Washington Smoke Forecast System

ECY HYSPLIT Project Team:

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DEPARTMENT OF
ECOLOGY
State of Washington

**Air Quality Program
Science & Analysis Section**

Overview

- Brief review of fire activity over the past decade
- Background of wildfire smoke forecasting at Ecology
- Forecast zone changes
- Model setup and comparison
- HYSPLIT processing steps
- Synopsis of model performance (2022)
- Sensitivity analysis for emissions scenarios
- New HYSPLIT scenario details
- Past issues and recent changes

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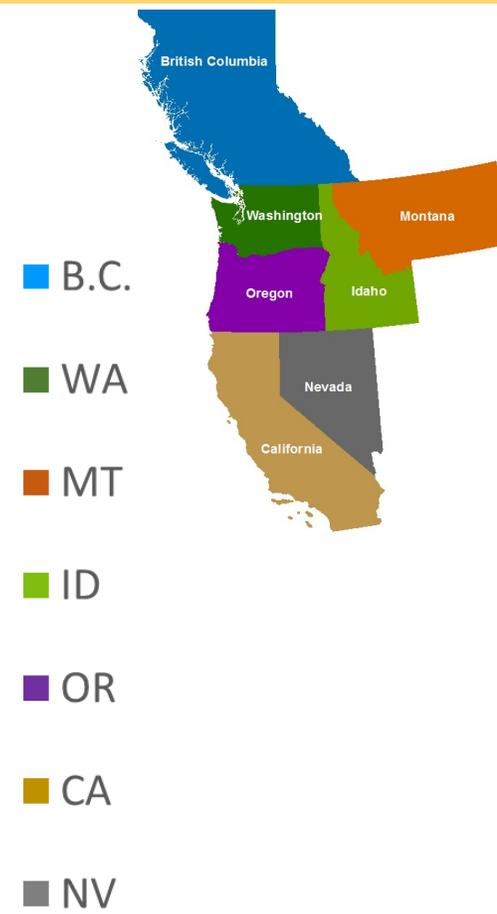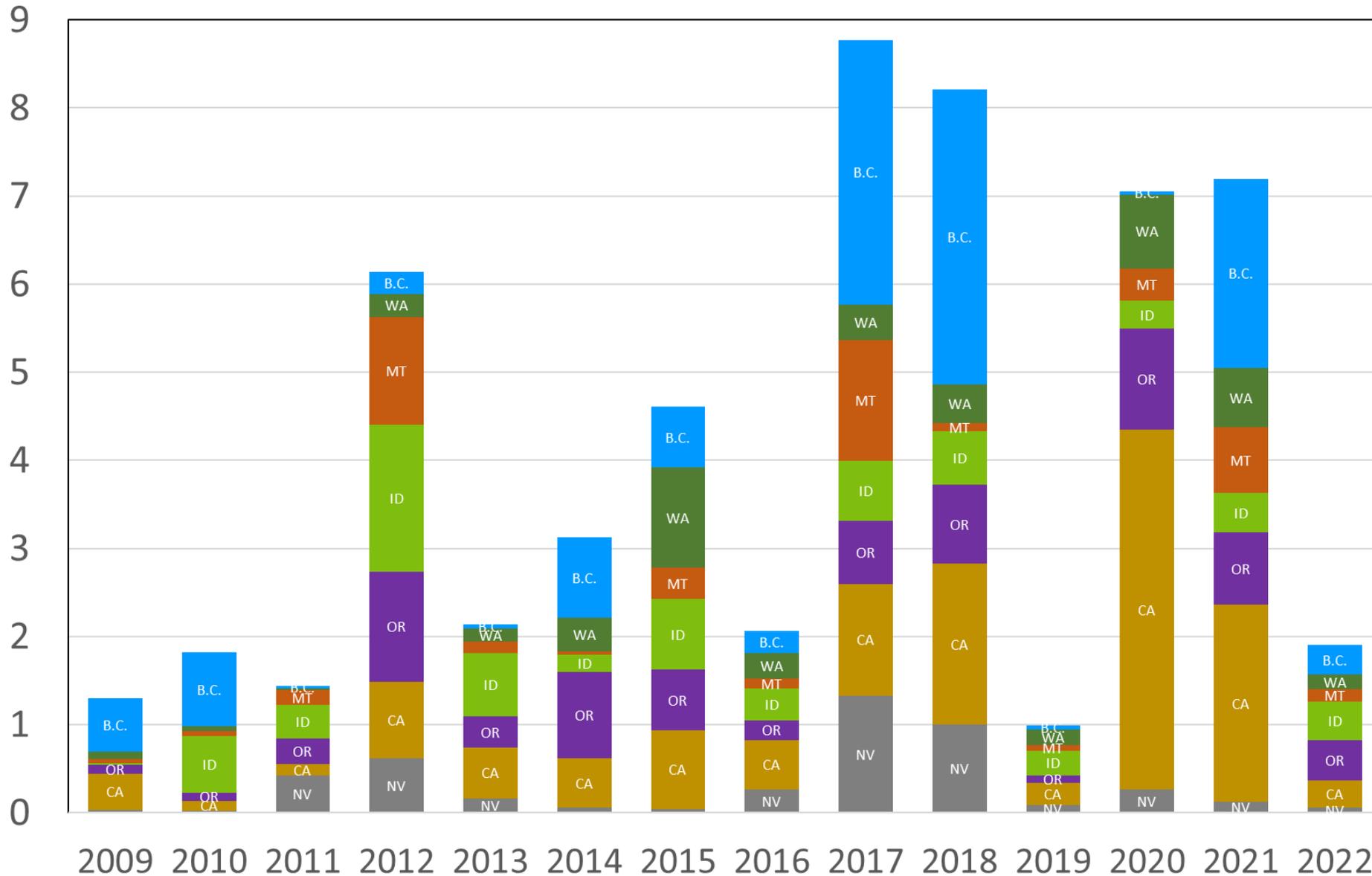
2023 Lesson: Add Alberta!
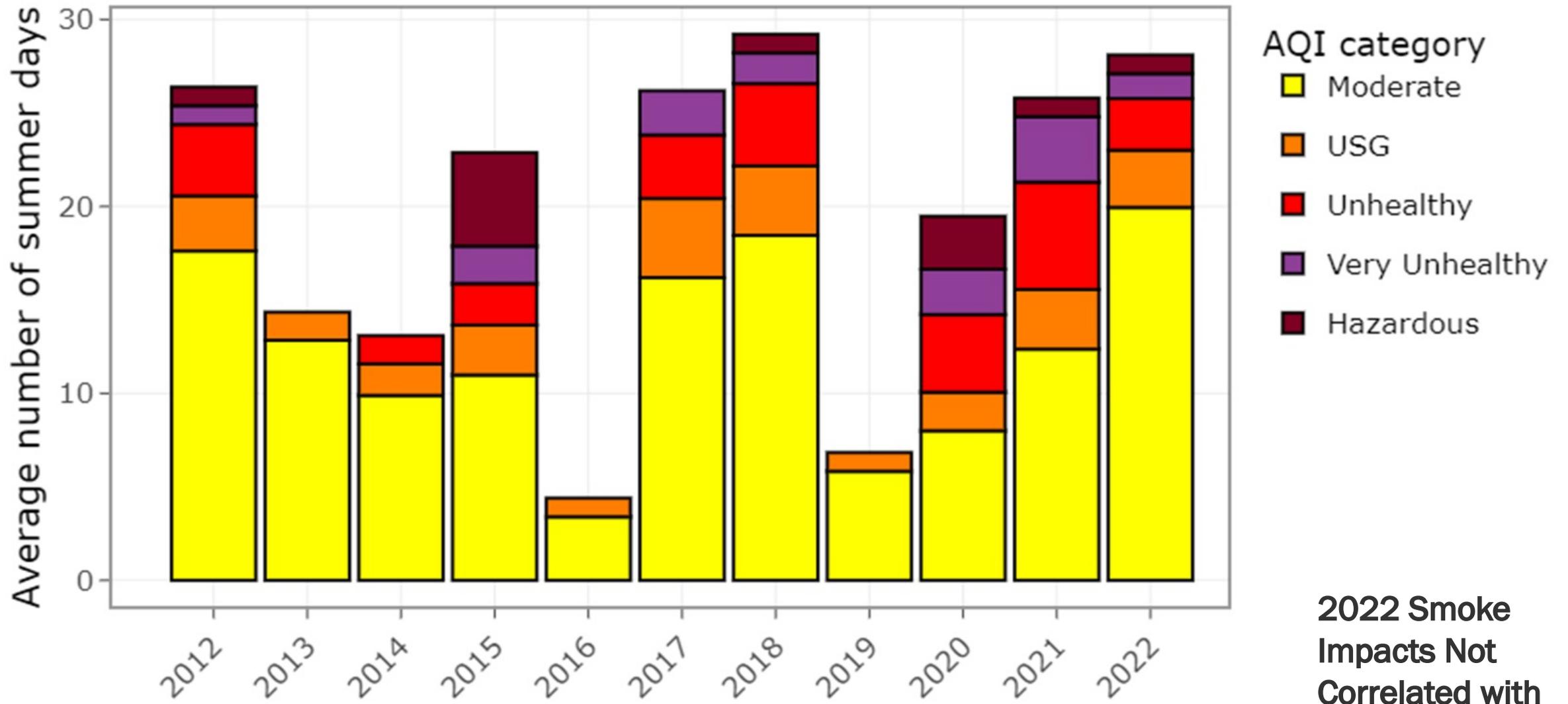
2022 Smoke Impacts Not Correlated with Acres Burned

Wildfire Smoke Forecasting
Project Background

Purpose:

Provide the public with a forecast of upcoming smoke impacts
from wildfires so people can plan ahead and reduce exposure.

Historical Perspective:

Smoke models are often inaccurate and difficult for the public to interpret. Historically,
Ecology would use many sources of info to synthesize a forecast to be posted on the WA
Smoke Blog (often multiple times per week), using daily PM2.5 AQI categories.

Project Development:

In 2020, WSU launched the 2-day Machine Learning model for PM2.5, which greatly
outperformed AIRPACT. Ecology developed a zone-forecast website to share the ML forecasts,
with an option for human/AirNow override.
In 2021, Ecology developed a 5-day wildfire smoke forecast using HYSPLIT and global models.

Original Forecast Zone Polygons

Each zone typically experiences similar smoke impacts and can be represented by a single PM2.5 monitor. Zone polygons are based on:

- Monitor Locations, Density, Proximity
- AIRPACT 4-km grid cells with similar 98th percentile PM$_{2.5}$ concentrations
- Tribe and County Boundaries
- Burn Ban Zones and Air Quality Management Zones
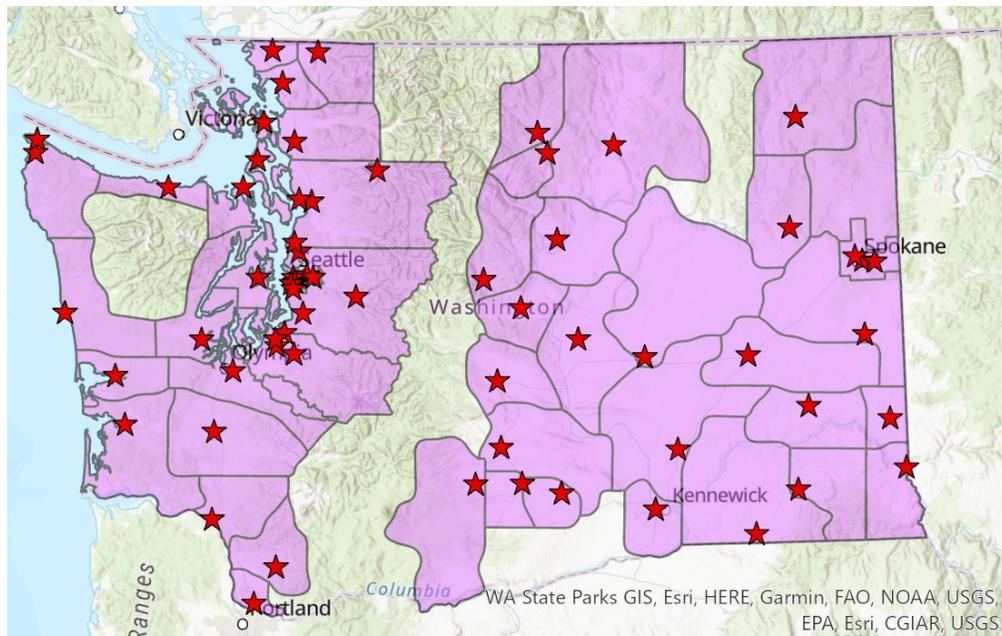
June thru October (5-day forecast)
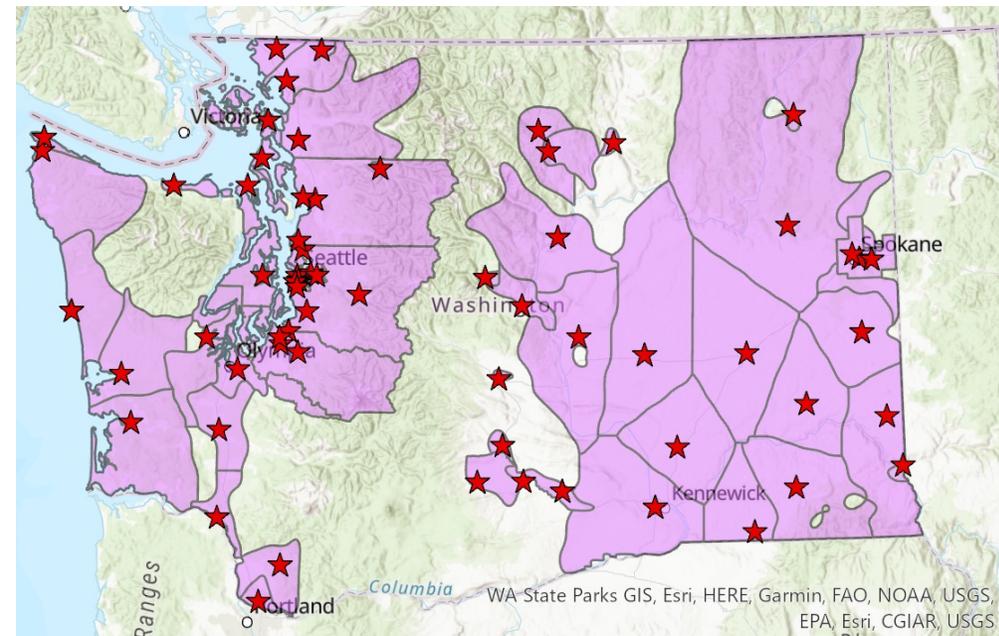
November thru May (2-day forecast)

Updated Smoke Forecast Tool

https://enviwa.ecology.wa.gov/

Priority of forecast issued:

1. LCAA's manual forecast submitted to AirNow
2. ECY modelers manually set polygon forecast
3. Automated forecast
    *   Days 1-2: WSU Machine Learning model
    *   Days 3-5: HYSPLIT Ensemble + background

The Ensemble smoke forecast is based on:
*   ~~Four global forecast models.~~
*   Ecology HYSPLIT forecasts (8 members).
    *   Originally based on 4 emissions scenarios and 2 vertical velocity schemes
    *   Now based on 8 emissions scenarios with identical meteorology
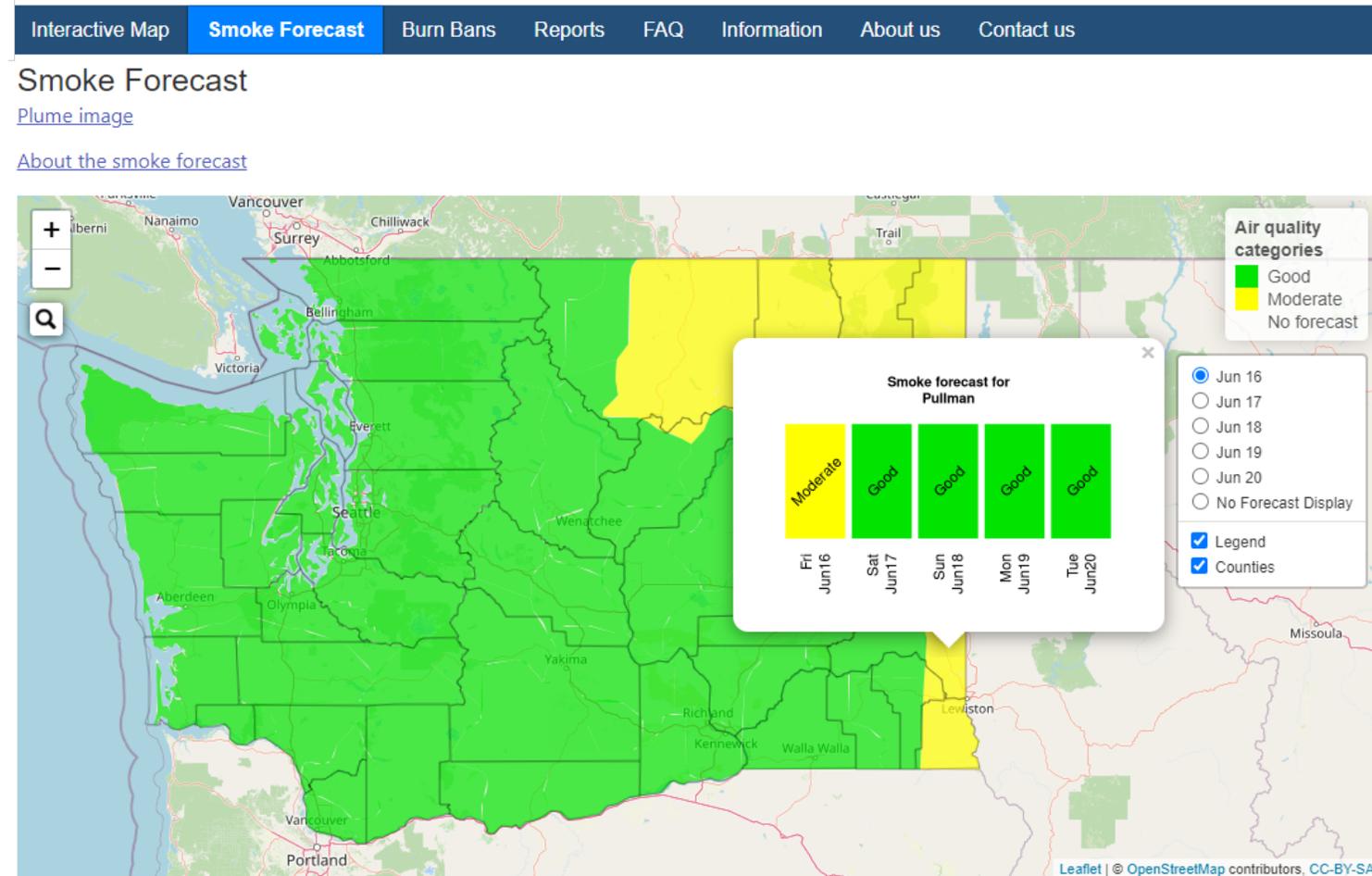
Model Setup Comparison

	WSU AIRPACT	WSU ML	ECY HYSPLIT
Days Forecasted	2	2	5
Ensemble?	No	No	Yes (8 members)
Initial Conditions	Previous day's simulation	*N/A*	None
Boundary Conditions	WACCM (NCAR)	*N/A*	None
Fire Date Inputs	3-Days Back	*N/A*	1-Day Back
Fire Locations	BlueSky FIS	*N/A*	NOAA HMS
Fire Emissions/Heat	Assumed Area x FCCS/Consume/FEPS	*N/A*	Modified FRP
Fire Behavior	Persist	*N/A*	FDR (Can.) and SFP (USA)
Chemistry/Deposition	CMAQ	*N/A*	None
Meteorology	4-km WRF	4-km WRF	12-km WRF
Forecast Coverage	WA, OR, ID, MT*, CA*, NV*	Monitor Locations	WA, OR, ID, MT, CA, NV, UT, WY, CO, BC*, AB*

* Partial Coverage Only

HYSPLIT Processing Steps

1. Download NOAA HMS file for "yesterday" fire locations (remove duplicates)
2. Assign 194 acres to each location and merge clusters (sum acres; max FRP)
3. Apply FRP modification formula for emissions; keep original FRP for heat
4. Use hourly emissions basis (66.1 Kg PM2.5 / MW) based on Wooster et al, (2005)
5. Apply fire potential (USA) and fire danger (Canada) and vegetation factors
6. Apply hourly diurnal profiles for heat and emissions
7. Create HYSPLIT input files (hourly emissions with heat and area for plume rise)
8. Run all 8 HYSPLIT scenarios for 5 days
9. Report the average PM2.5 within each zone on the forecast map
   - Previously we would use a correction term from the ML – now discontinued
   - We now add in a background value (5 ug/m3) since HYSPLIT is wildfire smoke only

HYSPLIT Hourly Emissions Basis
Converting Fire Radiative Power to Emissions

Wooster et al., 2005

$$0.37 \text{ MJ/kg} = 335 \text{ MJ/ton}$$

$$1 \text{ ton} / 335 \text{ MJ} = 0.003 \text{ tons/MJ}$$

Hourly PM2.5 (grams) =

| HMS | Wooster, Li, Mavko | units conversion | AP-42 emission factor (flaming) | units conversion |

FRP (MW) x 0.003 (tons cons./MJ) x 3600 (sec/hr) x 13.5 (lbs PM2.5 / tons cons.) x 453.6 (g/lb)

FRP Emissions Rate (g. PM2.5/hr) =
0.003 (ton veg./MJ) * 3600 (sec/hr) * 6123.6 (g. PM2.5/ton veg.)
66,134 g PM2.5 / HMS FRP MW

HYSPLIT Notes

- Runs at 2 am and ready for the web before 5:45 am
- UW WRF 12-km 5-day forecast meteorology
  - *Changed from 3-hr avg to 1-hr avg in 2023*
- Gaussian horizontal puff and vertical particle distribution
- Maximum age of particle is 36 hours
- No wet or dry deposition is assumed.
- Does not include initial or boundary conditions
- Scalar factors used for fire behavior (daily value) and vegetation (1993 global dataset - static)

Novel Scalar Factors

USA Significant Fire Potential (NIFC)	Moist = 0.25
	Dry = 1.00
	Lightning = 1.00
	Very Dry = 1.25
	Hot = 1.25
	Burn Env. = 1.25
	Windy = 1.25
	Hot & Dry = 1.50
Canada Fire Danger Rating	Low = 0.25
	Moderate = 0.50
	High = 0.75
	Very High = 1.00
	Extreme = 1.25
Vegetation	Barren = 0.01
	Scrub = 0.40
	Forest = 1.00
	Crops = 0.20

HYSPLIT Analysis Page
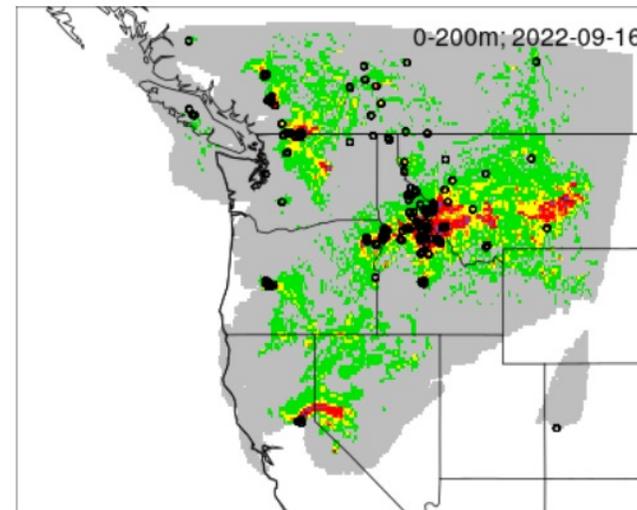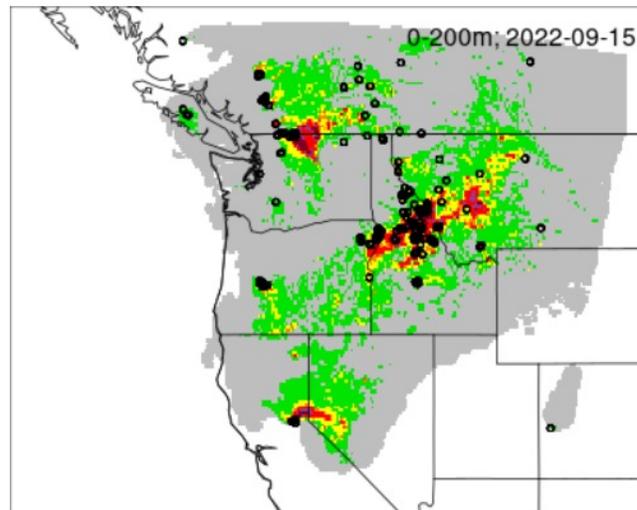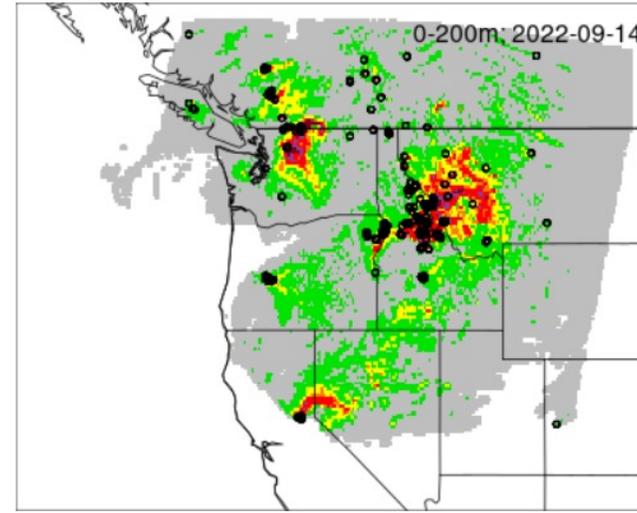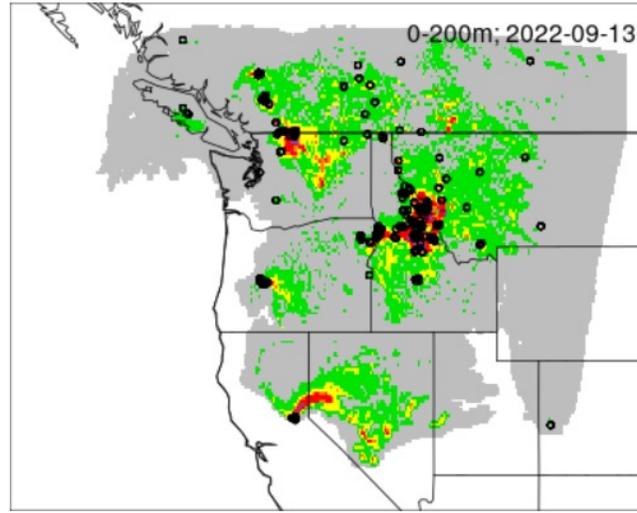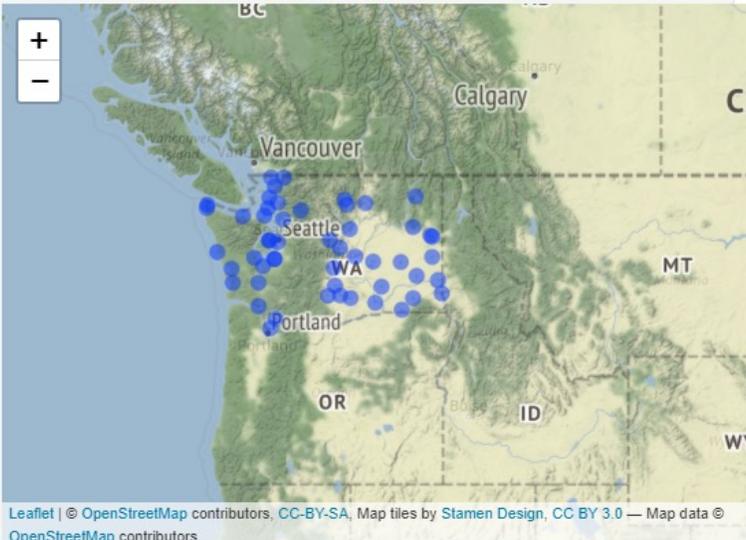
HYSPLIT Analysis Page
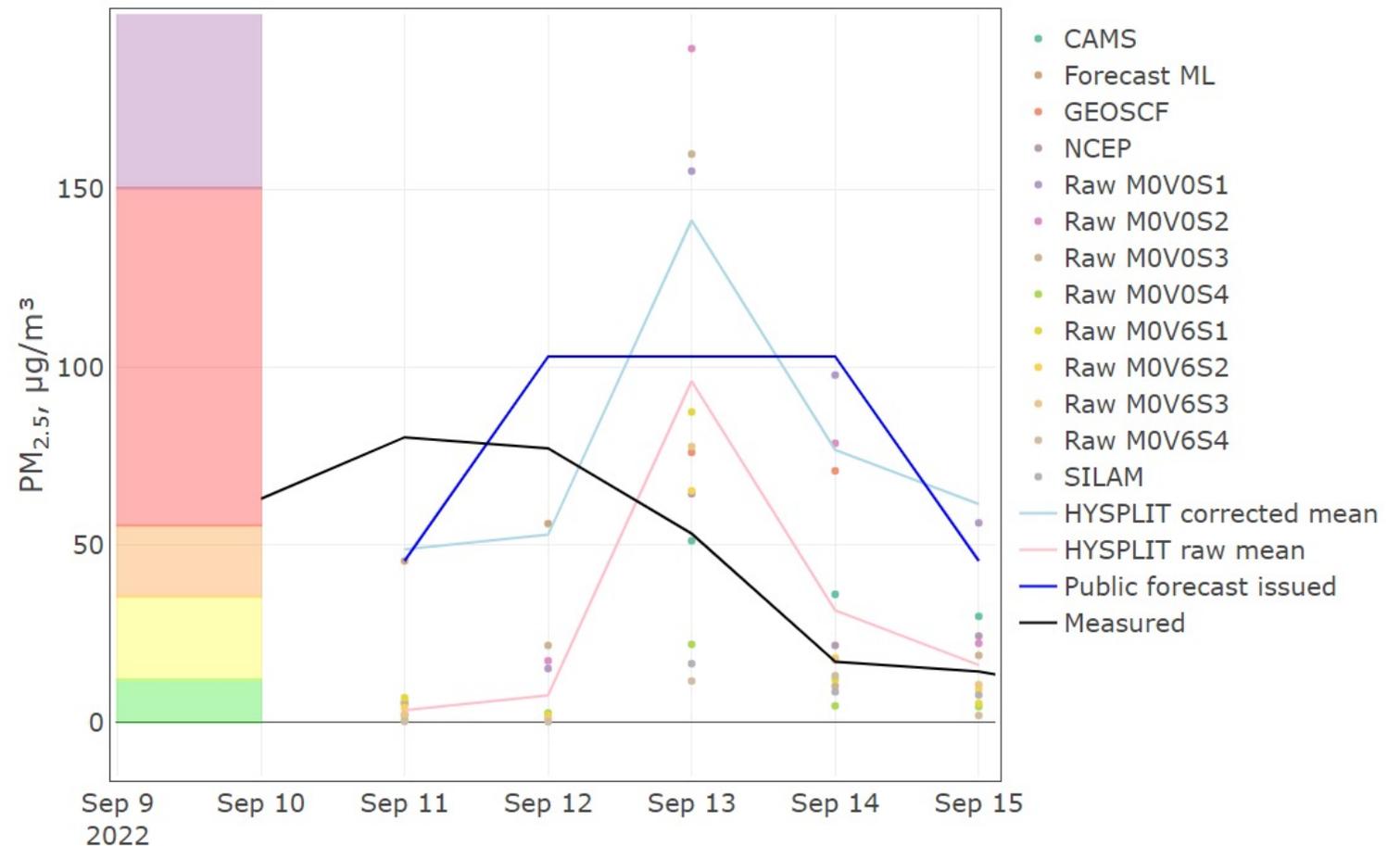
HYSPLIT Forecast Performance (2022)
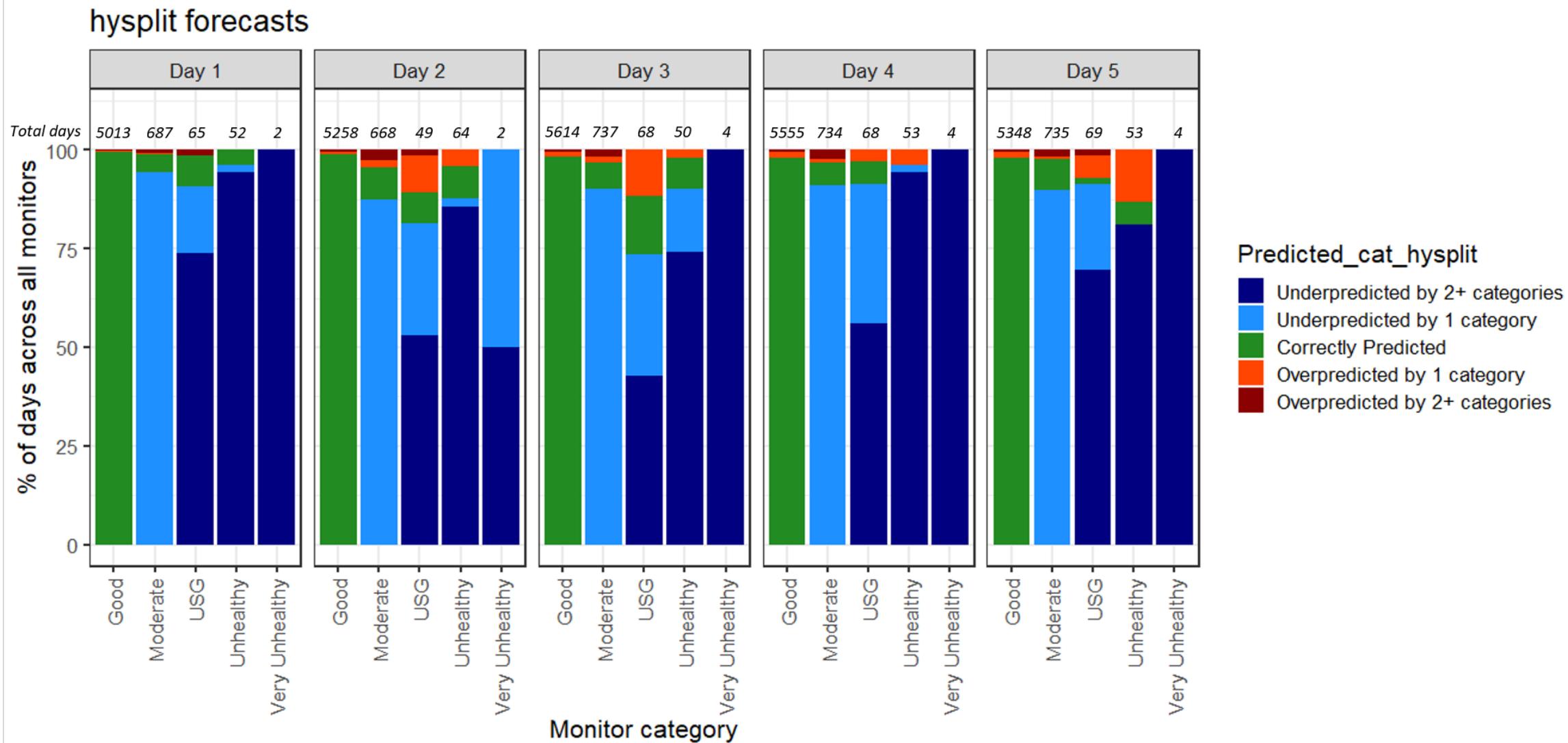
*24-hr PM2.5 At Monitor Locations

Ensemble Forecast Performance (2022)
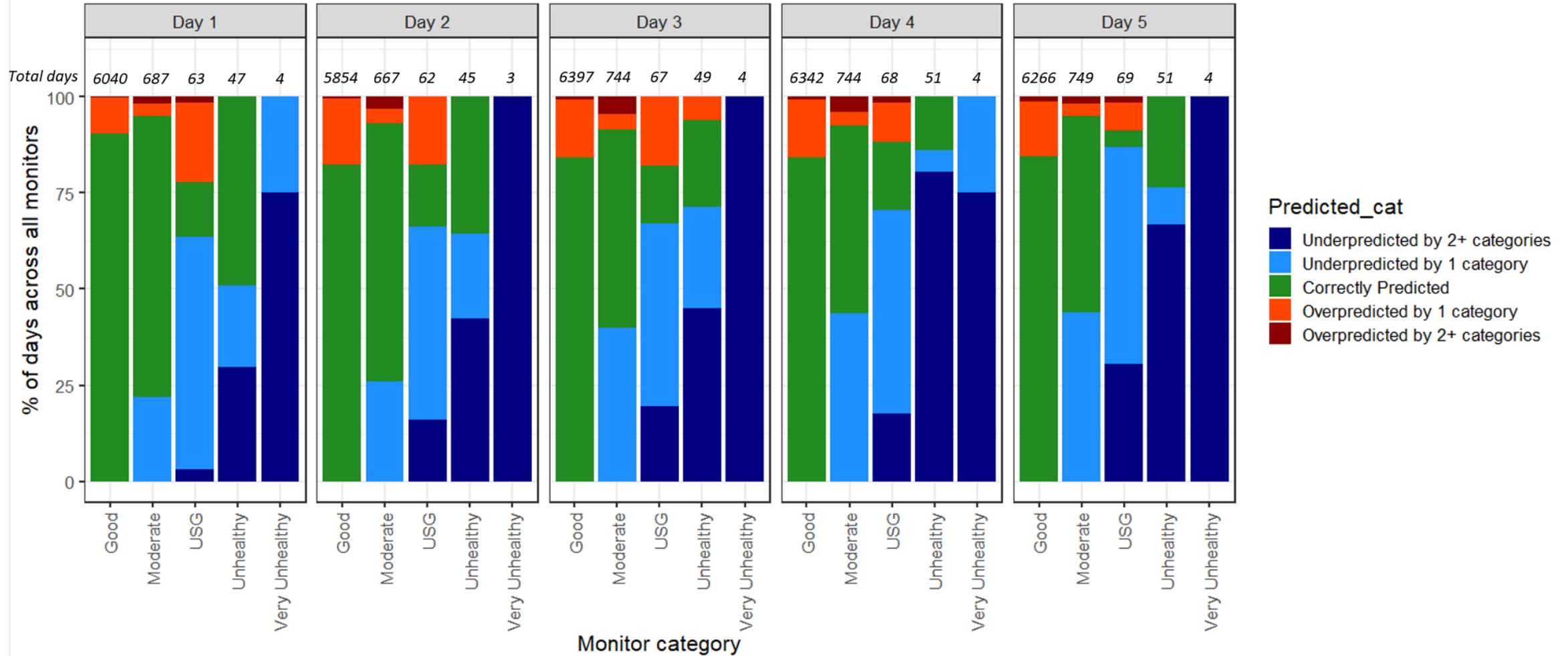
*24-hr PM2.5 At Monitor Locations

Manual Forecast Performance (2022)
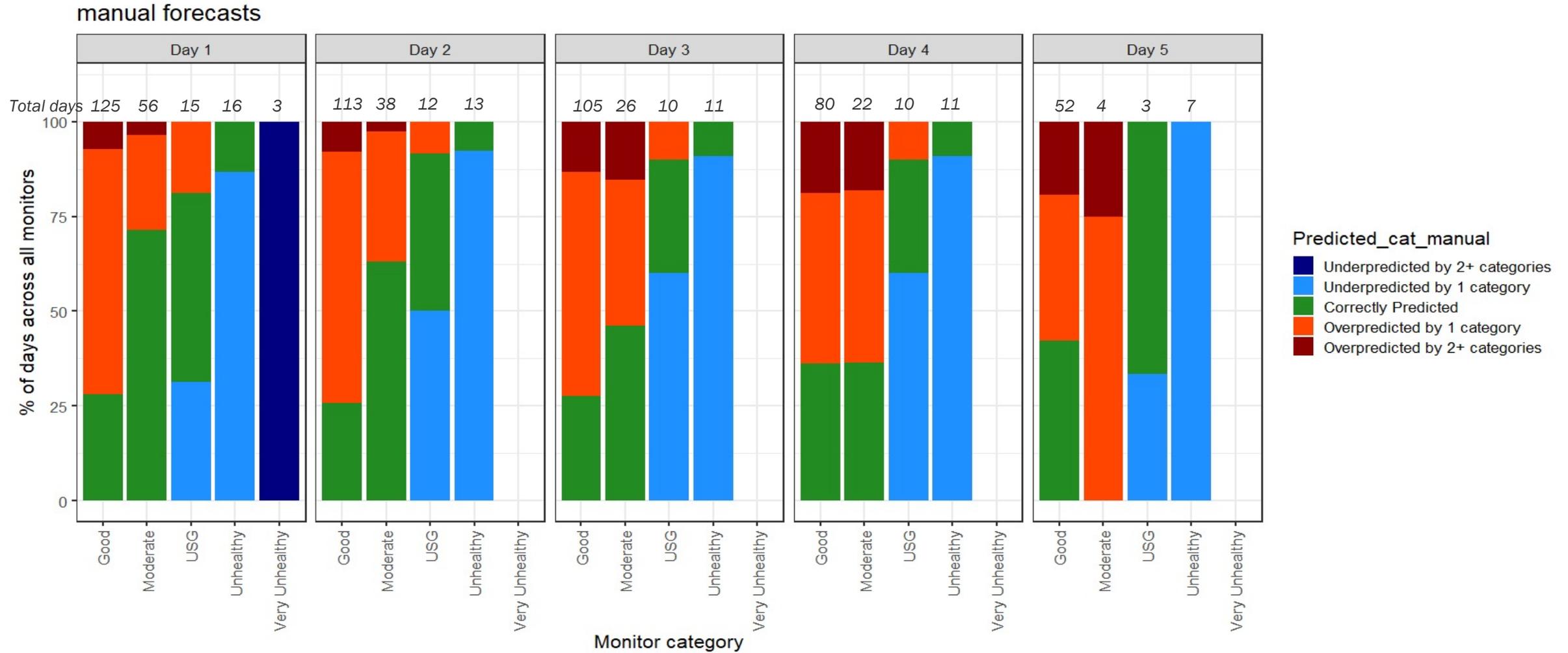
*24-hr PM2.5 At Monitor Locations

Sensitivity Analysis

Original HYSPLIT members were 4 emissions so
and 2 meteorological scenarios (vertical velocity

Prior tests showed the FRP to emissions conver
in low to mid-range FRP conditions, but overesti
FRP is large. So, FRP was constrained from 0.3

The linear rate with a 100 MW cap was compar
log functions as part of sensitivity analysis simu

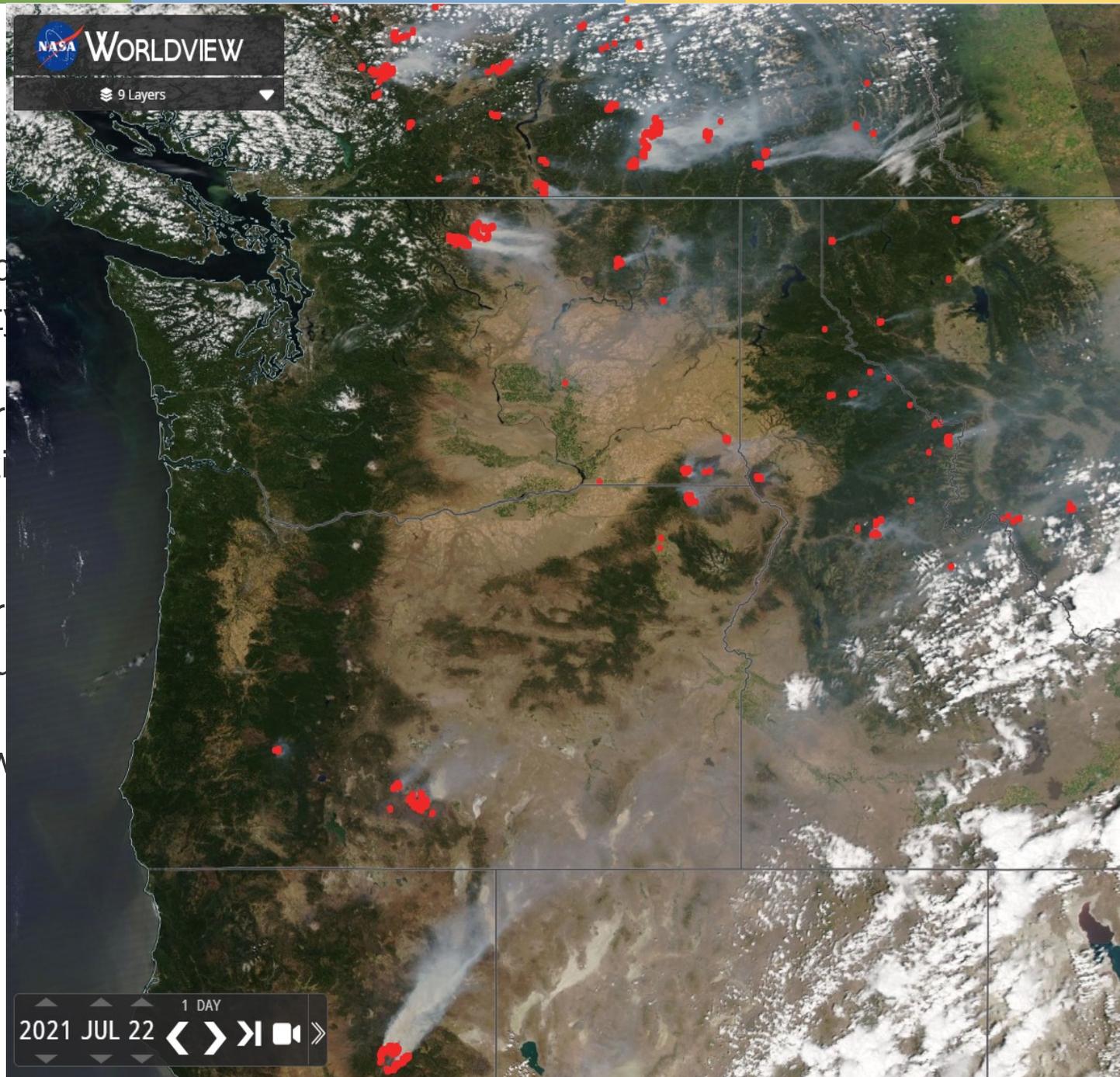July 17 - July 24 and Aug. 27 – Sept. 7 (2021) w

Sensitivity Analysis

Typical FRP Distribution

FRP (MW)	0 to 1	1 to 10	10 to 100	100 to 1000	1000+
Frequency	20%	50%	20%	10%	1%

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Legend:
- 1 x FRP
- 2 x root(FRP)
- 2.5 x root(FRP)
- log1.0818 (FRP)
- log1.1644 (FRP)
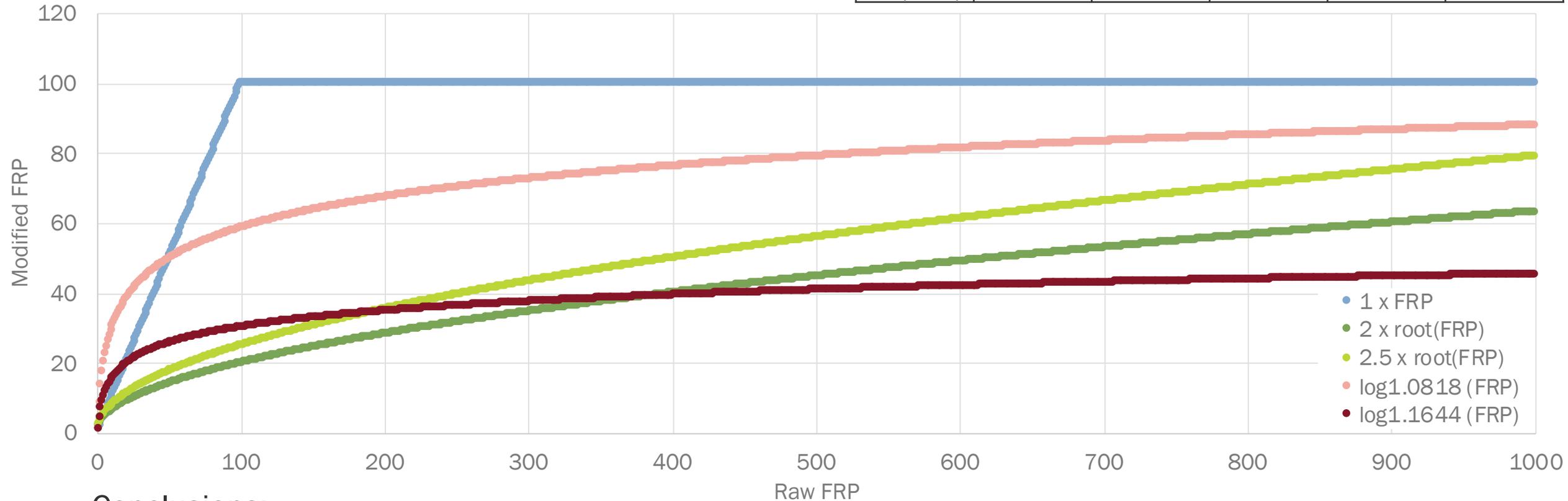
Conclusions:
- Linear with cap and root functions performed best
- Root function coefficients sometimes too low
- Log functions too high when FRP is low
- WRF-based vertical velocity always performed better

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HYSPLIT – New Scenario Details

Fire Location Treatment

|	S1	S2	S3	S4	S5	S6	S7	S8
First Hour Kept from HMS	Noon (-1 Day)	Noon (-1 Day)	Noon (-1 Day)	Noon (-1 Day)	Noon (-1 Day)	Noon (-1 Day)	Midnight (-3 Days)	Midnight (-3 Days)
Duplicate Dist.	10m	10m	10m	10m	10m	10m	50m	50m
FRP Modification Formula	FRP max = 100 min = 0.3	1.25 FRP max = 100 min = 0.3	2 sqrt FRP max = N/A min = 0.3	2 sqrt FRP max = N/A min = 0.3	4 sqrt FRP max = N/A min = 0.3	4 sqrt FRP max = N/A min = 0.3	FRP max = 100 min = 0.3	3 sqrt FRP max = N/A min = 0.3
Diurnal Profile	Legacy	Legacy	Legacy	WRF-CHEM	BlueSky	WRF-CHEM	BlueSky	Legacy

Diurnal Profile Hourly Factors

| Hour (PST)	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Emis. (Legacy)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.3	0.6	1	1.5	1.9	2.3	2.4	1.7	1	0.6	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Heat (Legacy)	0	0	0	0	0	0	0	0.5	1	1	10	20	20	20	10	1	0.5	0	0	0	0	0	0	0
Emis. (BlueSky)	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.28	0.55	0.97	1.39	1.80	2.22	2.36	1.66	0.97	0.55	0.14	0.14	0.14	0.14
Heat (BlueSky)	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.65	2.04	5.52	8.95	12.21	15.43	16.47	11.13	5.52	2.04	0.29	0.29	0.29	0.29
Emis. (WRF-CHEM)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.6	0.8	1	1.2	1.5	1.7	1.5	1.2	1	0.8	0.5	0.2	0.2	0.2	0.2
Heat (WRF-CHEM)	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.75	0.83	1.41	2.91	5.65	8.81	12.3	13.46	12.13	8.81	5.65	2.74	1.25	0.66	0.66	0.66	0.66

• Past Issues with Forecast Methods
▪ *and current status*

- Adjusting HYSPLIT based on ML – HYSPLIT difference ("bias correction" not based on obs.)
  - ▪ *Removed "correction" but added static background*
- Still stuck on the original monitors used, monitors added in past few years have no ML forecast
  - ▪ *Still an issue, need WSU ML forecast updated to include current monitors (may move in-house)*
- If ML fails for Days 1-2 (e.g. no monitoring data), no forecast is shown
  - ▪ *HYSPLIT is now used for Days 1-2 if ML is unavailable*
- Gaps in polygons where there is no representative monitor
  - ▪ *New polygons rely on nearest polygon for ML, all gaps are now filled*
- Original forecast source (e.g. LCAA, ML, Ensemble, or manual override) is unknown
  - ▪ *Internal page for manually assigning forecast now shows source of zonal forecast*
- Only one value per day per polygon (no spatial or temporal details)
  - ▪ *Still doing this but created plume animation.*
- Only used HYSPLIT forecast at monitor locations
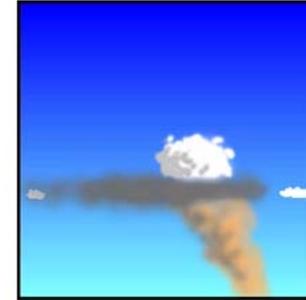 - ▪ *Now averaging all values within the polygon*

Final Thoughts
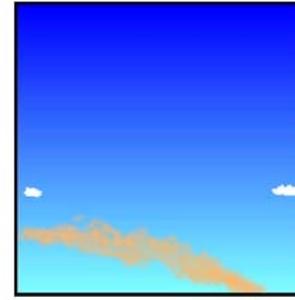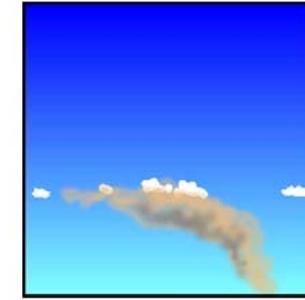
Low whispy plume. Raised columnar plume. Pyro-Cu plume.

- Zonal forecasts provide a simple and effective way to communicate with the public, and are available on both the smoke blog and on Ecology's dot map

- Manual forecast overrides continue to be an essential part of the system, for which we greatly rely on the Canadian FireWork forecast.

- Boundary conditions should be implemented next year (or maybe Cliff can expand the 12 km domain to include more of Canada?)

- New HYSPLIT emissions scenarios will provide a better forecast ensemble
  - More refinements to the system will be made through the summer

- Vegetation and fire behavior factors remain as novel values, which could benefit from scrutiny