Wildfire R&D with HYSPLIT

Hyun Cheol Kim [1,2], Charles Fite[1,3], Sonny Zinn [1], Tianfeng Chai [1], Christopher Loughner[1], Ravan Ahmadov[4], Shobha Kondragunta [5], Daniel Tong [3], and Mark Cohen [1]

[1] Air Resources Laboratory, National Oceanic and Atmospheric Administration, College Park, MD

[2] Cooperative Institute for Climate and Satellite, University of Maryland, College Park, MD

[3] Dept. of Atmospheric, Oceanic and Earth Sciences, George Mason University, Fairfax, VA

[4] Global Systems Laboratory, National Oceanic and Atmospheric Administration, Boulder, CO

[5] National Environmental Satellite, Data, and Information Service, National Oceanic and Atmospheric Administration, College Park, MD

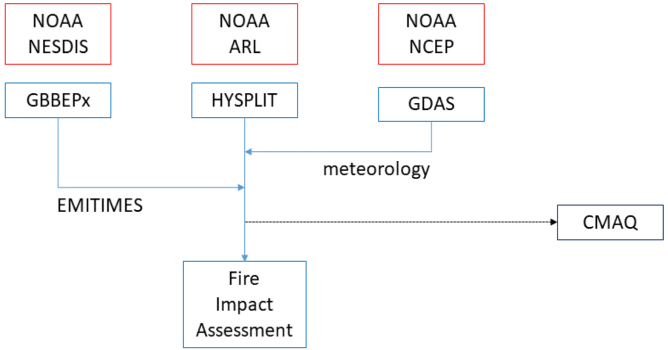
Upgrading HYSPLIT fire modeling system

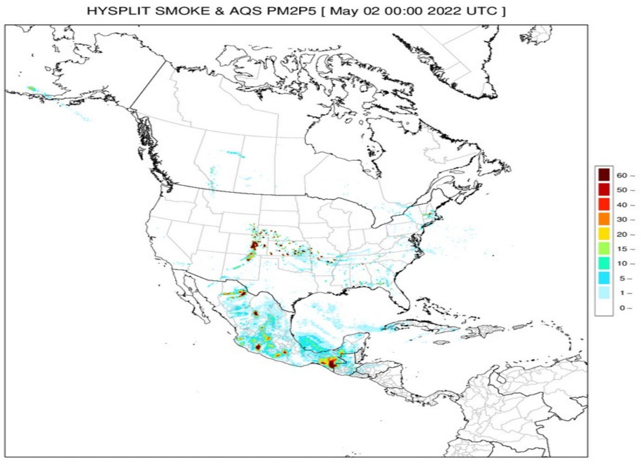
- **Why HYSPLIT?**
  - Fast & Linearized Lagrangian processes
  - TCM-based emissions inverse modeling
  - Ensemble fire modeling
  - Comprehensive fire modeling testbed
- **Coverage**
  - Spatial: Local to global
  - Temporal: Real-time (forecast) and retrospective (research) runs
  - Emission: Wild to prescribed (Satellite & BlueSky)
- **Fire science**
  - Plume rise algorithms – Briggs, Sofiev & Freitas schemes
  - Emissions inverse modeling (spatial, vertical and temporal)
- **Evaluation & Impact assessment**
  - Surface and satellite inter-comparisons
  - Burn permit guidance & cross-border impacts assessment

HYSPLIT fire System – Wildfire forecasts

HYSPLIT fire modeling system

- HYSPLIT dispersion model
- Fire emissions inventories
  - GBBEPx – FRP, daily
  - RAVE – FRP, hourly
  - FINN – MODIS/VIIRS fire detection, daily
  - Emissions inverse modeling
  - BlueSky – Bottom up
- AQS surface observations





Inverse modeling of fire emissions

- **An independent HYSPLIT simulation starting at each HMS fire location with given starting time and duration is run with a unit source, at several possible release height to generate a *Transfer Coefficient Matrix (TCM)*.**

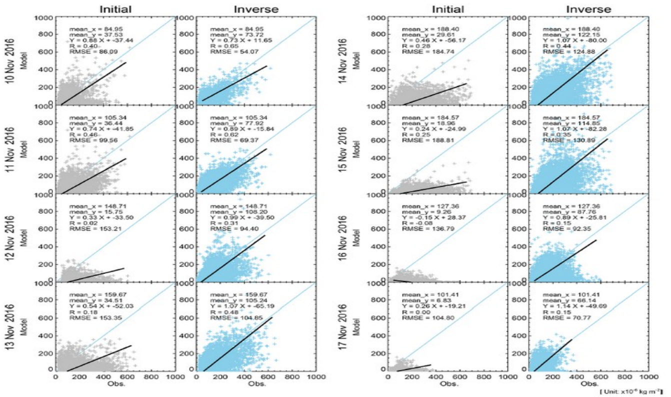
- **Source terms are solved by minimizing a cost function based primarily on the differences between model predictions and observations, following a general data assimilation approach.**

$$\mathcal{F} = \frac{1}{2}\sum_{i=1}^{N}\sum_{k=1}^{Z}\frac{(q_{ik} - q_{ik}^{b})^2}{\sigma_{ik}^2} + \frac{1}{2}\sum_{m=1}^{M}\frac{(c_m^h - c_m^o)^2}{\epsilon_m^2} + \mathcal{F}_{other}$$

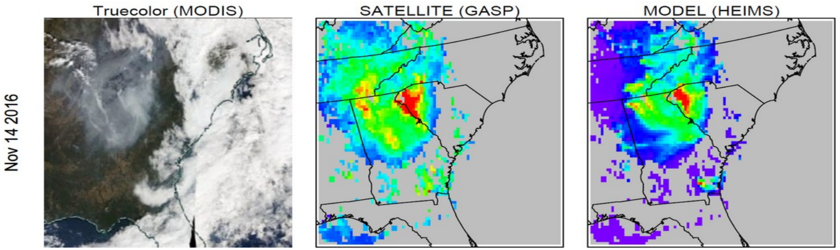
First guess

HYSPLIT

OBS



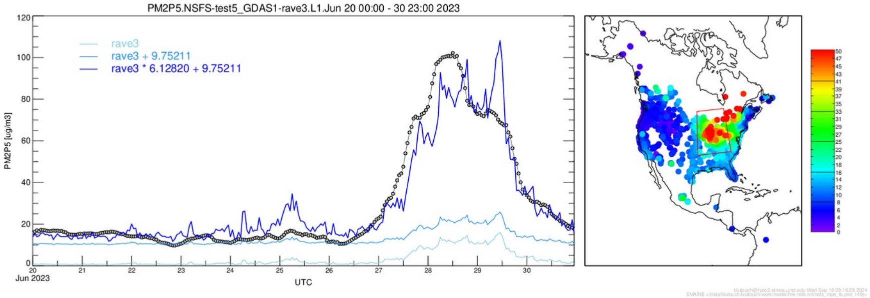
Scatterplot comparison between initial and assimilated smoke mass loading using adjusted fire emissions.



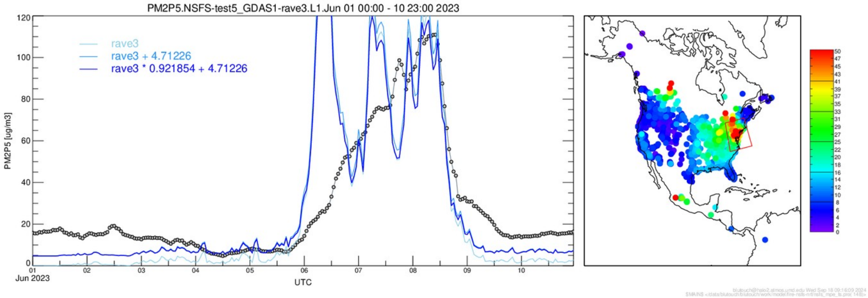
Fire emissions (HEIMS-f): Smoke forecasts have been challenged by high uncertainty in fire emission estimates. The HEIMS-f is designed to assimilate wildfire emissions based on the GOES Aerosol/Smoke Product (GASP) and HYSPLIT dispersion simulations (Kim et al., 2020)

Wildfire events and emissions adjustment

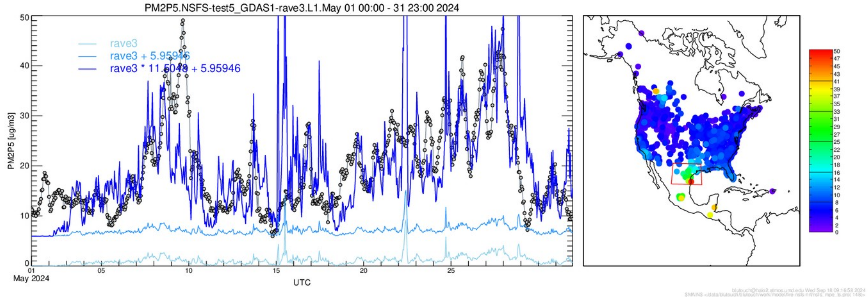
Canadian fires (2023)



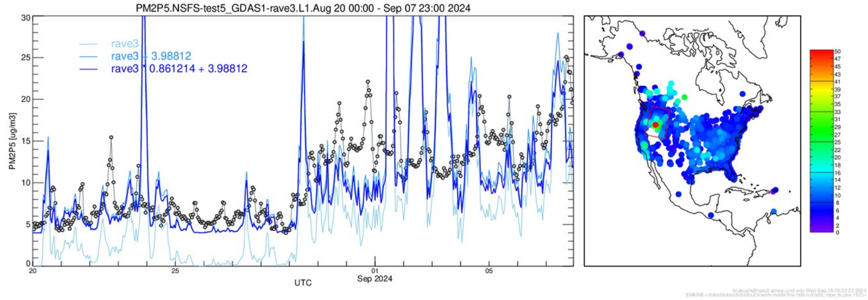
Canadian fires (2023)



Central American fires (2024)

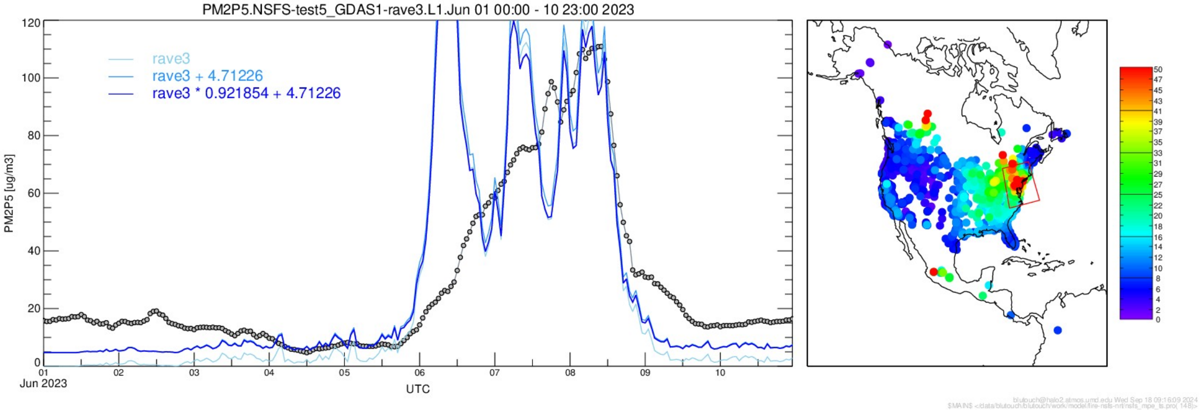


Wyoming/Idaho fires (2024)

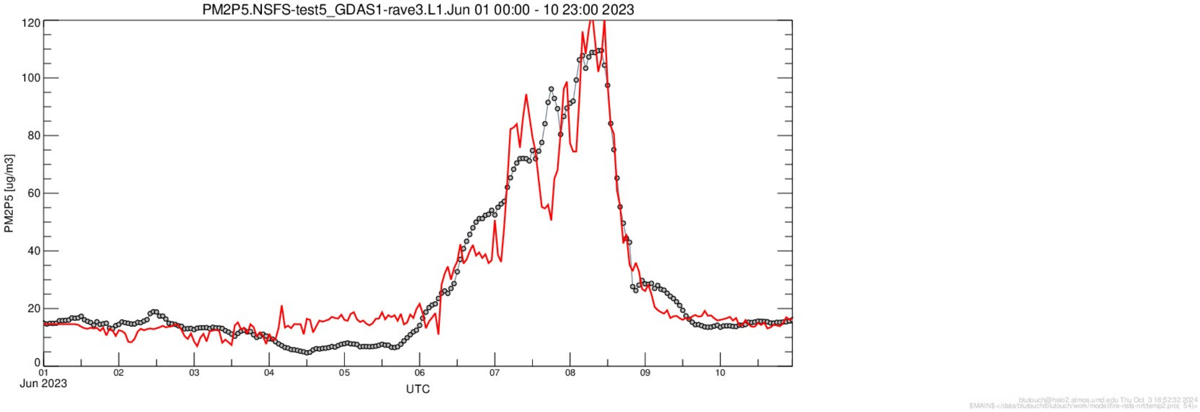


Emission adjustment (single source & multi source)

Single source adjustment



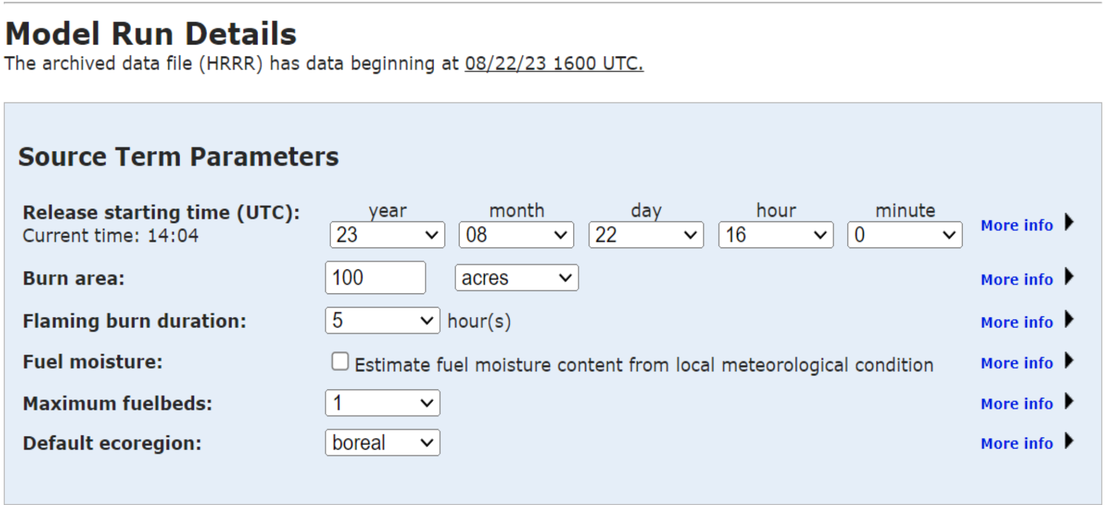
Multi source adjustment (daily)



Current HYSPLIT Prescribed Burn Capability

ARL has a current capability to calculate prescribed fire emissions estimates and run either a retrospective *or* forecast HYSPLIT dispersion simulation for a ***single*** fire using the BlueSky emissions modeling framework (https://www.ready.noaa.gov/HYSPLIT_disp.php)

Pros: bottom-up emissions estimate, easy to use, adjustable fuel/fire info knobs.
Cons: only one fire can be run at a time

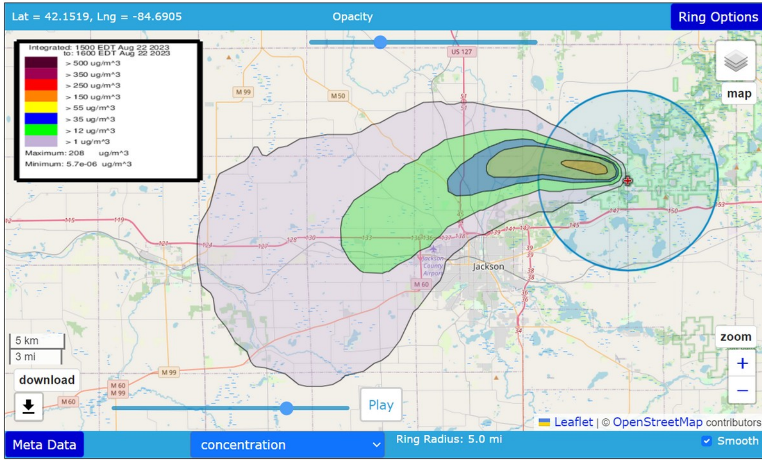


Model Run Details

The archived data file (HRRR) has data beginning at 08/22/23 1600 UTC.

Source Term Parameters

Release starting time (UTC): Current time: 14:04	year 23, month 08, day 22, hour 16, minute 0	More info
Burn area:	100 acres	More info
Flaming burn duration:	5 hour(s)	More info
Fuel moisture:	Estimate fuel moisture content from local meteorological condition	More info
Maximum fuelbeds:	1	More info
Default ecoregion:	boreal	More info



A multi-fire BlueSky-based emissions forecast methodology

- The BlueSky framework from the USFS takes inputs of burned area, fuel load information, and meteorology to model the fuel consumption and emissions process in a bottom-up manor.

- Bottom-up emissions estimates can be informative, but more difficult to use for air quality *forecasts* due to longer data latency times compared to NRT FRP-based emissions estimates.

- **We are trying to use a hybrid methodology that uses NRT FRP measurements to derive <u>burned area</u> estimates that can be fed into BlueSky to estimate emissions for HYSPLIT dispersion simulations**

NRT Burned area estimation from FRP

FRE

FRP x duration x DM factor / Fuel Consumption Rate (FC) = burned area

MW x sec. x kg/MJ / kg/acre = acres

Using hourly FRE from RAVE v2

0.368 kg/MJ from Wooster et al. (2005)

Field studies compilation from van Wees et al. (2022), IGBP land cover dependent

Capped at RAVE grid cell size

Burned area can then be fed into BlueSky emissions framework

First step is to IGBP classify each fire, and then map other conversion factors by IGBP type.
If using FRE from RAVE, would have FRE resolved hourly

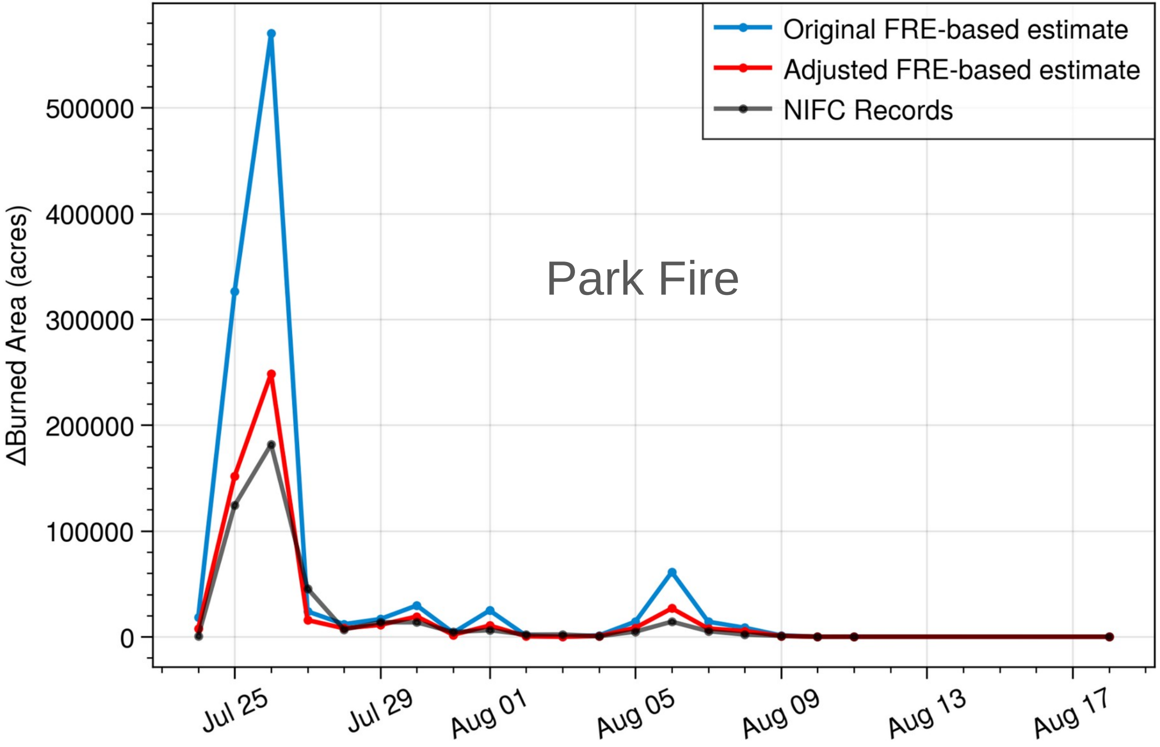
Fuel Consumption by IGBP land cover type

Western US is defined as west of 102°W
(western border of Kansas)

IGBP_Name	FC_WestNA	FC_EastNA	Unit
water	368.28	368.28	kg/acre
evergreen needleleaf forest	13500.14	6446.87	kg/acre
evergreen broadleaf forest	4831.07	4831.07	kg/acre
deciduous needleleaf forest	20906.56	20906.56	kg/acre
deciduous broadleaf forest	22893.64	19877.49	kg/acre
mixed forests	8133.98	8133.98	kg/acre
closed shrubland	12748.05	12748.05	kg/acre
open shrublands	13648.99	13648.99	kg/acre
woody savannas	4921.39	3791.31	kg/acre
savannas	2616.39	4896.87	kg/acre
grasslands	4807.43	4485.05	kg/acre
permanent wetlands	6475.20	6475.20	kg/acre
croplands	1698.20	1698.20	kg/acre
urban and built-up	1698.20	1698.20	kg/acre
cropland/natural vegetation mosaic	1698.20	1698.20	kg/acre
snow and ice	368.28	368.28	kg/acre
barren or sparsely vegetated	368.28	368.28	kg/acre

van Wees et al. (2022)

Evergreen Needleleaf Forest



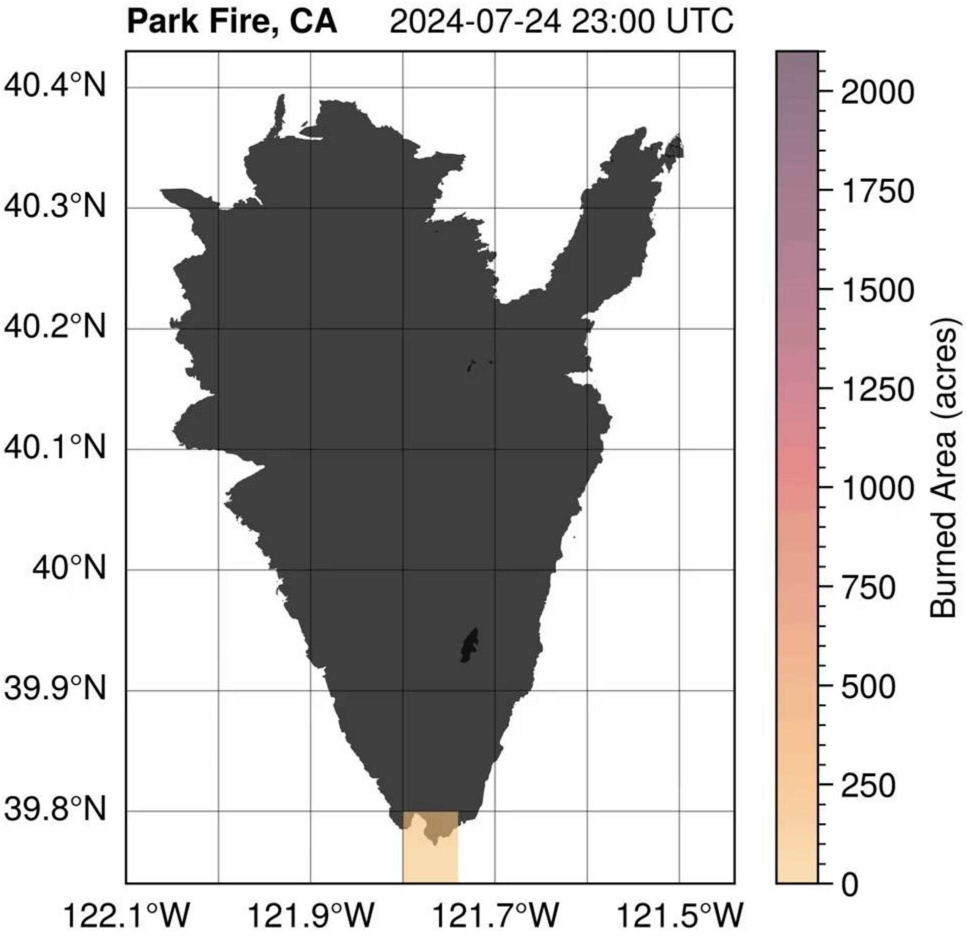
RAVE FRE-based Burned Area Estimate

Totals Acres:
Original estimate.: **1,127,889**
Adjusted estimate: **525,227**
NIFC Record: **429,387**

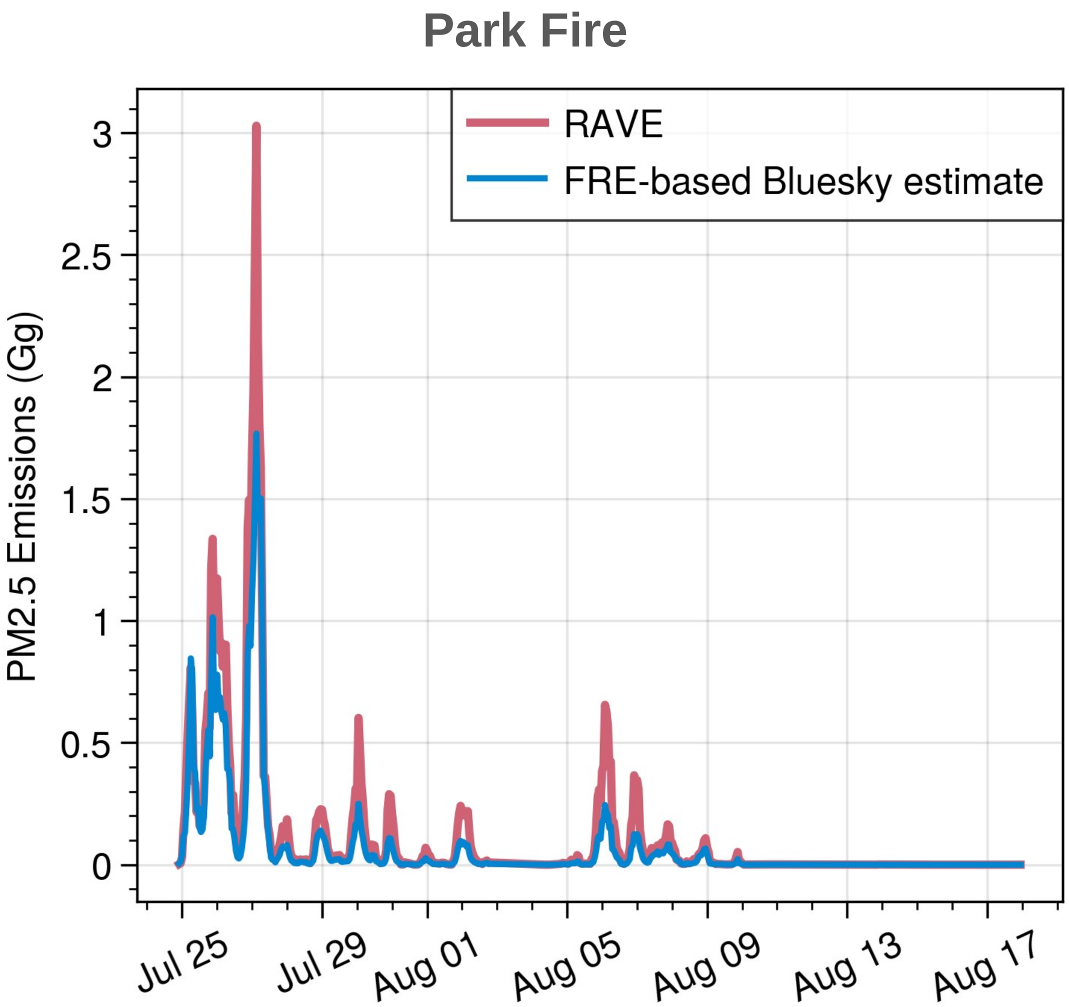
$$A_{\mathrm{adj},i,j,t} = \begin{cases} \left(\frac{A_{i,j,t}}{\sum_{t=0}^{n} A_{i,j,t}}\right) \cdot C_{i,j}, & \text{if } \sum_{t=0}^{n} A_{i,j,t} > C_{i,j} \\ A_{i,j,t}, & \text{if } \sum_{t=0}^{n} A_{i,j,t} \le C_{i,j} \end{cases}$$

Where “A” is original burned area estimate, “C” is grid cell area from RAVE, and “A_{adj}” is the ***adjusted*** burned area estimate

FRE-based burned area (adjusted)



Some of our overestimation after area-adjustment could be due to edges of burn scar where grid cell indicates more burned area than reality

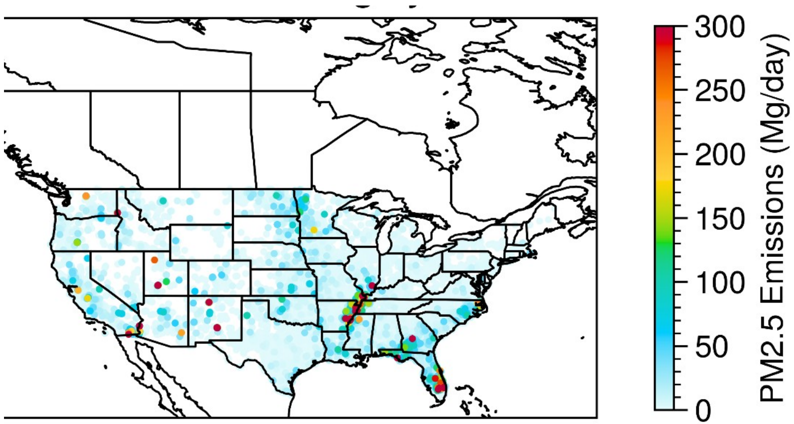


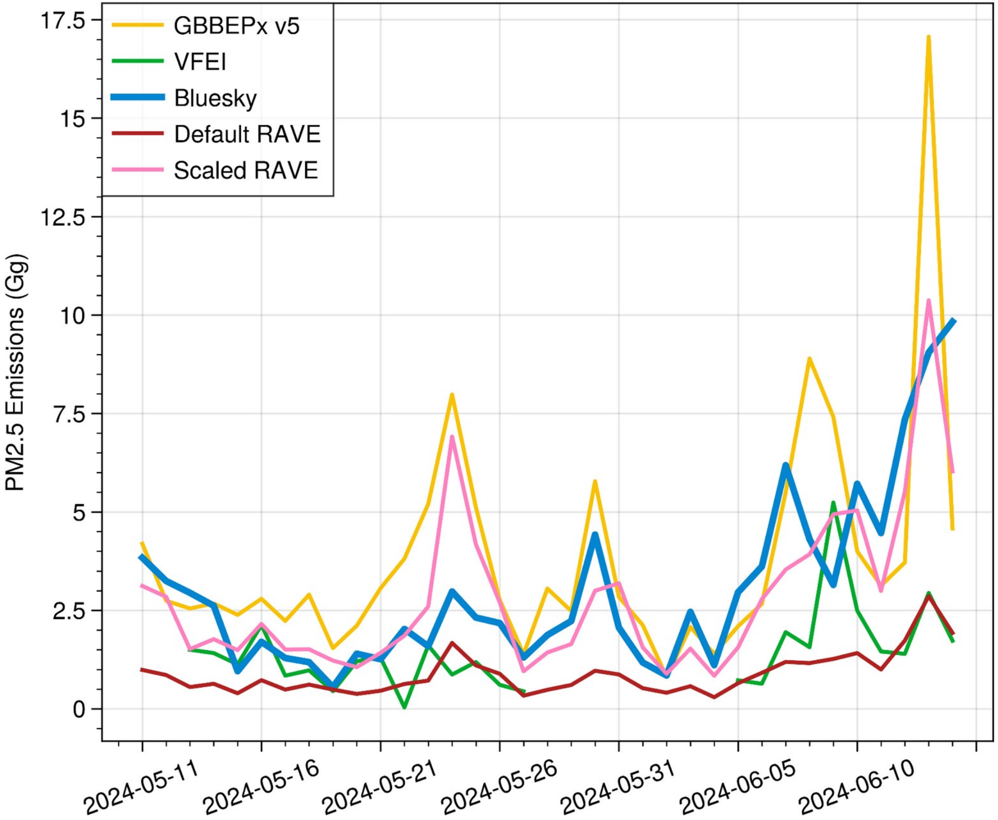
Bluesky PM2.5 emissions estimate using burned area

Bluesky based estimate is lower than RAVE v2, could be due to model fuel consumption processes, default configuration, or differences in emission factors…etc.

Daily Emissions CONUS sum
(May 11-June 14, 2024)

Bluesky is within range of all inventories (good to see!)





Future Steps

- Validate burned area estimates against observations for additional wildfires, and for eastern US prescribed fires against burn permit records
- Feed multi-fire BlueSky emissions estimates into HYSPLIT dispersion simulations for CONUS evaluation against AirNow PM2.5 observations

Conclusions/Applications

- At ARL, we have developed a methodology to estimate **burned area** using NRT satellite thermal detections (FRP), useful for **bottom-up** emissions estimates.
    - This method is *most* novel for representing burned area of **small** and **low intensity** fires that are smaller than the representative grid cell

- Bottom-up fire emissions estimates are rare to have for air quality ***forecasting*** applications, so this can be a good addition to other top-down fire emissions inventories developed by NOAA (e.g., RAVE, GBBEPx)

- BlueSky provides ***more*** outputs than traditional FRP-based inventories:
    - Numerous chemical species (PM2.5, CO, CO2, NOx, VOCs etc.)
    - A breakdown of fuel consumption and emissions into ***flaming*** *vs.* ***smoldering*** combustion, meaning custom emissions factors (EFs) can be applied based on combustion phase
    - **Heat release**, which can be used for determining **plume rise height** in dispersion modeling