Performance Assessment of Fire Inventory from the National Center for Atmospheric Research (FINN v2.2) Wildfire Emissions Estimates Using Satellite Aerosol Observations

By **Nathan Pavlovic, Crystal McClure, Steve Brown, and Fred Lurmann**
Sonoma Technology, Inc.

Elena McDonald-Buller and Yosuke Kimura
Center for Energy and Environmental Resources, The University of Texas at Austin

Christine Wiedinmyer
Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder

For U.S. EPA International Emissions Inventory Conference

August 2, 2019

Outline

- FINN Emissions Inventory

- Smoke modeling with HYSPLIT and CAMx

- Evaluation of FINN with satellite data

  – HYSPLIT results

  – CAMx results

- Conclusions

The FINN Emissions Inventory

- Designed for atmospheric chemical transport modeling:

  – Emissions estimates for particulate matter and trace gases with high spatial/time resolution across local to global scales

  – Speciation of NMOCs for chemical mechanisms

- FINN v1.5 released in 2014

- FINN v2.2 developed as part of this work

https://www2.acom.ucar.edu/modeling/finn-fire-inventory-ncar
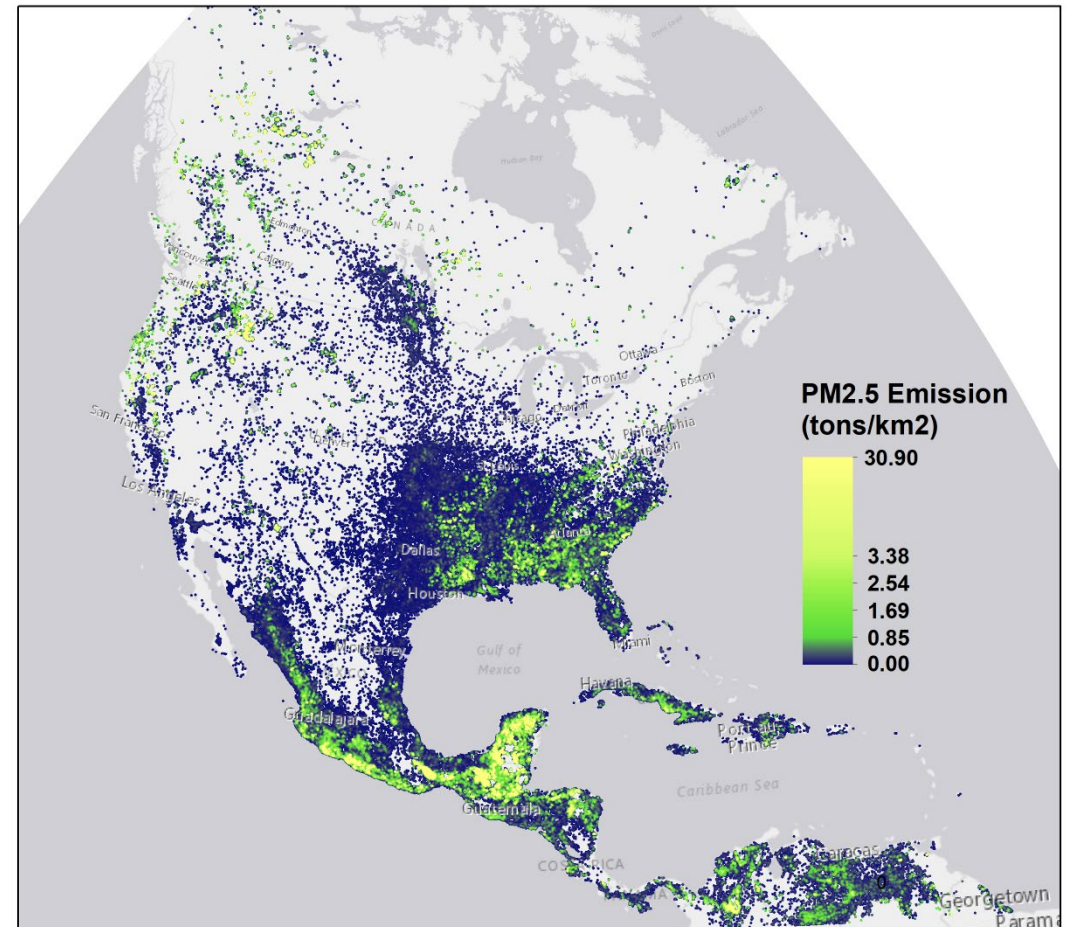
$PM_{2.5}$ emissions density of FINN v2.2, 2012
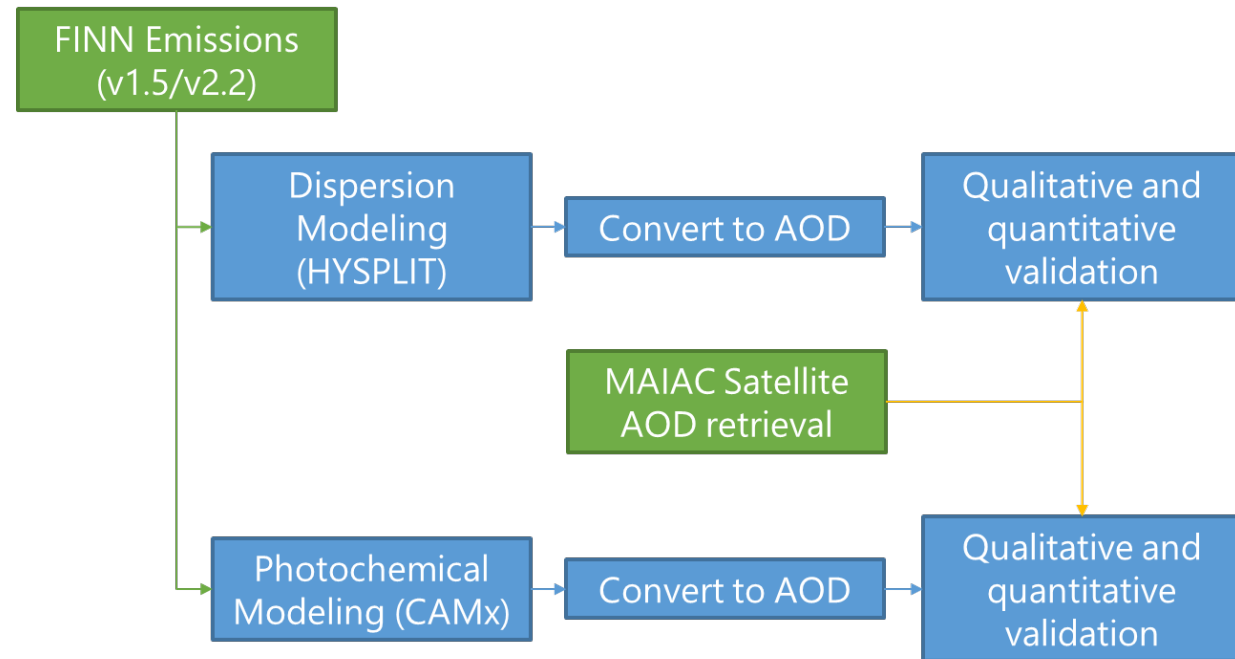
Updates to FINN

- Incorporated Visible Infrared Imaging Radiometer Suite (VIIRS) 375 m active fire data in addition to the Moderate Resolution Imaging Spectroradiometer (MODIS) active fire product

- Updates to forest and cropland emission factors

- Updated regional default fuel loadings

- After these updates – **how does air quality modeling perform using FINN emissions? Do recent updates impact model performance?**
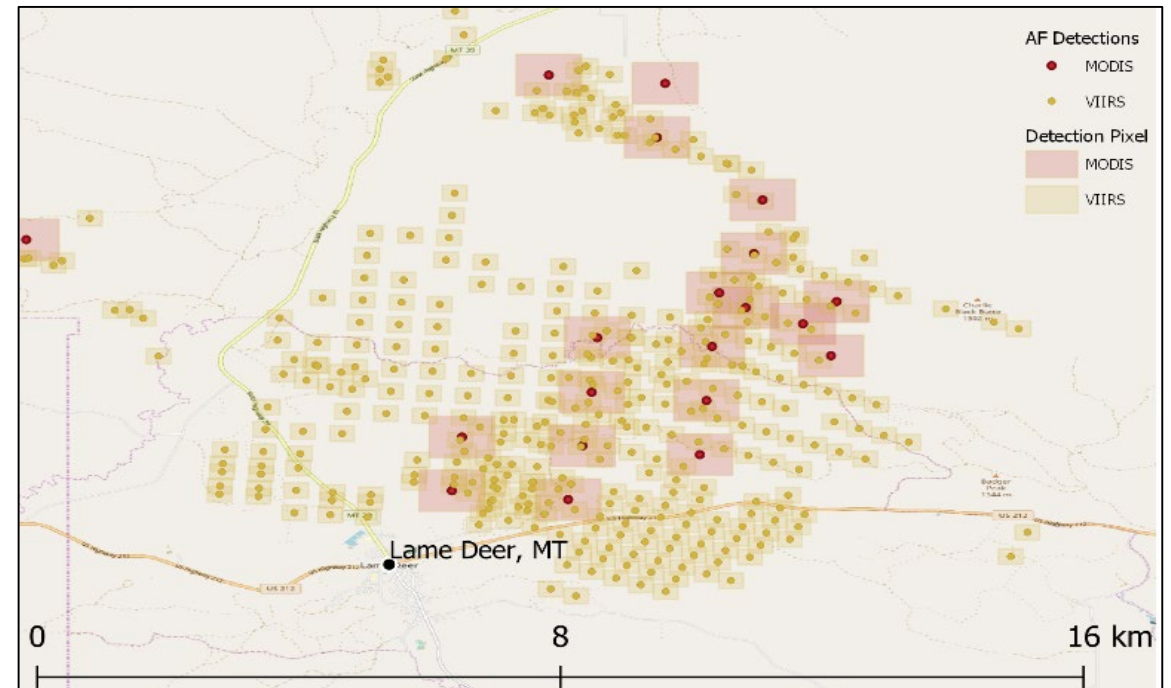
Evaluation Objectives

Use independent remote sensing data to evaluate FINN emissions results:

1. Estimate aerosol optical depths calculated from photochemical and dispersion modeling with FINN emissions

2. Compare to Multi-Angle Implementation of Atmospheric Correction (MAIAC) aerosol optical depth (AOD) retrievals from MODIS onboard NASA Aqua and Terra satellites. All comparisons conducted at time of satellite overpass

FINN Emissions (v1.5/v2.2)

Dispersion Modeling (HYSPLIT) → Convert to AOD → Qualitative and quantitative validation

MAIAC Satellite AOD retrieval

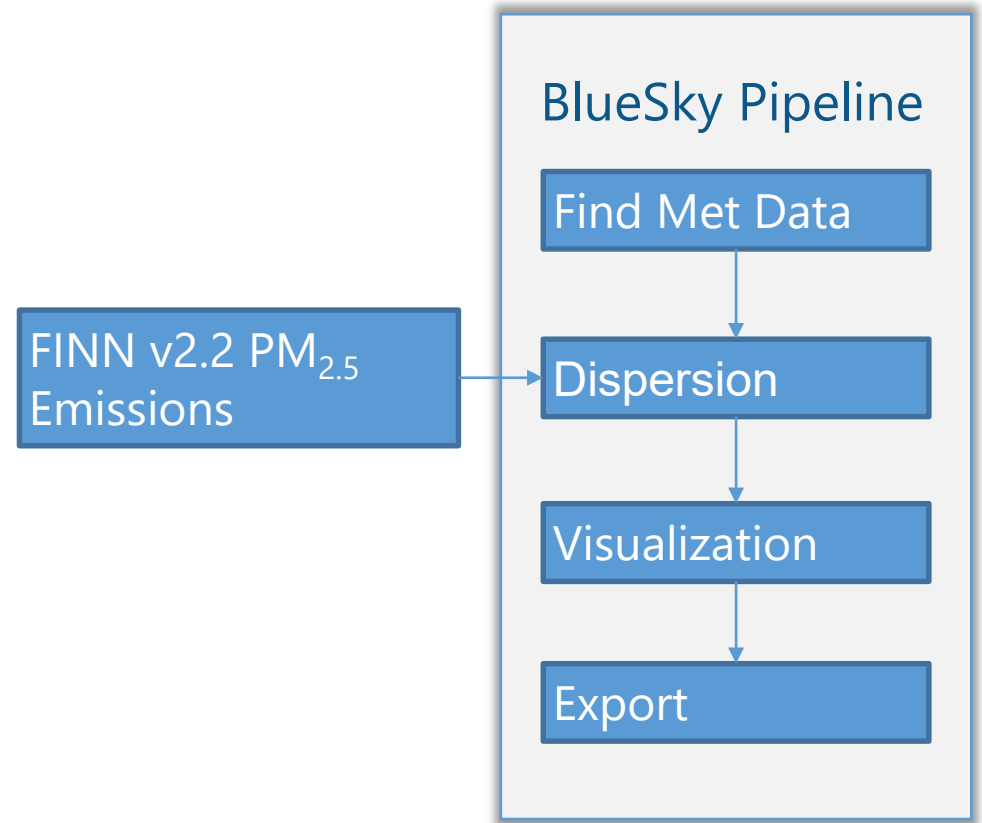Photochemical Modeling (CAMx) → Convert to AOD → Qualitative and quantitative validation

MAIAC AOD (MCD19A2)

- Satellite data retrieval at 1-km resolution
- Provides twice-daily snapshot of total-column aerosols
- Uses time series of MODIS images to retrieve AOD
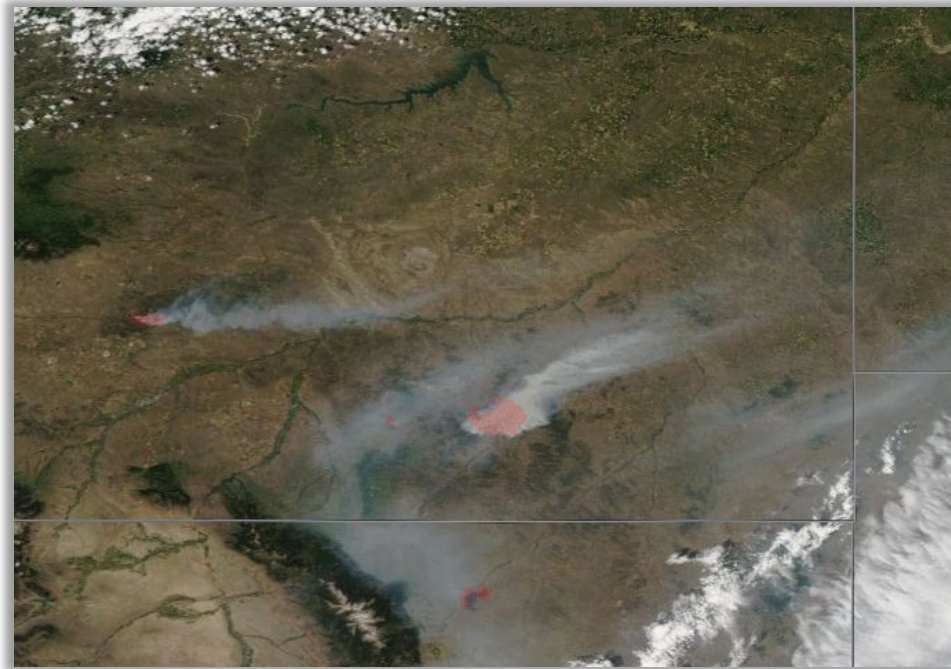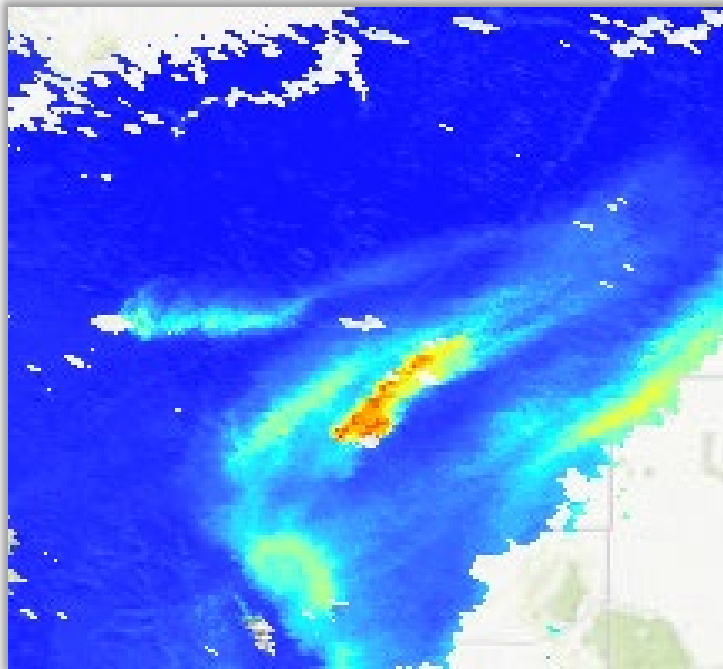
Dispersion Modeling: HYSPLIT

- Disperse FINN v2.2 emissions for 2012 and fire seasons for 2013-2017

- No other emissions sources included

- Processing conducted using BlueSky Pipeline to support meteorological data management, and dispersion and visualization of smoke

- https://github.com/pnwairfire/bluesky/

FINN v2.2 PM$_{2.5}$ Emissions

BlueSky Pipeline

Find Met Data

Dispersion

Visualization

Export

Dispersion Modeling: HYSPLIT

- Large domain
- GDAS05 3-hourly meteorology at half degree resolution
- 50-km resolution receptor grid
- AOD calculated using second IMPROVE equation (Pitchford et al., 2007) with MERRA-2 reanalysis relative humidity
- AOD represents smoke contribution only
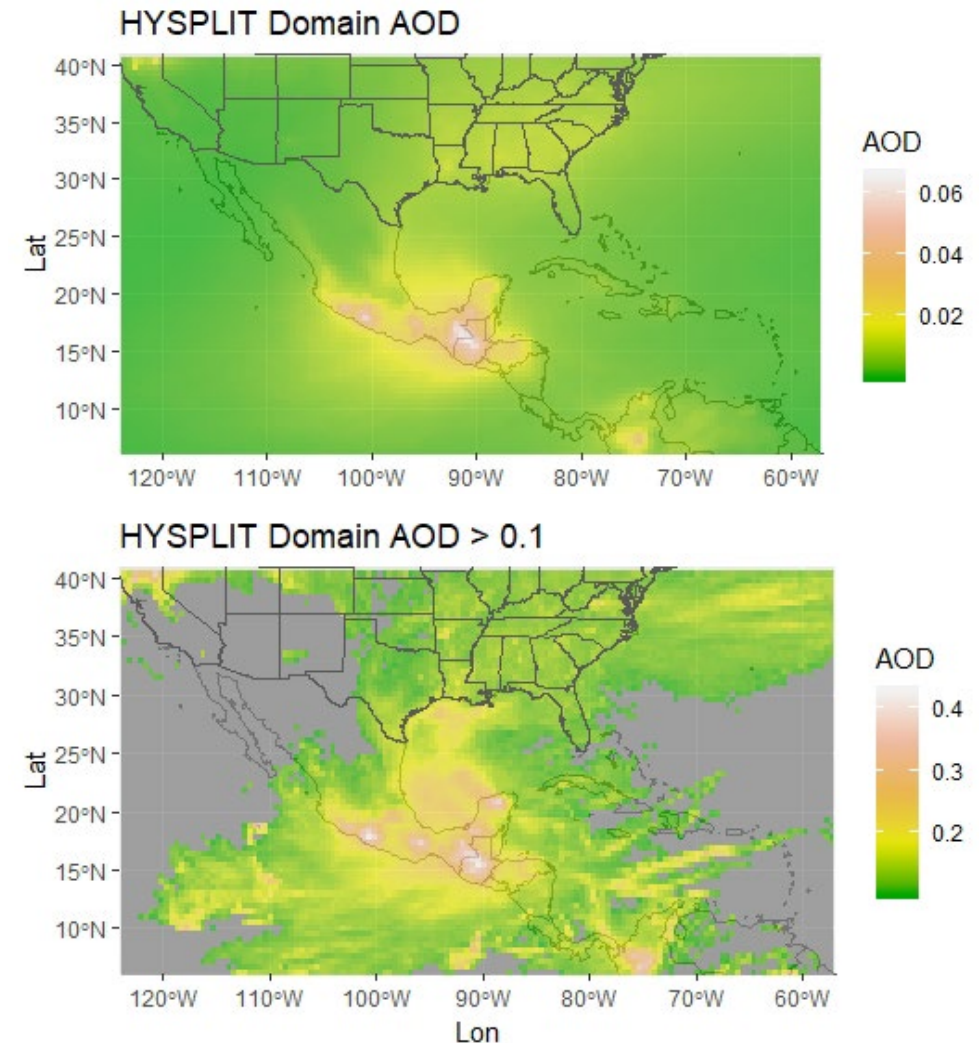
Photochemical Modeling: CAMx

- CAMx v.6.5

- May 1 – October 1, 2012, episode from Texas Commission on Environmental Quality (TCEQ)

- Modeled using three emissions scenarios:
  - No Fire
  - FINN v1.5 ("CAMx1")
  - FINN v2.2 ("CAMx2")

- Chemical Mechanisms:
  - Gas-phase: CB6r4
  - Particulate matter: CF/SOAP2.1/ISORROPIA

- WRF v.3.7.1 meteorological model

- Emissions inventories for anthropogenic and biogenic sources from TCEQ except for fire emissions
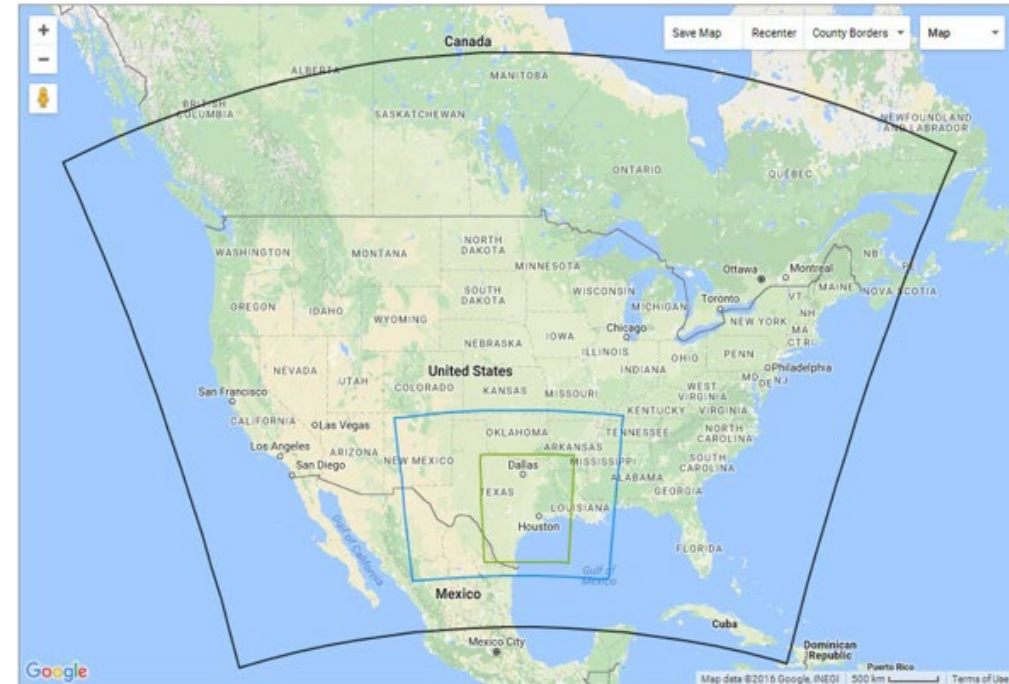
CAMx Nested Modeling Grids:
36 km (black)/12 km (blue)/4 km (green)

Photochemical Modeling: CAMx

- EPS v3.22
- Mapping of chemical speciation from MOZART-T1 to CB6r4
- Sensitivity studies with Randerson et al. (2012) and WRAP-FEJF (2005) diurnal emissions profiles
- Hourly vertical allocation from WRAP-FEJF approach* by classes based on burned area
    - Class 1: < 10 acres
    - Class 2: 10 – 100 acres
    - Class 3: 100 – 1000 acres
   - Class 4: 1000 – 5000 acres
    - Class 5: > 5000 acres
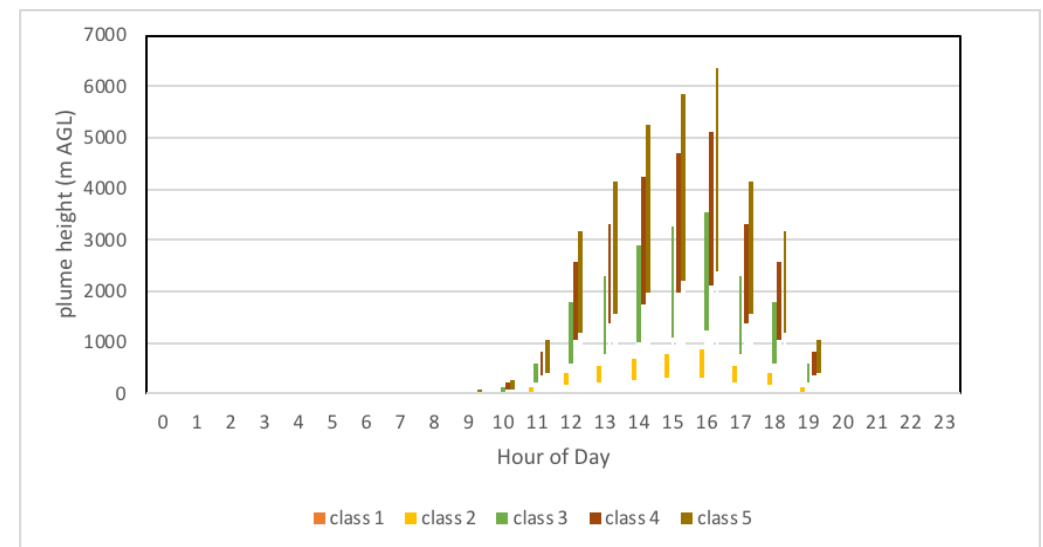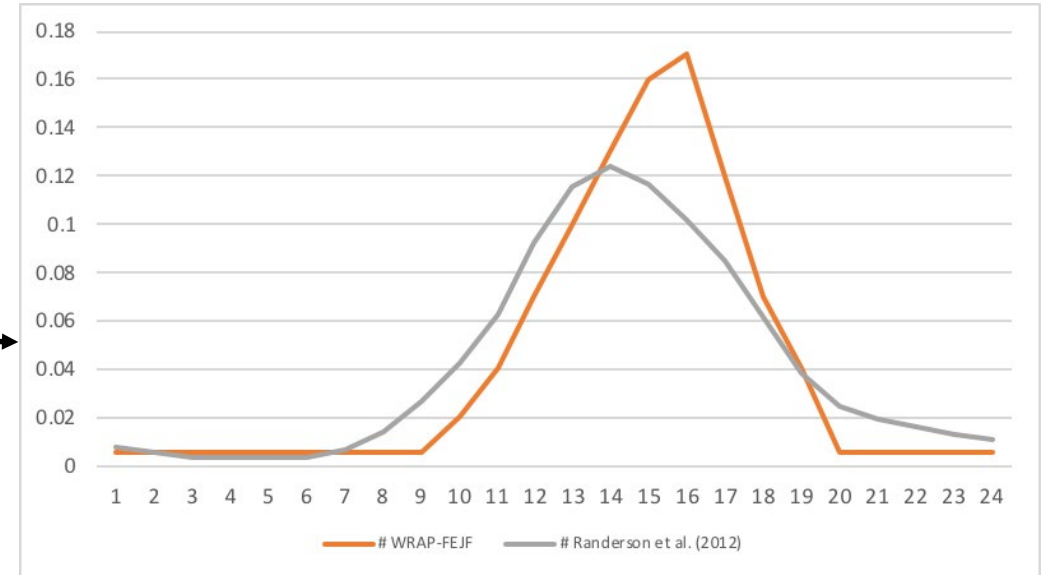
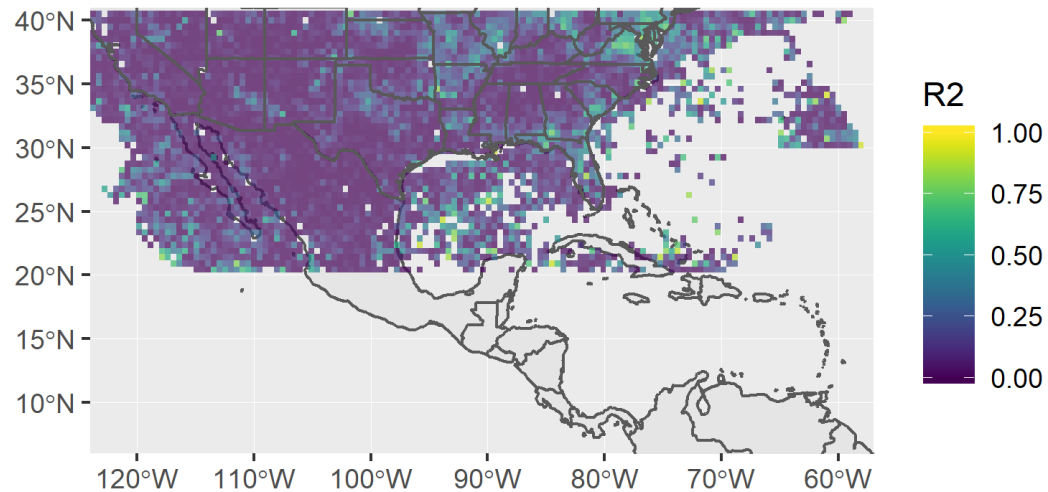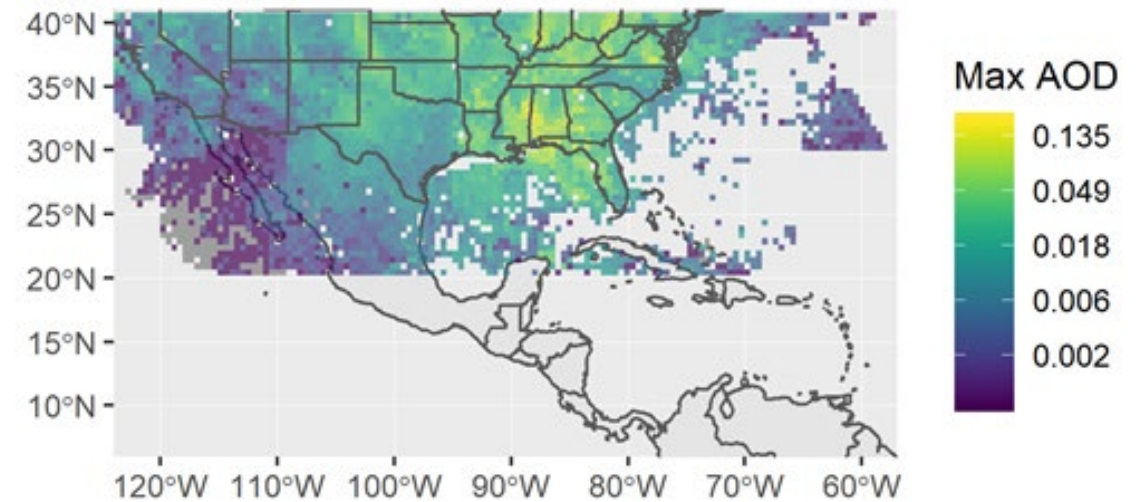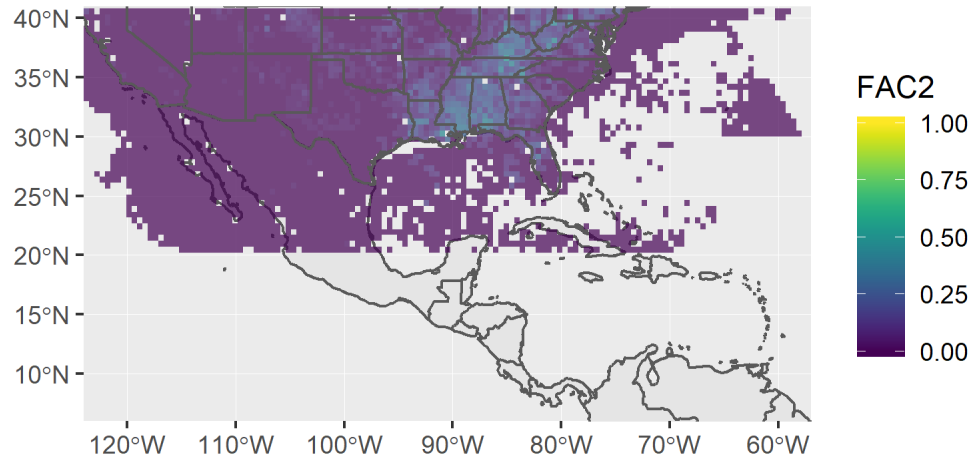*Air Sciences, 2005, Morris et al., 2012; Ramboll, 2016

Validation Statistics

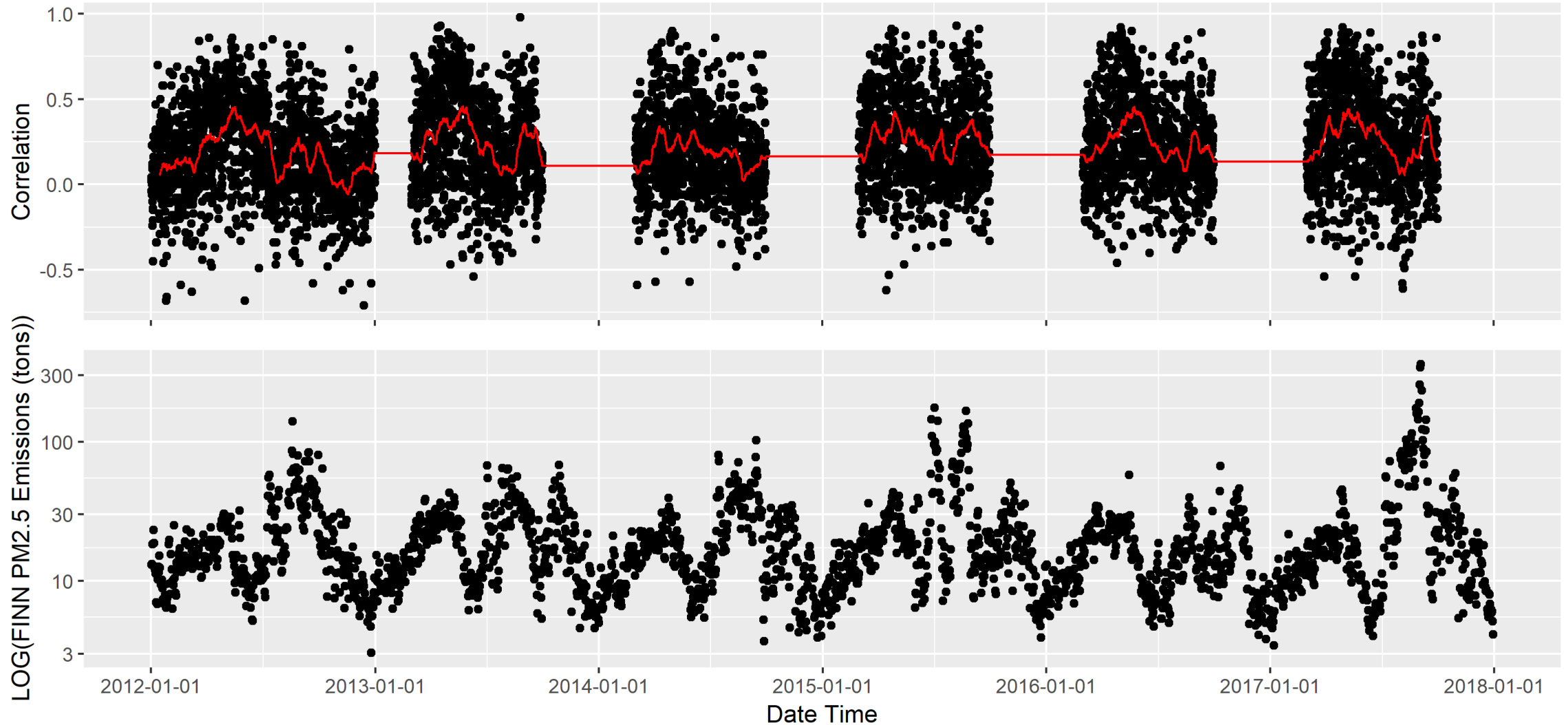| Type	Model Comparison (Obs/Model)	Years	Resolution (km)	Mean N	Mean Obs AOD	Mean Model AOD	Mean R	Mean R^2	Mean FB (%)	Mean NMSE	Mean FAC2
Wildfire	CAMx1/HYSPLIT	2012	50	322 ± 1	0.005 ± 0.004	0.010 ± 0.012	0.291 ± 0.273	0.159 ± 0.156	28.8 ± 56.4	3.9 ± 7.0	0.372 ± 0.442
	CAMx2/HYSPLIT	2012	50	322 ± 1	0.008 ± 0.008	0.010 ± 0.012	0.322 ± 0.279	0.181 ± 0.164	3.2 ± 61.6	3.4 ± 6.5	0.386 ± 0.456
Total AOD	MAIAC/CAMx1	2012	4	7251 ± 6983	0.157 ± 0.069	0.256 ± 0.036	0.137 ± 0.282	0.098 ± 0.130	58.8 ± 38.3	0.7 ± 0.8	0.558 ± 0.429
	MAIAC/CAMx2	2012	4	7251 ± 6983	0.157 ± 0.069	0.259 ± 0.038	0.134 ± 0.276	0.094 ± 0.125	59.6 ± 38.5	0.7 ± 0.8	0.552 ± 0.428
Mixed	MAIAC/HYSPLIT	2012-2017	50	419 ± 308	0.119 ± 0.048	0.006 ± 0.009	0.225 ± 0.265	0.121 ± 0.158	-185.5 ± 15.2	157.6 ± 764.6	0.016 ± 0.111

HYSPLIT Correlation, Bias and Error
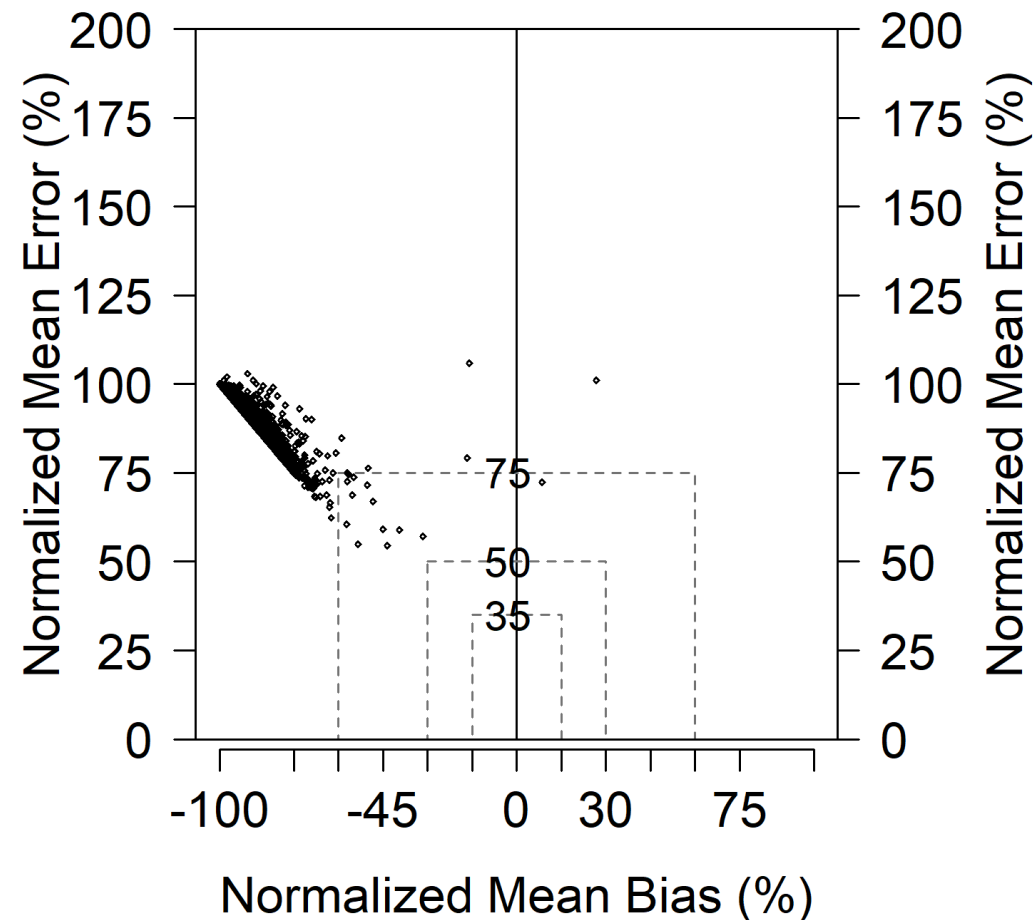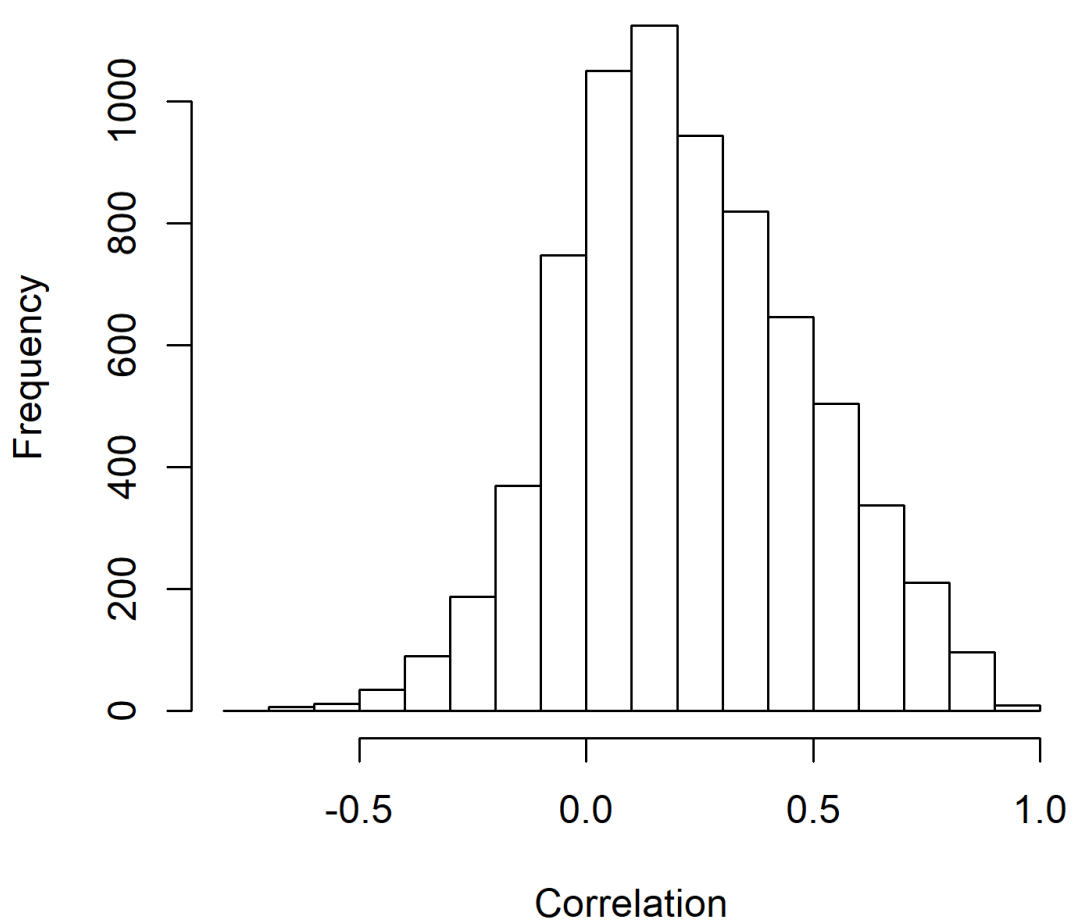
Statistics shown relative to MAIAC

HYSPLIT Comparison with MAIAC

- MAIAC comparison with HYSPLIT results shows higher agreement in locations with higher AOD

- October 2012 shown above

HYSPLIT Correlation with MAIAC


Red line indicates daily mean correlation

Validation Statistics

| Type	Model Comparison (Obs/Model)	Years	Resolution (km)	Mean N	Mean Obs AOD	Mean Model AOD	Mean R	Mean R^2	Mean FB (%)	Mean NMSE	Mean FAC2
Wildfire	CAMx1/HYSPLIT	2012	50	322	0.005 ± 0.004	0.010 ± 0.012	0.291 ± 0.273	0.159 ± 0.156	28.8 ± 56.4	3.9 ± 7.0	0.372 ± 0.442
	CAMx2/HYSPLIT	2012	50	322	0.008 ± 0.008	0.010 ± 0.012	0.322 ± 0.279	0.181 ± 0.164	3.2 ± 61.6	3.4 ± 6.5	0.386 ± 0.456
Total AOD	MAIAC/CAMx1	2012	4	7251	0.157 ± 0.069	0.256 ± 0.036	0.137 ± 0.282	0.098 ± 0.130	58.8 ± 38.3	0.7 ± 0.8	0.558 ± 0.429
	MAIAC/CAMx2	2012	4	7251	0.157 ± 0.069	0.259 ± 0.038	0.134 ± 0.276	0.094 ± 0.125	59.6 ± 38.5	0.7 ± 0.8	0.552 ± 0.428
Mixed	MAIAC/HYSPLIT	2012-2017	50	419	0.119 ± 0.048	0.006 ± 0.009	0.225 ± 0.265	0.121 ± 0.158	-185.5 ± 15.2	157.6 ± 764.6	0.016 ± 0.111

Targets: FAC2 is greater than 50%, the relative mean bias is within 30% or less, and the normalized mean square error is less than a factor of three (Chang and Hanna, 2004).

CAMx2 Validation Statistics by Month

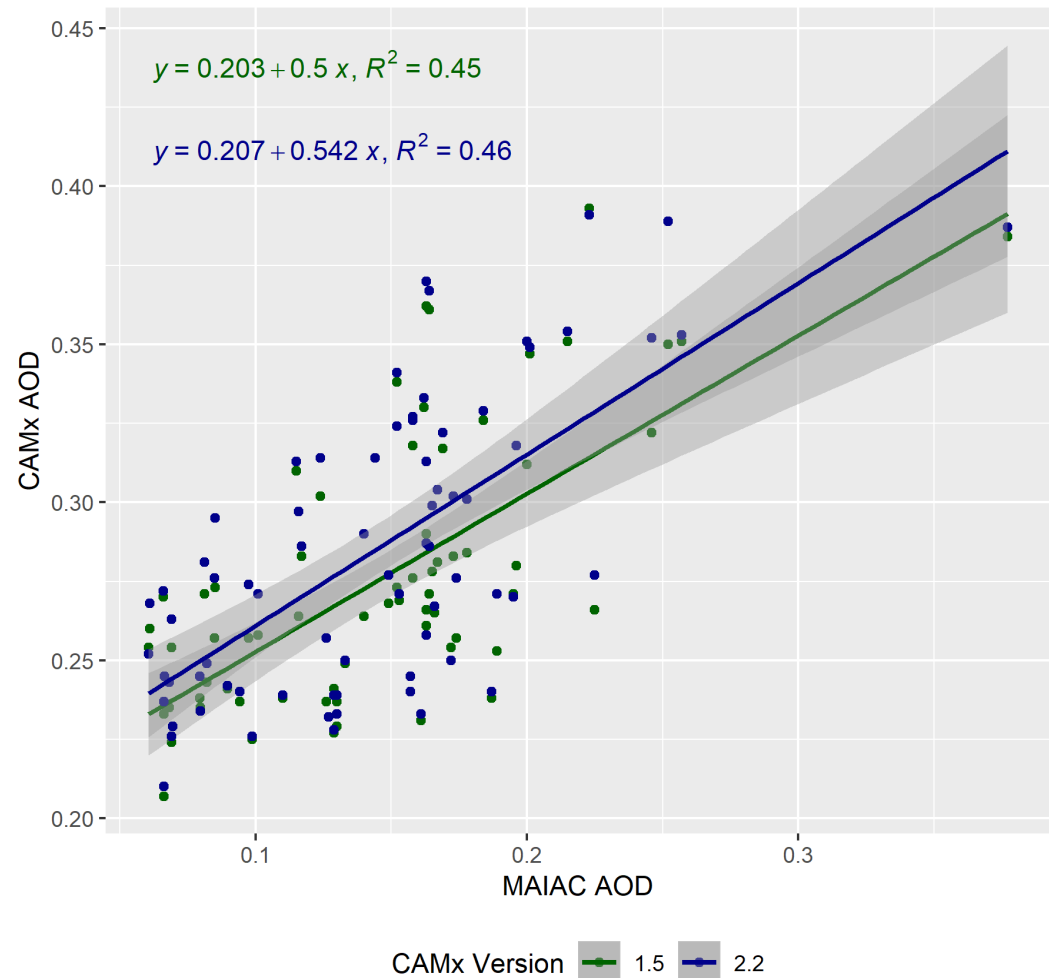| Month	N	Mean MAIAC AOD	Mean CAMx2 AOD	R	R²	FB (%)	NMSE	FAC2
5	6710	0.179 ± 0.066	0.266 ± 0.038	0.137 ± 0.294	0.104 ± 0.142	48 ± 37	0.517 ± 0.510	0.587 ± 0.492
6	6613	0.169 ± 0.068	0.275 ± 0.040	0.164 ± 0.290	0.110 ± 0.150	57 ± 34	0.569 ± 0.513	0.567 ± 0.495
7	5436	0.155 ± 0.082	0.244 ± 0.031	0.061 ± 0.264	0.073 ± 0.100	60 ± 43	0.778 ± 0.856	0.379 ± 0.485
8	7430	0.152 ± 0.054	0.248 ± 0.027	0.120 ± 0.256	0.079 ± 0.095	56 ± 33	0.576 ± 0.533	0.534 ± 0.499
9	10635	0.123 ± 0.056	0.265 ± 0.042	0.202 ± 0.257	0.106 ± 0.129	82 ± 33	1.197 ± 1.148	0.267 ± 0.442
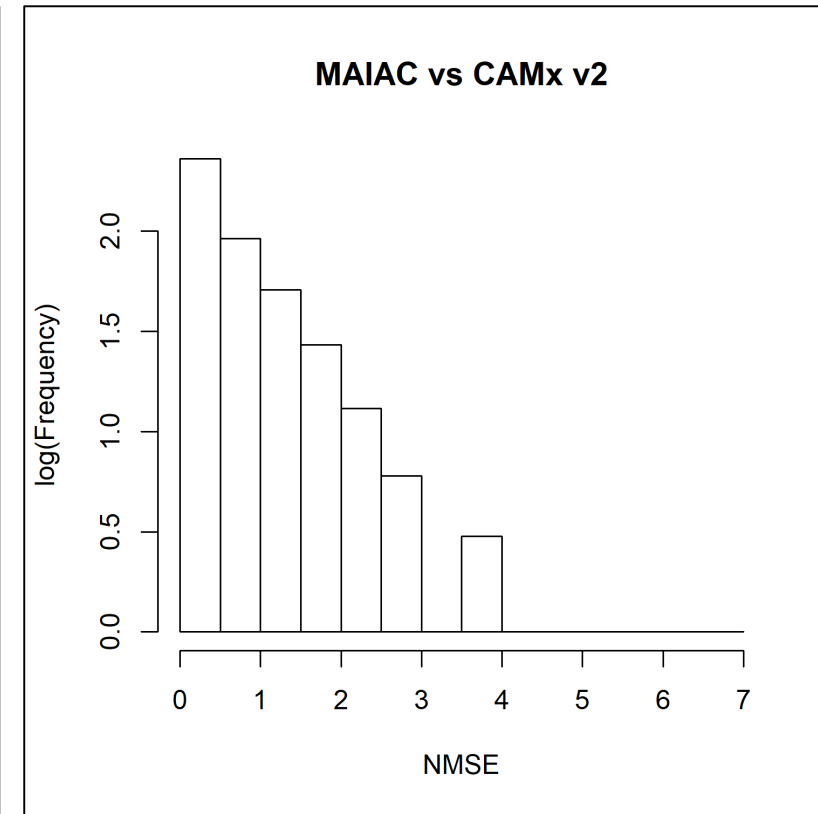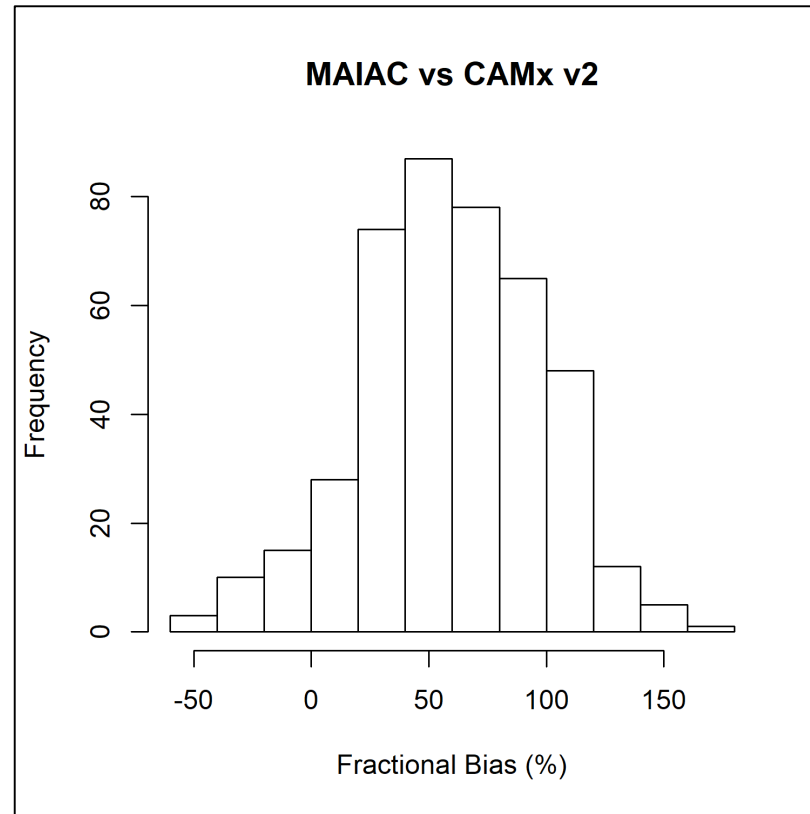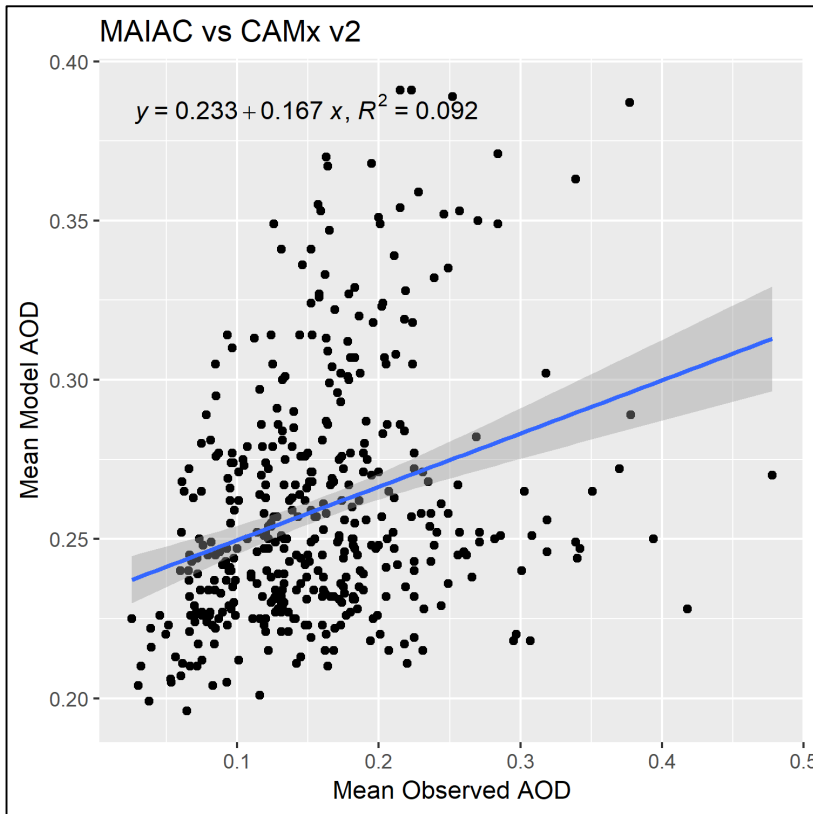
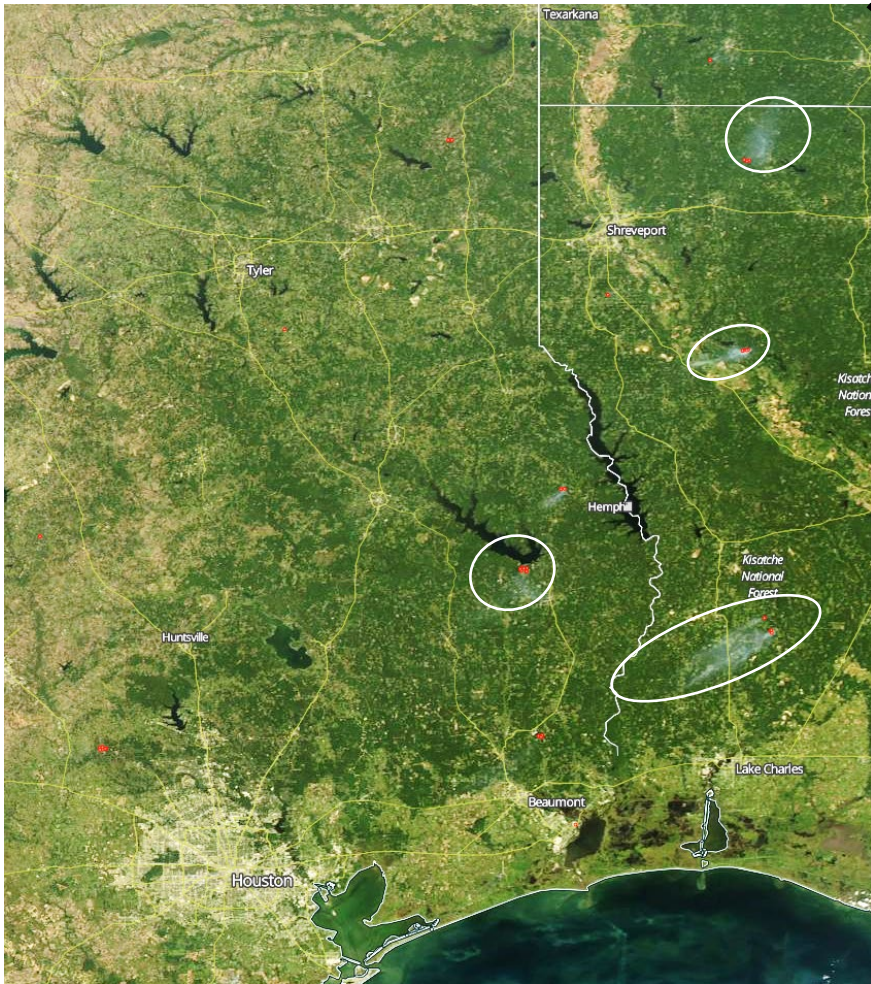# CAMx2 vs MAIAC Validation
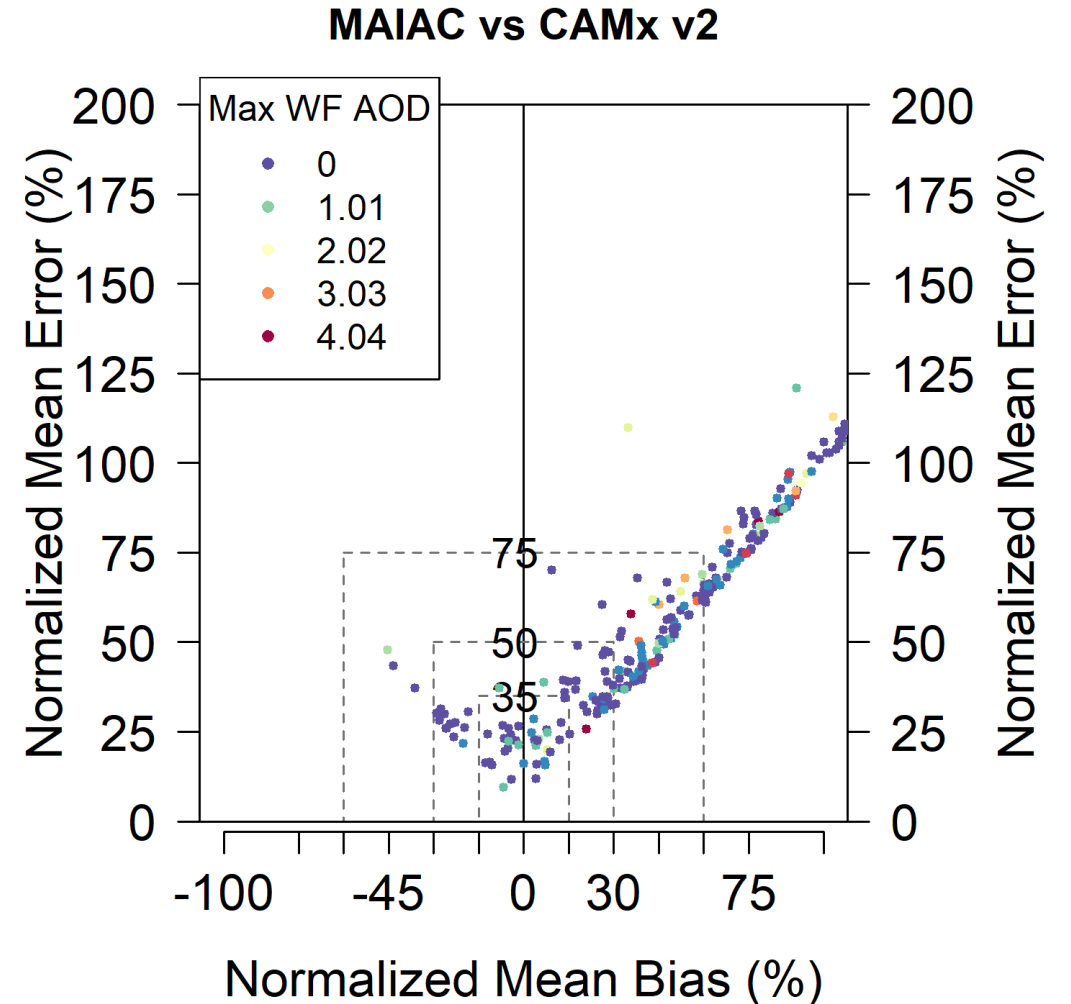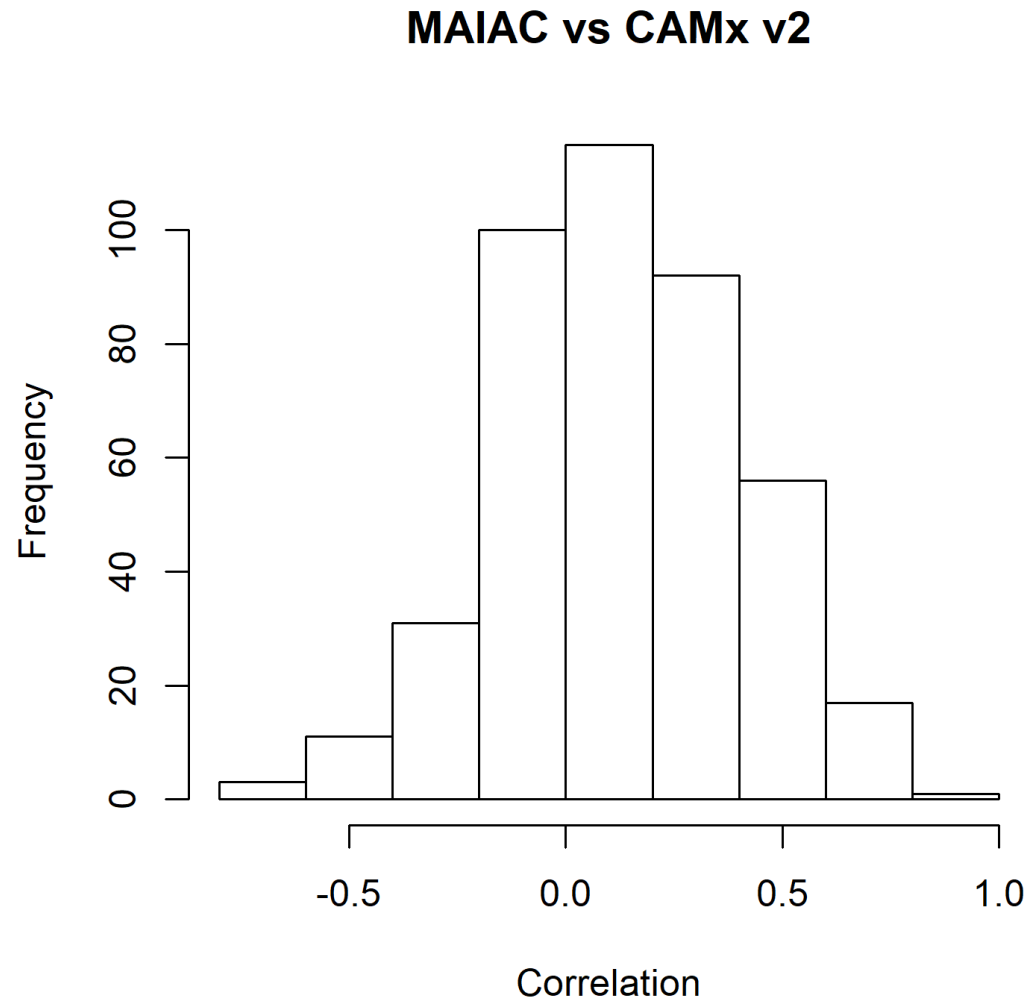
CAMx2 Fractional Bias and Error
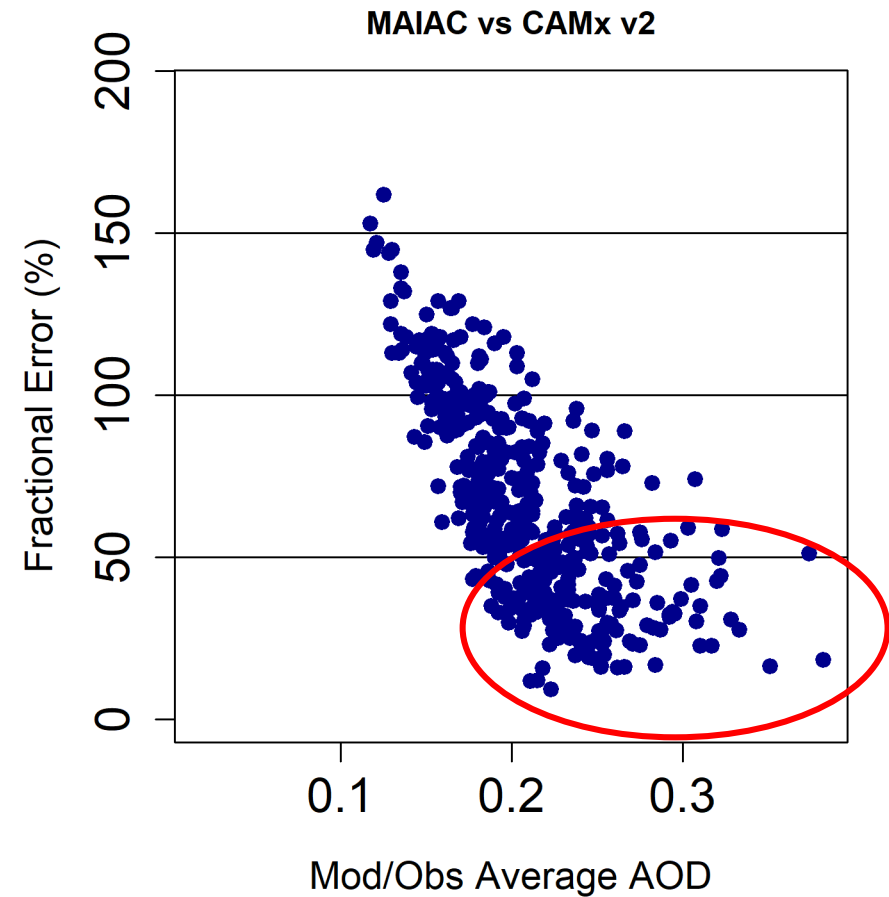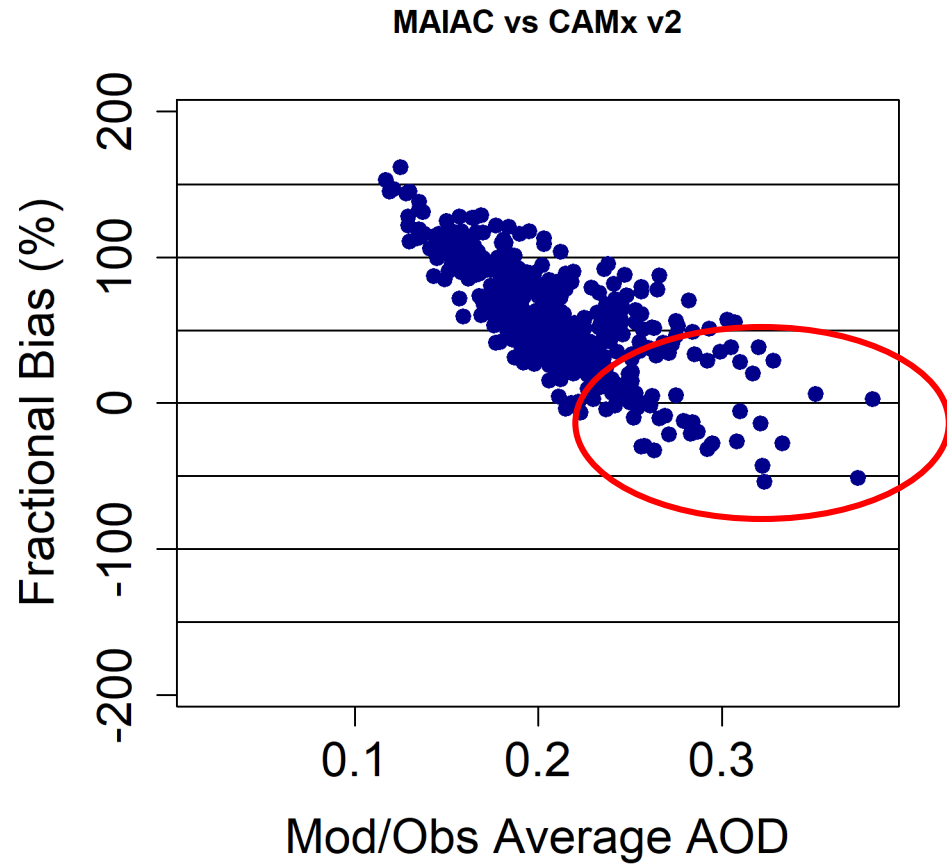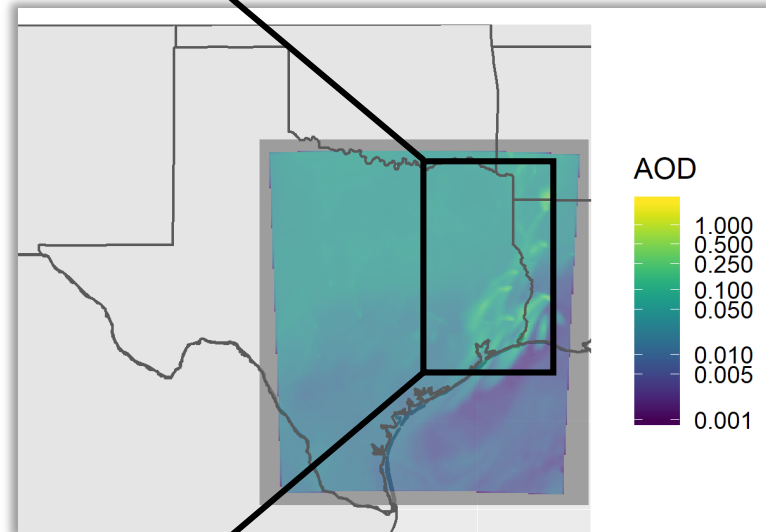
Model Results for High-Smoke Periods

- Calculate "wildfire-only AOD" by subtracting **No Fire** results from CAMx2

- Identify days when "wildfire-only AOD" was above 75th percentile

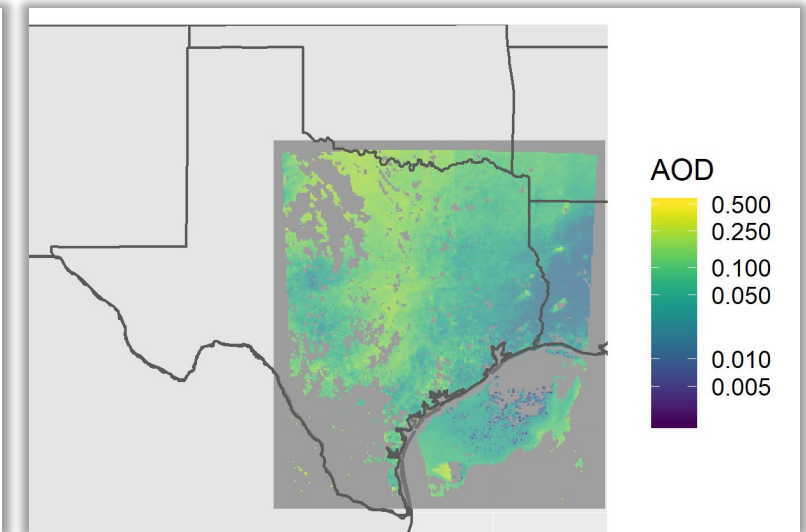- Compare hourly domain-average (mean) total AOD from CAMx2 and MAIAC

$y = 0.203 + 0.5\,x$, $R^2 = 0.45$

$y = 0.207 + 0.542\,x$, $R^2 = 0.46$

CAMx AOD (y-axis)

MAIAC AOD (x-axis)

CAMx Version   1.5   2.2

Case Study: September 20, 2012

CAMx2

MAIAC

Conclusions

- Photochemical modeling using FINN v2.2 shows reasonable agreement with independent satellite data (FB ~50%, FAC2 ~55%)

- Agreement for dispersion and photochemical modeling improves at higher AOD levels and when models predict smoke is present

- CAMx model results using FINN v2.2 show slight improvement in agreement with satellite data over FINN v1.5 for smoke-impacted cases (R^2 0.46 vs 0.45, slope 0.54 vs 0.5,)

Acknowledgment

Sonoma Technology

Nathan R. Pavlovic
Lead Geospatial Data Scientist
npavlovic@sonomatech.com

HYSPLIT Results Ground Validation

- Use Total Carbon (TC) as a proxy for BB portion of $PM_{2.5}$ because wildfire PM is comprised of up to 80% OC (Clarke et al., 2007; US EPA RHR Guidance, 2016; McClure and Jaffe, 2018)

- Total Carbon can be calculated using EC and OC concentrations

    TC = (EC + 1.8*OC)

- 10 IMPROVE sites around Texas, including NM, OK, AR, and LA

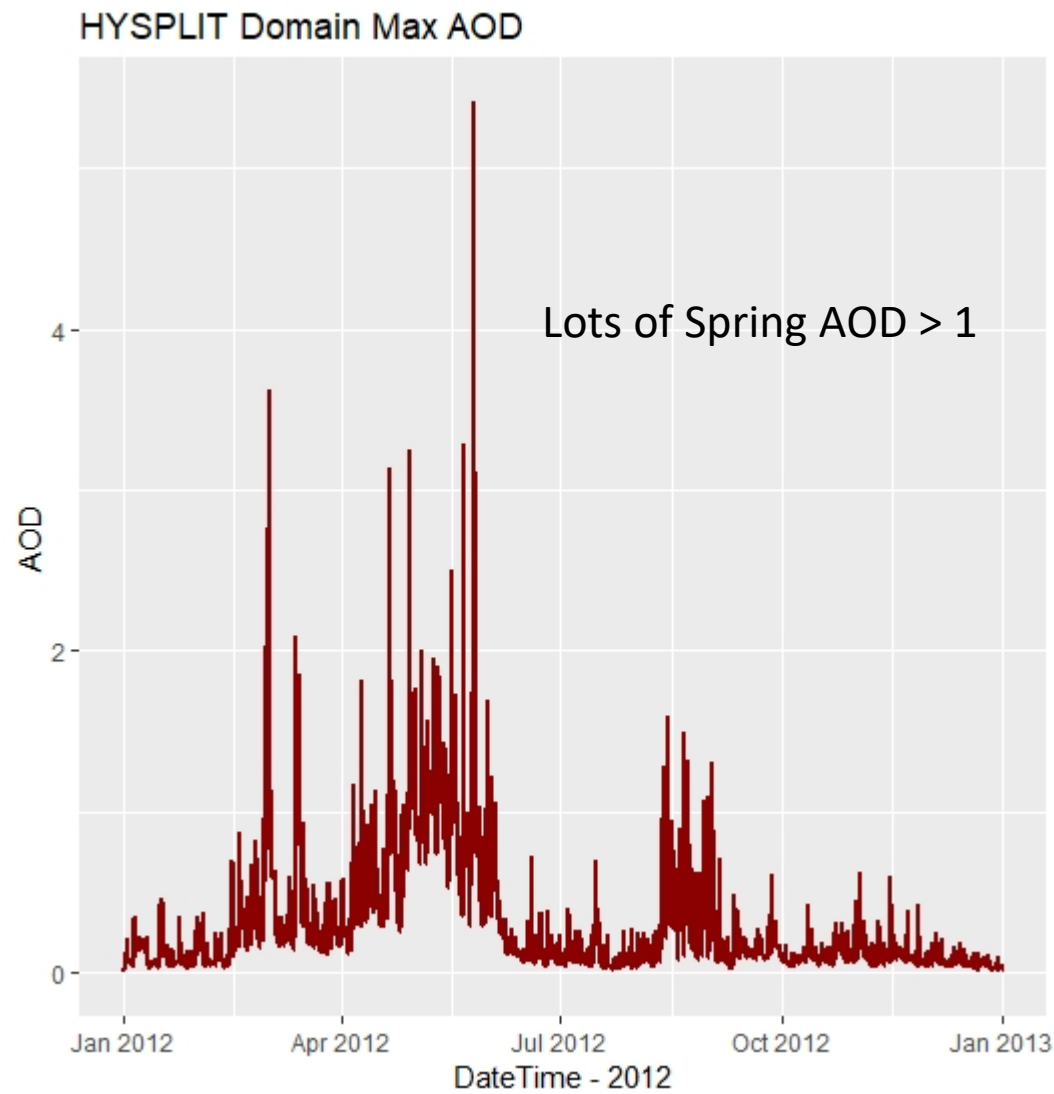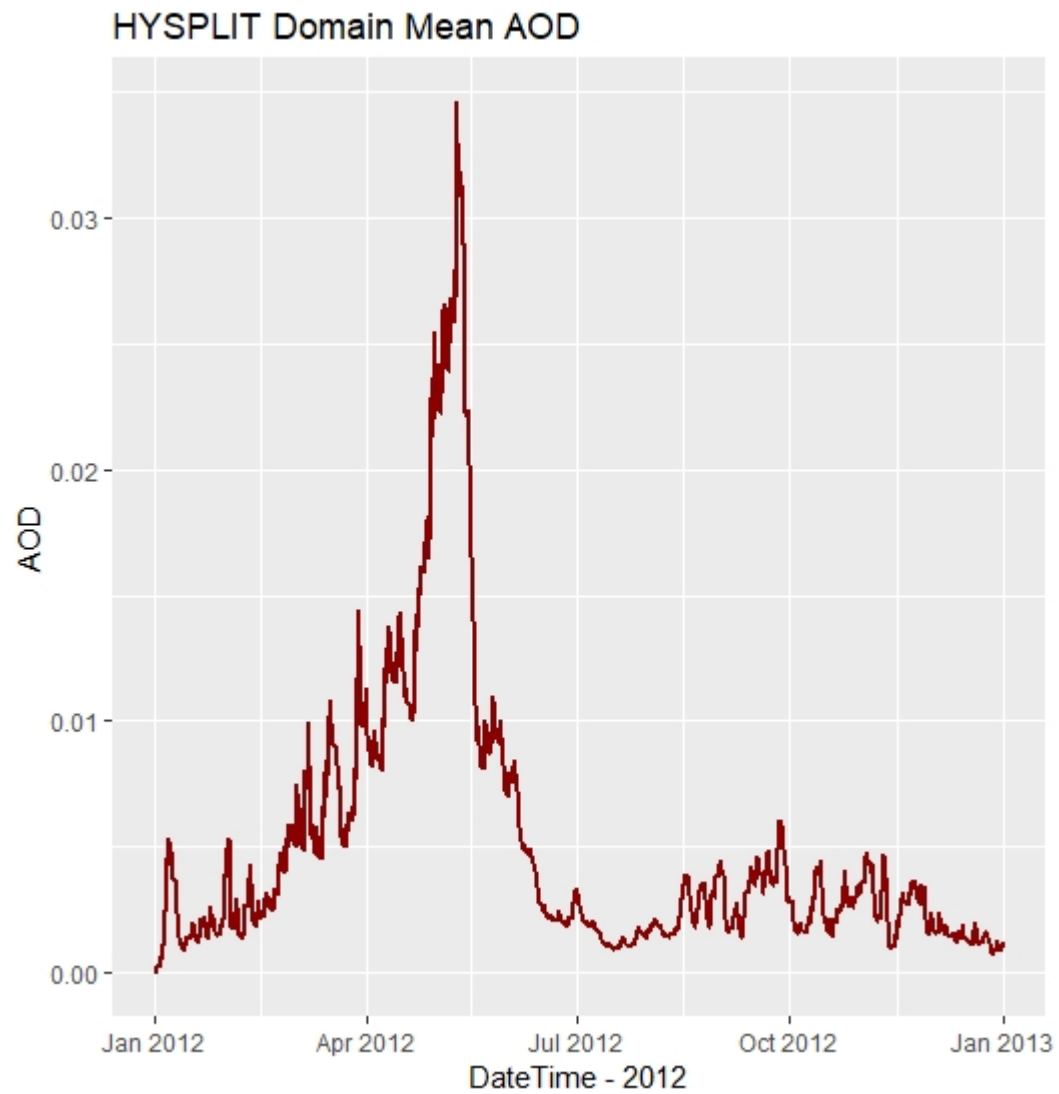- Calculate Pearson correlation between HYSPLIT calculated and IMPROVE for summer 2012

Mean: 0.55
Median: 0.55
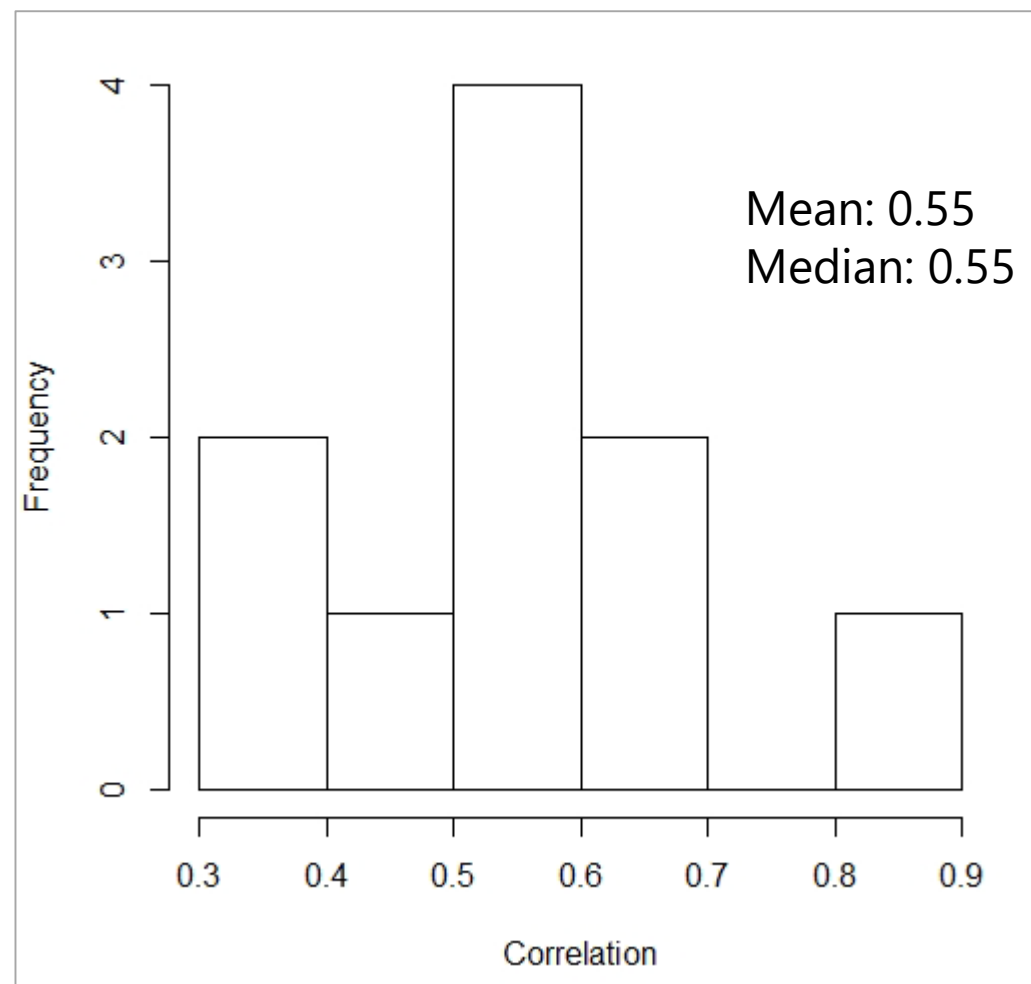
2012 Emissions Time Series
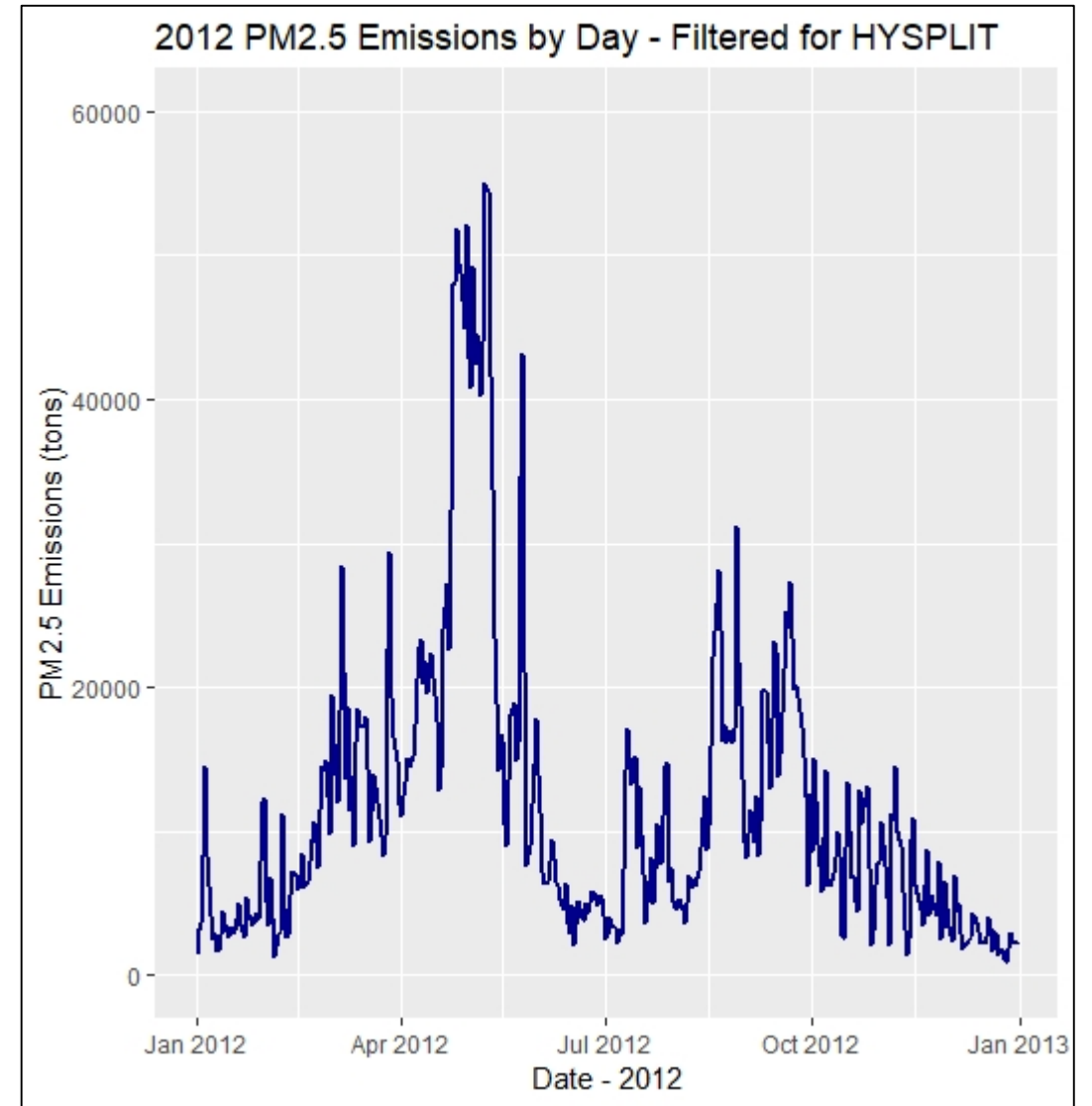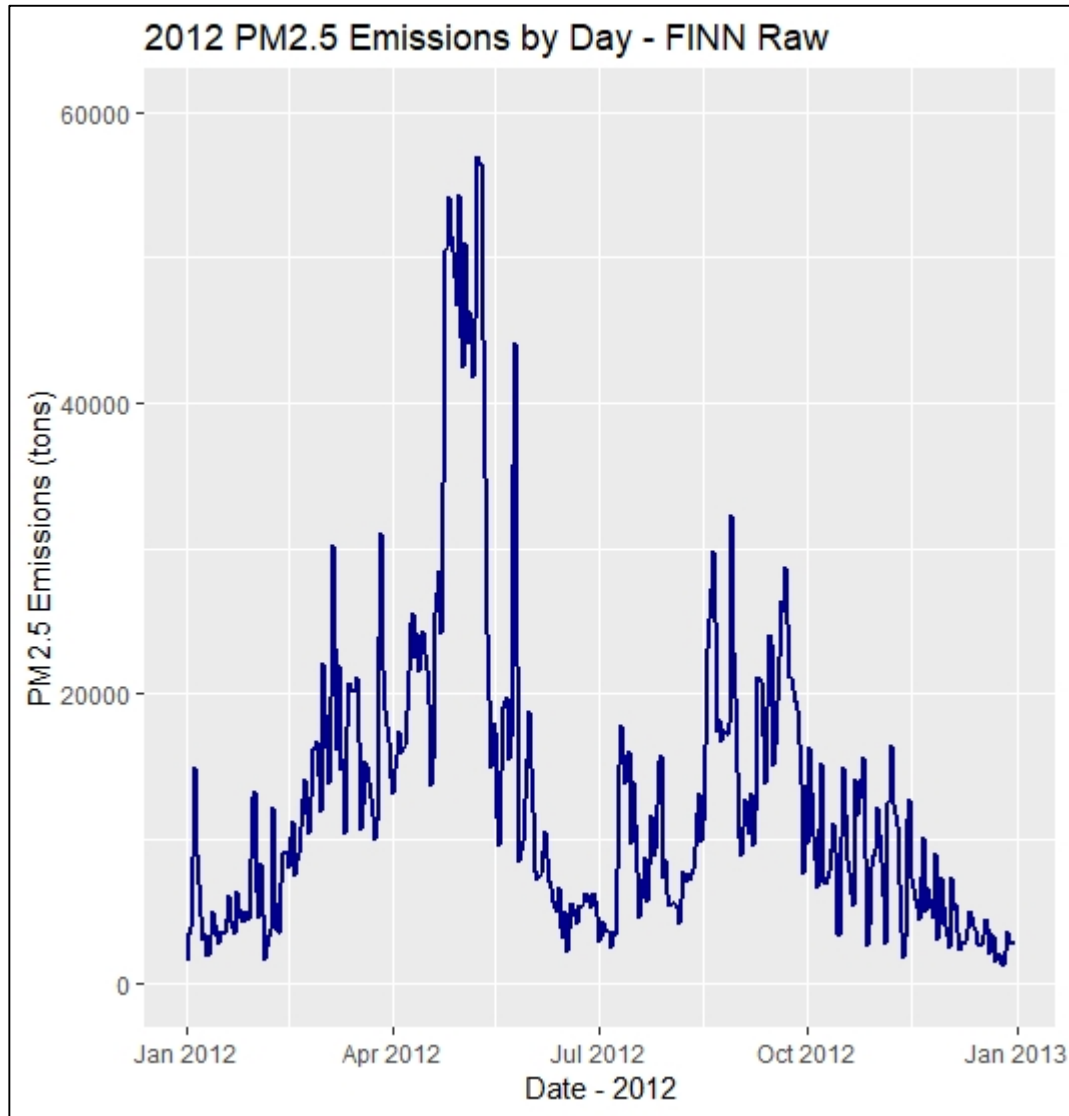
HYSPLIT Domain AOD

AOD Calculated from IMPROVE 2 Eqn

Lots of Spring AOD > 1

Evaluation Approach