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
STI-7113
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**
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 (1 of 2)

- 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/](https://github.com/pnwairfire/bluesky/)
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 (1 of 2)

- 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
Photochemical Modeling: CAMx (2 of 2)

- 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

<table>
<thead>
<tr>
<th>Type</th>
<th>Model Comparison (Obs/Model)</th>
<th>Years</th>
<th>Resolution (km)</th>
<th>Mean N</th>
<th>Mean Obs AOD</th>
<th>Mean Model AOD</th>
<th>Mean R</th>
<th>Mean R²</th>
<th>Mean FB (%)</th>
<th>Mean NMSE</th>
<th>Mean FAC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildfire</td>
<td>CAMx1/HYSPLIT</td>
<td>2012</td>
<td>50</td>
<td>322 ± 1</td>
<td>0.005 ± 0.004</td>
<td>0.010 ± 0.012</td>
<td>0.291 ± 0.273</td>
<td>0.159 ± 0.156</td>
<td>28.8 ± 56.4</td>
<td>3.9 ± 7.0</td>
<td>0.372 ± 0.442</td>
</tr>
<tr>
<td></td>
<td>CAMx2/HYSPLIT</td>
<td>2012</td>
<td>50</td>
<td>322 ± 1</td>
<td>0.008 ± 0.008</td>
<td>0.010 ± 0.012</td>
<td>0.322 ± 0.279</td>
<td>0.181 ± 0.164</td>
<td>3.2 ± 61.6</td>
<td>3.4 ± 6.5</td>
<td>0.386 ± 0.456</td>
</tr>
<tr>
<td>Total AOD</td>
<td>MAIAC/CAMx1</td>
<td>2012</td>
<td>4</td>
<td>7251 ± 6983</td>
<td>0.157 ± 0.069</td>
<td>0.256 ± 0.036</td>
<td>0.137 ± 0.282</td>
<td>0.098 ± 0.130</td>
<td>58.8 ± 38.3</td>
<td>0.7 ± 0.8</td>
<td>0.558 ± 0.429</td>
</tr>
<tr>
<td></td>
<td>MAIAC/CAMx2</td>
<td>2012</td>
<td>4</td>
<td>7251 ± 6983</td>
<td>0.157 ± 0.069</td>
<td>0.259 ± 0.038</td>
<td>0.134 ± 0.276</td>
<td>0.094 ± 0.125</td>
<td>59.6 ± 38.5</td>
<td>0.7 ± 0.8</td>
<td>0.552 ± 0.428</td>
</tr>
<tr>
<td>Mixed</td>
<td>MAIAC/HYSPLIT</td>
<td>2012-2017</td>
<td>50</td>
<td>419 ± 308</td>
<td>0.119 ± 0.048</td>
<td>0.006 ± 0.009</td>
<td>0.225 ± 0.265</td>
<td>0.121 ± 0.158</td>
<td>185.5 ± 15.2</td>
<td>157.6 ± 764.6</td>
<td>0.016 ± 0.111</td>
</tr>
</tbody>
</table>
HYSLIP 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
HYPLIT Correlation with MAIAC

Red line indicates daily mean correlation
## Validation Statistics

<table>
<thead>
<tr>
<th>Type</th>
<th>Model Comparison (Obs/Model)</th>
<th>Years</th>
<th>Resolution (km)</th>
<th>Mean N</th>
<th>Mean Obs AOD</th>
<th>Mean Model AOD</th>
<th>Mean R</th>
<th>Mean R²</th>
<th>Mean FB (%)</th>
<th>Mean NMSE</th>
<th>Mean FAC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildfire</td>
<td>CAMx1/HYSPLIT</td>
<td>2012</td>
<td>50</td>
<td>322</td>
<td>0.005 ± 0.004</td>
<td>0.010 ± 0.012</td>
<td>0.291 ± 0.273</td>
<td>0.159 ± 0.156</td>
<td>28.8 ± 56.4</td>
<td>3.9 ± 7.0</td>
<td>0.372 ± 0.442</td>
</tr>
<tr>
<td></td>
<td>CAMx2/HYSPLIT</td>
<td>2012</td>
<td>50</td>
<td>322</td>
<td>0.008 ± 0.008</td>
<td>0.010 ± 0.012</td>
<td>0.322 ± 0.279</td>
<td>0.181 ± 0.164</td>
<td>32.2 ± 61.6</td>
<td>3.4 ± 6.5</td>
<td>0.386 ± 0.456</td>
</tr>
<tr>
<td>Total AOD</td>
<td>MAIAC/CAMx1</td>
<td>2012</td>
<td>4</td>
<td>7251</td>
<td>0.157 ± 0.069</td>
<td>0.256 ± 0.036</td>
<td>0.137 ± 0.282</td>
<td>0.098 ± 0.130</td>
<td>58.8 ± 38.3</td>
<td>0.7 ± 0.8</td>
<td>0.558 ± 0.429</td>
</tr>
<tr>
<td></td>
<td>MAIAC/CAMx2</td>
<td>2012</td>
<td>4</td>
<td>7251</td>
<td>0.157 ± 0.069</td>
<td>0.259 ± 0.038</td>
<td>0.134 ± 0.276</td>
<td>0.094 ± 0.125</td>
<td>59.6 ± 38.5</td>
<td>0.7 ± 0.8</td>
<td>0.552 ± 0.428</td>
</tr>
<tr>
<td>Mixed</td>
<td>MAIAC/HYSPLIT</td>
<td>2012-2017</td>
<td>50</td>
<td>419</td>
<td>0.119 ± 0.048</td>
<td>0.006 ± 0.009</td>
<td>0.225 ± 0.265</td>
<td>0.121 ± 0.158</td>
<td>-185.5 ± 15.2</td>
<td>157.6 ± 764.6</td>
<td>0.016 ± 0.111</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Month</th>
<th>N</th>
<th>Mean MAIAC AOD</th>
<th>Mean CAMx2 AOD</th>
<th>R</th>
<th>R²</th>
<th>FB (%)</th>
<th>NMSE</th>
<th>FAC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>6710</td>
<td>0.179 ± 0.066</td>
<td>0.266 ± 0.038</td>
<td>0.137</td>
<td>0.294</td>
<td>0.104</td>
<td>0.142</td>
<td>0.517</td>
</tr>
<tr>
<td>6</td>
<td>6613</td>
<td>0.169 ± 0.068</td>
<td>0.275 ± 0.040</td>
<td>0.164</td>
<td>0.290</td>
<td>0.110</td>
<td>0.150</td>
<td>0.569</td>
</tr>
<tr>
<td>7</td>
<td>5436</td>
<td>0.155 ± 0.082</td>
<td>0.244 ± 0.031</td>
<td>0.061</td>
<td>0.264</td>
<td>0.073</td>
<td>0.100</td>
<td>0.778</td>
</tr>
<tr>
<td>8</td>
<td>7430</td>
<td>0.152 ± 0.054</td>
<td>0.248 ± 0.027</td>
<td>0.120</td>
<td>0.256</td>
<td>0.079</td>
<td>0.095</td>
<td>0.576</td>
</tr>
<tr>
<td>9</td>
<td>10635</td>
<td>0.123 ± 0.056</td>
<td>0.265 ± 0.042</td>
<td>0.202</td>
<td>0.257</td>
<td>0.106</td>
<td>0.129</td>
<td>1.197</td>
</tr>
</tbody>
</table>

#### MAIAC vs CAMx v2

- Equation: $y = 0.233 + 0.167x$, $R^2 = 0.092$

#### MAIAC vs CAMx v2

- Fractional Bias (%)
- NMSE

#### MAIAC vs CAMx v2

- Frequency
- Log(Frequency)
CAMx2 vs MAIAC Validation

MAIAC vs CAMx v2

Frequency

Correlation

Normalized Mean Error (%)

Normalized Mean Bias (%)
CAMx2 Fractional Bias and Error

MAIAC vs CAMx v2

Fractional Bias (%) vs Mod/Obs Average AOD

Fractional Error (%) vs Mod/Obs Average AOD

-200 -100 0 100 200
0

0 50 100 150 200
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
Case Study: September 20, 2012
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

The preparation of this presentation was funded by a grant from the Texas Air Quality Research Program (AQRP) at The University of Texas at Austin through the Texas Emission Reduction Program (TERP) and the Texas Commission on Environmental Quality (TCEQ). The findings, opinions, and conclusions are the work of the author(s) and do not necessarily represent findings, opinions, or conclusions of the AQRP or the TCEQ.
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
  \[ TC = (EC + 1.8 \times OC) \]
- 10 IMPROVE sites around Texas, including NM, OK, AR, and LA
- Calculate Pearson correlation between HYSPLIT calculated and IMPROVE for summer 2012
2012 Emissions Time Series

2012 PM2.5 Emissions by Day - FINN Raw

2012 PM2.5 Emissions by Day - Filtered for HYSPLIT
HYSLIP Domain AOD

AOD Calculated from IMPROVE 2 Eqn

HYSLIP Domain Mean AOD

HYSLIP Domain Max AOD

Lots of Spring AOD > 1
Evaluation Approach

- FINN Emissions (v1.5/v2.2)
- Dispersion Modeling (HYSPLIT)
  - Convert to AOD
  - Qualitative and quantitative validation
- Photochemical Modeling (CAMx)
  - Convert to AOD
  - Qualitative and quantitative validation
- MAIAC Satellite AOD retrieval