Google Earth Engine: A Cloud-based Laboratory for Assessing Smoke, Dust, and Ozone Air Quality with Satellites

HAQAST St. Louis

Meeting of the NASA Health and Air Quality Applied Sciences Team

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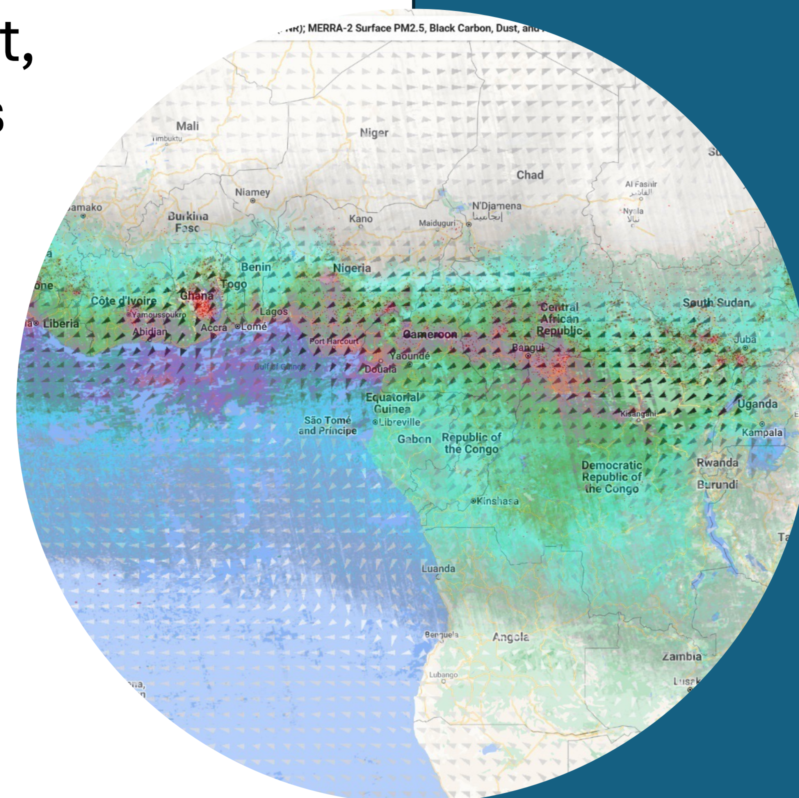


Google Earth Engine: A Cloud-Based Platform for Analyses of Earth Observations

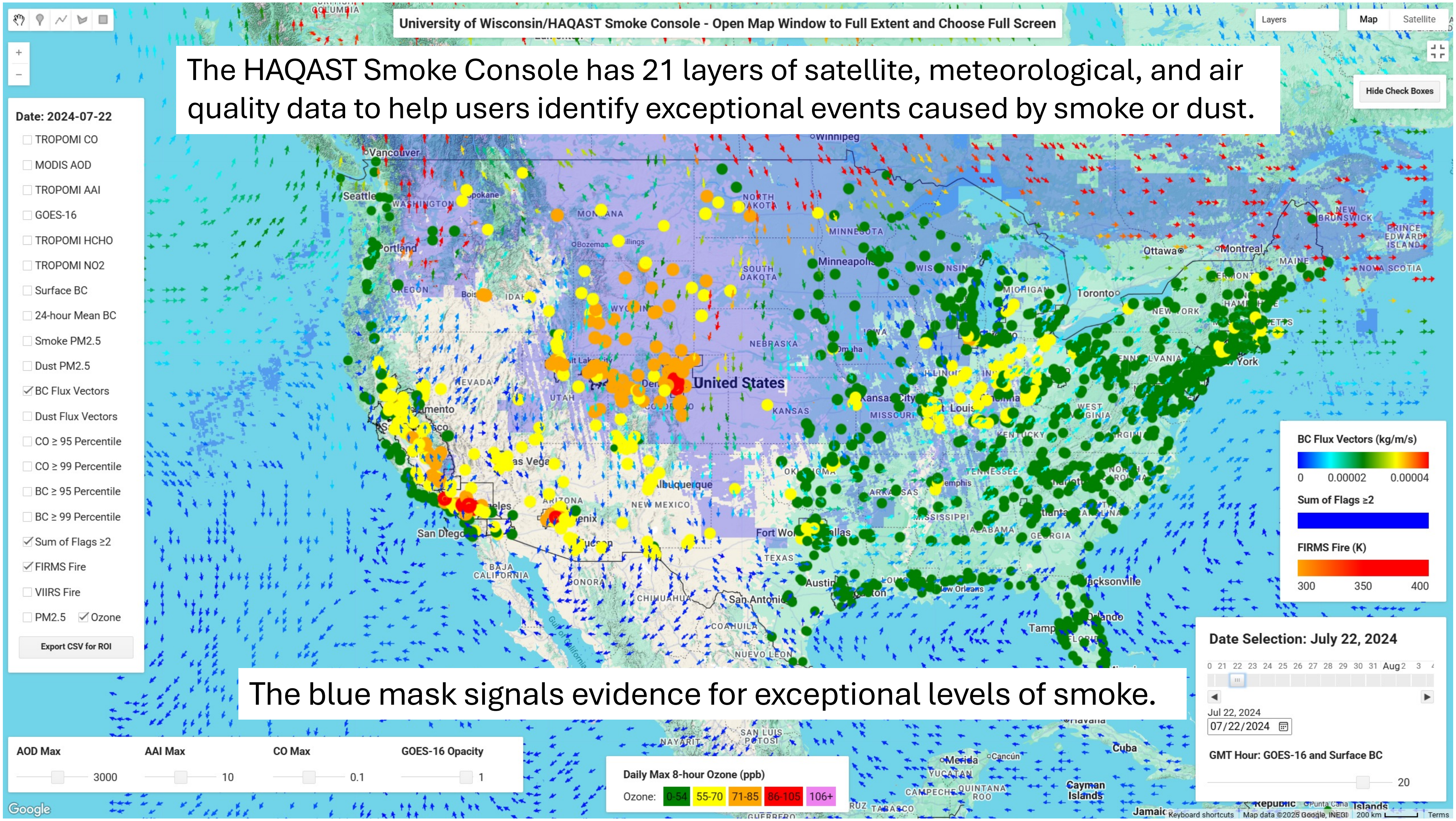
Fundamental Applied Sciences

My Google Earth Engine Applications

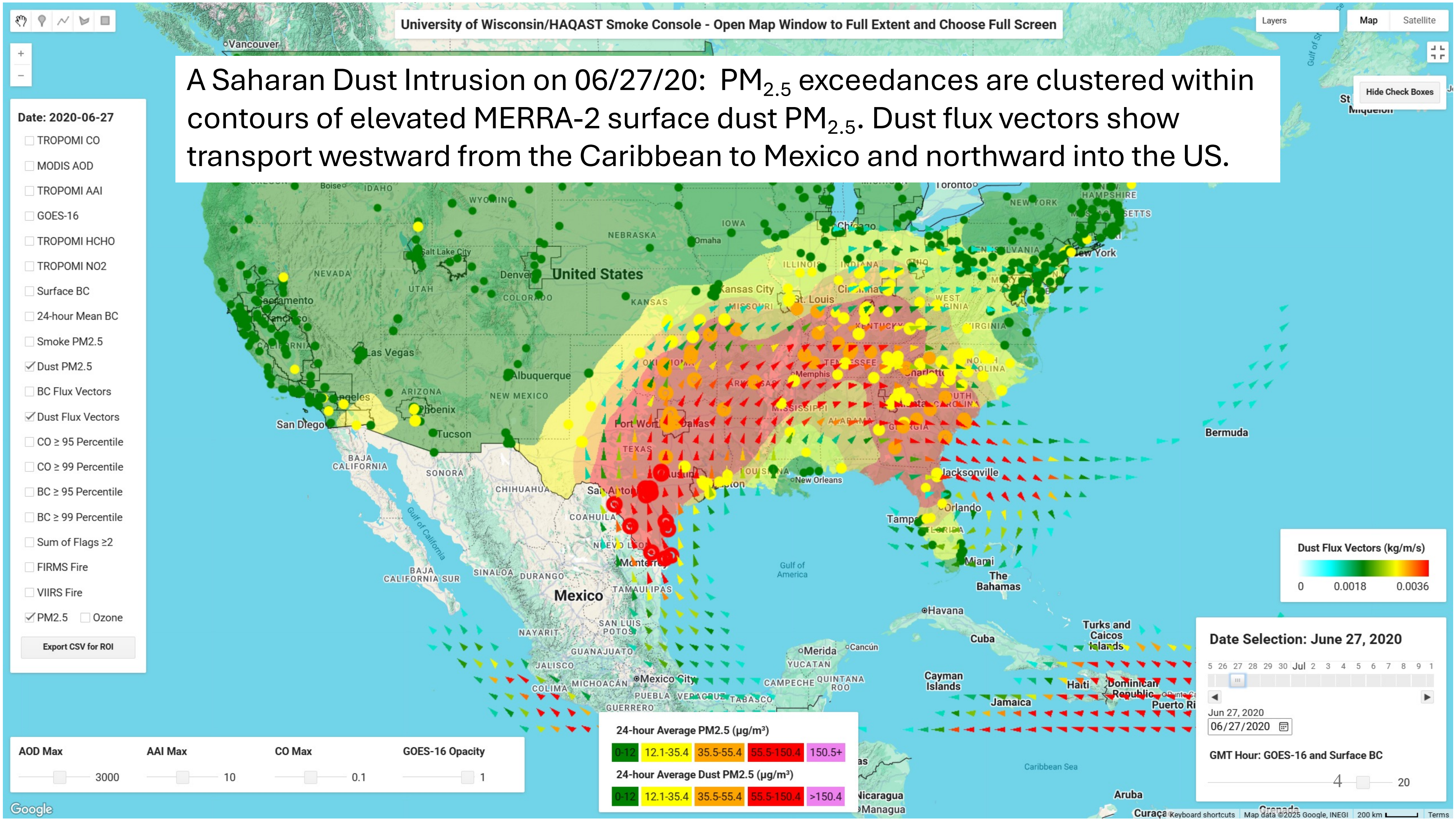
Policy Analysis

- The HAQAST Smoke Console - Analysis of potential exceptional events associated with smoke or dust.
- Air Quality Regions in the Four Corners States - Machine learning exploration of factors contributing to ozone. Utah Division of Air Quality, Science for Solutions project.
- The TEMPO Explorer: Comprehensive analyses of NO_2, HCHO, FNRs, O_3, meteorology, and smoke. Utah Division of Air Quality, Science for Solutions project.
- Africa Air Quality: Exploration of air quality, meteorology, climate, and land cover. Volunteer work and capacity building for Africa.
- Economic and Social Impacts of the War in Ukraine: Machine learning analysis of satellite data.

The HAQAST Smoke Console has 21 layers of satellite, meteorological, and air quality data to help users identify exceptional events caused by smoke or dust.



The blue mask signals evidence for exceptional levels of smoke.



A Saharan Dust Intrusion on 06/27/20: $PM_{2.5}$ exceedances are clustered within contours of elevated MERRA-2 surface dust $PM_{2.5}$. Dust flux vectors show transport westward from the Caribbean to Mexico and northward into the US.

Links for the HAQAST Smoke Console

- HAQAST Smoke Console Users Guide: https://uwmadison.box.com/s/5b892fgxs24if88w3s36a4jz5wqe401d
- JavaScript code to drop into the GEE code editor: https://github.com/turtlesands/HAQAST_SMOKE_CONSOLE/blob/main/Code051425
- Web App (GEE web apps do not have data export capabilities): HAQAST Smoke Console 102925

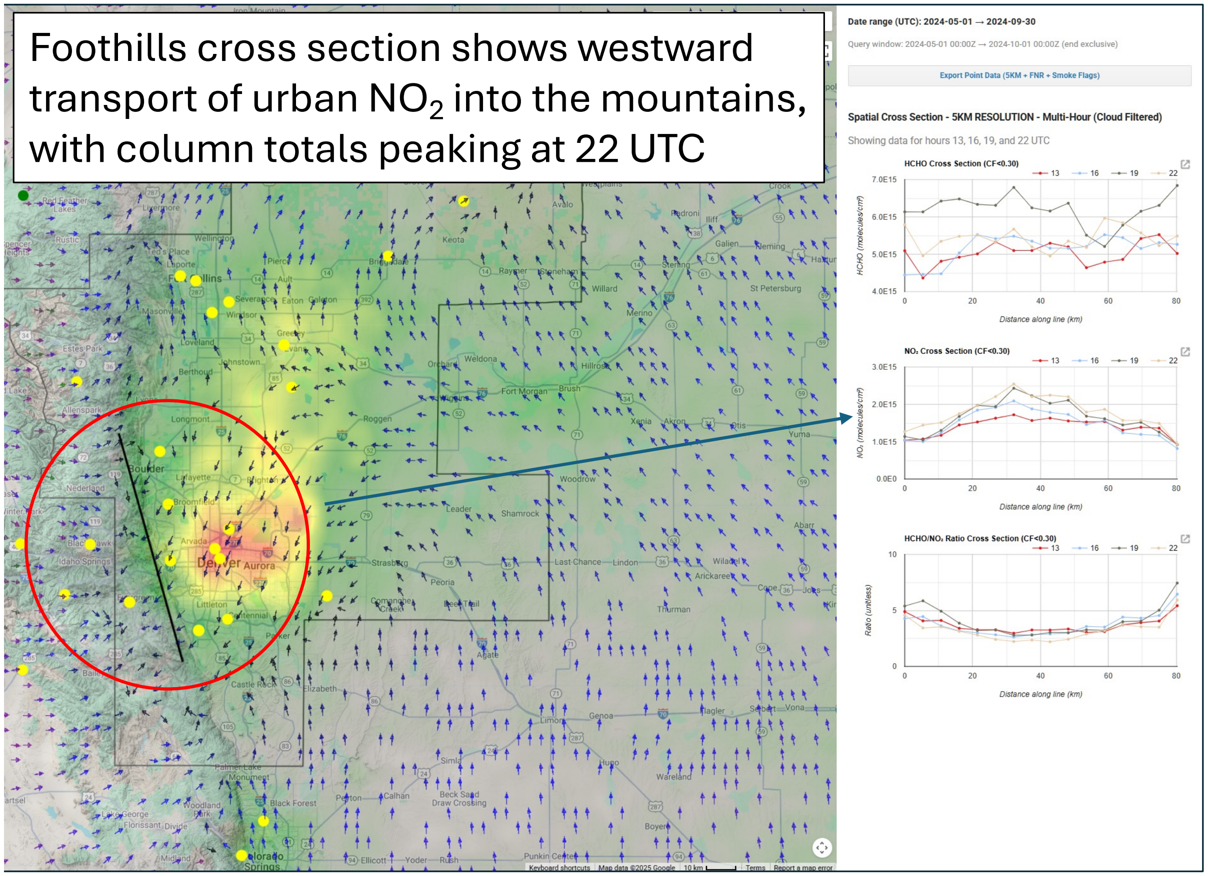
I was starting to determine the best ways to access TEMPO data for the Utah project when I discovered that Google Earth Engine (GEE) released Level 3 TEMPO data collections with the highest QA level this summer.

I realized that I could do much of the planned analyses and data processing in GEE itself.

The TEMPO Explorer is the result.

The TEMPO Explorer: a Digital, Cloud-based GEE Laboratory Designed for the Utah Division of Air Quality

- Level 3 TEMPO data, best QA, and cloud fraction of <50% for hours 13-23 UTC.
- Maps & charts of hourly TEMPO NO_2, HCHO, and HCHO/ NO_2. Point, transect, and cross section sampling.
- Vector mean RTMA surface winds by hour. Low wind speed mask (<1 m/s).
- Daily Max 8-hour O_3 & hourly O_3.
- Hour slider and cloud fraction threshold slider (20%-50%). Cloud fraction sensitivity tests across products.
- High and low O_3 event filters, and weekend-weekday filters: maps and charts.
- Smoke indicators and fire detections.
- FNR and O_3 production regime analysis.



The O_3 production regime routine applies a bootstrap method to 4,608 hourly O_3-FNR pairs for 18-22 UTC in 80 FNR bins and with filters to exclude low-count bins and data outside of a percentile window. Up to 80 bootstrap curves are created with a Gaussian smoother (0.6 FNR) to determine peaks and median crossing points at 90% of peak and their uncertainties.

OZONE PRODUCTION REGIMES BASED ON FNR

O3 PRODUCTION REGIMES BASED ON FNR

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Date range: 2024-05-01 to 2024-10-01 (Hours 18-22 UTC)
Cloud fraction threshold: CF < 0.30
(applied to TEMPO NO_2 and HCHO)

PEAK HOURLY O3 EXCEEDANCE PROBABILITY

FNR at peak: 2.81

95% confidence interval: 2.44-3.19

P(O3≥70ppb) at peak: 28.4% (highest risk)
Method: Median of 80 bootstrap curve peaks

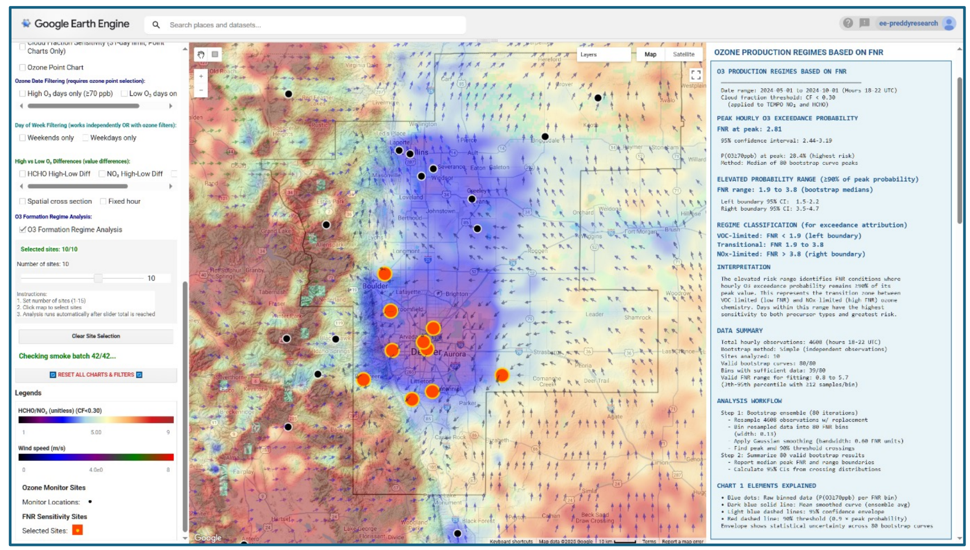
ELEVATED PROBABILITY RANGE (≥90% of peak probability)

FNR range: 1.9 to 3.8 (bootstrap medians)

Left boundary 95% CI: 1.5-2.2
Right boundary 95% CI: 3.5-4.7

REGIME CLASSIFICATION (for exceedance attribution)

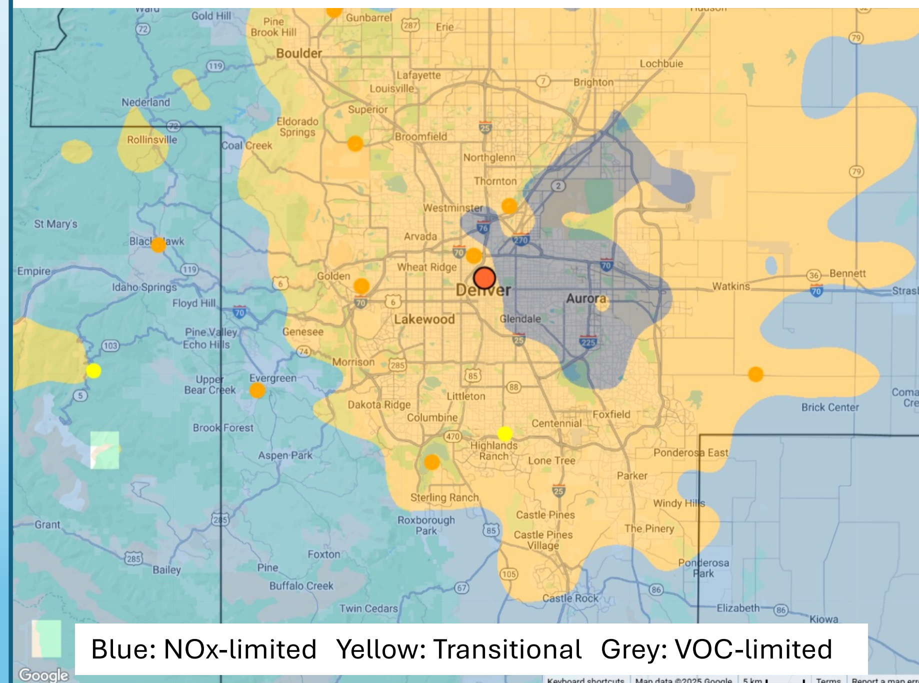
VOC-limited: FNR < 1.9 (left boundary)
Transitional: FNR 1.9 to 3.8
NOx-limited: FNR > 3.8 (right boundary)



Preliminary Ozone Production Regime Analyses using TEMPO HCHO and NO_2 for 10 sites in Denver-Boulder, May-Sep 2024*

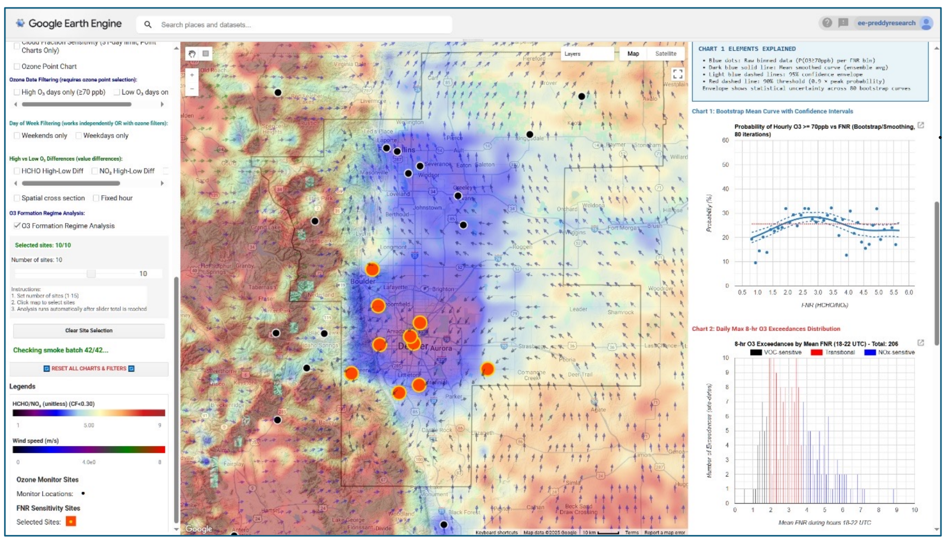
- 4608 O_3/FNR pairs, hours 18-22 UTC
- Peak probability **FNR: 2.81 (95% confidence interval: 2.44-3.19)**
- Transitional Range: **1.9-3.8**
- Left boundary 95% confidence interval: **1.5-2.2**
- Right boundary 95% confidence interval: **3.5-4.7**
- Five high-O_3 sites downwind of Denver are overwhelmingly Transitional or NO_x-limited.
- Testing a TROPOMI version with the same data pipeline parameters and sampling process.
- Can future TEMPO O_3 for 0-2 km and PBL data be used to fine tune this ozone regime analyses?

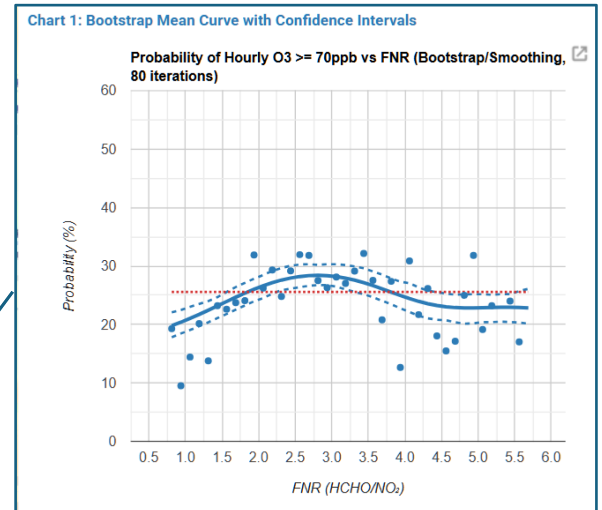
Mean regime conditions for all high-O_3 days: downtown Denver CAMP site in 2024, 22 UTC.

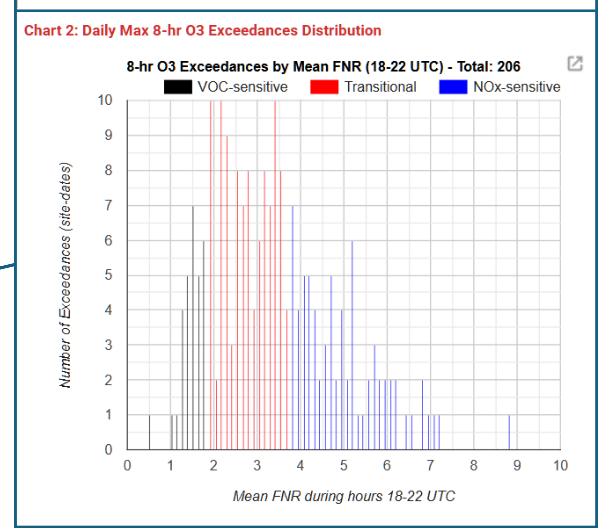


*Site FNRs represent an effective, primary footprint of ~150 km^2 (~15 TEMPO pixels) after re-projection, smoothing, and point buffer sampling.

Performance metrics for Salt Lake City, Las Vegas, and Denver are all good. The analyses suggest that 2024 O_3 exceedances in each city are predominantly in the Transitional and NO_x-limited regimes. 95th percentile uncertainties for the VOC-limited cutoff suggest that this is true across the uncertainty range.

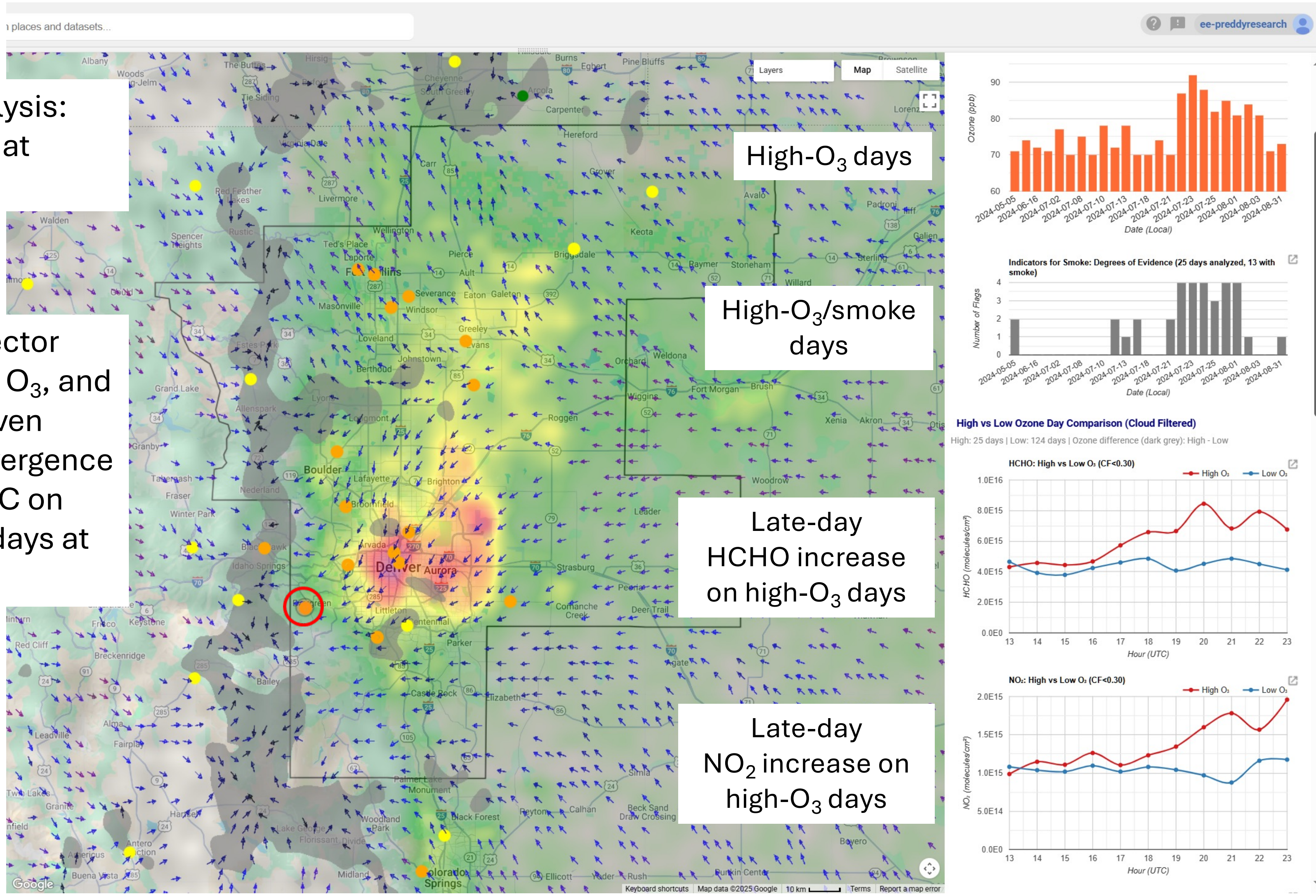


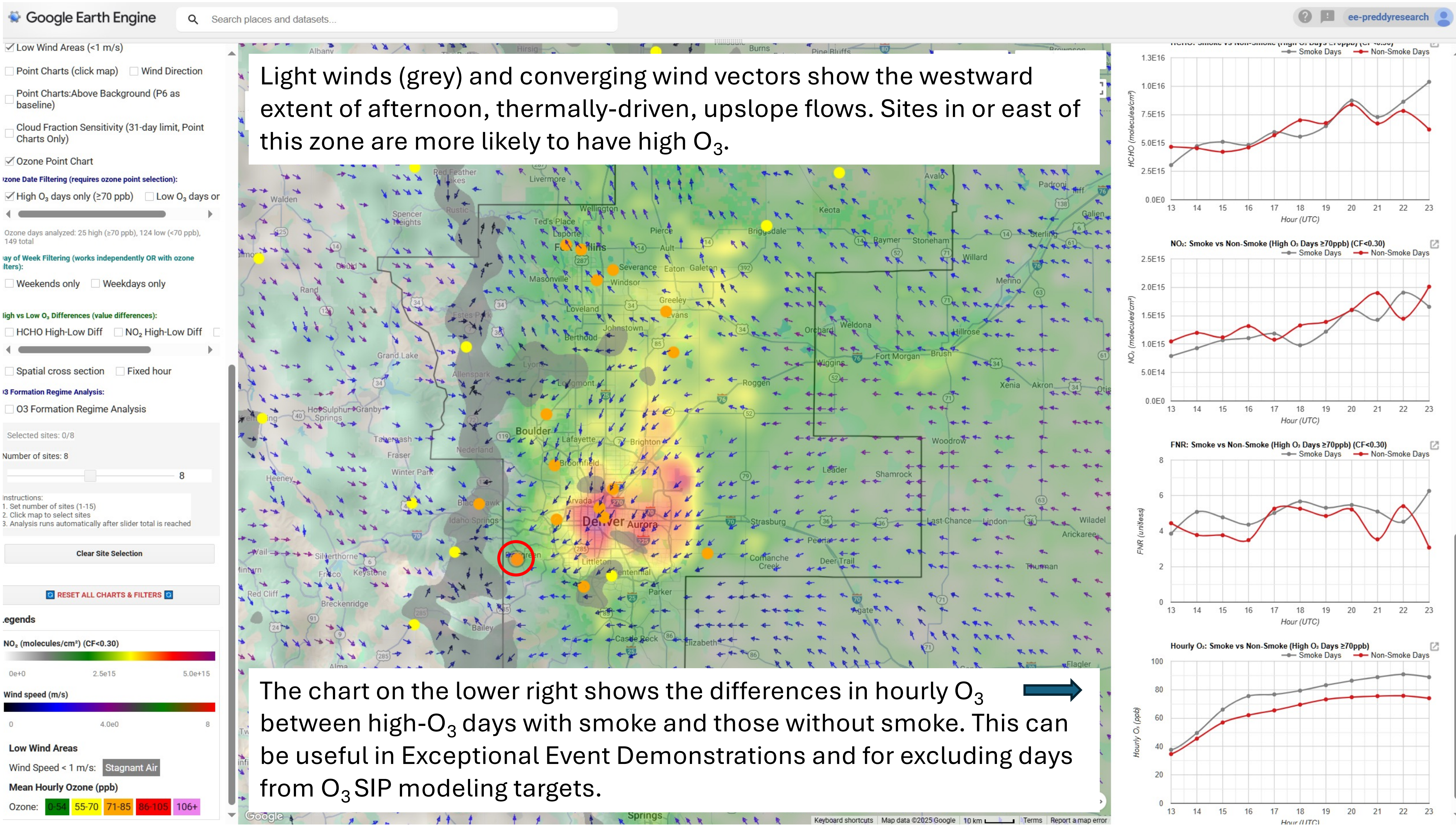




Regional Analysis: High-O_3 days at Evergreen

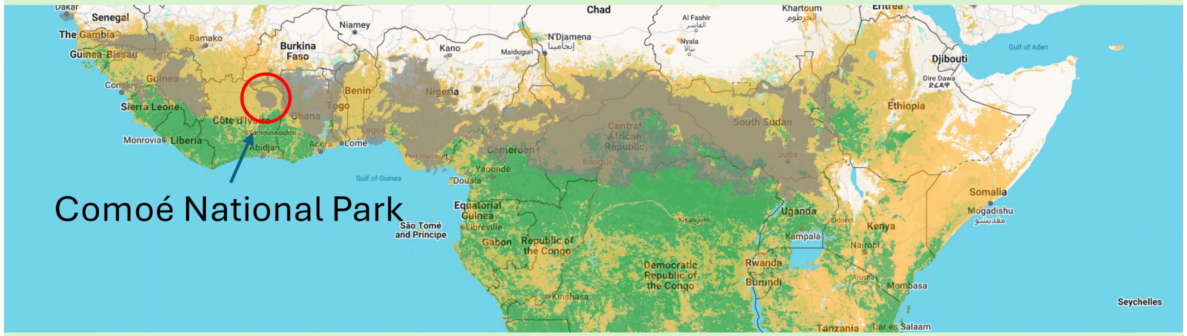
Mean NO_2, vector winds, hourly O_3, and thermally-driven upslope convergence zone at 21 UTC on exceedance days at Evergreen



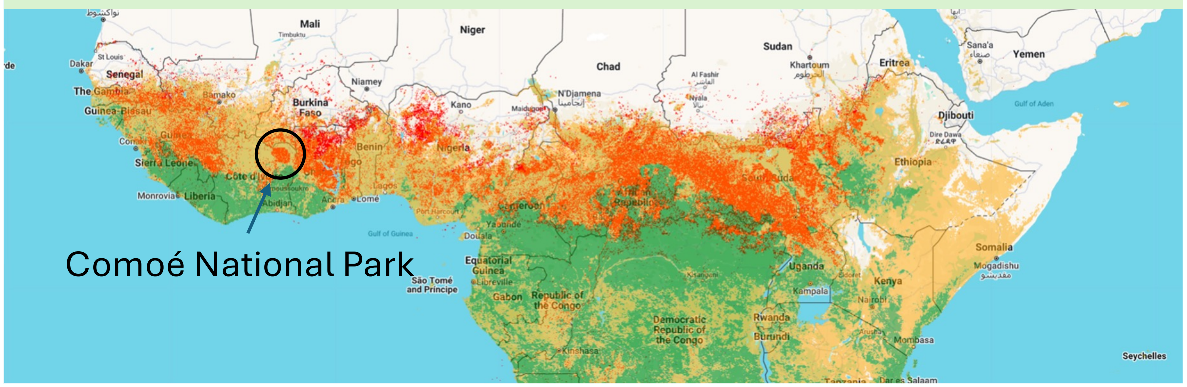

Light winds (grey) and converging wind vectors show the westward extent of afternoon, thermally-driven, upslope flows. Sites in or east of this zone are more likely to have high O3.
The chart on the lower right shows the differences in hourly O3 between high-O3 days with smoke and those without smoke. This can be useful in Exceptional Event Demonstrations and for excluding days from O3 SIP modeling targets.
Google Earth Engine
Low Wind Areas (<1 m/s)
Ozone Point Chart
High O3 days only (≥70 ppb)
Ozone days analyzed: 25 high (≥70 ppb), 124 low (<70 ppb), 149 total
O3 Formation Regime Analysis
Clear Site Selection
RESET ALL CHARTS & FILTERS
Legends
Wind speed (m/s)
Low Wind Areas
Wind Speed < 1 m/s: Stagnant Air
Mean Hourly Ozone (ppb)
Ozone: 0-54 55-70 71-85 86-105 106+
NO2: Smoke vs Non-Smoke (High O3 Days ≥70ppb) (CF<0.30)
FNR: Smoke vs Non-Smoke (High O3 Days ≥70ppb) (CF<0.30)
Hourly O3: Smoke vs Non-Smoke (High O3 Days ≥70ppb)
Smoke Days
Non-Smoke Days
Hour (UTC)

Precipitation & Greenness (NDVI) Are Key Drivers of Air Quality in Sub-Saharan Africa.

TROPOMI NO_2 >= 0.00003 moles/m^2 (grey), NDVI 0.30-0.66 (tan) and >= 0.66 (green), December 1, 2023, - January 31, 2024



NASA FIRMS fire detections in red.

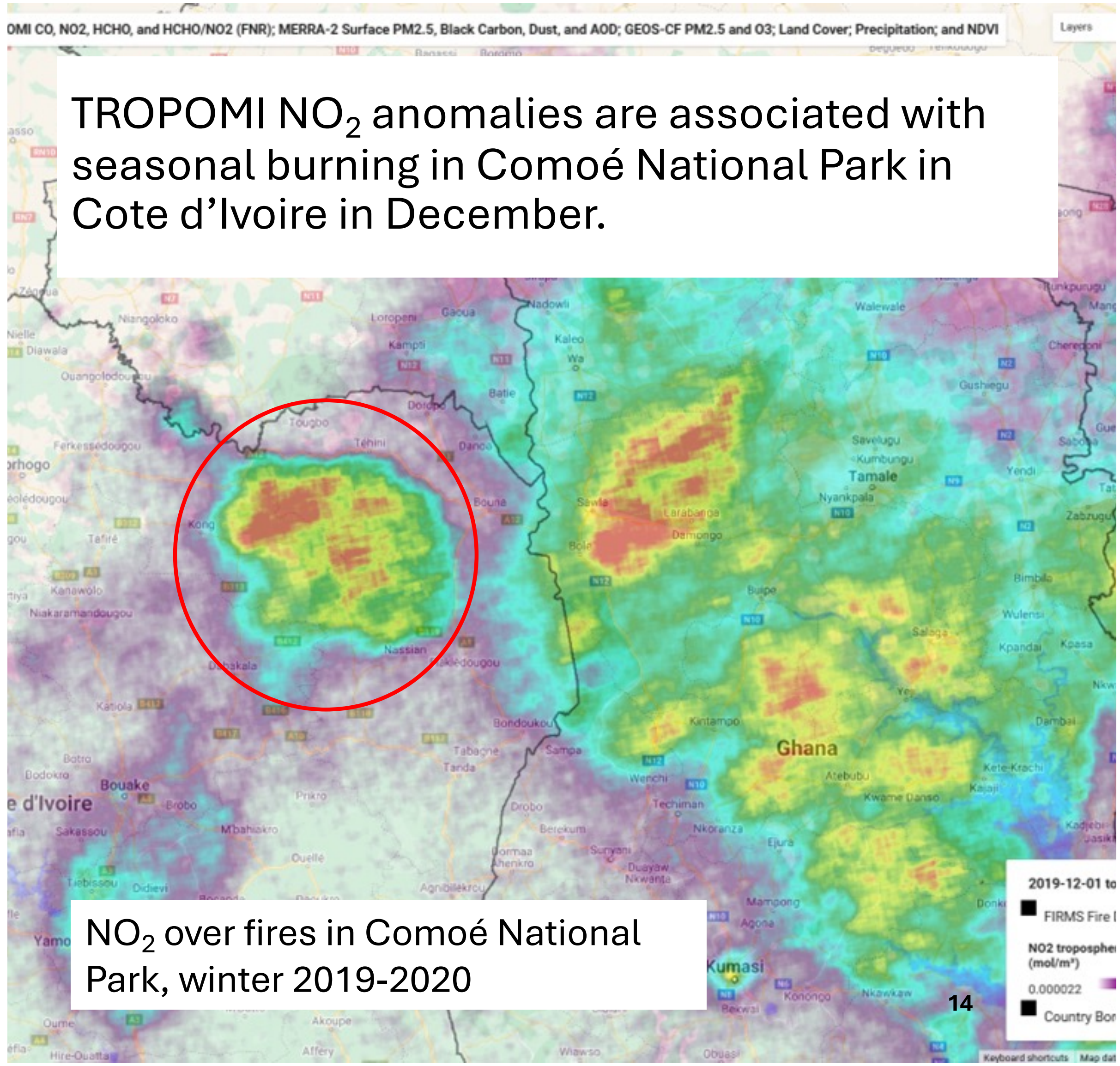


- Seasonal burning just below the Sahel peaks in the boreal winter.
- Most fires coincide with the high NO_2 mask (grey) and in an area with NDVI between 0.30 and 0.66.
- Sea surface temperature regimes and the position of the Intertropical Convergence Zone can influence burning and air quality.
- Machine learning in GEE can help classify air quality regimes, their severity, and how these shift from year-to-year in response to weather.

Source :Wikipedia, https://creativecommons.org/licenses/by-sa/4.0/

- In Cote d'Ivoire and Ghana, TROPOMI NO_2 anomalies are clustered over fires and urban areas. ***High column totals for NO_2 are present over cropland and savanna land-cover categories in December.***
- I exported NO_2, CHIRPS precipitation, and NDVI data for a polygon around the park.

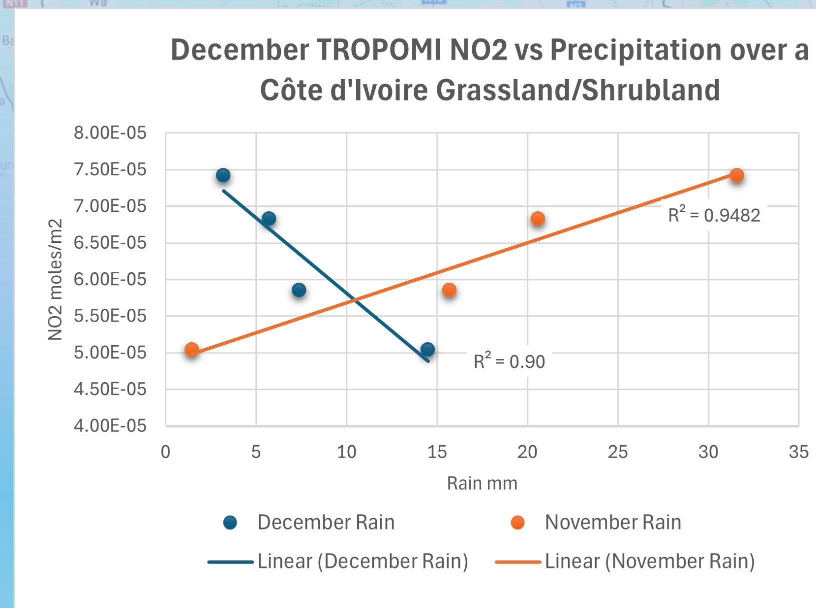
TROPOMI NO_2 anomalies are associated with seasonal burning in Comoé National Park in Cote d'Ivoire in December.



NO$_2$ over fires in Comoé National Park, winter 2019-2020

December TROPOMI NO_2 versus Precipitation over Comoé National Park:

- The correlation between NO_2 and December rain is -0.95. The correlation between NO_2 and November rain is 0.97.
- High rainfall in November leads to increased grass biomass for burning in December.
- High rainfall in December leads to decreased burning.
- High NO_2 is also inversely correlated with NDVI.
- ***A model based on these interrelationships could be used to track changes due to new land management practices.***



Google Earth Engine

A comprehensive workspace for research, exploring air quality, and providing accessible information for air quality managers.

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