Summer Smoke Forecasting

Summary and improvement of Washington's multi-model system

NW-AIRQUEST Meeting

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State of Washington

Overview

- Smoke Forecast Tool - Webpage
- Monitor Representative Polygons and Air Quality Management Zone Polygons (Local CAAs)
- Machine Learning 2-Day Forecast
- Wildfire smoke ensemble forecast (Days 3-5)
- HYSPLIT ensemble member details
- Manual overrides and AIRNow forecasts from locals
- Model Performance (2022)
- Plans for future improvement

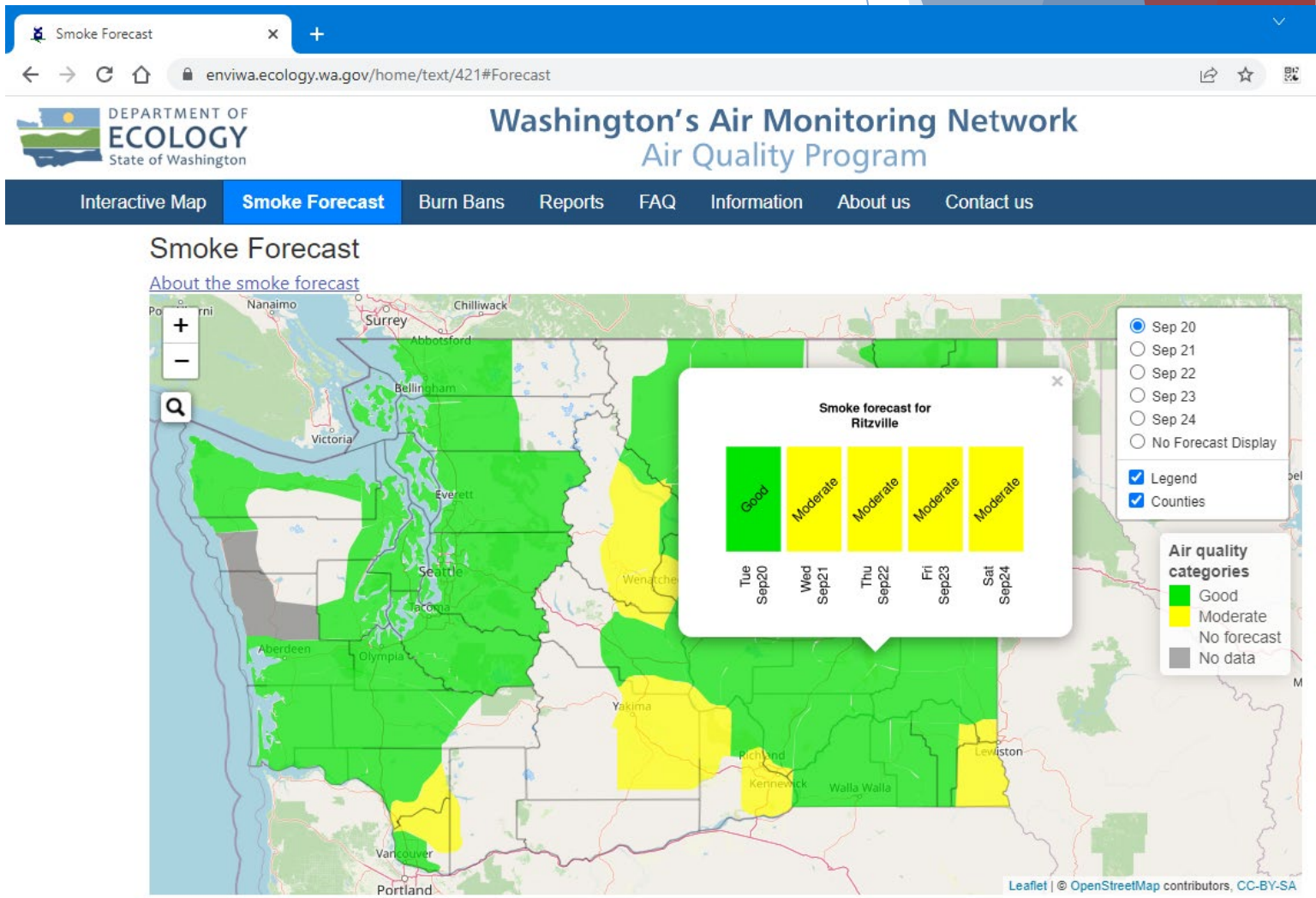
Washington Smoke Forecast Tool:

Collaborative Project Developed by ECY (Ghidey, Thorpe, Dhammapala, Pierce, Schulte, Friedman);
A mix of forecasts from WSU (2-day ML), LCAAs (AirNow), and 5-day smoke ensemble.

Manual override is also used when necessary.

Recalculation & reupload of forecast 4 times each morning

Original product was just the 2-day ML forecast. The WA Smoke Blog users inspired the need for a 5-day forecast, but the ML system isn't available past 2 days. So, an ensemble of smoke forecasts was used.



Forecast Zone Polygons

Represent areas that typically experience similar smoke impacts and can be represented by a single PM2.5 monitor.

Polygons are based on one or a combination of factors:

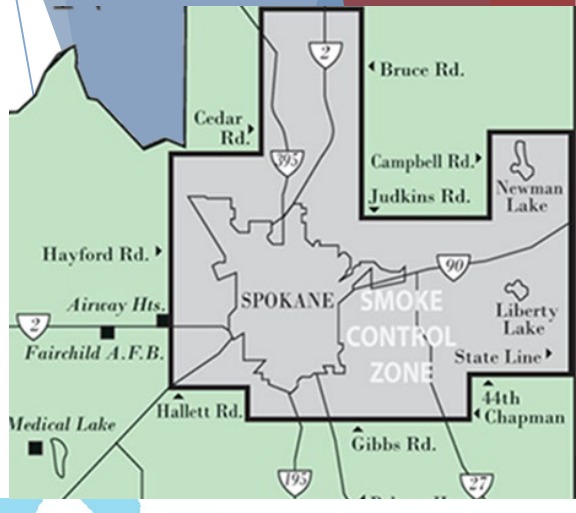
- Monitor Locations, Density, Proximity
- AIRPACT 4-km grid cells with similar 98th percentile $PM_{2.5}$ concentrations in multiple years
- Tribe and County Boundaries
- Burn Ban Zones
- Air Quality Management Zones

Forecasts Submitted to AirNow

PSCAA, ORCAA, NWCAA, and SRCAA submit daily forecasts to EPA's AirNow system. These forecasts range from 1 to 5 days in length.

LCAA forecasts are retrieved several times a day from AirNow. If no AirNow forecast is available, the ensemble method is used.

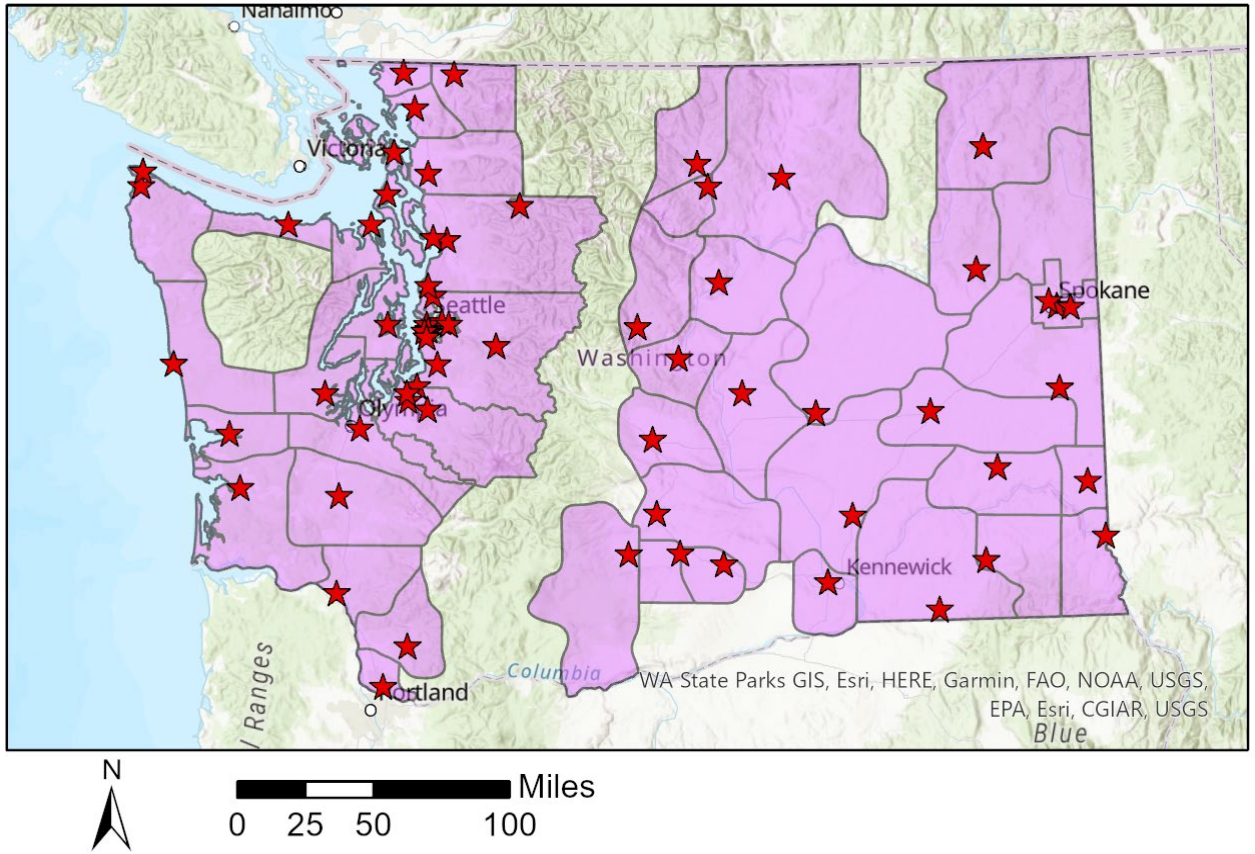
PSCAA and SRCAA provided Ecology with maps and shapefiles of their air quality management zones. ORCAA and NWCAA forecasts are assigned to ECY polygons.



Forecast Zone Polygons

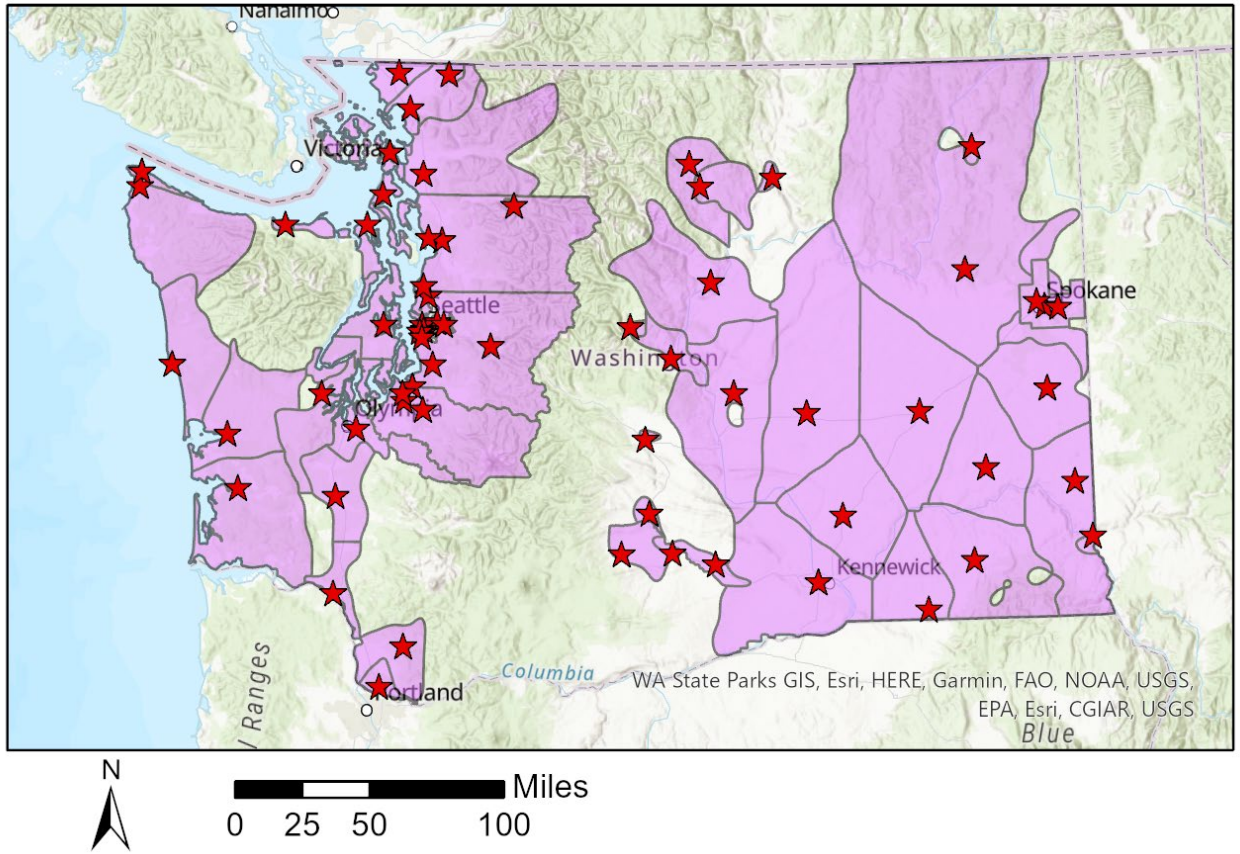
Summer Forecast Zones

June 1 – October 31 (5-day forecast)



Winter Forecast Zones

November 1 – May 31 (2-day forecast)



Machine Learning 2-Day Forecast

- Tri-Cities Ozone Machine Learning Forecast Model was developed at WSU
  - Site-specific O3 versus meteorology relationships were developed from several years of 4-km WRF forecast archives
  - Describes how the airshed's ozone levels have responded under different meteorological conditions
  - Uses Random Forest and Multiple Linear Regression approaches

- Similar approach was later developed for all PM2.5 (and ozone) monitoring sites in Washington, Oregon and Idaho.
  - The relationships, recent PM2.5 observations, and ensemble forecasts from UW WRF are used to construct a two day smoke forecast
  - No forecasts if the monitor didn't report data the previous day

Smoke ensemble 5-day forecast

- Wildfire smoke ensemble forecast (Days 3-5)
- Ensemble Members:
    - ECMWF CAMS (same day's 0Z run, 0.4 degree resolution)
    - NASA GEOS-CF (previous day's 12Z run, 0.25 degree resolution).
    - NOAA GEFS-Aerosol (same day's 6Z run, 0.25 degree resolution).
    - Finnish SILAM (same day's 0Z run, 0.5 degree resolution).
    - 8 x ECY HYSPLIT Forecasts (using UW WRF 12km 5-day forecast)
        - 2 Meteorology Scenarios (vertical velocity from HYSPLIT or WRF)
        - 4 Emissions Scenarios (Area-based, FRP-based, etc.)

- Bias corrected ensemble average is reported (based on ML bias on previous day)

* Published forecast sometimes based on manual entry
* Bias correction based on manual forecast when available.

HYSPLIT Forecast

- No wet or dry deposition is assumed.
- Vertical motion option, **0**, (data) = A default "data" selection will use the meteorological model's vertical velocity fields.
- Vertical motion option, **6**, (mls2agl) = A special transformation to correct the vertical velocities when mapped from quasi-horizontal surfaces (such as relative to MSL) to HYSPLIT's internal terrain following sigma coordinate.
- Top of model domain = 7000 m (agl)
- The number of particles released per cycle NUMPAR (10,000) would be the maximum number of particles or puffs released over the duration of the emission.
- 3 - Gaussian-horizontal puff and vertical particle distribution (Gh-Pv) [particle dispersion in the vertical direction and puff dispersion in the horizontal]
- In a Gh-Pv simulation (INITD = 3), NUMPAR represents the total number of particles that are released during one release cycle. Multiple release cycles cannot produce more than MAXPAR number of particles.
- The maximum number of particles MAXPAR (500,000) is the maximum number permitted to be carried at any time during a simulation.
- The maximum particle duration KHMAX (36 hrs) is the number of hours after release that a particle is dropped from the simulation.
- Stability – (Mixing layer - Boundary layer stability) - Fluxes of heat and momentum are provided by the meteorological model (WRF)

HYSPLIT Emissions Processing

NOAA HMS

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
(HMS FRP is constrained from 0.3 to 100 MW)

Area Emissions Rate =
300,000 g PM2.5 / HMS Detect
(Equivalent to a 4.5 MW FRP Detect)

HMS Preprocessing:

- Get yesterday HMS (14 hrs)
- Remove MODIS (double counts VIIRS)
- Remove duplicate coordinates (Keep max FRP)
- Remove locations outside WRF domain
- Assign low FRP where N/A
- Assign 97 Acres to each location
- Merge locations within 1000m buffer (Sum Acres; Max FRP)
- Use FRP and Area for plume rise variable inputs

Scenario Details:

FRP = Fire Radiative Power *DF = Diurnal Factor*
FPF = Fire Potential Factor *LCF = Land Cover Factor*

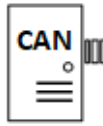
Scenario 1 Emissions = FRP Rate x DF
Scenario 2 Emissions = FRP Rate x DF x FPF x LCF
Scenario 3 Emissions = FRP Rate x DF x FPF x LCF x 1.25
Scenario 4 Emissions = Area Rate x DF x FPF x LCF

Fire Scaling Factors:

Fire Potential

US NIFC 7-Day Fire Potential Forecast (Day Specific)

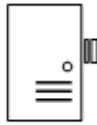
Moist = 0.25
Dry = 1.0
Very Dry = 1.25
Windy = 1.25
Hot = 1.25
Lightning = 1.0
Burn Env. = 1.25
Hot & Dry = 1.5



Canada Fire Danger Rating (Most Recent)

Low = 0.25
Moderate = 0.5
High = 0.75
Very High = 1.0
Extreme = 1.25

Land Cover



Global LCLU

Non-Veg = 0.01
Shrub/Grass = 0.4
Crops = 0.2
Forested = 1.0

Diurnal Factors:

Emissions Rate Factor

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
Rate	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

Plume Rise Forcing Factor

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
Heat	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

HYSPLIT Analysis Page

ECY Internal Network:
http://aeolus.ecy.wa.gov:3838/ensemble_forecasts/

1. Select forecast issue date

2022-09-12

2. Select smoke level:

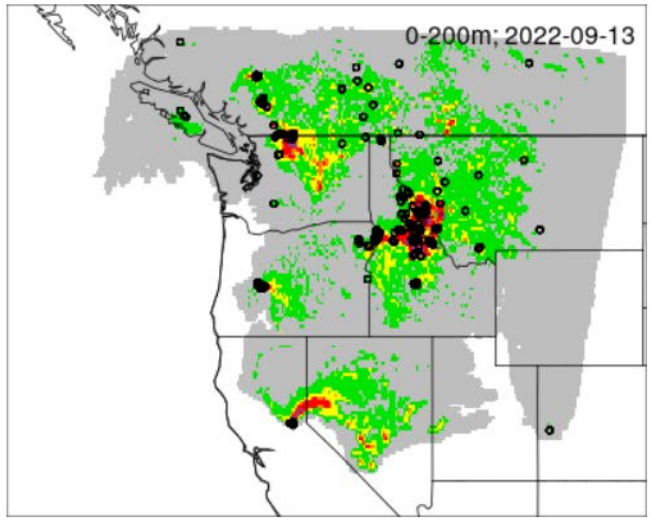
0-200m

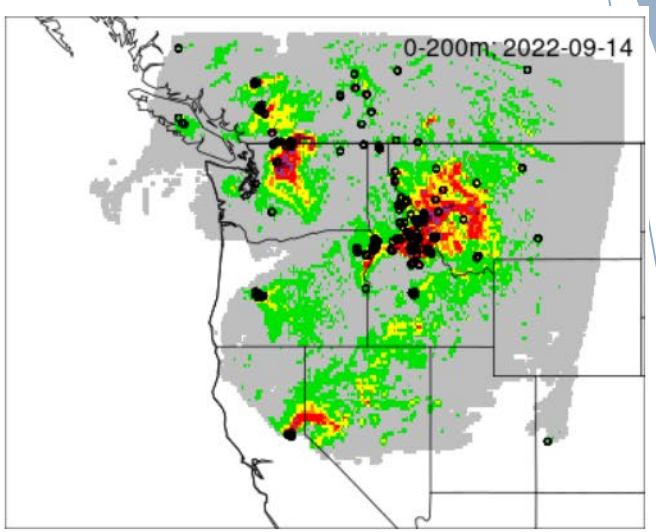
3. Select model config:

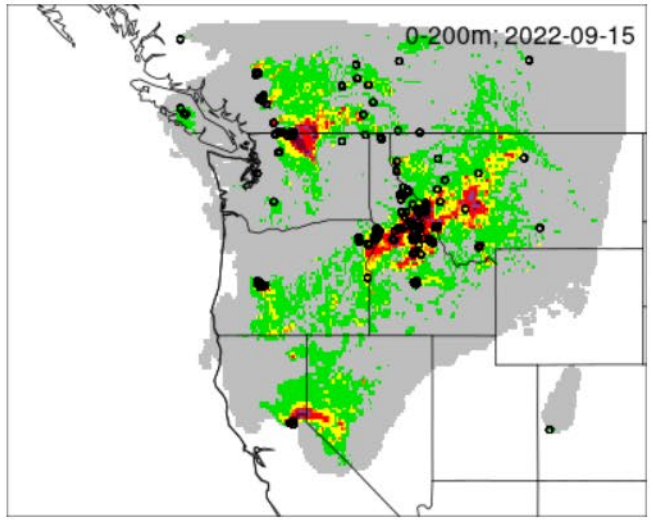
M0V6S2

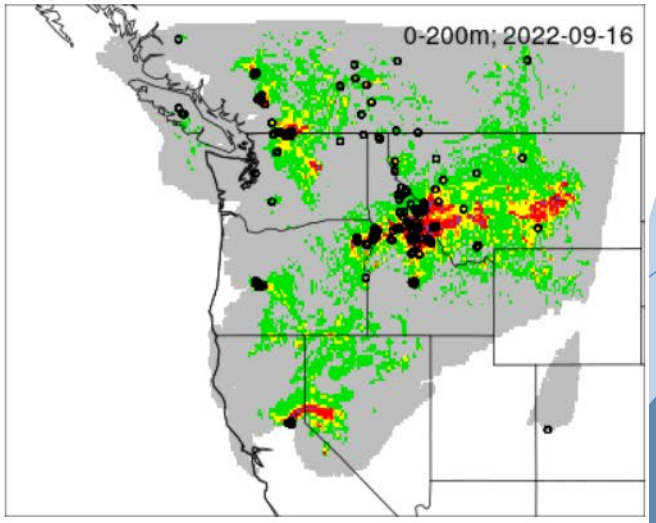
4. Click for map of days 2-5

Map legend
- Good
- Moderate
- USG
- Unhealthy
- Very Unhealthy
- Hazardous
- <1 µg/m³
- Fires









HYSPLIT Analysis Page

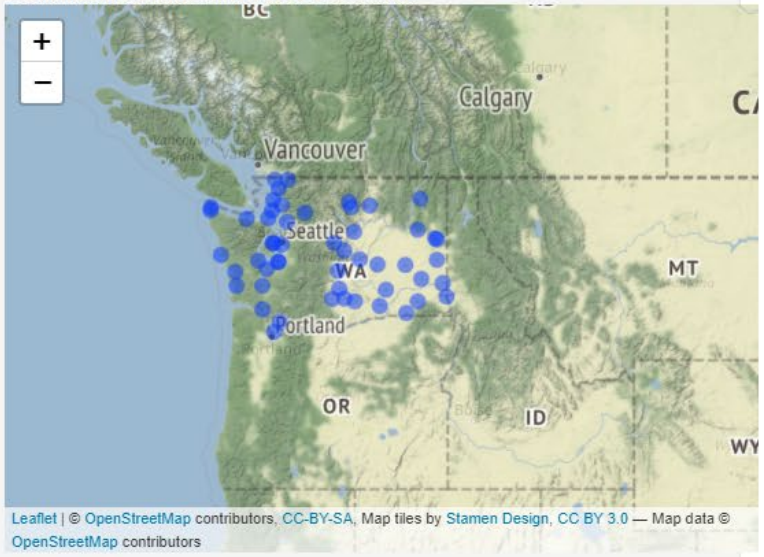
ECY Internal Network:
http://aeolus.ecy.wa.gov:3838/ensemble_forecasts/

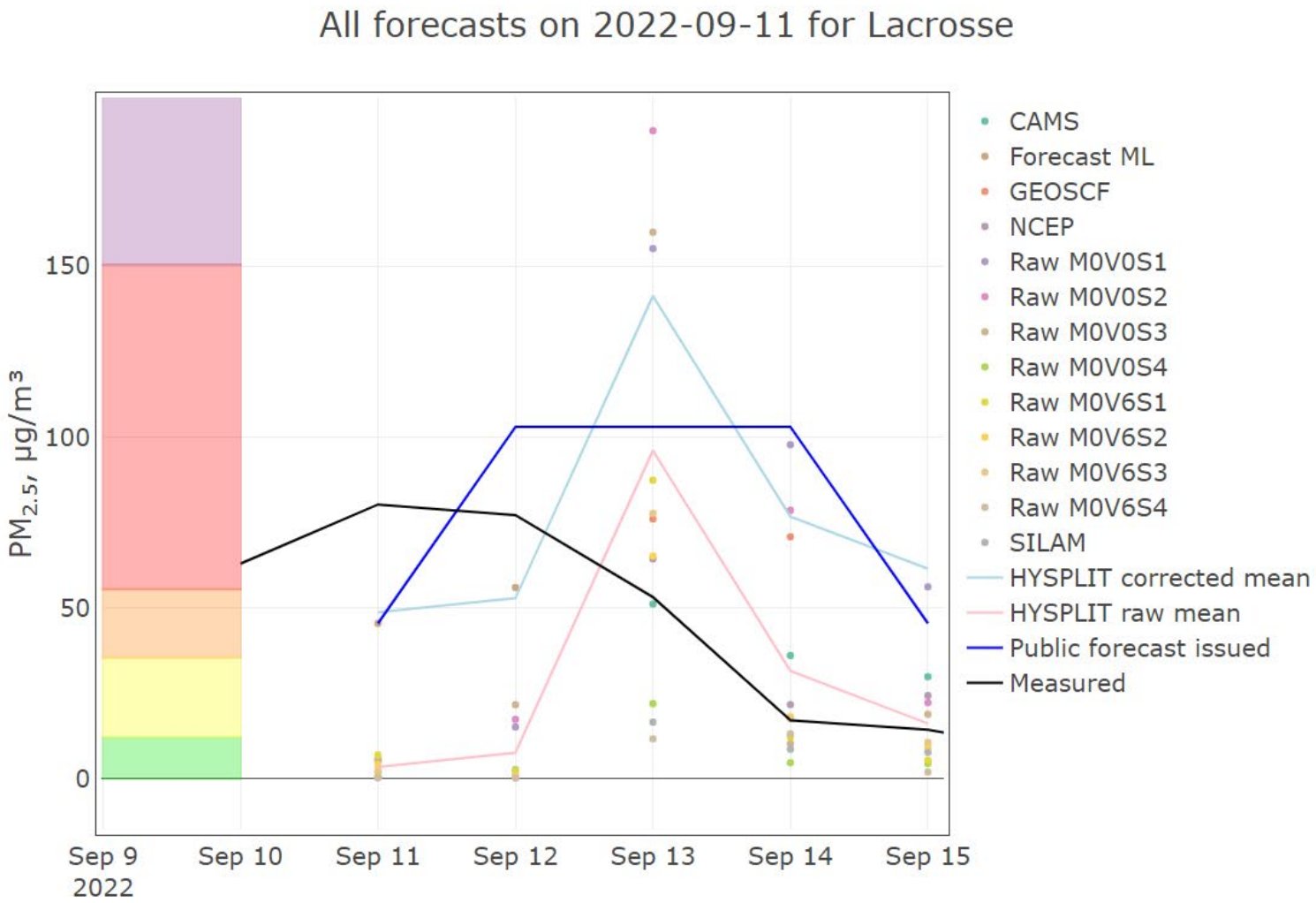
Ensemble members in the last 10 days | Vertical distribution of smoke | Day 2-5 maps at different heights

1. Select forecast issue date

2022-09-11

2. Click on monitor for interactive time series





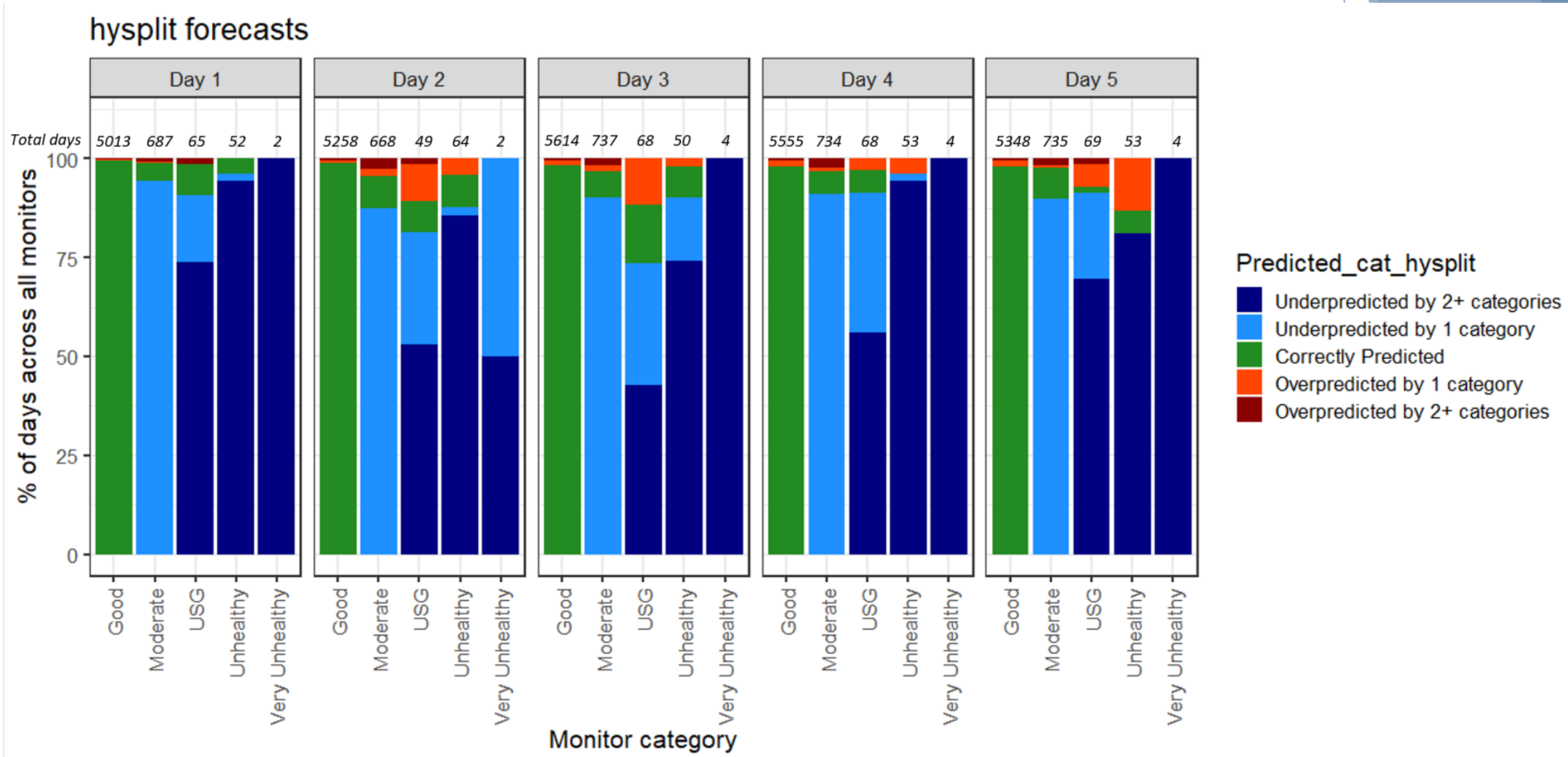
Raw HYSPLIT Performance

	Good	Moderate	USG	Unhealthy	Very Unhealthy	All Matches	All Matches (no goods)	Overpredicted	Underpredicted
M0V0S1_cat	97.7%	12.2%	13.1%	11.3%	0.0%	90.3%	9.7%	3.2%	6.5%
M0V0S2_cat	98.4%	11.9%	16.5%	11.8%	5.3%	91.0%	10.6%	2.5%	6.5%
M0V0S3_cat	98.1%	12.3%	14.6%	14.8%	5.3%	90.7%	10.6%	3.0%	6.2%
M0V0S4_cat	99.6%	3.5%	1.5%	5.4%	0.0%	91.4%	3.3%	0.5%	8.2%
M0V6S1_cat	98.6%	8.0%	5.0%	8.4%	0.0%	90.7%	6.6%	1.7%	7.6%
M0V6S2_cat	99.2%	7.3%	5.8%	6.9%	0.0%	91.3%	6.5%	1.2%	7.5%
M0V6S3_cat	99.0%	9.5%	10.4%	6.4%	0.0%	91.2%	8.3%	1.5%	7.3%
M0V6S4_cat	99.9%	1.6%	0.4%	2.5%	0.0%	91.5%	1.5%	0.1%	8.4%

*Forecast Days 1-5

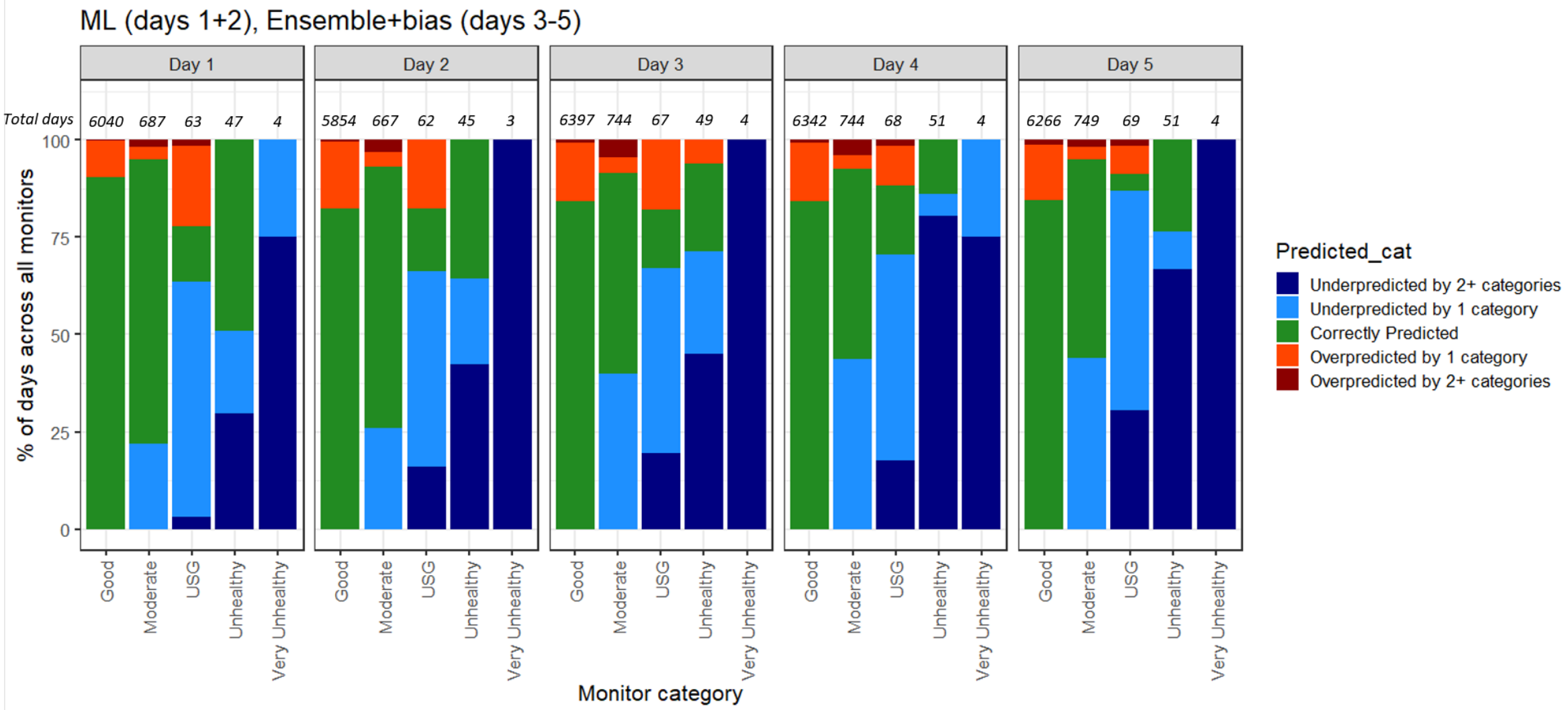
Note that this would likely look different for last year, as we see evidence of more over-prediction as fires get bigger (smaller fires this year).

HYSPLIT (avg) Forecast Performance



*24-hr PM2.5 At Monitor Locations

Ensemble Forecast Performance



*24-hr PM2.5 At Monitor Locations

Issues with forecast methods

Current Issues:

- Bias correcting ensemble based on ML performance (or manual override)
- Ensemble results are only used at monitor locations
  - New monitors are not used, since they don't have ML forecast
- ML is not able to account for recent or expected changes in fire activity
  - This is OK when there is carryover/old smoke lingering but problematic when fire conditions change considerably (e.g. rain or new fires)
    - Any new event predicted by ensemble is ignored for Day 1-2
    - Over-predicts Day 1-2 after large event
    - Location-specific bias corrections lead to ambiguous Day 3-5 results
      - Difficult to assess "why" public forecast issued particular AQI.
      - What method is used for that particular zone and day prediction?
- Bias correction is updated every 2 hours from 6 am to noon, changing forecasts
- Forecast could be from LCAA, ML, Ensemble, or manual override (unknown to user)
- Only one value per day per polygon (no spatial or temporal details)

Consider changes to forecast methods

Potential Changes:

- Somehow incorporate smoke models for all days/locations
- Replace ML-based bias correction
- Update monitor-based polygons and fill in the zone gaps
- Use all forecast values within polygons (not just monitor locations)
- Show plume contours
- Provide diurnal information
- Consolidate update frequency/timing (forecast changes multiple times per day)
- Report source of forecast
- Conduct sensitivity study and tune-up HYSPLIT members
  - Use more (older) fire locations in some HYSPLIT members
  - Redefine “Moderate” threshold
  - Constrain range of factors (e.g. FRP, Veg, FDR)

Potential Benefits:

- No discontinuity of methodology between Days 2 and 3
- Simpler to assess validity of public forecast issued.
- Complete coverage of entire state
- No “grey” zones when monitors have interruption in reporting
- Provides more information to user

Summary

Smoke Ensemble:

- Uses complicated processes which provides valuable information to users but can be difficult to interpret (black box)
- Relies on historical monitor locations, limiting spatial coverage
- Performance benefits from ML, which essentially predicts "persistence"
  - Persistence can often be a better predictor than a fresh HYSPLIT run, except when conditions change rapidly
  - Our raw HYSPLIT results often under-predict smaller fire impacts and over-predict larger fire impacts
- ML method is limited in space and time

Summary

Proposed changes for forecast tool:

- Use max prediction within each polygon (instead of monitor location)
- Consider adding polygons for all areas and allow predictions even when monitor data is unavailable
- Replace pop-up images with hourly timeline and/or forecast source
- Add plume contour image overlay
  - Consider if this replaces polygons or is an additional overlay
- Add more frequent updates in early morning to capture manual entries
  - Consider removing re-calculation of bias correction so forecast doesn't change at 10 am and noon
- Conduct sensitivity runs and implement code changes for HYSPLIT members to increase ensemble performance

Questions/Comments?