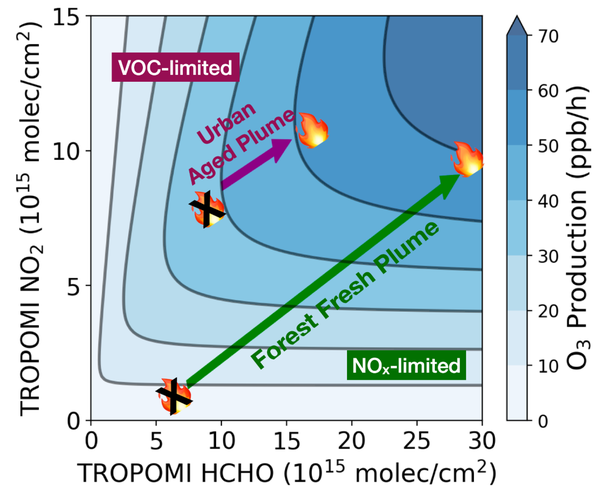
Wildfire NO_2 increase offsets emission reduction from COVID-19 lockdown

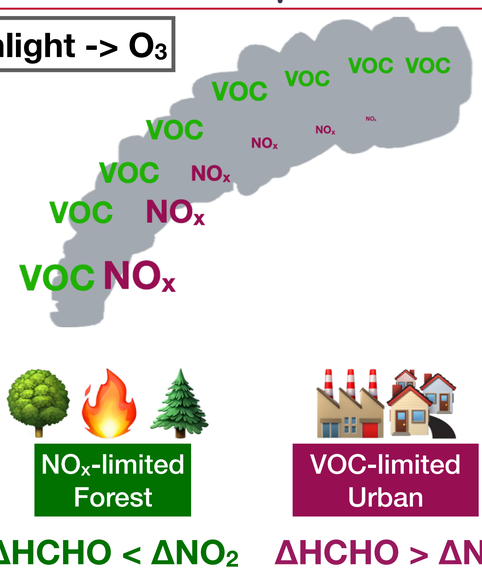




Impacts of wildfire NO_x and VOCs on ozone production

NO_x + VOC + Heat&Sunlight -> O_3





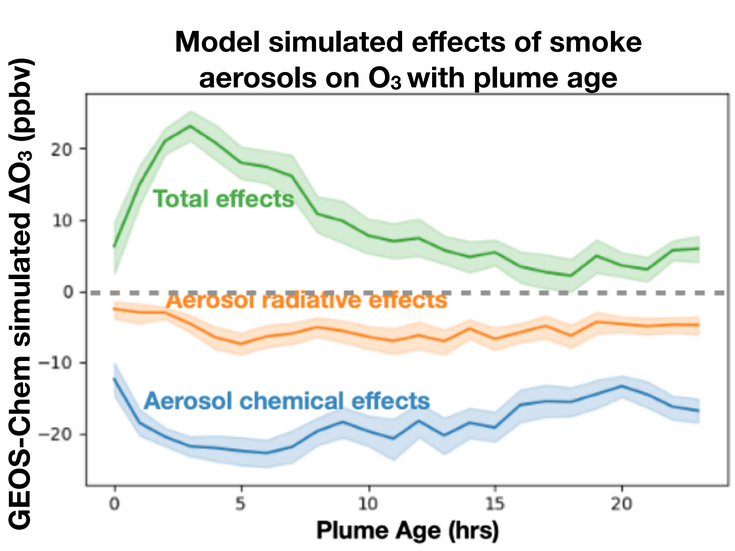
ΔHCHO < ΔNO₂ **ΔHCHO > ΔNO₂**

Impacts of smoke aerosols on O_3

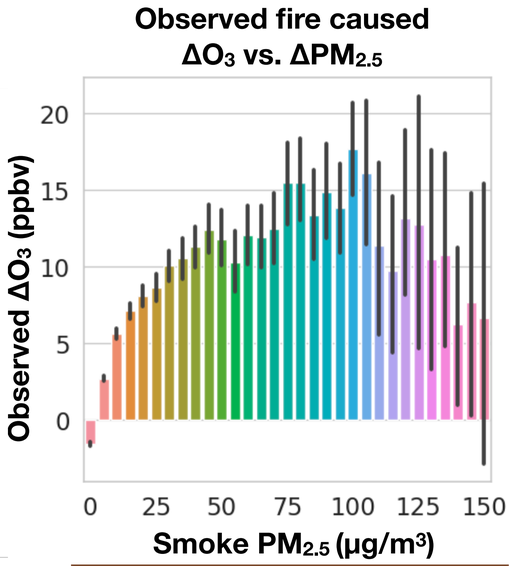
Wildfires can affect O_3 production in three ways:

1. Emissions of NO_x and VOCs ⬆O_3
2. Radiative effects of aerosols: Photolysis rates ⬇O_3
3. Chemical effects of aerosols: Heterogeneous reaction with HO_x ⬇O_3

We find that the emission effects are overall higher than the aerosol effects. Aerosol chemical effects are more important than radiative effects, except for extreme fires.



The aerosols effects are simulated with GEOS-Chem by comparing the control simulation with perturbation simulations that turn off the effects wildfire aerosols on photolysis rate (orange) and the HO_2 uptake (blue). Plume age is determined as the time it takes to transport from source to downwind areas.



ΔO_3 is estimated by comparing the AQS ground-based O_3 measurements on days with vs. without smoke at the same temperature. Smoke $PM_{2.5}$ is estimated using a ML approach as described in Childs et al. [3].

Summary

- **Satellite observations detect large increase of both NO_2 and HCHO from wildfires.**
- **The increase of NO_2 is concentrated near NO_x-limited forest regions, while the increase of HCHO is more widespread, extending to VOC-limited urban areas, both favoring O_3 production.**
- **O_3 production is also affected negatively by smoke aerosols through radiative and chemical pathways.**

References:

1. Jin, X., Fiore, A. M. & Cohen, R. C. Space-Based Observations of Ozone Precursors within California Wildfire Plumes and the Impacts on Ozone-NOx-VOC Chemistry. *Environ. Sci. Technol.* (2023).
2. Permar, W. et al. Emissions of Trace Organic Gases From Western U.S. Wildfires Based on WE-CAN Aircraft Measurements. *J Geophys Res Atmospheres* 126, (2021).
3. Childs, M. L. et al. Daily Local-Level Estimates of Ambient Wildfire Smoke PM2.5 for the Contiguous US. *Environ Sci Technol* 56, 13607–13621 (2022).

Acknowledgement:

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