The NASA HAQAST Smoke Console: a Google Earth Engine Tool for Assessing the Impacts of Wildfire Smoke on Surface Concentrations of Ozone and PM$_{2.5}$

WESTAR WRAP Fire and Smoke Workgroup and the National Wildfire Coordinating Group Smoke Committee

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Project Goals & Objectives

Air quality management agencies can submit Exceptional Event Demonstrations (EEDs) to the EPA to seek exclusion of air quality monitoring data influenced by smoke from determinations of exceedances or violations of the NAAQS.

❑ Extensive data analysis and evidence are required for an effective EED.

❑ We are leveraging Google Earth Engine (GEE) for event screening and EEDs with NASA Health and Air Quality Applied Sciences Team (HAQAST) Rapid Response funding.

❑ Merging 21 layers of satellite, reanalysis, and surface monitoring data in a single, comprehensive tool.

❑ Using GEE's extensive collections of NASA, NOAA, and Copernicus satellite and reanalysis products we can automate maps and time series analyses for EEDs .

❑ Developing an automated flagging routine for exceptional events related to PM$_{2.5}$ and O$_3$.

Consilience

❑ In 1998, biologist E. O. Wilson popularized the term which refers to the convergence of evidence from multiple *independent* sources of information.

❑ Consilience is a requirement of the Exceptional Event Demonstration process.

❑ The HAQAST Smoke Console integrates multiple, independent sources of information to demonstrate the effects of smoke on air quality.

Key Satellite Products Used in the HAQAST Smoke Console

- ❑ TROPOMI CO: Is an important tracer for wildfire smoke and can be strongly correlated with O_3.
- ❑ TROPOMI AAI: High-resolution smoke plume tracking, most sensitive to high-altitude smoke.
- ❑ MODIS MAIAC AOD: Provides high-resolution smoke plume tracking, is sensitive to smoke concentrations closer to the surface and is strongly correlated with $PM_{2.5}$.
- ❑ NASA FIRMS and VIIRS fire detections: Identify fire locations and intensity.
- ❑ TROPOMI NO_2: Is high in fresh smoke and is an indicator for urban emissions and NO_x photochemistry.
- ❑ TROPOMI HCHO: Remains high in aged smoke and is a tracer for smoke VOC photochemistry.
- ❑ GOES 16 true color imagery and MERRA-2 BC flux vectors: Provide evidence of smoke location and transport routes. Maps of BC flux vectors can complement or replace trajectory modeling.
- ❑ MERRA-2 surface BC and Smoke $PM_{2.5}$ concentrations: Provide evidence of ground-level smoke even at night and when clouds are present .
- ❑ MERRA-2 surface dust $PM_{2.5}$: Used for tracking plumes of Saharan dust.

The Smoke Console Generates Five Mask Layers for Identification of Areas with Exceptional Levels of Smoke.

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- ***Exceedances of the 95th and 99th Percentile TROPOMI CO and MERRA-2 surface BC***: Percentiles were computed using May-September of 2019 and 2022 as a baseline. These were years with fewer wildfire and smoke events in the US.

- ***Internal Flags***: Exceedances of the percentiles are stored as a "1", and otherwise a "0" is stored. Percentile exceedances are used to create selectable map layers.

- ***Sum-of-Flags***: Values of the percentile exceedance flags are summed creating a variable and mask with a range of 0 to 4. ***This represents degrees of evidence for exceptional smoke***.

- ***Sum-of-Flags ≥ 2***: This condition can be used for automatic flagging of possible exceptional events in the Console or with multi-year time series exported to a CSV file.

The Smoke Console Has a Data Extraction and Export Feature for User-Selected Regions of Interest (ROIs)

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ROI Drawing Tools

ROI coordinates and 15 variables can be exported.

ROI In Light Green
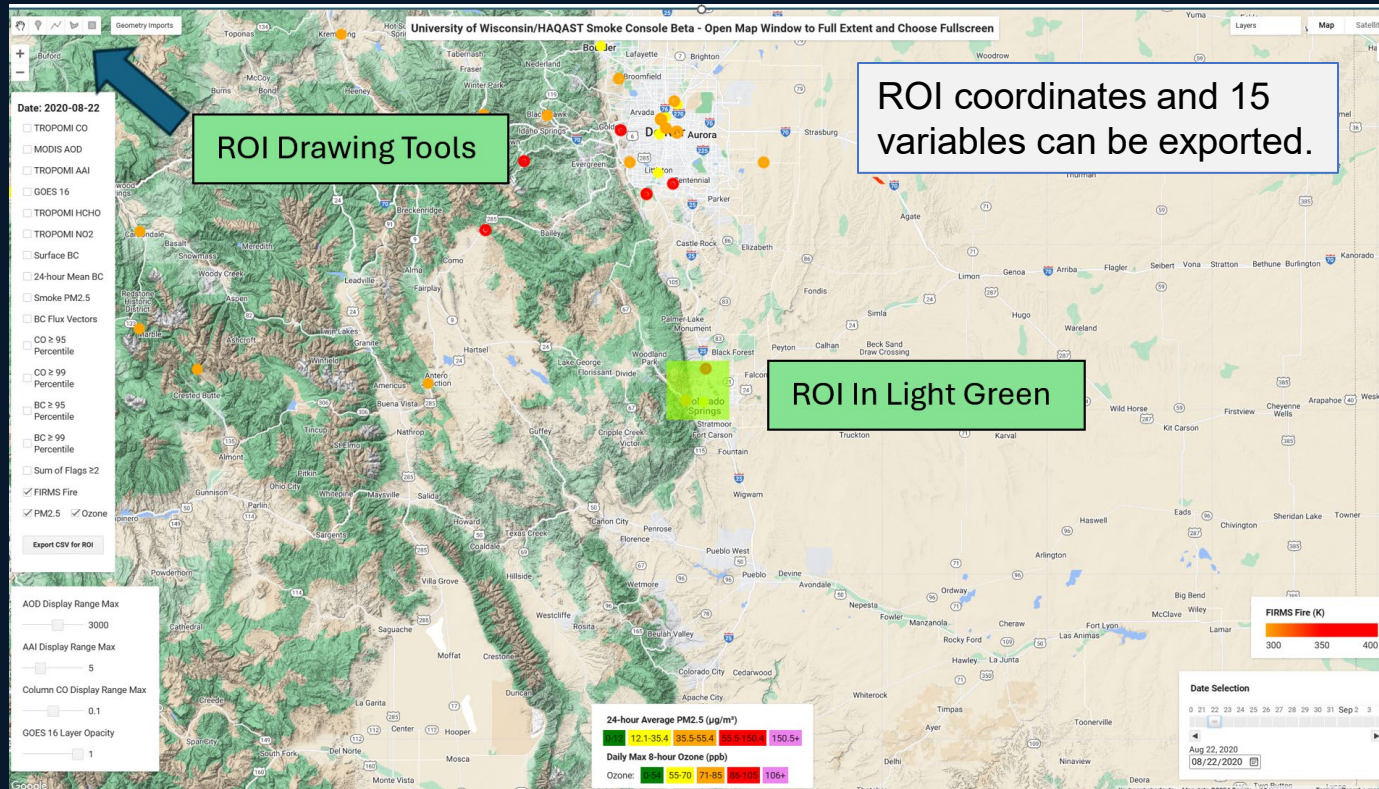
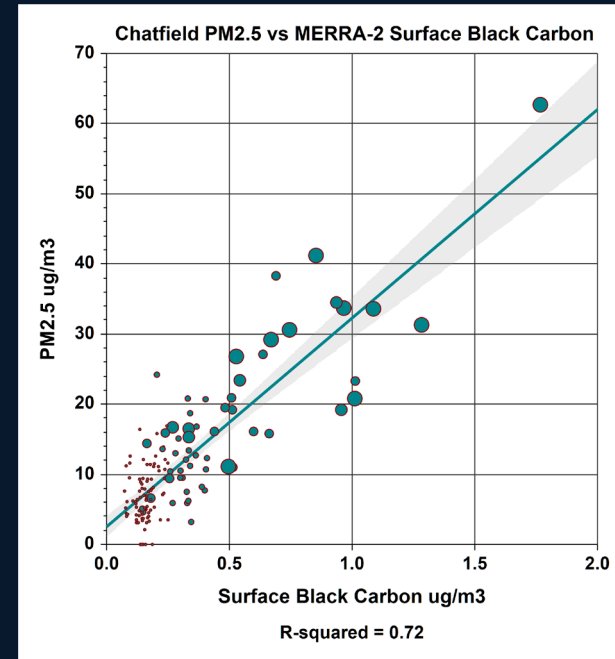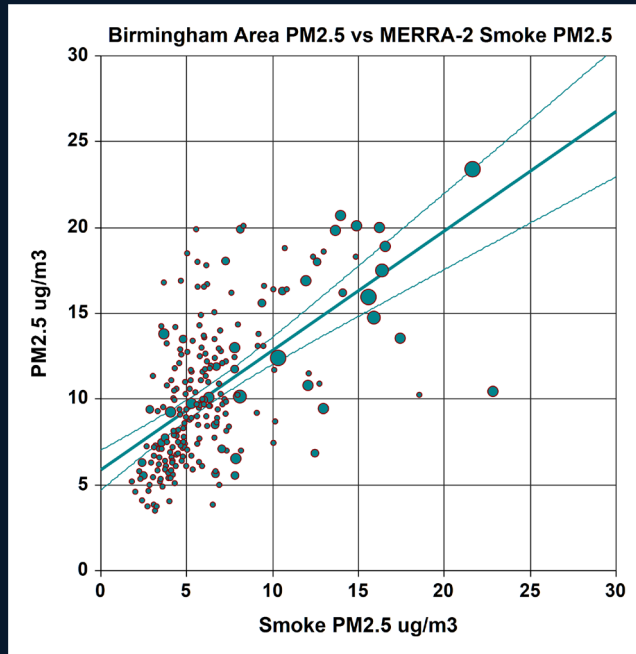# Exported Data Can Be Analyzed to Generate Additional Evidence for an Exceptional Event.

❑ On the right is a box plot of surface $PM_{2.5}$ at a monitor near Denver, CO, versus the Sum-of-Flags variable for the 2021 O_3 season.

❑ Below is a time series analysis of surface O_3 and exported Smoke Console variables for a small ROI around a monitor near Colorado Springs, CO, for the 2020 O_3 season.

Air Force Academy MDA8 O3 Screening Chart

Chatfield Daily 24-hour Mean PM2.5

Daily mean PM$_{2.5}$ vs surface Smoke PM$_{2.5}$ for Birmingham, AL (left, r^2 ~0.3), and Chatfield surface BC near Denver, CO (right, r^2 ~0.7). Circles are scaled by the sum of flags variable.

❑ Right: is a box plot of Salt Lake City $PM_{2.5}$ and exported sum of flags variable (degrees of evidence for smoke) for summers 2019-2024 .

❑ Below: K-means clusters for O_3, surface black carbon (BCSMASS at 13:00 LST and for the 24-hour period), TROPOMI HCHO and CO, surface $PM_{2.5}$, and the sum of flags variable at the Hawthorne monitor site for summers 2019-2024 . Clusters 1, 4, and 10 likely represent smoke events. The r^2 for this analysis is 0.72.
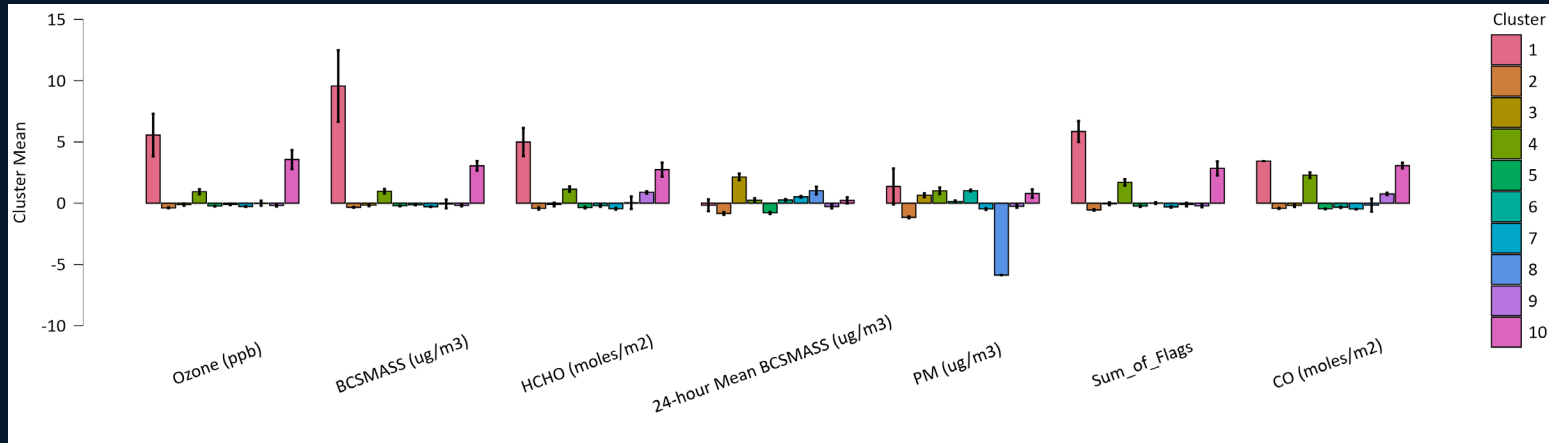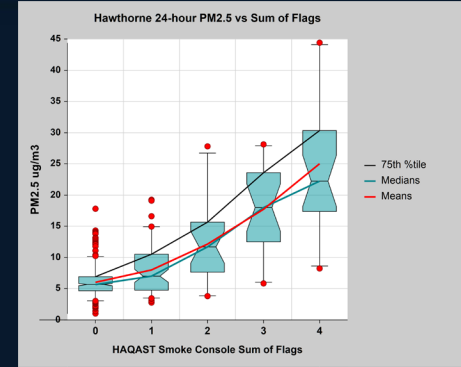
Real-World Use of Extracted Smoke Console Data in a PM$_{2.5}$ EED for Jefferson County, Alabama

❑ Right: K-means cluster center standard deviations for standardized PM$_{2.5}$ in Birmingham for a Saharan dust cluster (dust PM$_{2.5}$ top) and two wildland or prescribed fire smoke clusters (BC PM$_{2.5}$ bottom).

❑ Below is a box plot of Birmingham PM$_{2.5}$ and exported Sum of Flags variable (degrees of evidence for smoke).

❑ Smoke Console data provided strong evidence for smoke influences.

Mean Birmingham Area 24-hour PM2.5
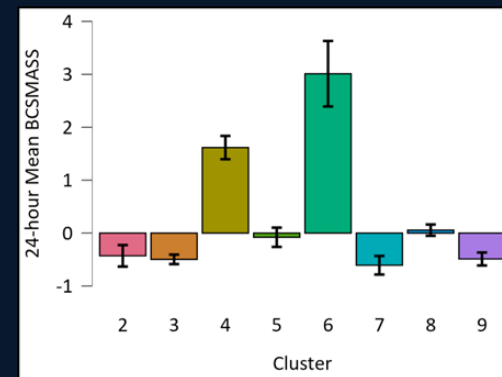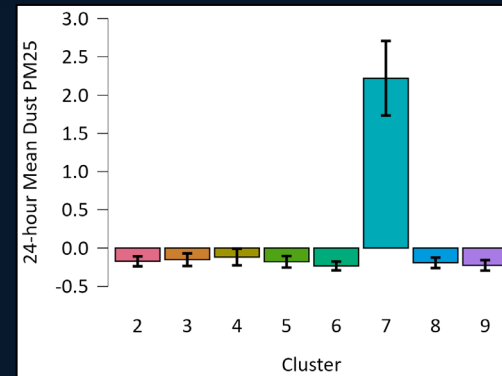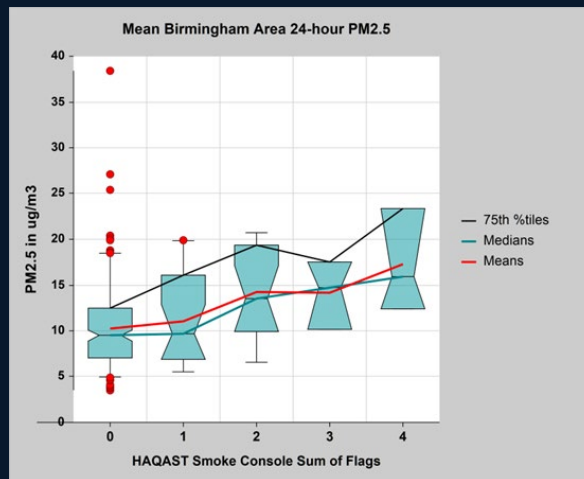
Mutiple Layers Identify Likely Exceptional Event Exceedances: Canadian Wildfire Smoke - June 27, 2023.

Contours of reconstructed Smoke $PM_{2.5}$ from MERRA-2 surface BC and OC (left), the Sum-of-Flags ≥ 2 mask (blue, right), BC flux vectors and surface $PM_{2.5}$ (left), and O_3 (right) all provide strong evidence for the sources and causes of widespread exceedances and the presence of smoke at the surface.
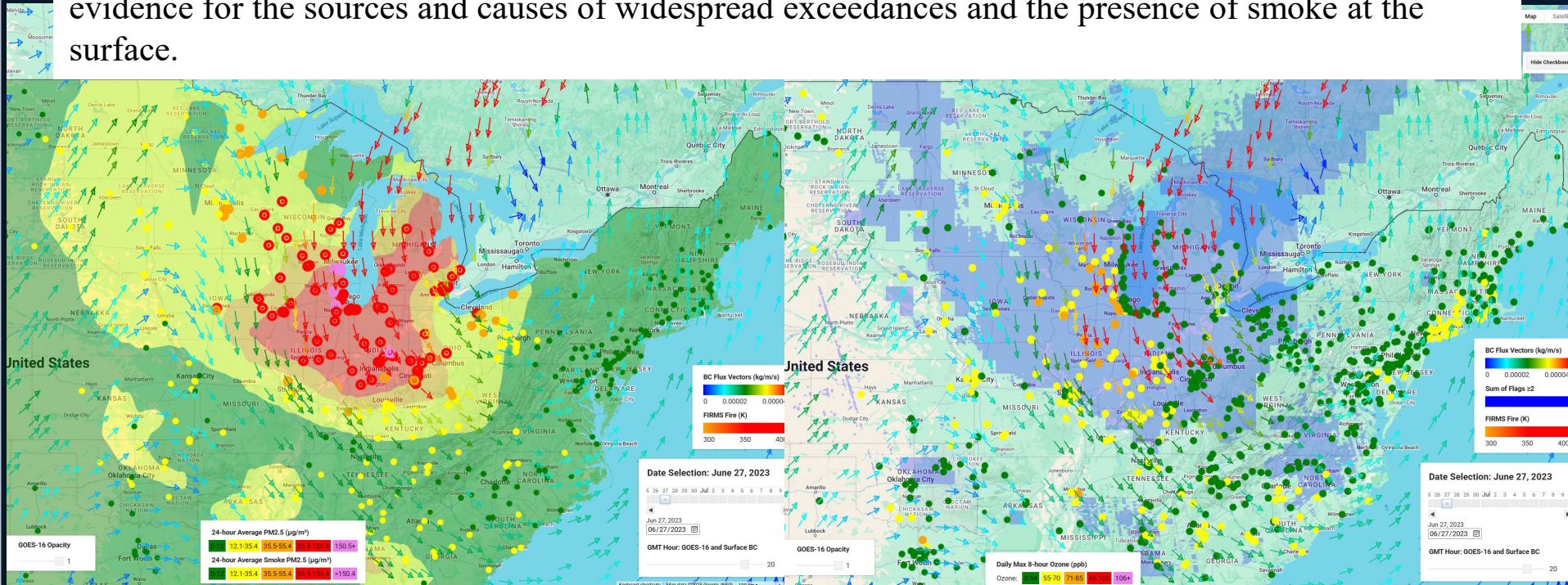
O_3 exceedances clustered in Sum-of-Flags ≥ 2 mask. BC flux vectors show smoke transport from fires in California.

Enhanced BC flux aligns with visible smoke in GOES-16 image.

Enhanced BC flux aligns with visible smoke in GOES-16 image.

Enhanced BC flux (from CA fires) and surface O$_3$ behind a cold front.

Enhanced BC flux (from CA fires) and smoke PM$_{2.5}$ behind cold front.
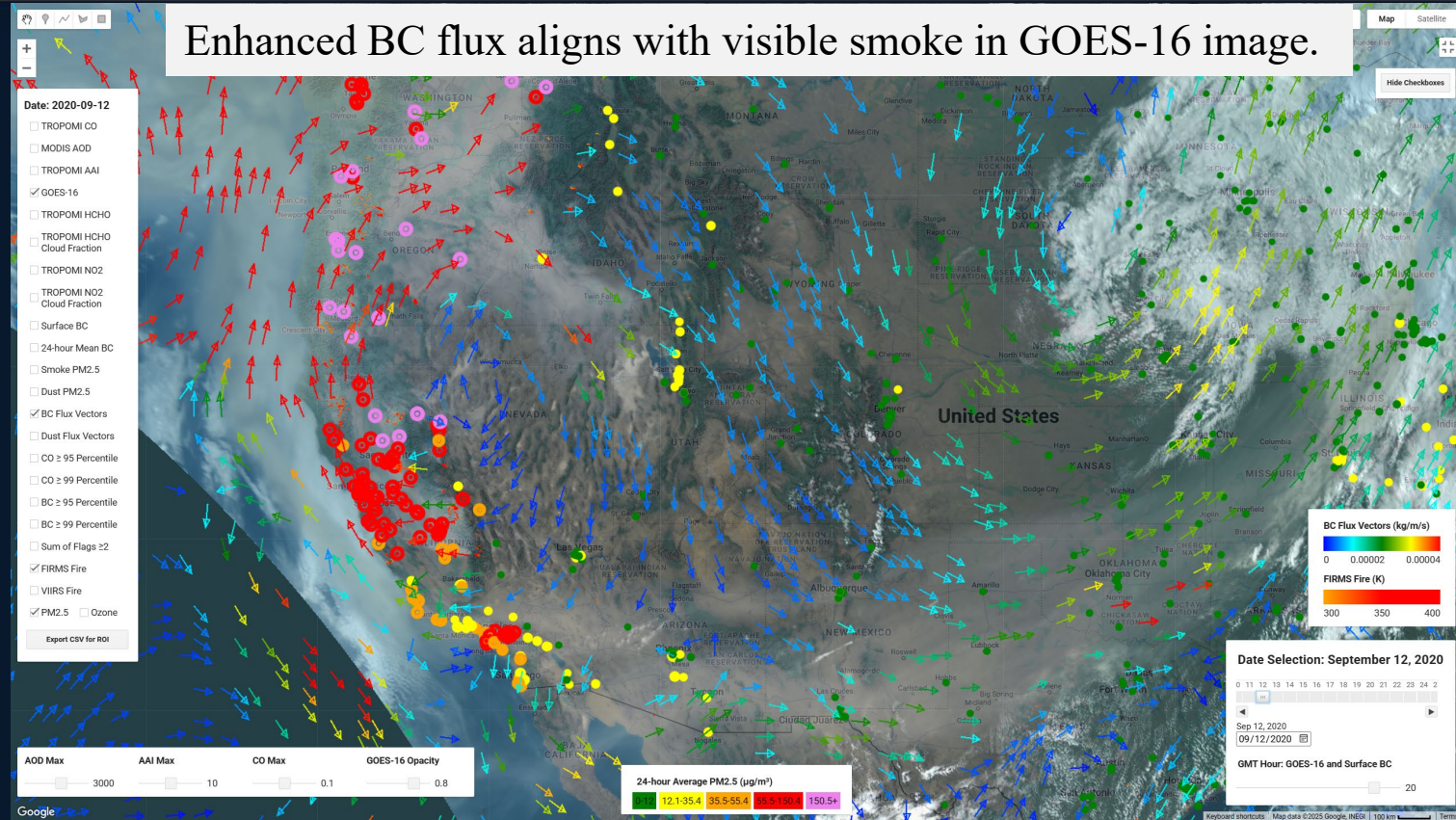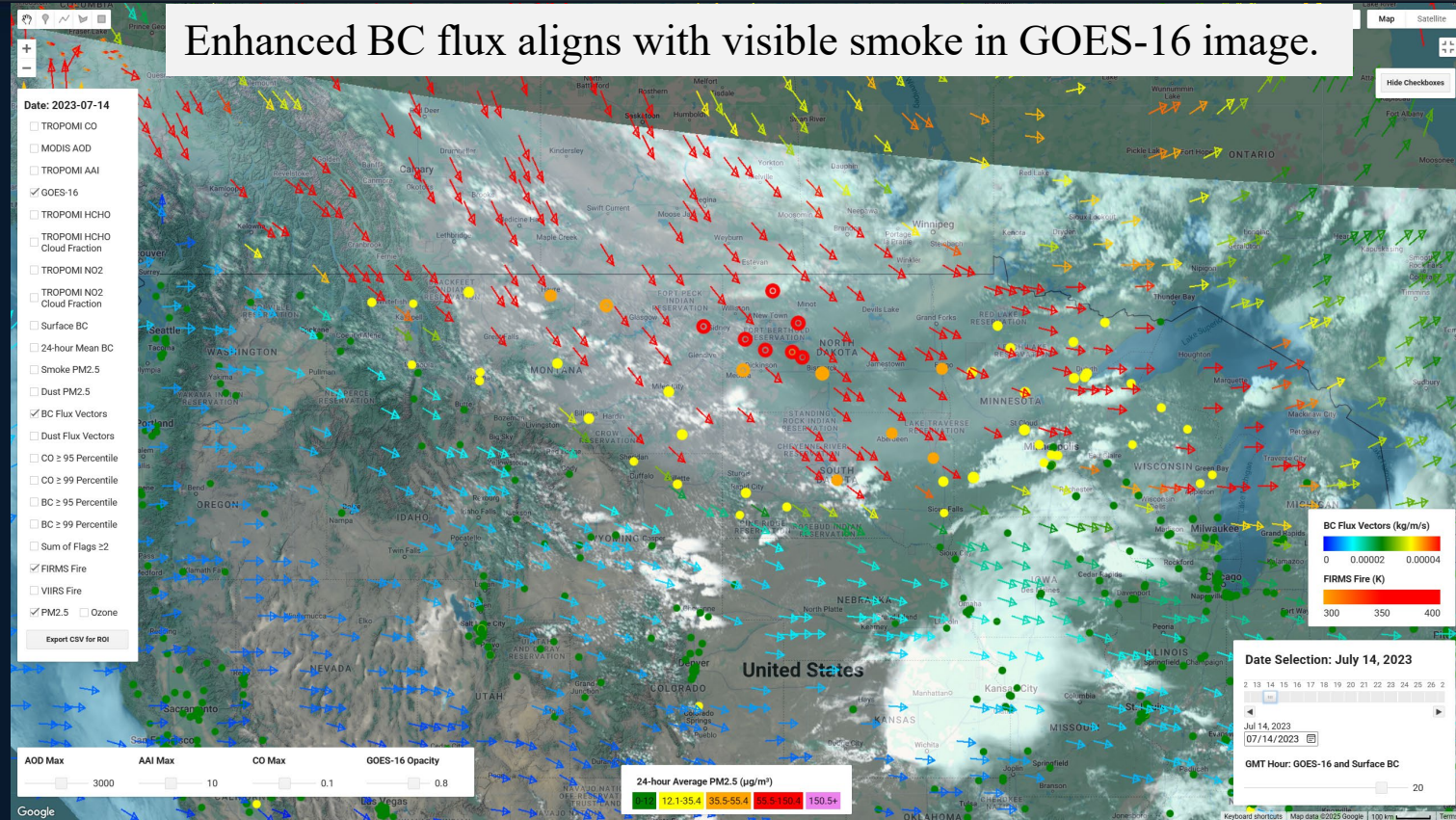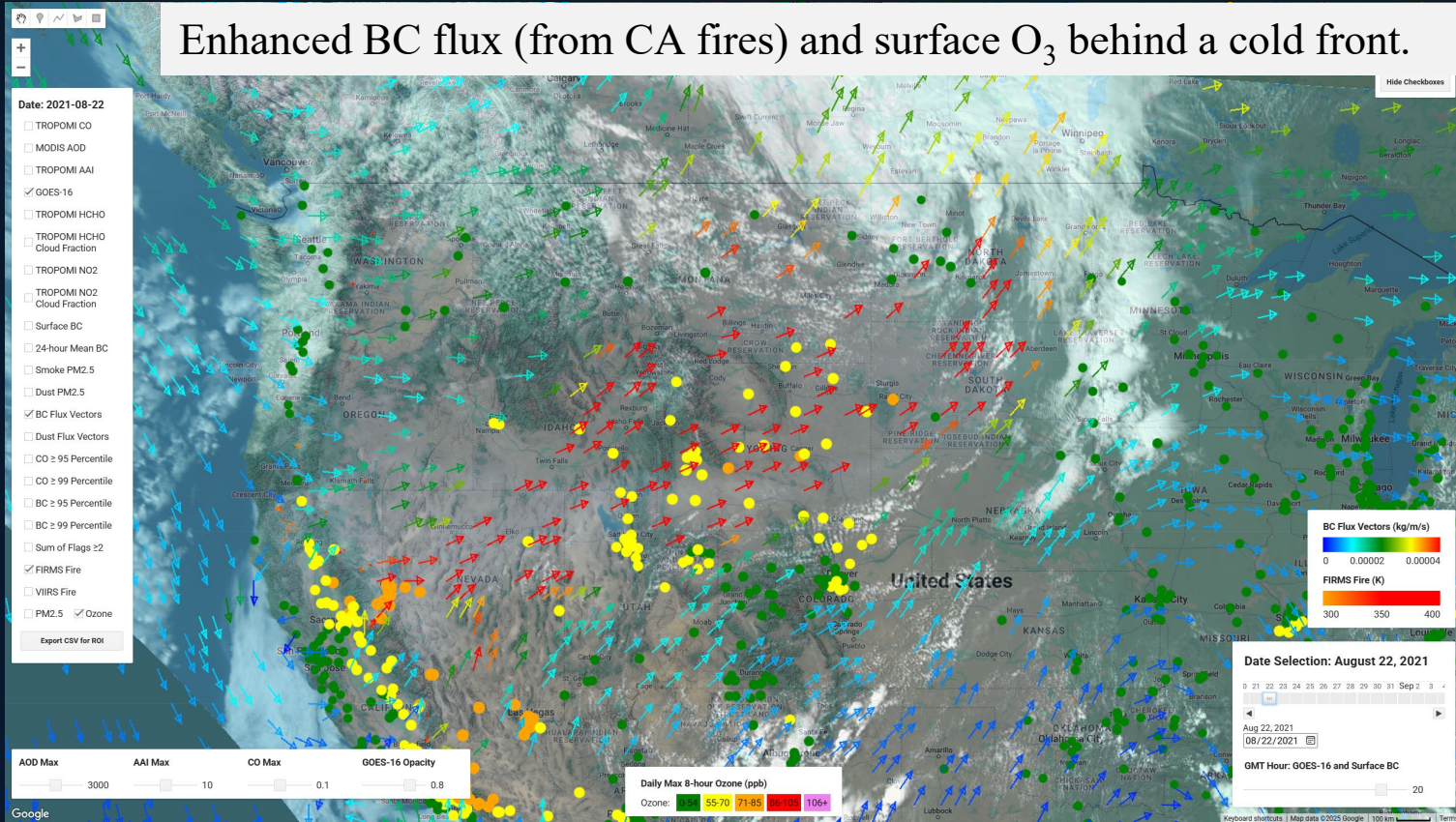
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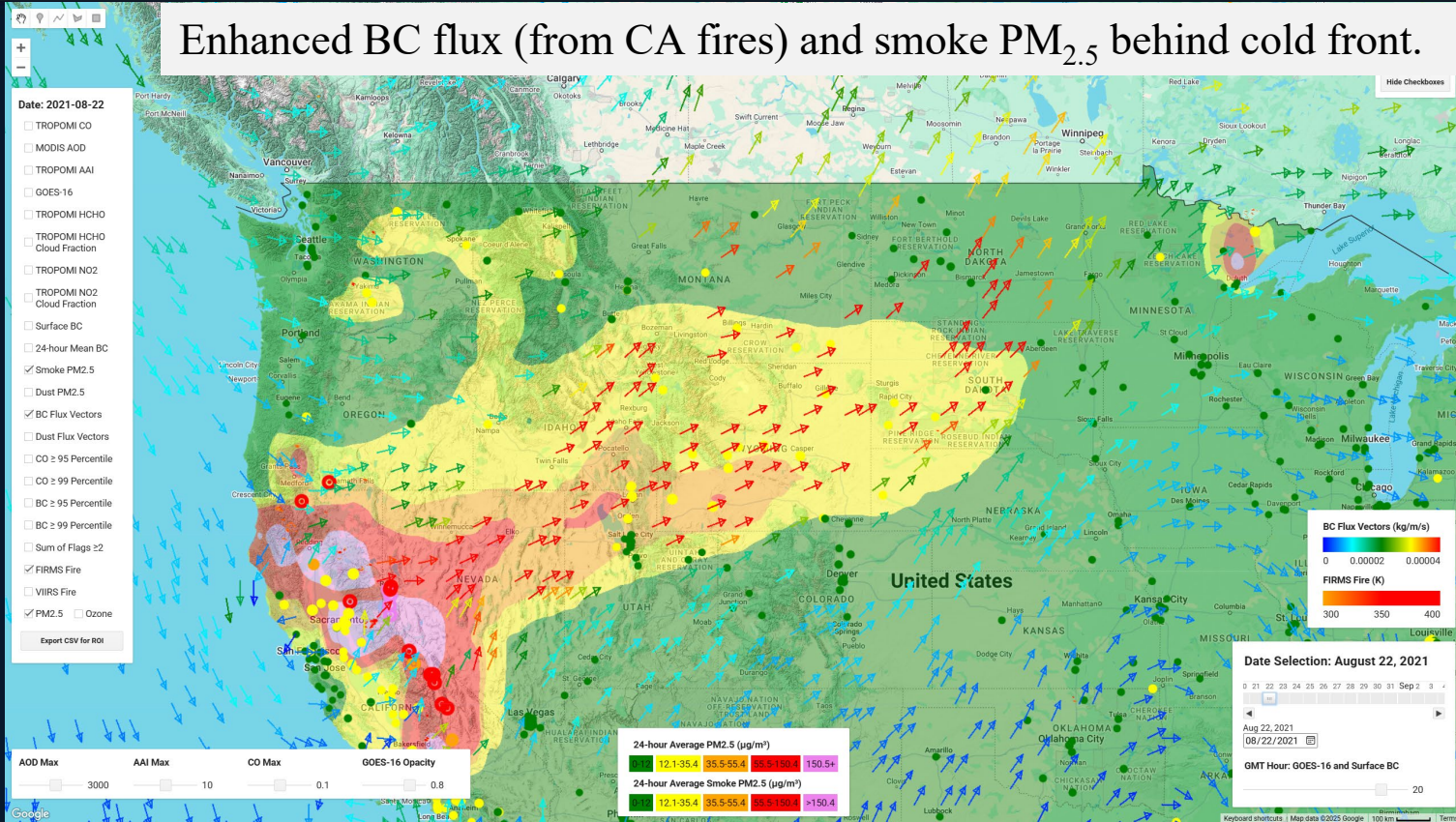
PM$_{2.5}$ exceedances clustered within contours of elevated MERRA-2 surface dust PM$_{2.5}$. Dust flux vectors show transport westward from the Caribbean to Mexico and northward into the US.
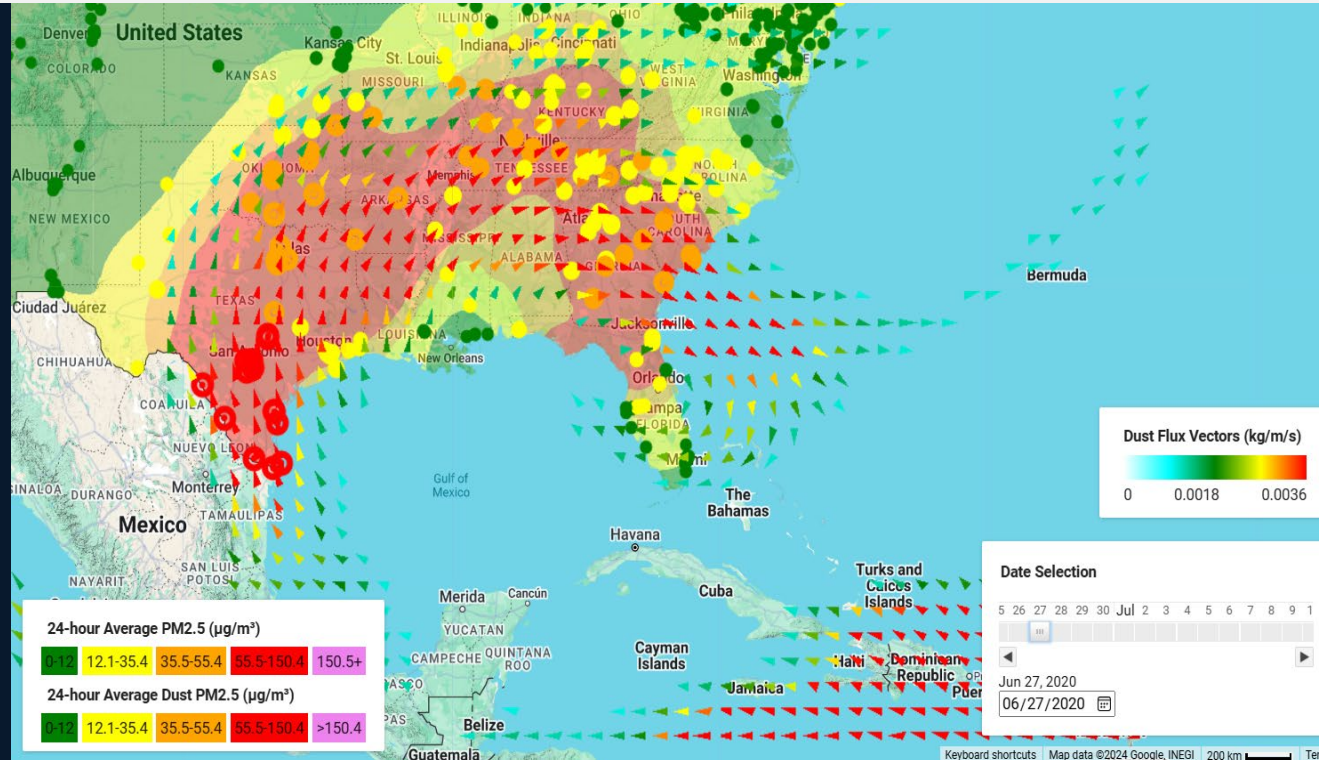
I am developing a separate program that classifies smoke and dust events by day, month, or season. This plot shows clusters with high smoke loadings and high 4th Max ozone for May-September 2023.
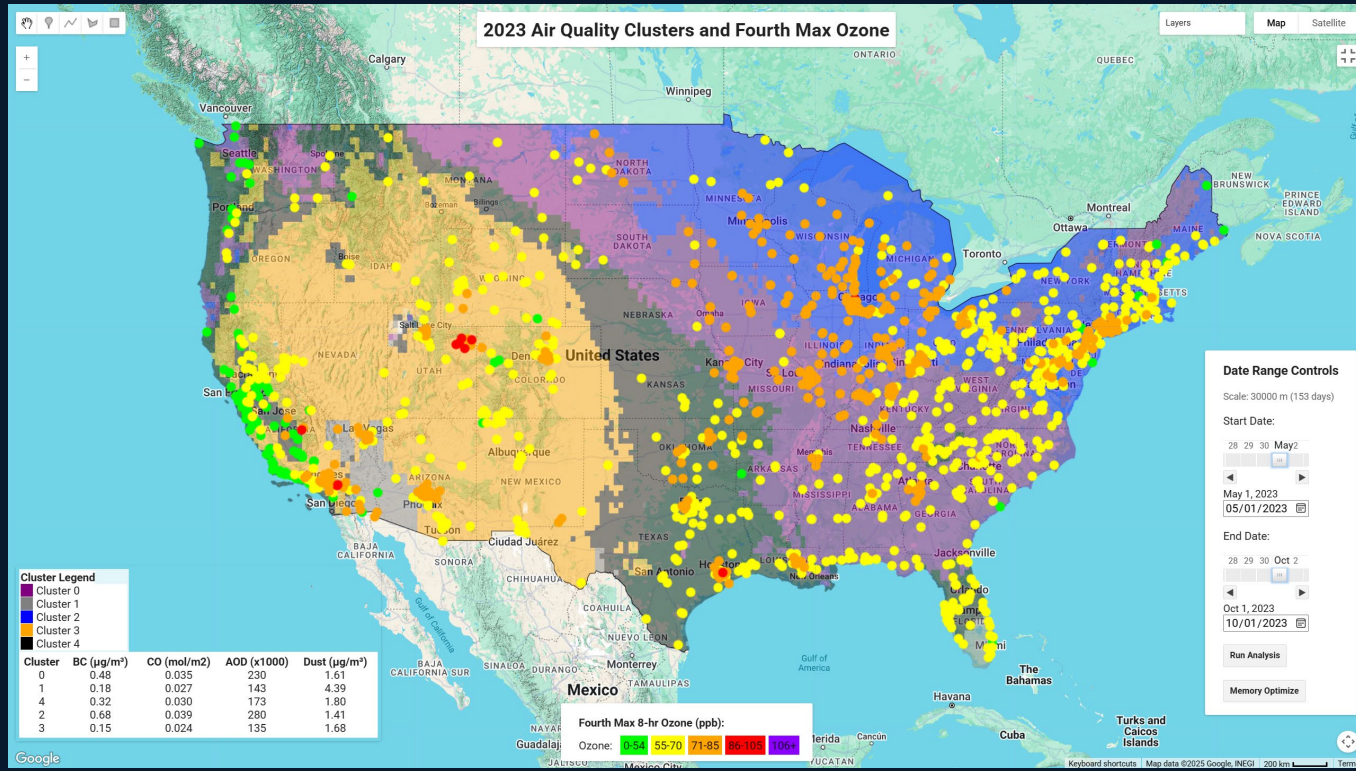
There are no clusters with a smoke fingerprint in 2022, but a Saharan dust cluster stands out along the Gulf Coast. 2022 is one of the years used as a baseline for CO and BC percentile calculations.
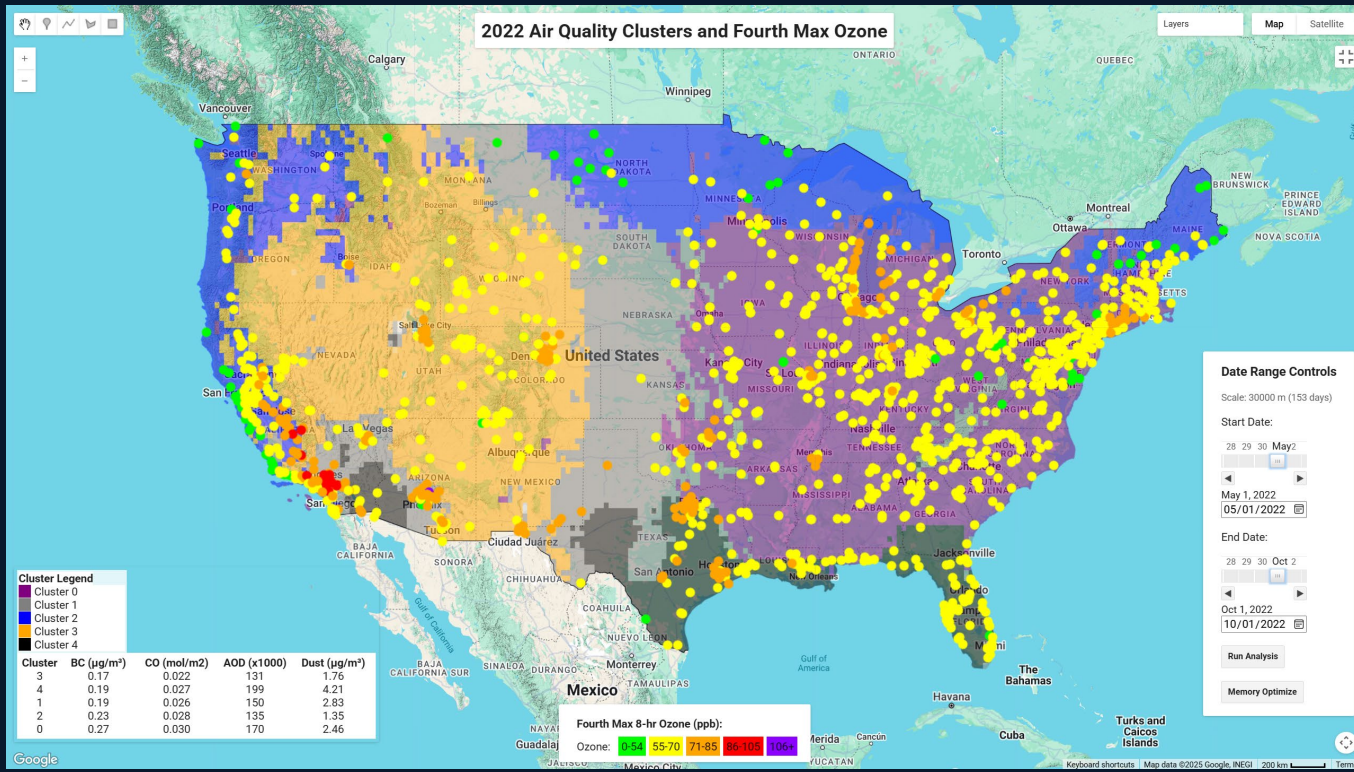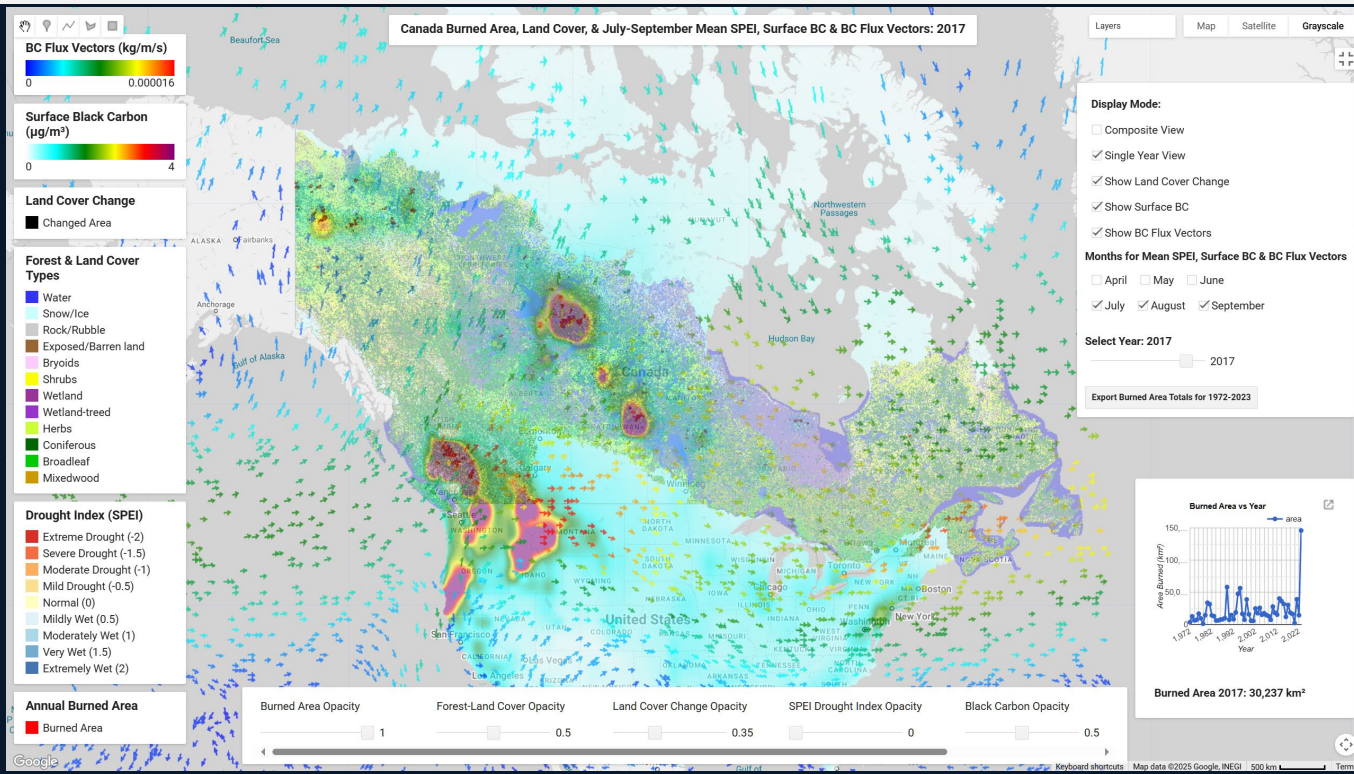
This incorporates existing scripts for burned area calculations and land cover type developed by Canadian scientists. It is possible to track fire, smoke transport, drought, and burned area trends by time and forest type.

Other Projects with GEE

❑ ***Utah Science for Solutions FY2026 Grant***: "Comprehensive Google Earth Engine and Satellite Data Analysis Tools to Assess the Impacts of VOC-NOx Sensitivity, Smoke, Heat, Drought, and Plant Stress on Ozone Concentrations in Utah and the Northern Wasatch Front".

❑ ***The Africa Air Quality Console***: I discussed the use of satellite and land cover data to track air quality, climate, smoke, and fire effects for the African Air Quality Society 2-day webinar in October 2024.

❑ In the planning stages for a possible seminar as a part of the ***AfriGEO Symposium*** in Senegal in October 2025.
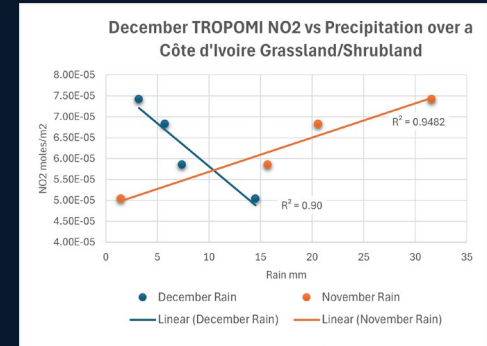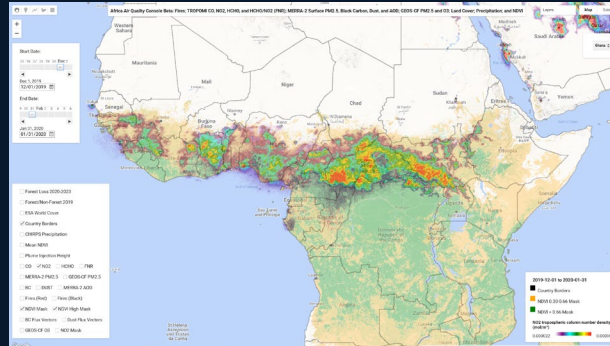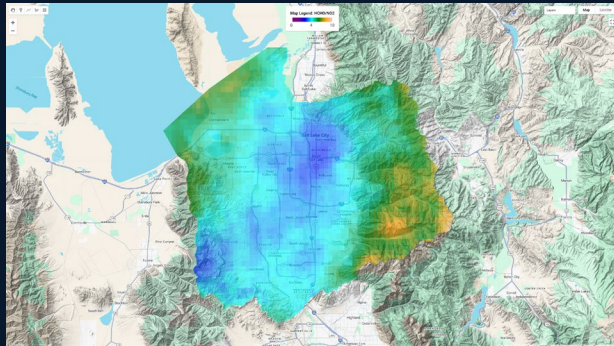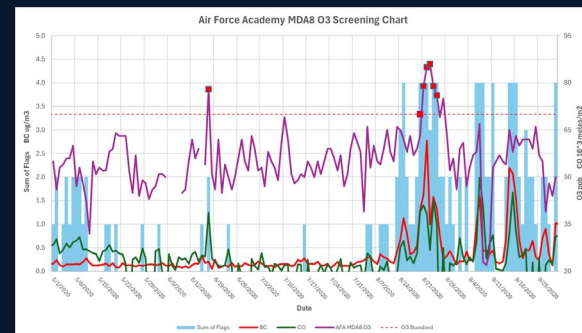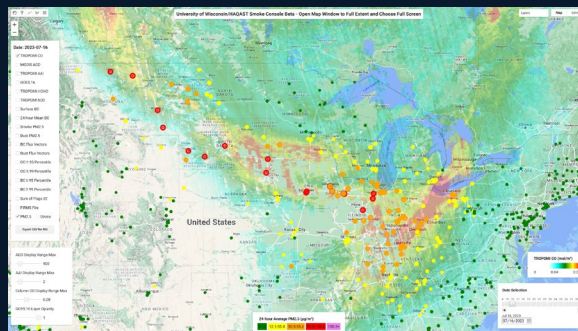
The Smoke Console is Available
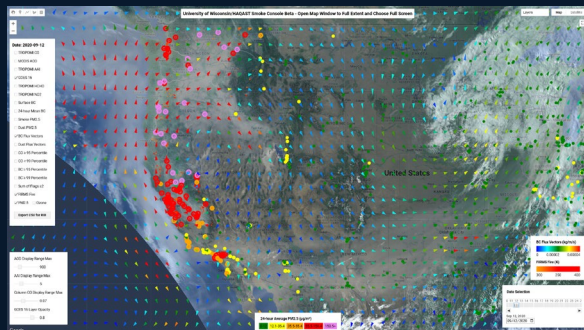
GEE is free for research and non-production government work. If you are using it for a client or routine government work, you will need a commercial plan. Preparing hundreds of maps for 14 candidate exceptional events in EEDs cost ~ $150.00


If you want to get started exploring GEE see:
https://haqast.org/wp-content/uploads/sites/91/2023/12/mcginnis.pdf

Questions?

- ❑ Smoke Console Users Guide:
  https://uwmadison.box.com/s/5b892fgxs24if88w3s36a4jz5wqe401d
- ❑ Smoke Console JavaScript:
  https://github.com/turtlesands/HAQAST_SMOKE_CONSOLE/blob/main/Code051425
- ❑ Smoke Console App (without active data export feature):
  https://preddyresearch.users.earthengine.app/view/smoke-console-051425
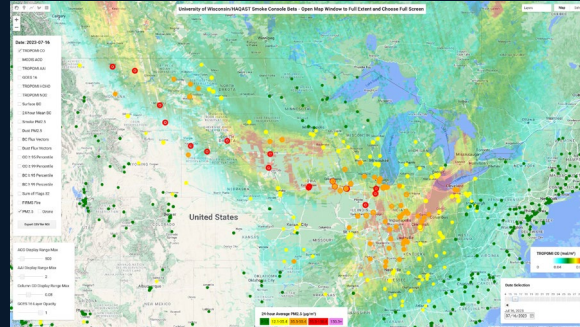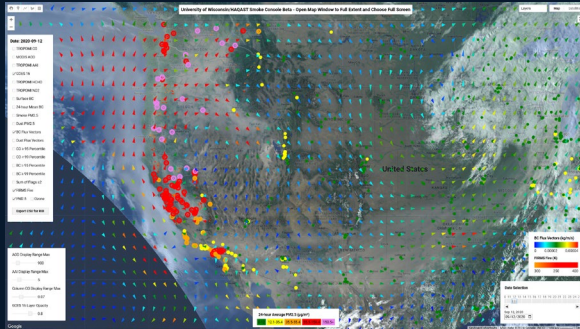
- ❑ A Quick Start Users Guide will be posted this month.
- ❑ I hope to submit a manuscript on the Console and the science behind it to the Journal of the Air & Waste Management Association this summer.