Reactive nitrogen and ozone photochemistry in the northwestern U.S. wildfire smoke plumes during the 2022 CalFiDE campaign

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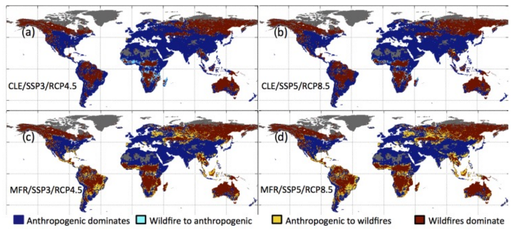
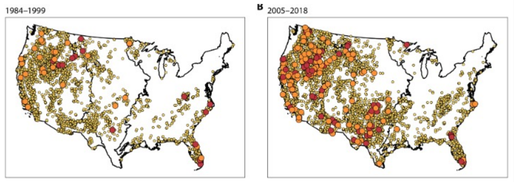
Background and Importance

Trends in the frequency and intensity of wildfire activity in the past four decades have been escalating. These trends have the potential to lead to more extreme burning in future years as a result of global warming which makes understanding wildfire-atmosphere interactions increasingly important.



Dominant PM2.5 sources at by 2090. (Knorr et al, Atmos. Chem. Phys. 17, 9223, 2017.)

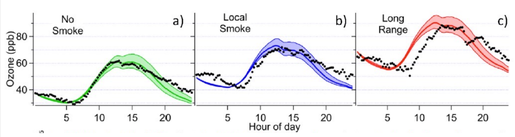
The impacts of increased wildfire activity are happening on a global scale. In the United States, California and Oregon are a few of the primary regions that are especially vulnerable to wildfire activity due to a combination of geographical, climatic, and ecological factors. These regions have a history of large and destructive wildfires, including the 2018 Camp Fire, which destroyed a town and resulted in dozens of fatalities, and the 2020 North Complex Fire, which burned over 300,000 acres.



Iglesias et al., Sci. Adv.8, eabc0020 (2022)

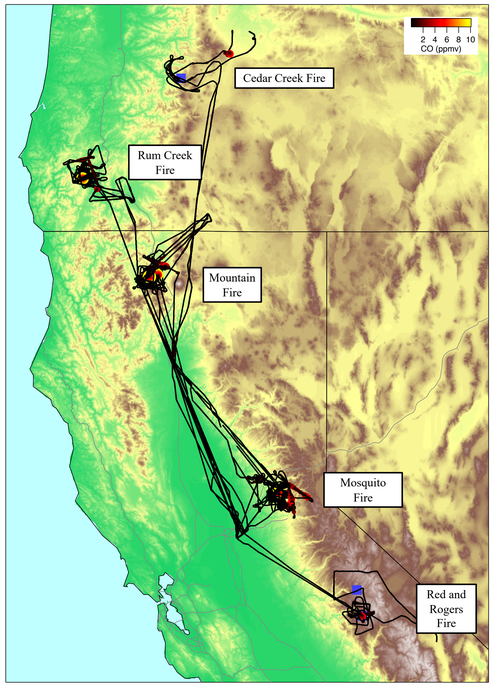
Wildfires can have significant impacts on both the environment and human health, often extending far beyond the immediate area where the fire occurs. A few of these primary impacts include the destruction of habitats, soil degradation, air pollution, and water contamination. Human health is impacted by the emission of volatile organic compounds and nitrogen oxides (NOx) during the wildfires, which also leads to increases in tropospheric ozone and other secondary pollutants.

Both local (generally within a few hundred kilometers of the fire) and long-range smoke emissions, which are often transported several hundreds or even thousands of kilometers away from the fire source, can influence tropospheric ozone levels through complex interactions with atmospheric chemistry, meteorology, and smoke characteristics.



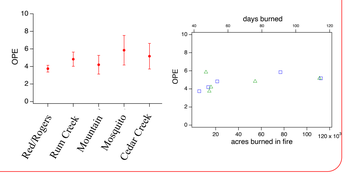
Understanding these interactions is essential for assessing the air quality impacts of wildfires. This work discerns the spatial and temporal variability of ozone production in six wildfires with the aim to understand the dynamics of ozone sensitivity within and between wildfire plumes.

Chemistry and Dynamics in the Wildfire Plumes



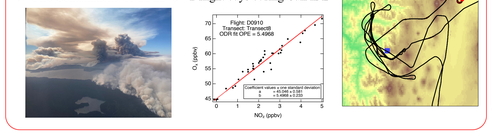
Comparisons between the average OPE value across the plumes in each fire, the dependence of OPE on the size of the fire (days and acres burned), and

Fire	Avg. OPE
Red/Rogers	3.73 (0.77)
Rum Creek	4.83 (1.62)
Mountain	4.2 (2.13)
Mosquito	5.85 (3.37)
Cedar Creek	5.17 (2.92)



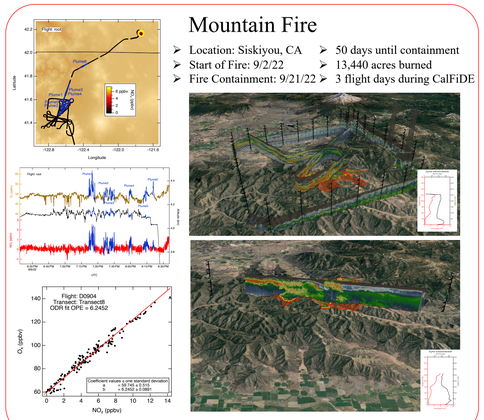
Cedar Creek Fire

- Location: Central OR
- Start of Fire: 8/1/22
- Fire Containment: 11/22/22
- 114 days until containment
- 112,287 acres burned
- 2 flight days during CalFiDE



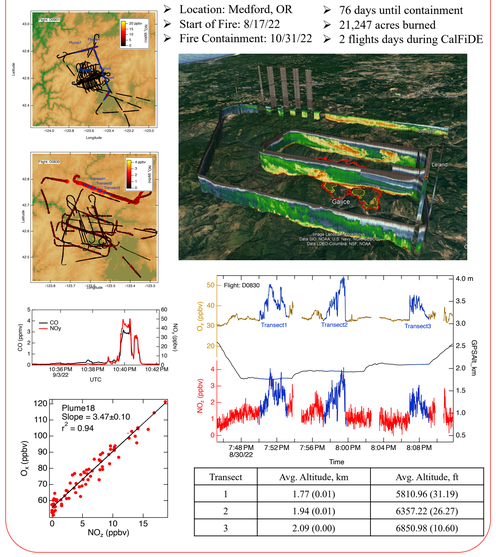
Mountain Fire

- Location: Siskiyou, CA
- Start of Fire: 9/2/22
- Fire Containment: 9/21/22
- 50 days until containment
- 13,440 acres burned
- 3 flight days during CalFiDE



Rum Creek Fire

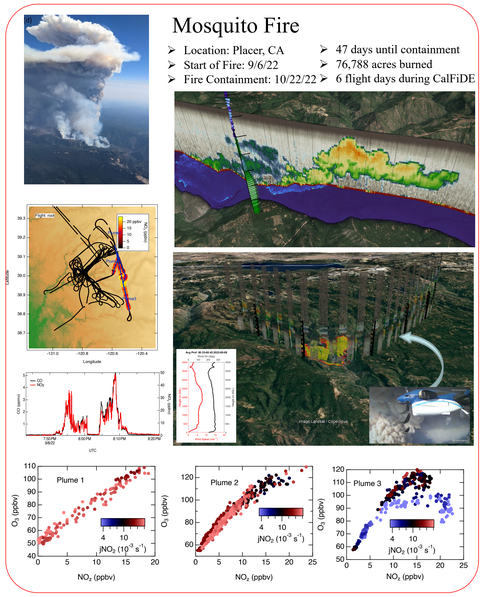
- Location: Medford, OR
- Start of Fire: 8/17/22
- Fire Containment: 10/31/22
- 76 days until containment
- 21,247 acres burned
- 2 flights days during CalFiDE



Transect	Avg. Altitude, km	Avg. Altitude, ft
1	1.77 (0.01)	5810.96 (31.19)
2	1.94 (0.01)	6357.22 (26.27)
3	2.09 (0.00)	6850.98 (10.60)

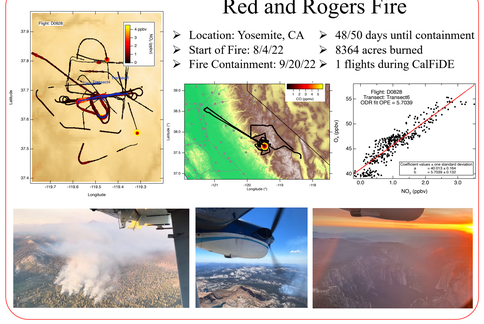
Mosquito Fire

- Location: Placer, CA
- Start of Fire: 9/6/22
- Fire Containment: 10/22/22
- 47 days until containment
- 76,788 acres burned
- 6 flight days during CalFiDE



Red and Rogers Fire

- Location: Yosemite, CA
- Start of Fire: 8/4/22
- Fire Containment: 9/20/22
- 48/50 days until containment
- 8364 acres burned
- 1 flights during CalFiDE



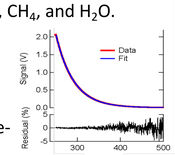
CalFiDE 2022

- Location: Northern California and Oregon
- Dates: August 28th-Sept. 25th 2022

The 2022 California Fire Dynamics Experiment (CalFiDE) campaign leveraged a dual approach by taking measurements aboard the NOAA Twin Otter aircraft included in-situ trace gas measurements of nitrogen oxides (NO_x), reactive nitrogen, ozone (O_3), and greenhouse gases alongside remote sensing measurements via a scanning Doppler lidar and a thermal imaging camera. The sampling strategy combined capturing fire weather and dynamics using the remote sensing and measuring the chemistry via smoke penetrations

NOAA Twin Otter Aircraft
The aircraft payload included in-situ chemistry measurements, a Doppler lidar system, and an infrared imager for fire mapping.

The in-situ chemistry measurements included:
1. PICARRO to measure CO, CO_2, CH_4, and H_2O.
2. A custom cavity ringdown spectroscopy instrument that contains four optically identical ringdown cavities that measure NO_2 at 405 nm. Prior to measurement, O_3, NO, and NO_y (total reactive nitrogen) are quantitativelyconverted to NO_2.



$$[NO_2] = \frac{1}{c\sigma_{NO_2}}\left(\frac{1}{\tau} - \frac{1}{\tau_0}\right)$$

Ground-based remote measurements were captured using the NOAA Pick-Up Based Mobile Atmospheric Sounder (PUMAS), which sampled each fire on multiple days using a two-channel system for obtaining continuous 3D winds.

PUMAS
Mobile micro-pulse doppler lidar

Ozone Pollution Generated by Wildfires

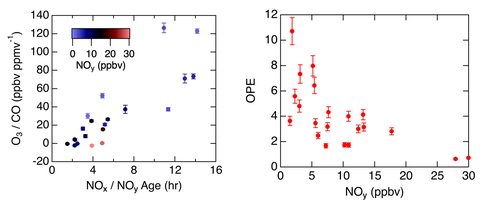
The ozone production efficiency (OPE) is defined as the number of molecules of ozone (O_3) produced per NO_x molecule emitted and lost to termination reactions. It can be calculated by monitoring the changes in O3 + NO2 (Ox) and the difference between total reactive nitrogen (NO_y) and NO_2 (NO_y–NO_2 = NO_z). This metric provides a quantitative evaluation of the O_3 yield (per unit of emitted and oxidized NO_x) during the wildfire plume transects.

$$OPE = \frac{\Delta O_x}{\Delta NO_z} = \frac{\Delta(O_3 + NO_2)}{\Delta(NO_y - NO_x)}$$

The smoke age can also be estimates from NO_x / NO_y ratio. Some of the plumes in this study had fairly long ages based on this estimate.

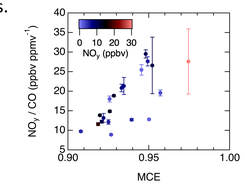
$$\frac{NOx}{NOx_0} \approx \frac{NOx}{NOy} \approx e^{-\frac{t}{\tau_{NOx}}}$$

t = chemical plume age
assume τ_{NOx} is approx. constant
chemical plume age ∝ -ln(ΔNOx/ΔNOy)



The modified combustion efficiency (MCE) works as a measure of emissions from flaming versus smoldering fire sources.

$$MCE = \frac{CO_2}{CO_2 + CO}$$



Future Objectives

- Ratio of emitted NO_x to CO and other species measured
- Closer look at the effects of aerosol shading
- Photochemistry in plumes that were transported aloft with comparison to drainage flows of the smoke into valleys.
- Use of satellite remote sensing data, such as TROPOMI NO_2 or HCHO, and VIIRS FRP.

https://csl.noaa.gov/groups/csl7/measurements/2022calfide/