Development and Evaluation of the FINNv.2.2 Global Model Application and Fire Emissions Estimates for the Expanded Texas Air Quality Modeling Domain

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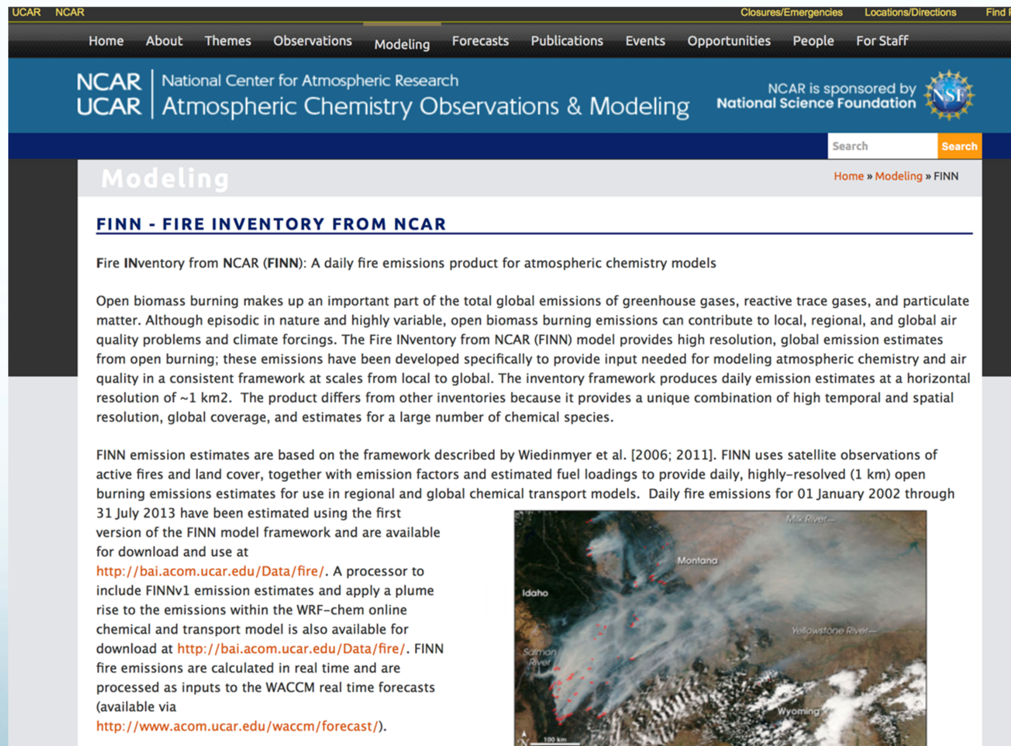
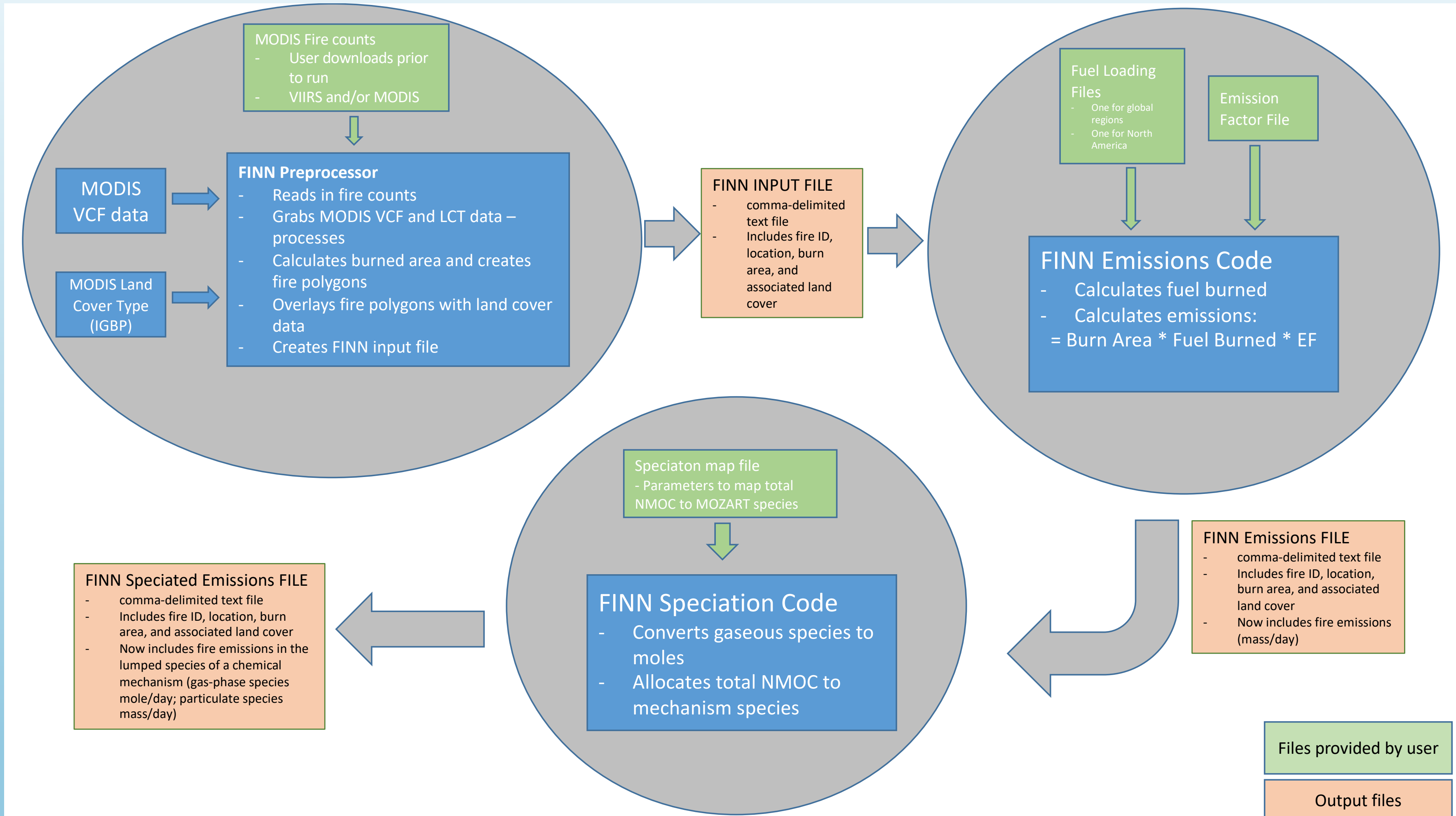
FINN Fire Emissions Model

- 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
- FINNv1 released in 2010
- FINNv1.5 released in 2014

NCAR hosts central repository for global FINN v1.5 emissions files spanning 2002-2018: https://www2.acom.ucar.edu/modeling/finn-fire-inventory-ncar



FINN v2.2 Modeling System

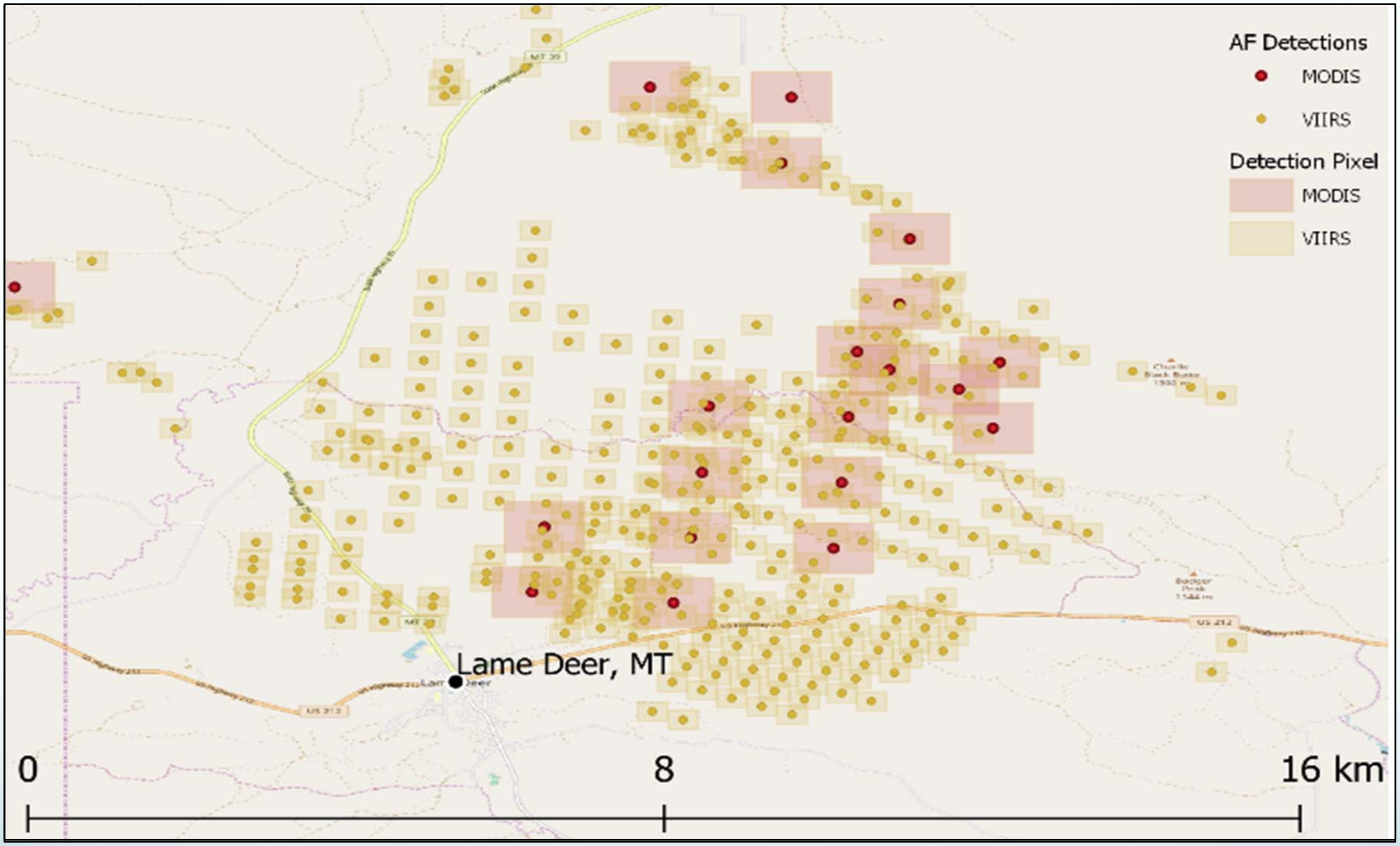


- AQRP 12-018, 14-011, 18-022 instrumental to **FINNv2.2** development
- STI conducting FINNv.2.2 evaluations using Multi-Angle Implementation of Atmospheric Correction (MAIAC) AOD product

Preprocessor: Active Fire Detections

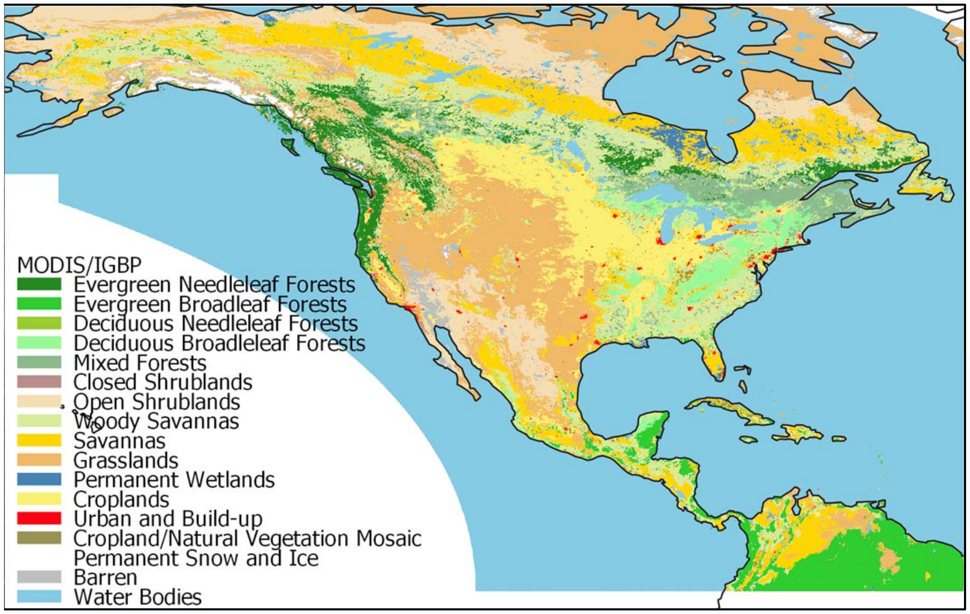
- Preprocessor estimates burned area from daily satellite detections of active fires and characterizes underlying land cover
- Previous versions used MODIS active fire products as default
- Added **option to use VIIRS (375m) active fire product** alone or in combination with MODIS Collection 6 (MCD14DL) product
- Uses **local time** to specify date of fire detection for easier comparisons with observations

Preprocessor: New Approach for Burned Area Estimation



Each detection assigned square area (0.14 km^2 VIIRS or 1 km^2 MODIS)
Detection rectangles formed from scan and track sizes of satellite pixel
Convex hulls from detection clusters joined to form “**fire polygon**”

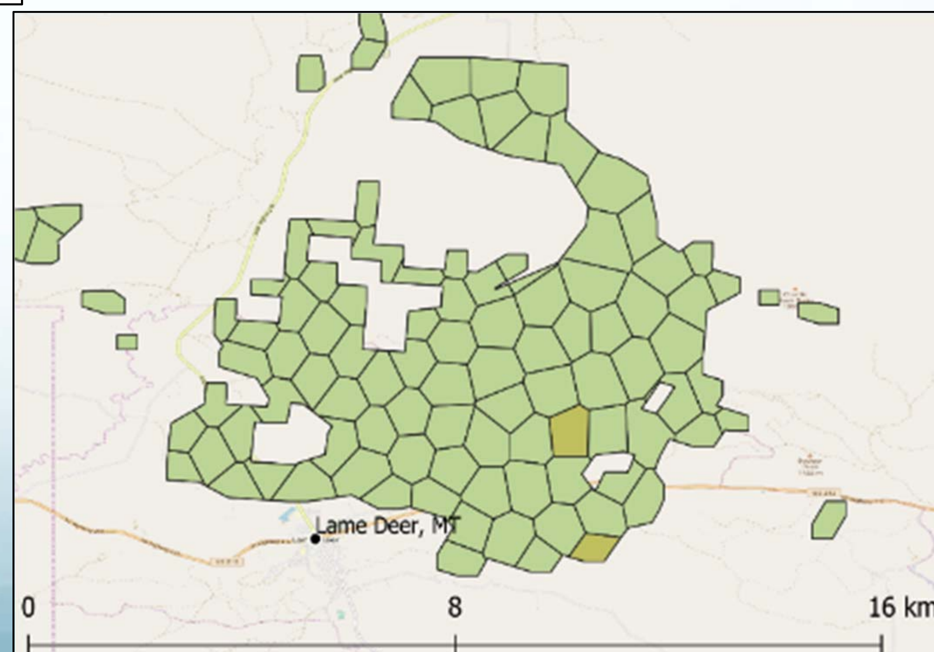
Preprocessor: New Approach for Land Cover Characterization



Terra and Aqua combined MODIS Land Cover Type (MCD12Q1) Version 6 data product with the International Geosphere-Biosphere Programme (IGBP) classifications

Fire polygon subdivided to analyze underlying land cover

MOD44B v006 MODIS/Terra Vegetation Continuous Fields (VCF) yearly product used to determine tree, grass, and bare cover



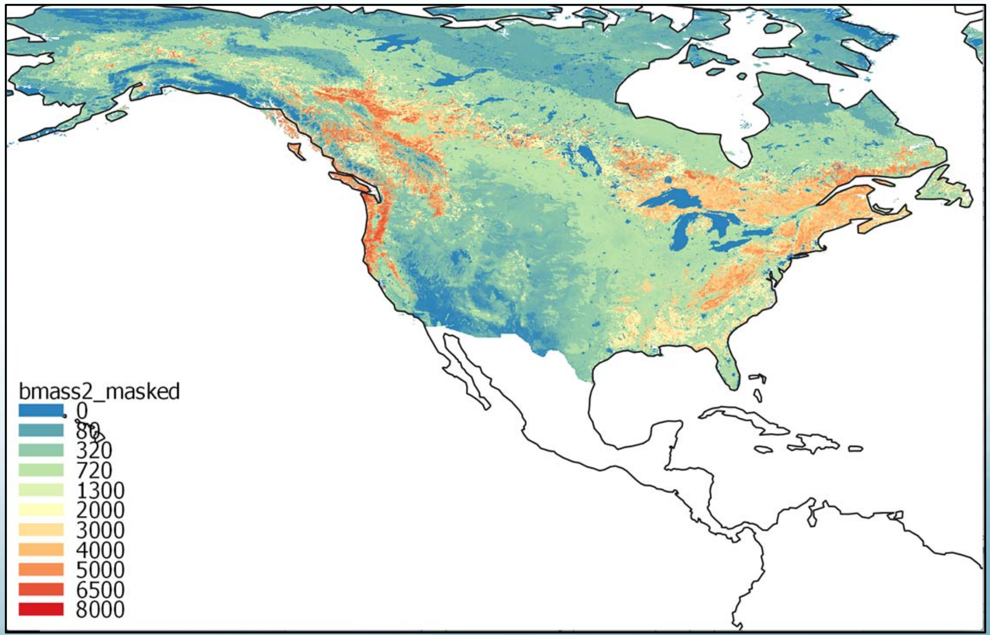
Emissions Model and Chemical Speciation: Highlights

Emission Factors

- 16 IGBP classes mapped to seven vegetation types
- Akagi et al (2011) and updates in 2015
- New studies* between 2014-2018 for **forests and croplands**
- **NMOC** includes identified and unidentified compounds; new NMOC emissions mapping for MOZART-T1 chemical mechanism

Fuel Loadings

- Updated regional defaults†
- USFS Fuel Characteristic Classification System (**FCCS**) supersedes regional defaults for **North American region**



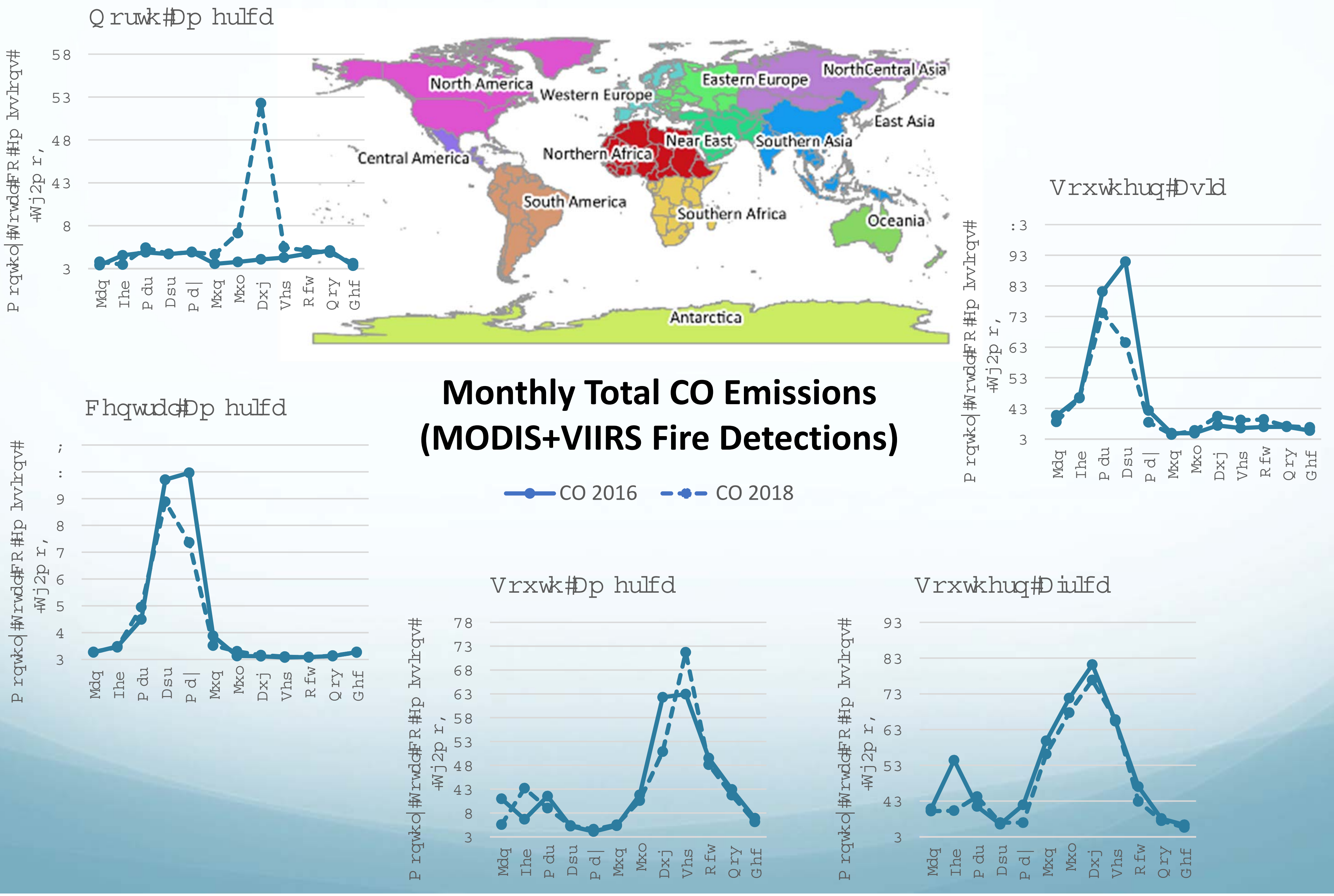
*Liu et al (2017), Urbanski (2014), and Paton-Walsh (2014); Liu et al (2017), Fang et al. (2017), Santiago De La Rosa et al. (2018), Stockwell et al. (2015)

†Hoelzemann et al. (2004); van Leeuwen et al. (2014); Akagi et al. (2011); Pouliot et al. (2017)

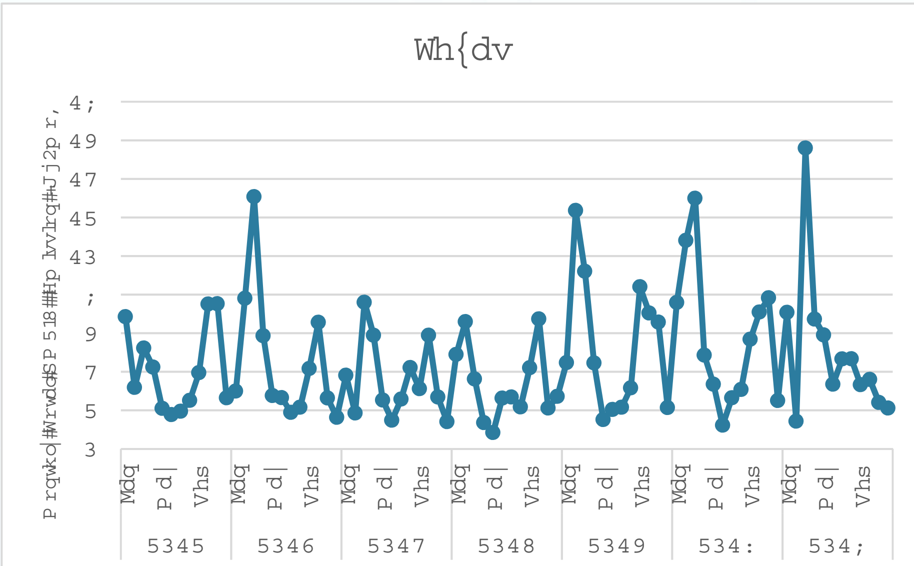
FINN v2.2 Computing Environment

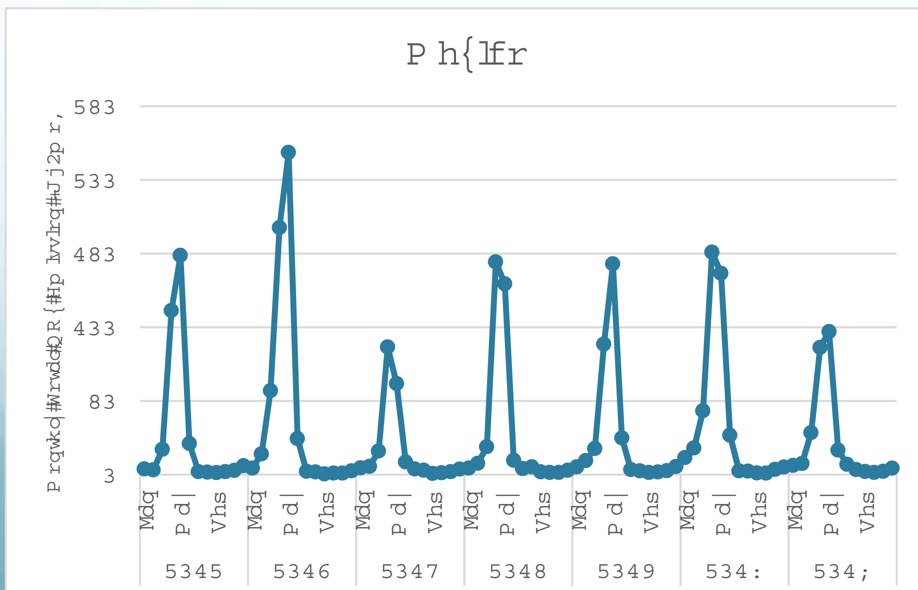
- Open source
- Preprocessing algorithm implemented in PostGIS to improve performance (i.e., shorter execution time)
- Docker environment houses FINN preprocessor tools
- Emissions model and chemical speciation codes written in IDL, but new versions in Python are being developed in a separate effort

FINN v2.2 Global Simulations: 2016 and 2018

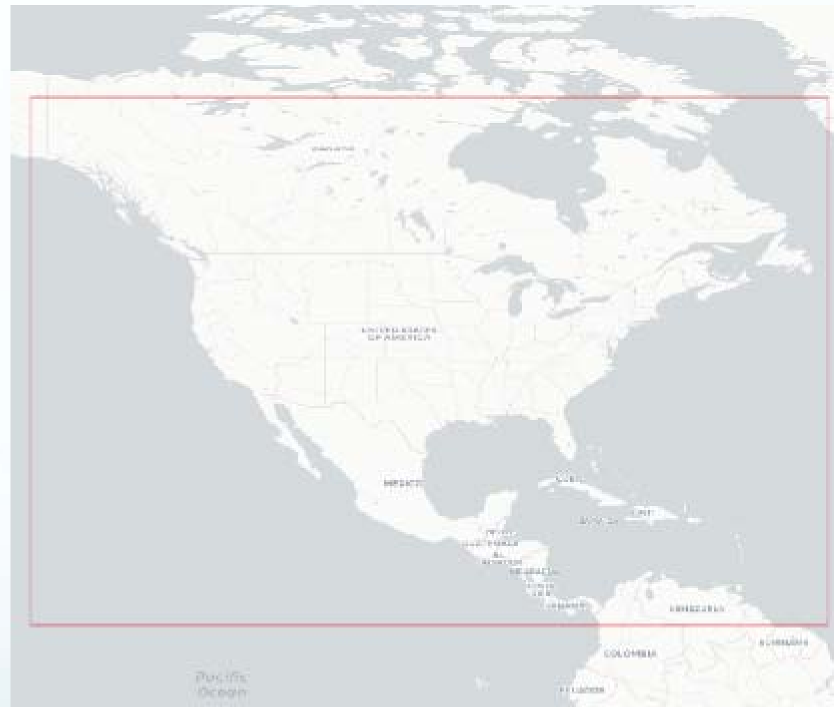


FINNv2.2 North American Simulations: 2012-2018

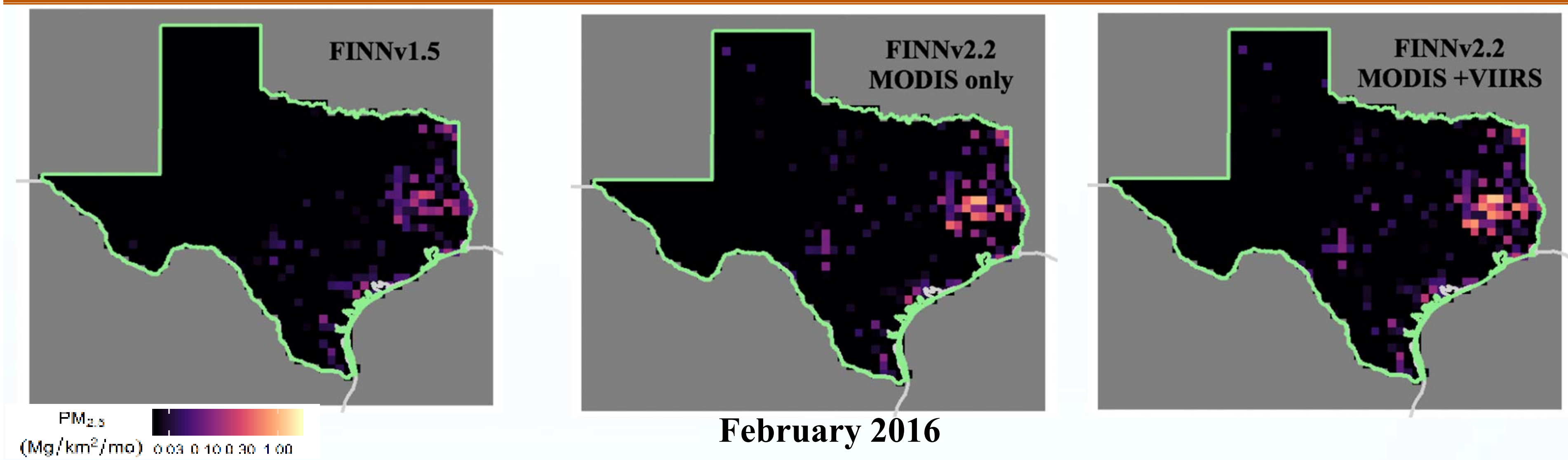




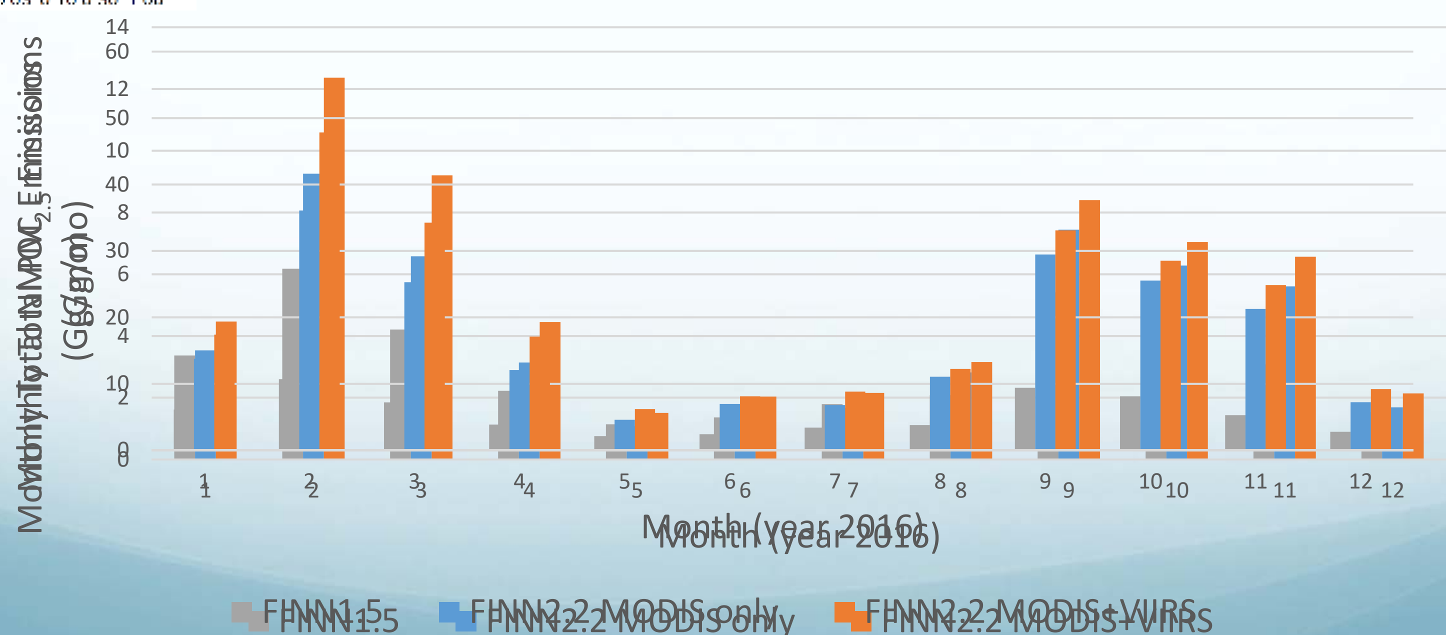
Monthly Total CO Emissions
(MODIS+VIIRS Fire Detections)



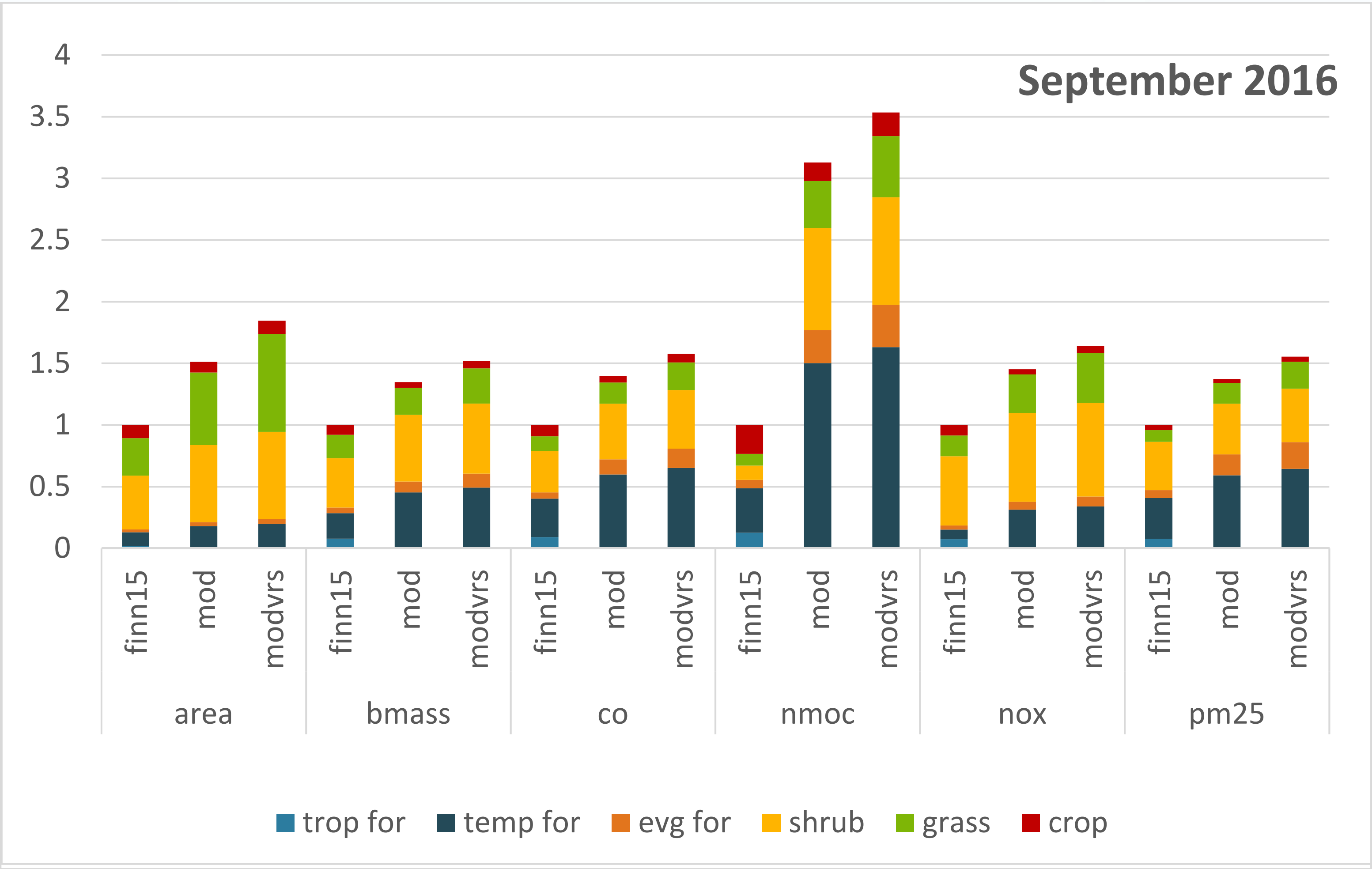
Monthly Total $PM_{2.5}$ and NMOC Emissions in Texas in 2016: FINN 1.5, FINN v2.2 (MODIS only, MODIS+VIIRS)



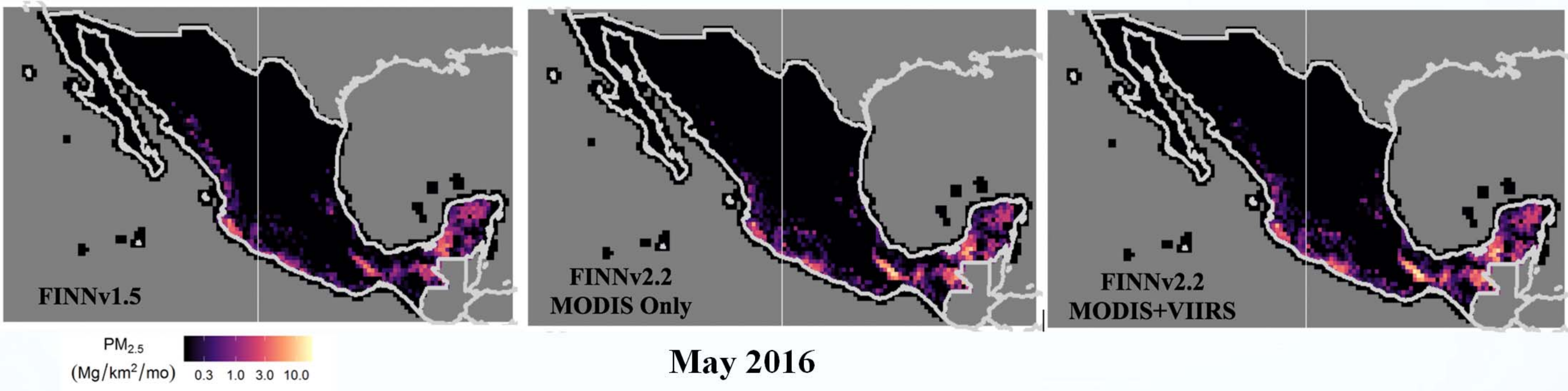
February 2016



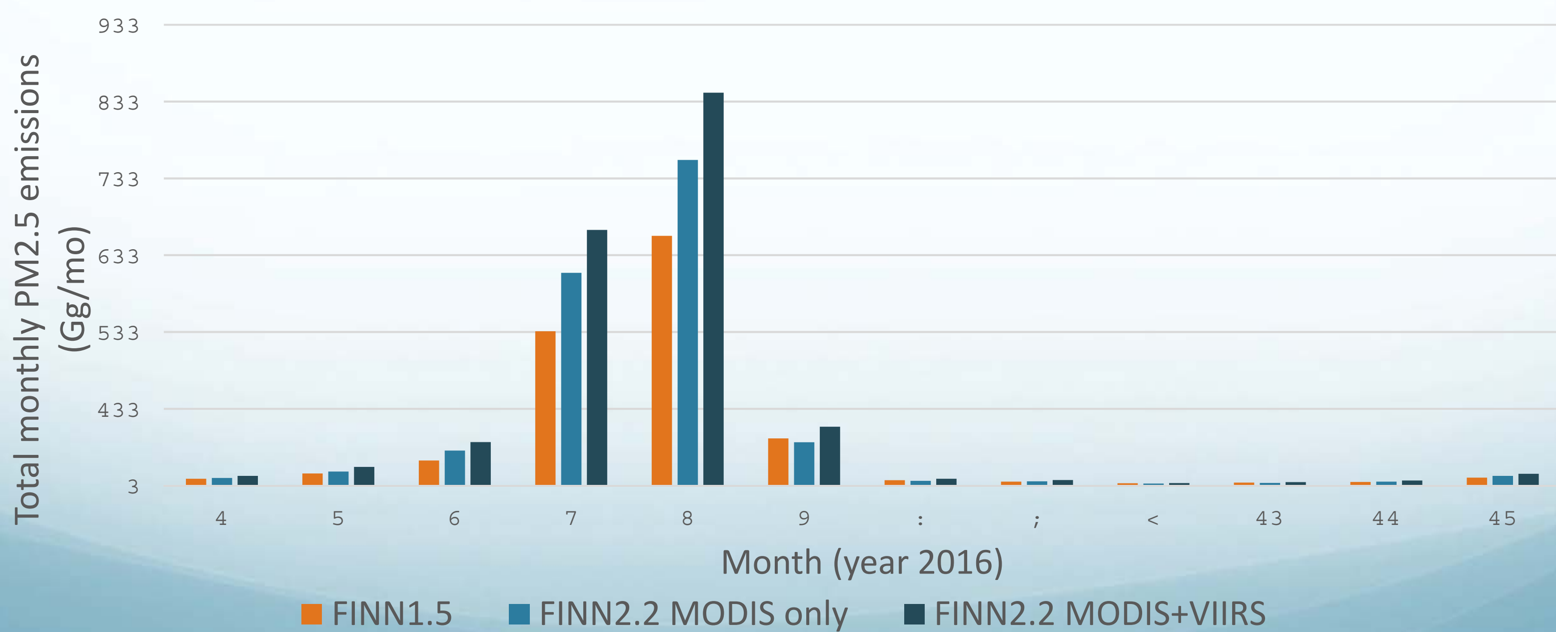
Contributions by land cover type to area burned, biomass loading, and total monthly emissions during September and February 2016 in Texas from FINN v2.2 normalized by v1.5



Monthly Total $PM_{2.5}$ Emissions in Mexico Valley in 2016: FINN 1.5, FINN v2.2 (MODIS only, MODIS+VIIRS)



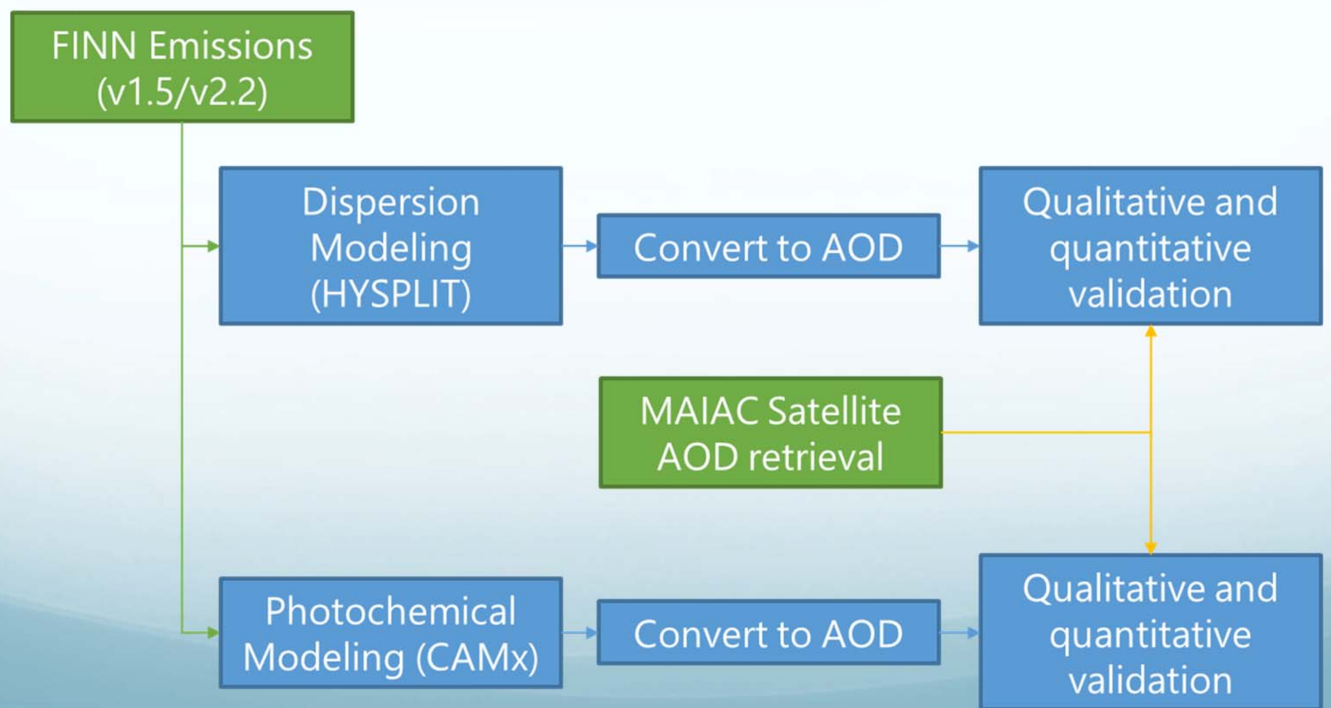
May 2016



Evaluation Objectives

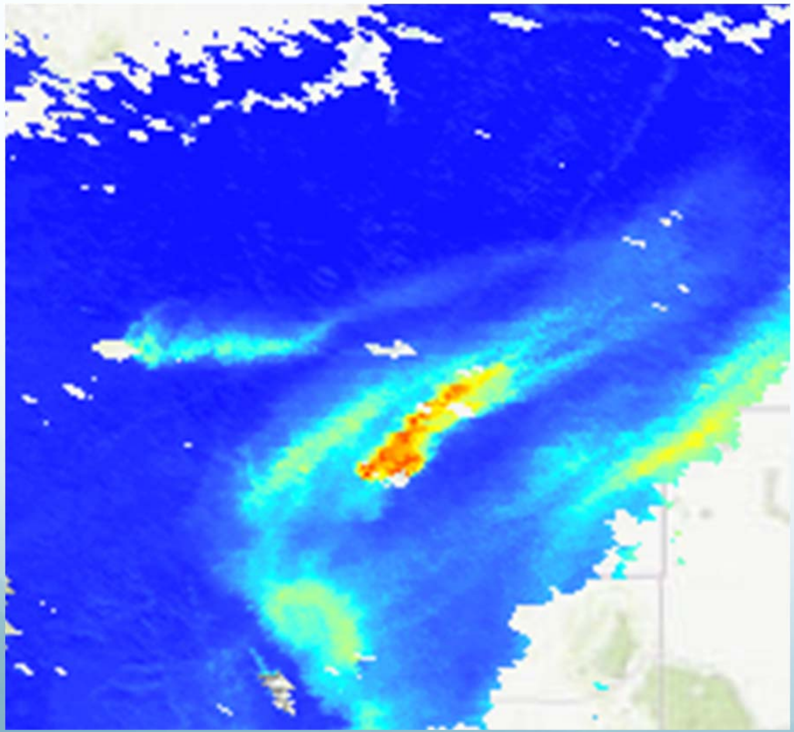
Use independent remote sensing data to evaluate FINN emissions results:

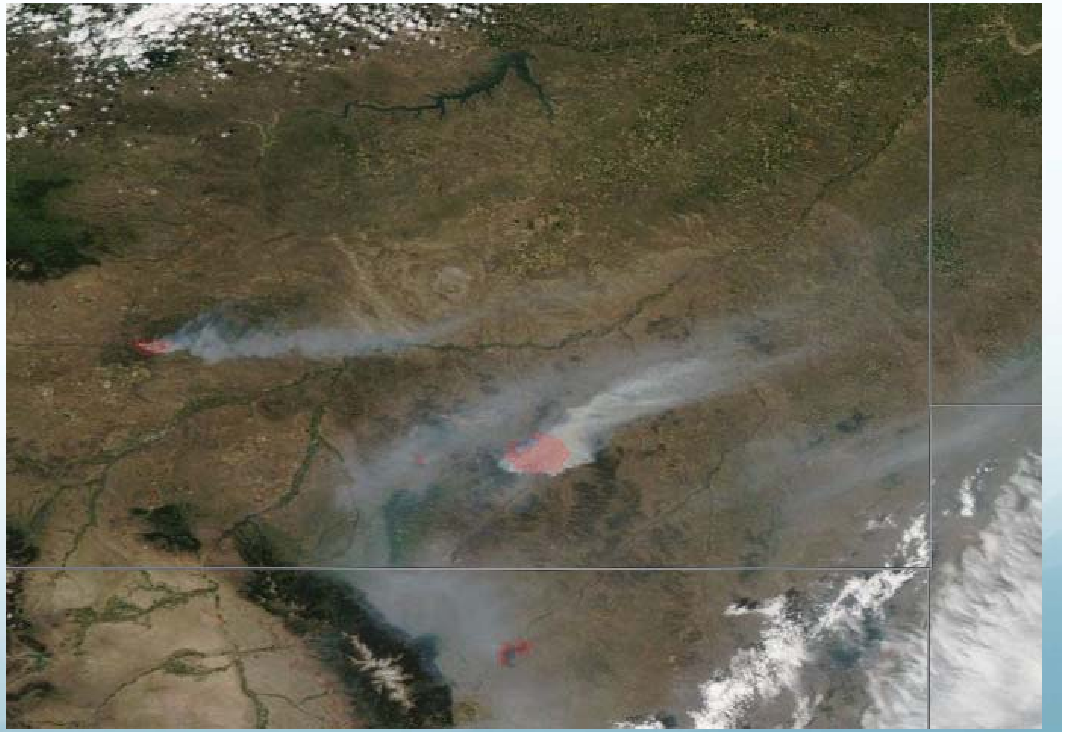
- Estimate aerosol optical depths calculated from photochemical and dispersion modeling with FINN emissions
- Compare to Multi-Angle Implementation of Atmospheric Correction (MAIAC) aerosol optical depth (AOD) retrievals from MODIS onboard NASA Aqua and Terra satellites. All comparisons conducted at time of satellite overpass



MAIAC AOD (MCD19A2)

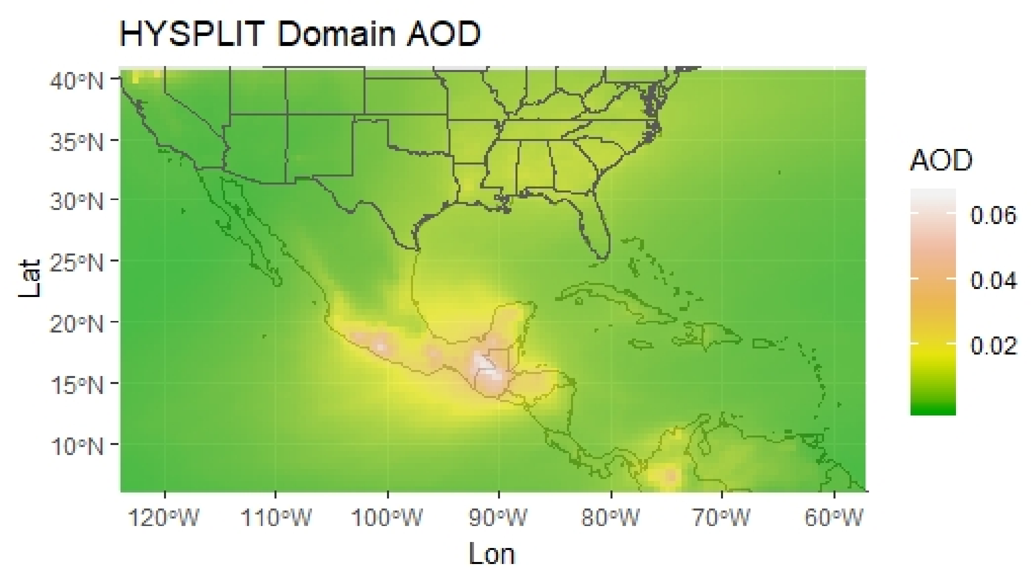
- Satellite data retrieval at 1-km resolution
- Provides twice-daily snapshot of total-column aerosols
- Uses time series of MODIS images to retrieve AOD

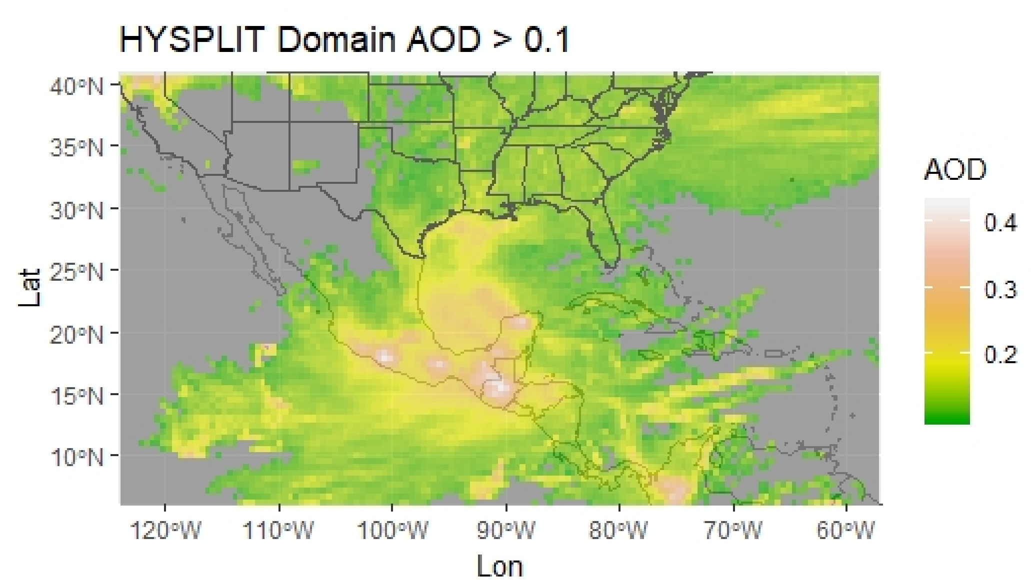




Dispersion Modeling: HYSPLIT (2 of 2)

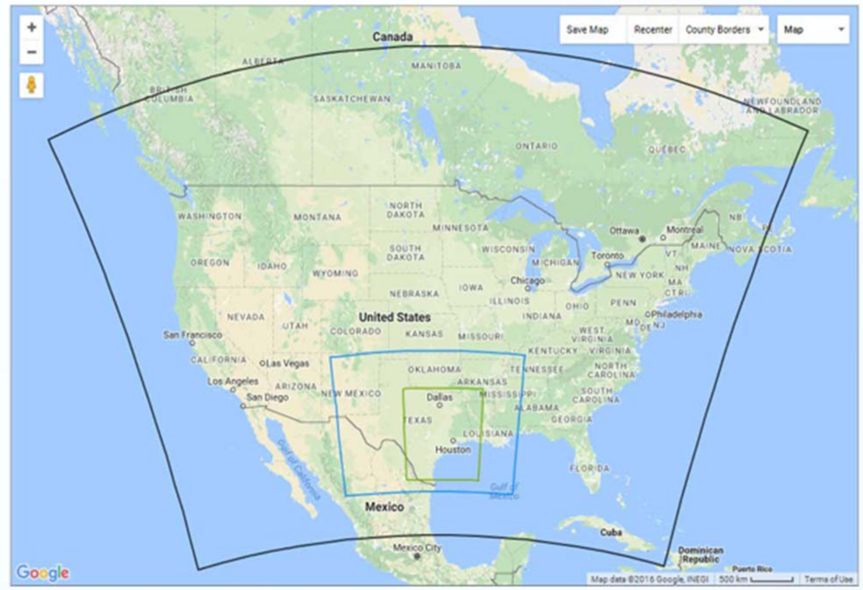
- Large domain
- GDAS05 3-hourly meteorology at half degree resolution
- 50-km resolution receptor grid
- AOD calculated using second IMPROVE equation (Pitchford et al., 2007) with MERRA-2 reanalysis relative humidity
- AOD represents smoke contribution only





Photochemical Modeling: CAMx (1 of 2)

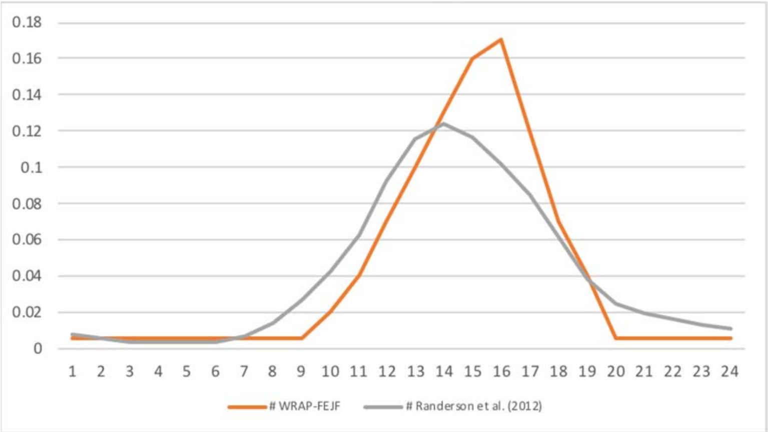
- CAMx v.6.5
- May 1 – October 1, 2012, episode from Texas Commission on Environmental Quality (TCEQ)
- Modeled using three emissions scenarios:
- No Fire
- FINN v1.5 (“CAMx1”)
- FINN v2.2 (“CAMx2”)
- Chemical Mechanisms:
- Gas-phase: CB6r4
- Particulate matter: CF/SOAP2.1/ISORROPIA
- WRF v.3.7.1 meteorological model
- Emissions inventories for anthropogenic and biogenic sources from TCEQ except for fire emissions

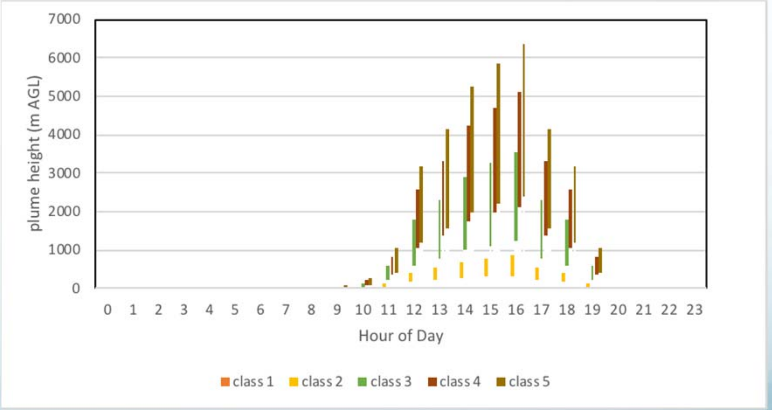


CAMx Nested Modeling Grids:
36 km (black)/12 km (blue)/4 km (green)

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



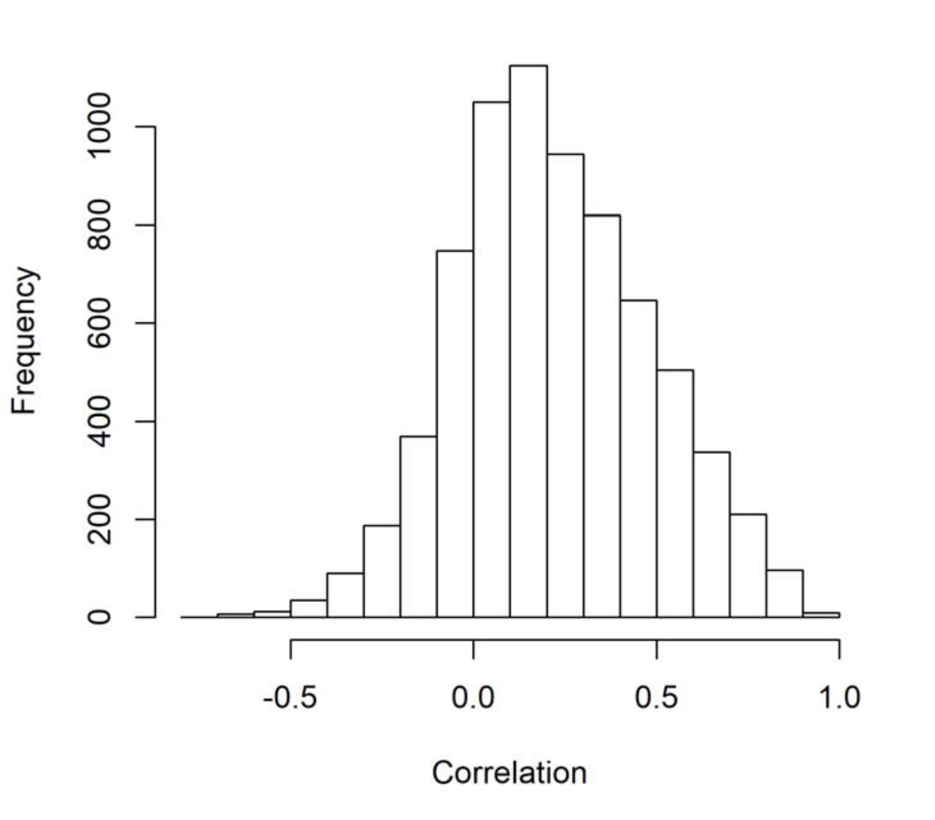


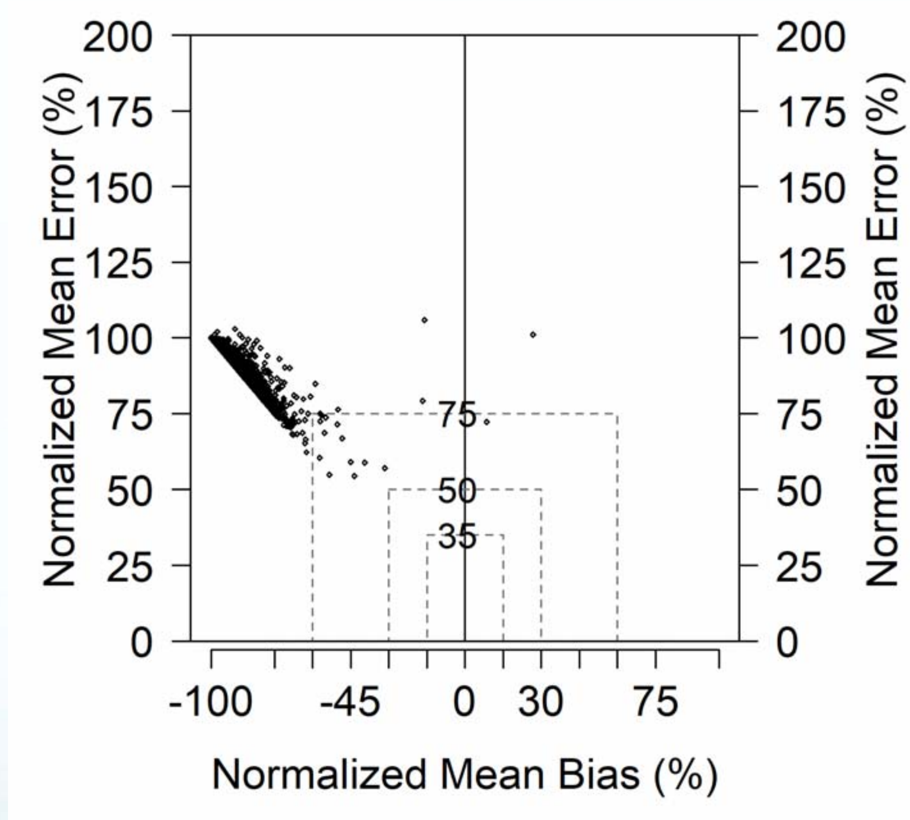
*Air Sciences, 2005, Morris et al., 2012; Ramboll, 2016

Validation Statistics

Type	P rghc# Frp sdulvrq# +Rev2P rgho,	Years	Resolution (km)	P hdq# Q	P hdq#Rev DRG	P hdq# P rghc# DRG	P hdq#U	P hdq#U5	P hdq# IE#+(,	P hdq# QP VH#	P hdq# IDF5
Wildfire	FDP {42K\VSOIW	2012	50	655#e 4	31338#e 31337	31343#e 31345	315<4# œ 315:6	3148<#e 31489	5;1;#e 8917	61<#e :13	316:5#e 31775
	FDP {52K\VSOIW	2012	50	655#e 4	3133;#e 3133;	31343#e 31345	31655# œ 315:<	314;4#e 31497	615#e 9419	617#e 918	316;9#e 31789
Total AOD	P DIDF2FDP {4	2012	4	:584# œ 9<;6	3148:#e 3139<	31589#e 31369	3146:# œ 315;5	313<;#e 31463	8;1;#e 6;16	31:#e 31;	3188;#e 3175<
	P DIDF2FDP {5	2012	4	:584# œ 9<;6	3148:#e 3139<	3158<#e 3136;	31467# œ 315:9	313<7#e 31458	8<19#e 6;18	31:#e 31;	31885#e 3175;
Mixed	P DIDF2K\VSOIW	2012-2017	50	74<#e 63;	3144<#e 3137;	31339#e 3133<	31558# œ 31598	31454#e 3148;	04;818# œ 4815	48:19#e :9719	31349#e 31444

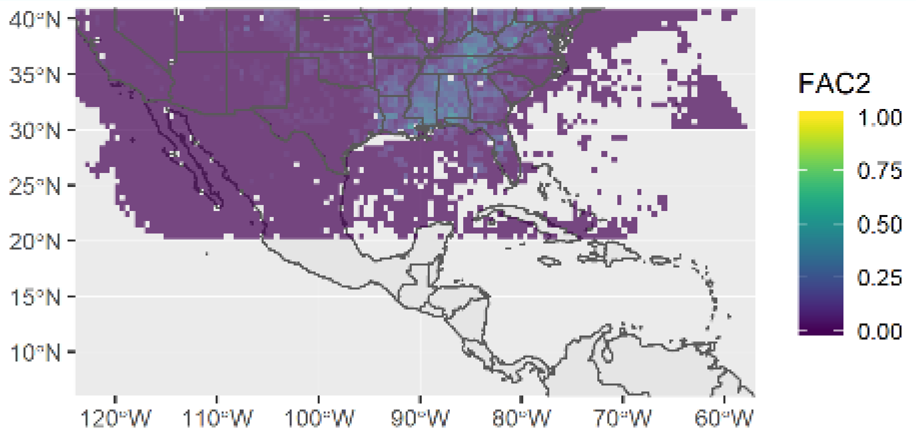
HYSPLIT Correlation, Bias and Error

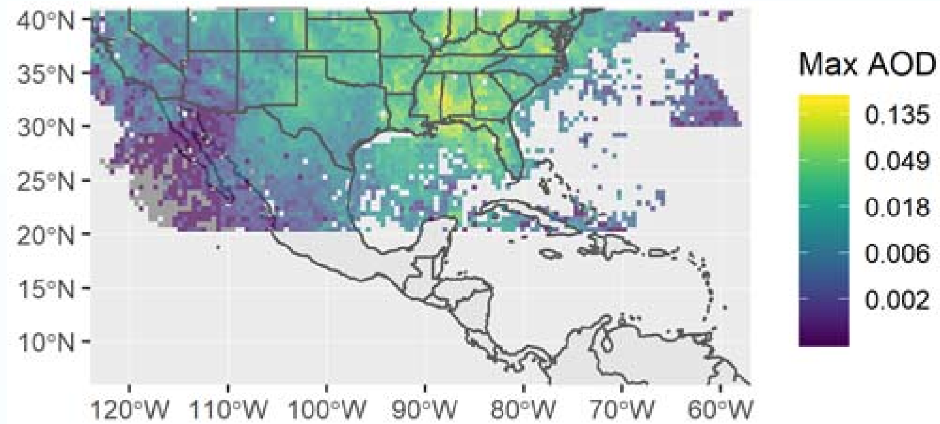


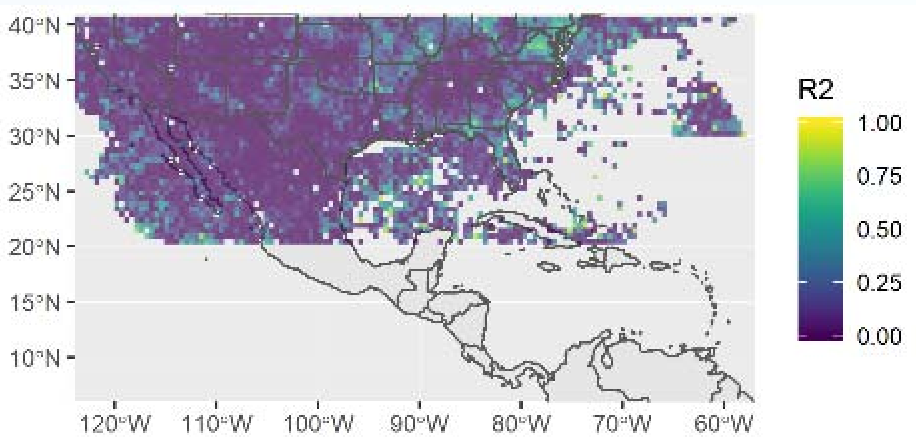


Statistics shown relative to MAIAC

HYSPLIT Comparison with MAIAC

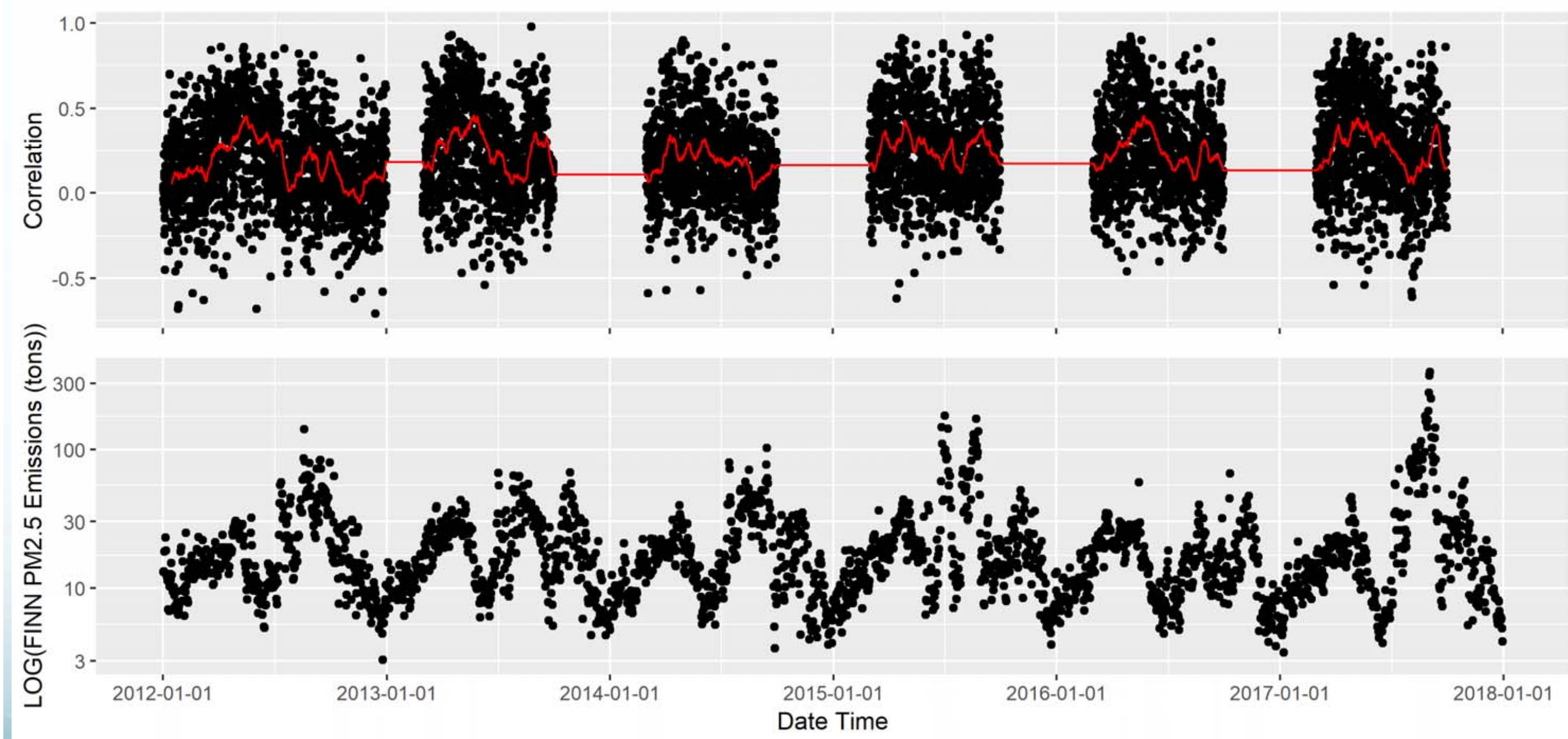






- MAIAC comparison with HYSPLIT results shows higher agreement in locations with higher AOD
- October 2012 shown above

HYSPLIT Correlation with MAIAC



Red line indicates daily mean correlation

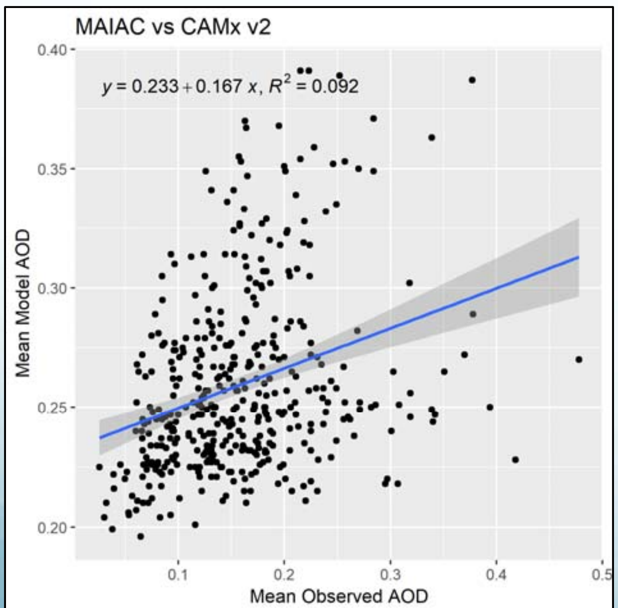
Validation Statistics

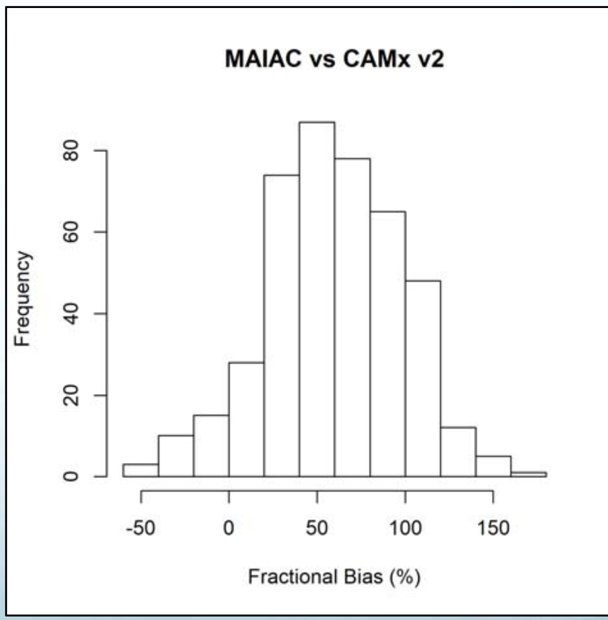
Type	P rghc# Frp sdulvrq# +Rev2P rgho,	Years	Resolution (km)	P hdq# Q	P hdq# Rev DRG	P hdq# P rghc# DRG	P hdq# U	P hdq# U5	P hdq# IE#+(,	P hdq# QP VH#	P hdq# IDF5
Wildfire	FDP {42K\VSOL W	2012	50	655	31338#œ 31337	31343#œ 31345	315<4# œ 315:6	3148<#œ 31489	5;1;#œ 8917	61<#œ :13	316:5#œ 31775
	FDP {52K\VSOL W	2012	50	655	3133;#œ 3133;	31343#œ 31345	31655# œ 315:<	314;4#œ 31497	615#œ 9419	617#œ 918	316;9#œ 31789
Total AOD	P DIDF2FDP {4	2012	4	:584	3148:#œ 3139<	31589#œ 31369	3146:# œ 315;5	313<;#œ 31463	8;1;#œ 6;16	31:#œ 31;	3188;#œ 3175<
	P DIDF2FDP {5	2012	4	:584	3148:#œ 3139<	3158<#œ 3136;	31467# œ 315:9	313<7#œ 31458	8<19#œ 6;18	31:#œ 31;	31885#œ 3175;
Mixed	P DIDF2K\VSOIW	2012-2017	50	74<	3144<#œ 3137;	31339#œ 3133<	31558# œ 31598	31454#œ 3148;	04;818# œ 4815	48:19#œ :9719	31349#œ 31444

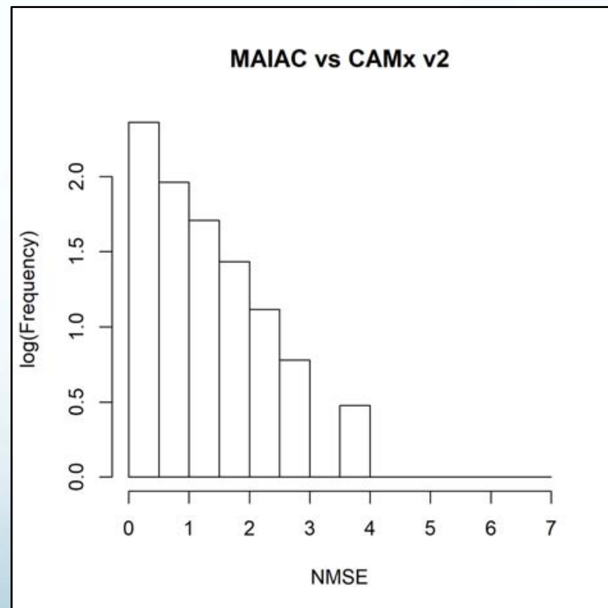
Targets: FAC2 is greater than 50%, the relative mean bias is within 30% or less, and the normalized mean square error is less than a factor of three (Chang and Hanna, 2004).

CAMx2 Validation Statistics by Month

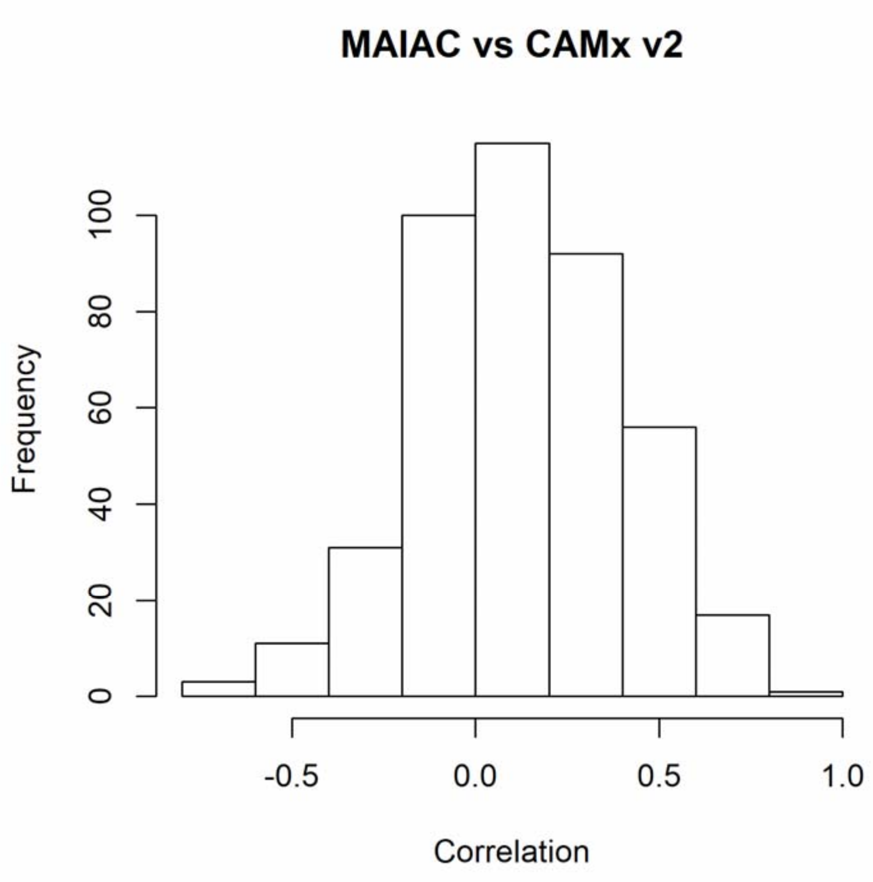
P rqwk	Q	P hdq#P DIDF#DRG	P hdq#FDP {5# DRG	U	U5	IE#+(,	QP VH	IDF5
5	6710	0.179 ± 0.066	0.266 ± 0.038	0.137 ± 0.294	0.104 ± 0.142	48 ± 37	0.517 ± 0.510	0.587 œ 317<5
6	6613	0.169 ± 0.068	0.275 ± 0.040	0.164 ± 0.290	0.110 ± 0.150	57 ± 34	0.569 ± 0.513	0.567 œ 317<8
7	5436	0.155 ± 0.082	0.244 ± 0.031	0.061 ± 0.264	0.073 ± 0.100	60 ± 43	0.778 ± 0.856	0.379 œ 317;8
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 œ 317<<
9	10635	0.123 ± 0.056	0.265 ± 0.042	0.202 ± 0.257	0.106 ± 0.129	82 ± 33	1.197 ± 1.148	3159: œ 31775

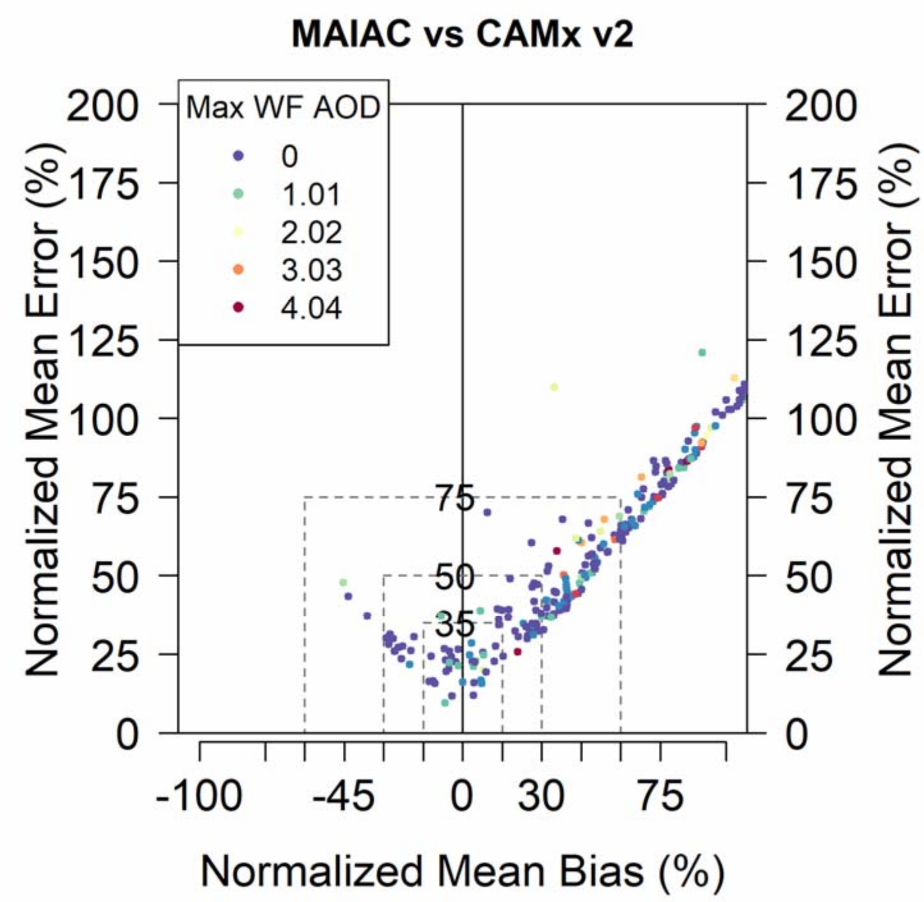




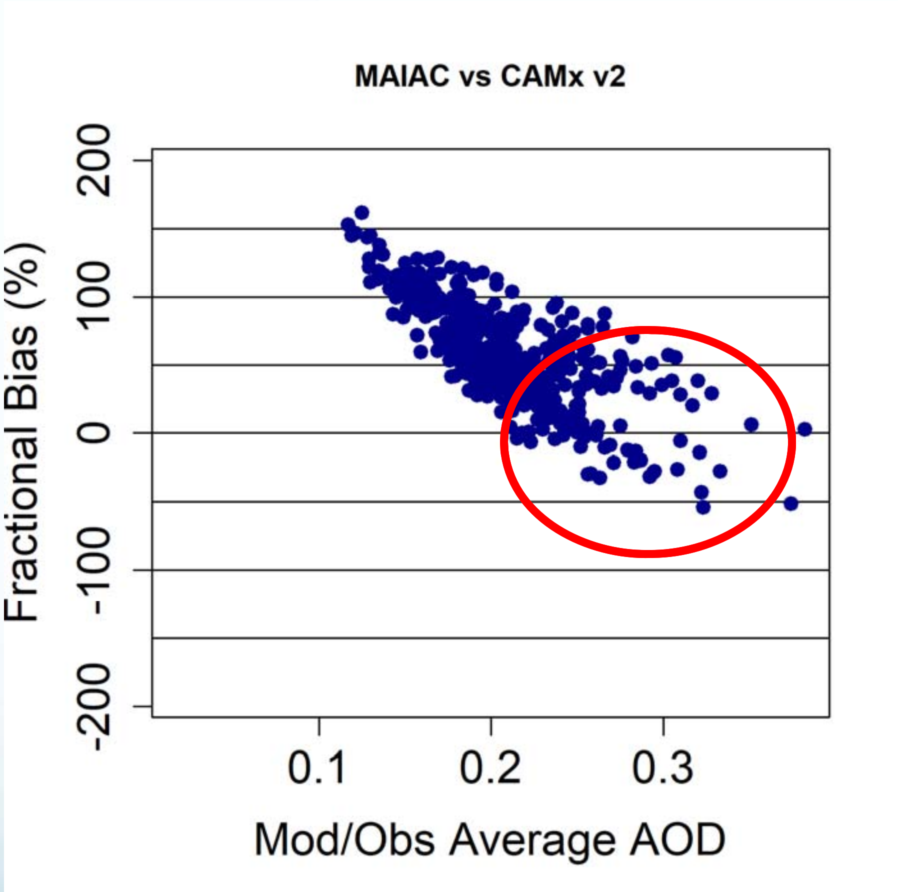


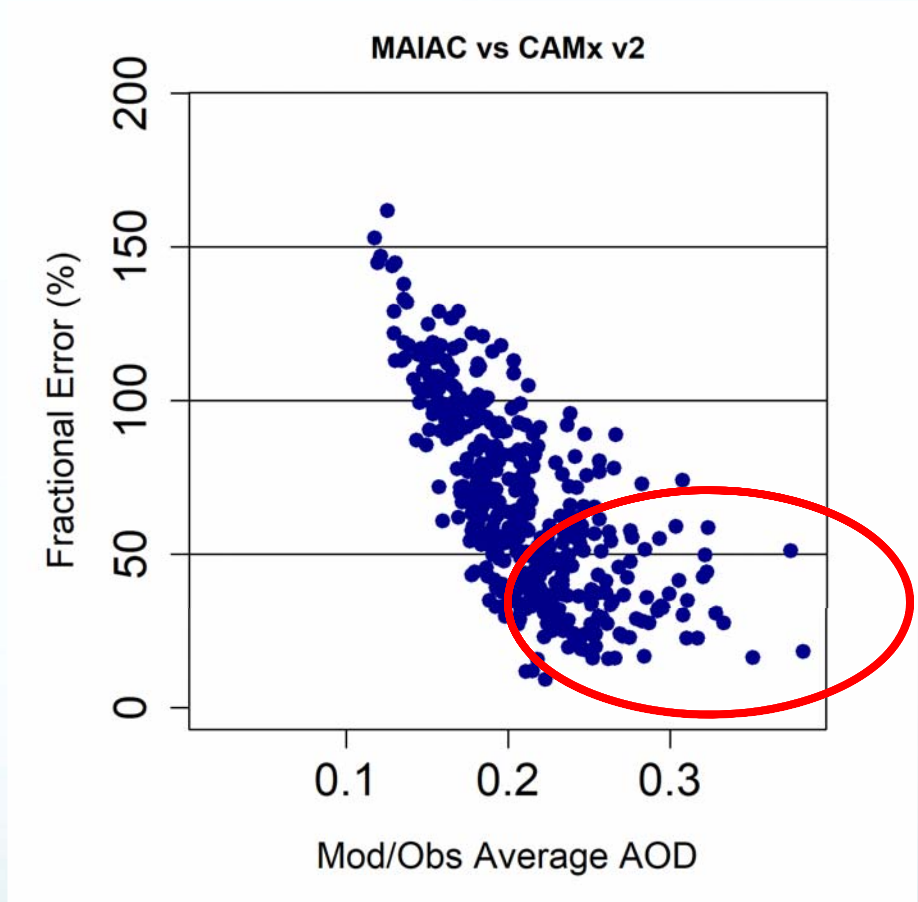
CAMx2 vs MAIAC Validation





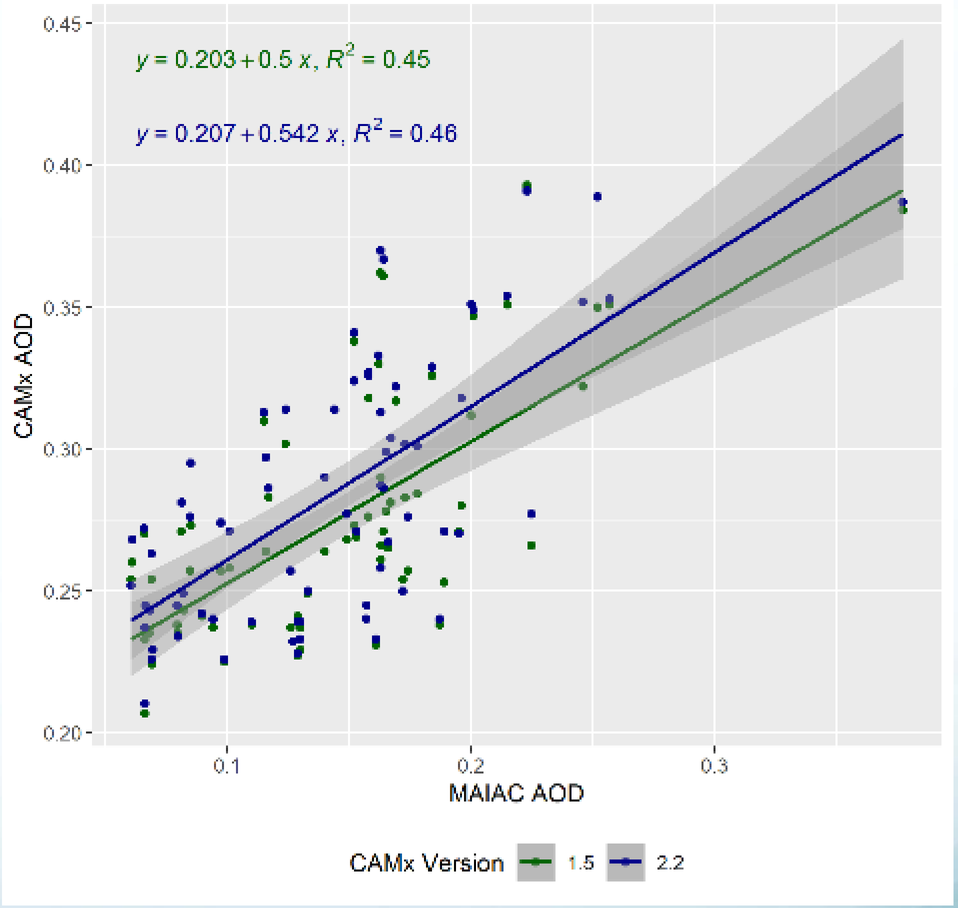
CAMx2 Fractional Bias and Error





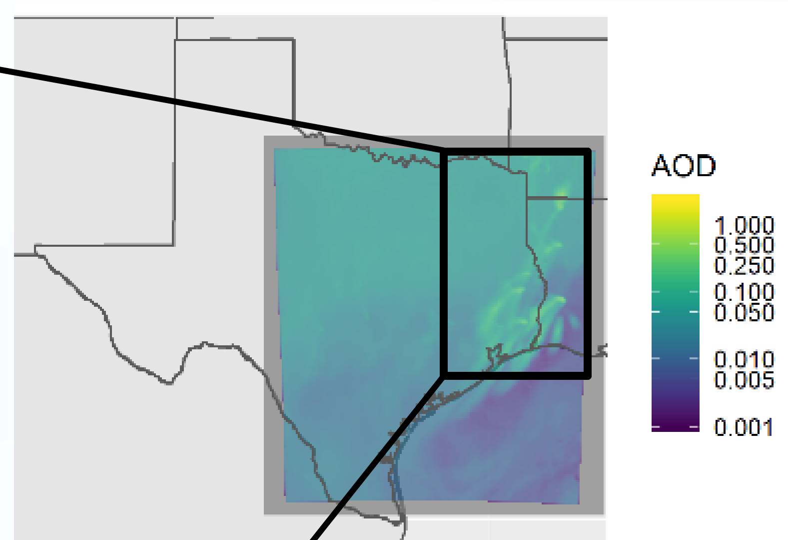
Model Results for High-Smoke Periods

- 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

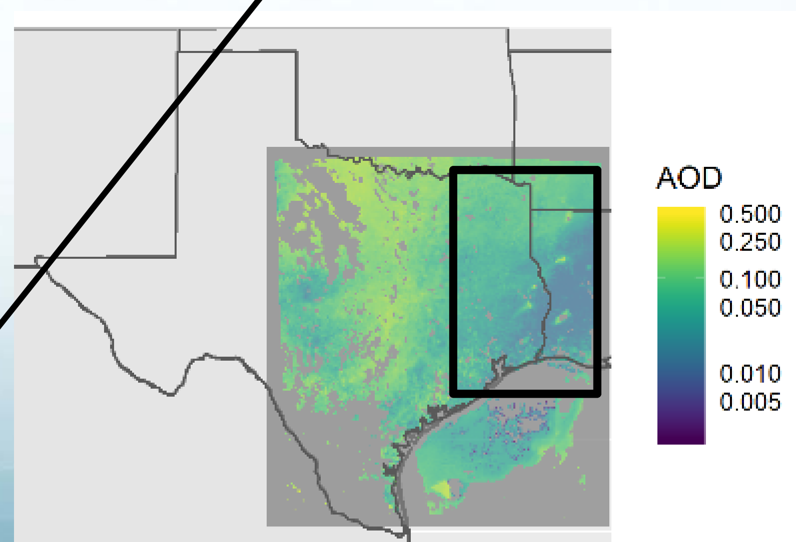


Case Study: September 20, 2012

CAMx2



MAIAC



Summary

- **FINN v2.2 Development:**
  - Addresses improvements to earlier versions (e.g. burned area estimates, detection of smaller fires)
  - Incorporates recent data (e.g., land cover, fuel loading, emission factors, chemical speciation)

- **Evaluation:**
  - 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 improvement inagreement with satellite data over FINN v1.5 for smoke-impacted cases (R2 0.46 vs 0.45, slope 0.54 vs 0.5, case studies show additional strengths)

Recommendations and Plans for Model Availability

- **Plans for Availability:**
  - Open source code: NCAR GitHub
  - FINNv2.2 code and global-scale simulations released via NCAR data portal currently serving as repository of FINNv1.5 files
  - **We encourage community feedback**

- **Recommendations for Future Work:**
  - Continued evaluation across different regions of the world
  - On-going field campaigns should inform future evolution

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Emissions Factors: FINN v1.5 and v2.2

Fkhp lfdo# Vshflhv	IIQQ#y418#dqg#IIQQ#y515#Hp lvvlrq#Idfwruv#e|#Odqg#Fryhu#W|sh# +j#nj#elrp dvv#exuqhg−4,													
	Wursl fdo# Iruhvw4		Whp shudwh# Iruhvw5		Whp shudwh# Hyhujuhhq# Iruhvw5		Eruhdo6		Zrrg|# Vdydqqdk7		Vdydqqd#dqg# Judvvodqgv4		Fursv8	
	y418	y515	y418	y515	y418	y515	y418	y515	y418	y515	y418	y515	y418	y515
FR5	4976	4976	4843	4843	497:	4956	47;<	4898	4:49	49;4	49<5	49;9	486:	4777
FR	<5	<6	455	455	;;	445	45:	444	9;	9:	8<	96	444	<4
FK7	814	814	8194	8194	6169	617	9	9	519	6	418	5	9	81;5
QPRF9	59	841<	5;18	89	5618	7<16	5<16	7;18	71;	571;	<16	5;15	8:	8417
K5	617	617	5	5	5	5	516	516	31<:	31<:	31<:	41:	517	518<
QR{ dv# QR	519	519	4137	4137	41<5	41<9	31<	31<8	61<	6198	51;	61<	618	5176
VR5	317	317	414	414	414	414	4	4	319;	319;	317;	31<	317	317
SP518	<14	<1<	48	48	451<	4:1<	4816	4;17	<16	:14	817	:14:	81;	9176
WSP	4;18	4;18	4;	4;	4;	4;	4;	4;17	4817	4817	;16	;16	46	46
WSF	815	815	<1:	<1:	<1:	<1:	;16	;16	:14	:14	6	6	7	7
RF	71:	71:	:19	:19	:19	:19	:1;	:1;	919	61:	519	519	616	5199
EF	3185	3185	3189	3189	3189	3189	315	315	318	4164	316:	316:	319<	3184
QK6	4166	416	517:	517:	31;7	414:	51:	41;	415	415	317<	3189	516	5145
QR	31<4	31<	3167	31<8	3167	31<8	418	31;6	417	31::	31:7	5149	41:	414;
QR5	619	619	51:	5167	51:	5167	6	3196	417	518;	615	6155	61<	51<<
QPKF	41:	41:	81:	81:	81:	81:	81:	81:	617	617	617	617	:	:

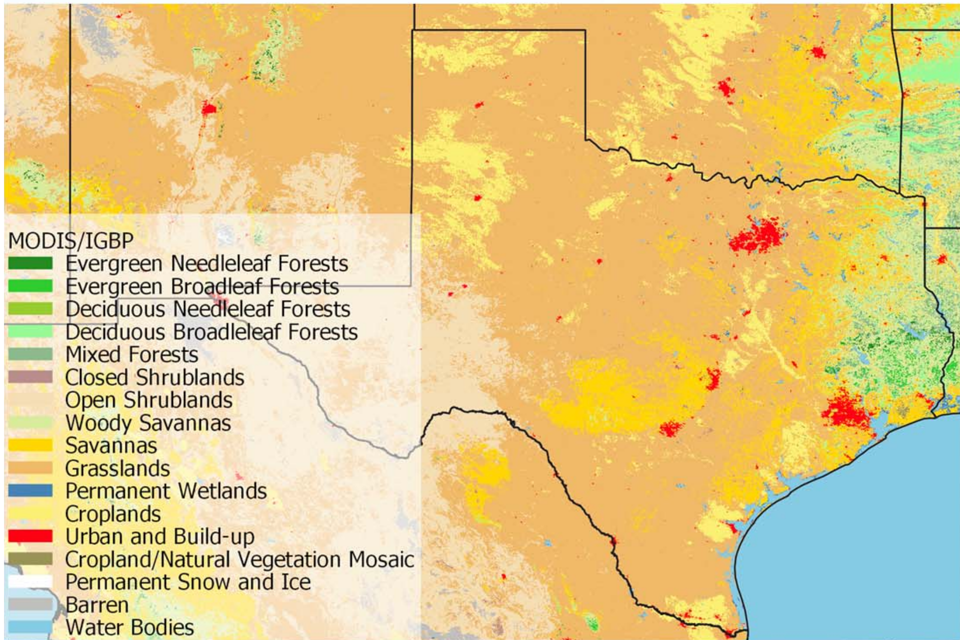
Biomass Loading by Global Region: FINN v1.5 and v2.2

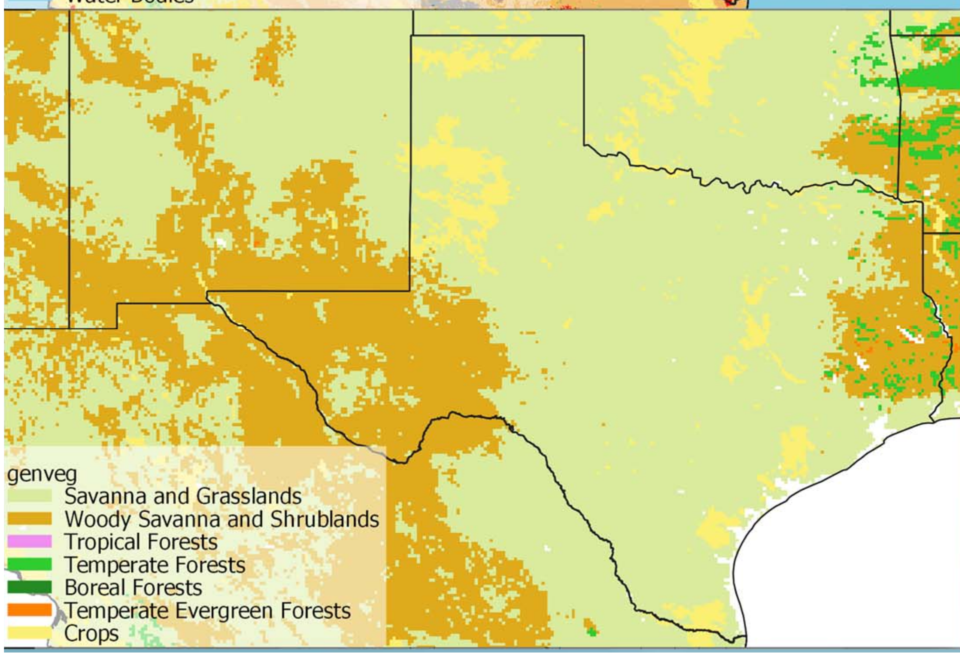
Joredd# Uhjlrq	Elrp dvv#Ordglqj#e|#Odqg#Fryhu#W|sh#iru#IlQQ#y418#dqg#IlQQ#y515 +j#p 05,									
	Wursfldo#Iruhvw		Whp shudwh#Iruhvw		Eruhdo#Iruhvw		Zrrg|#Vdydqqd2##### Vkuxeodqgv		Vdydqqd#dqg Judvvodqgv[j]	
	y418	y515	y418	y515	y418	y515	y418	y515	y418	y515
Qruwk# Dp hulfd	5;/3:9[e]	5;/3:9	43/7<5	43/994[h]	58/333[d]	4:/;:8[h]	8/:38	7/:95	<:9	<:9
Fhqwudo# Dp hulfd	53/593	59/833[h]	44/333[d]	44/333			5/557	5/557	74;	74;
Vrxwk# Dp hulfd	58/98<	59/:88[h]	:/733[d]	:/733			6/3::	6/3::	885	957[h]
Qruwkhuq# Diulfd	58/699	58/699	6/7<:	6/7<:			5/834	5/834	64;	6;5[h]
Vrxwkhuq# Diulfd	58/5<8	58/5<8	9/433	9/433			5/7;6	5/7;6	693	744[h]
Zhvwhuq# Hxursh	5;/3:9[e]	5;/3:9	:/453	:/453	9/55;	9/55;	7/856	7/856	4/654	4/654
Hdvwhuq# Hxursh	5;/3:9[e]	5;/3:9	44/6;9	44/6;9	;/479	;/479	:/:85	:/:85	4/945	4/945
Qruwk# Fhqwudo# Dvld	9/4;4[f]	9/4;4	53/;3:	53/;3:	58/333[d]	47/<58[h]	44/33<	44/33<	5/4:3	5/4:3
Qhdu#Hdvw	9/4;4[f]	9/4;4	43/649	43/649			5/<79	5/<79	988	988
Hdvw#Dvld	9/4;4[f]	47/<74[h]	:/;98	:/;98			7/5<5	7/5<5	:55	:55
Vrxwkhuq# Dvld	5:/<9<	59/879[h]	47/95<	47/95<			8/35;	8/35;	4/778	4/778
Rfhdqld	49/6:9	49/6:9	44/9<9[g]	46/868[h]			4/5:4	5/7;6[i]	578	885[h]
Dqwdufwlfd	3	3	3	3	3	3	3	3	3	3

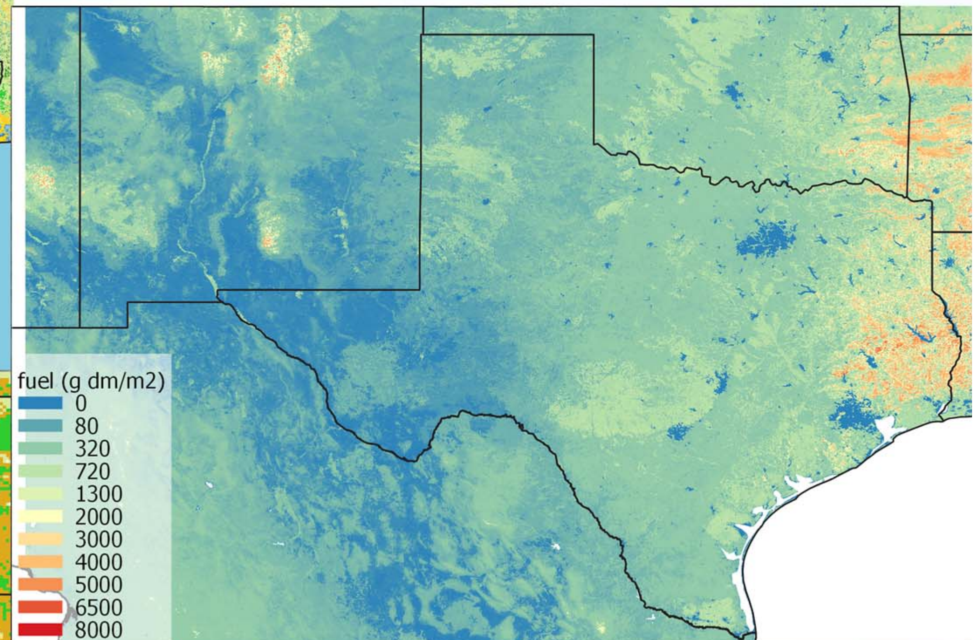
FCCS Biomass Loadings

Odqg#Fryhu#W|sh	Elrpdvv#Ordglqj +j#p 05,	
	Frduvh2Zrrg|	Khuedfhrxv
Zdwhu	3	3
Hyhujuhhq#Qhhgohohdi#Iruhvw	5;/<63	76:
Hyhujuhhq#Eurdgohdi#Iruhvw	4</4:	983
Ghflgxrxv#Qhhgohohdi#Iruhvw	48/986	874
Ghflgxrxv#Eurdgohdi#Iruhvw	4</;5	<97
Pl{hg#Iruhvw	53/66<	:99
Forvhg#Vkuxeodqgv	8/469	55<
Rshq#Vkuxeodqgv	5/;;<	49<
Zrrg|#Vdydqqdv	45/<3:	99;
Vdydqqdv	43/<3:	:97
Judvvodqgv	5/;55	73:
Shupdqhqw#Zhwodqgv	;/83<	:45
Fursodqgv	3	<35d
Xuedq#dqg#Exlow0Xs	3	3
Fursodqg2Qdwxudo#Yhjhwdwlrq	</3;3	;55
Vqrz#dqg#Lfh	3	3
Eduuhq#ru#Vsduvho|#Yhjhwdwhg	4/688	437

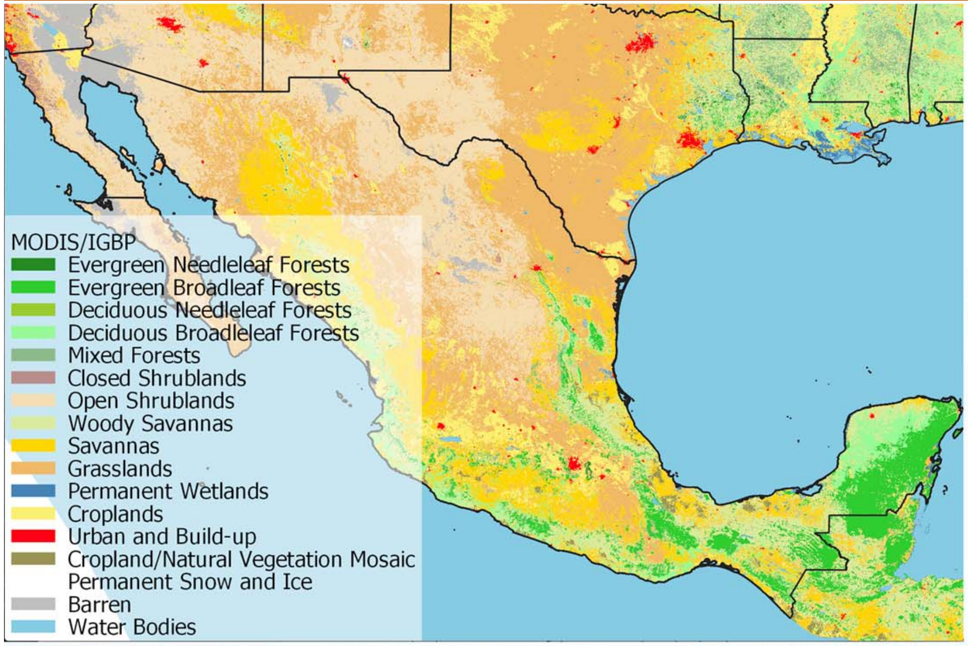
Land Cover and Fuel Loading in Texas

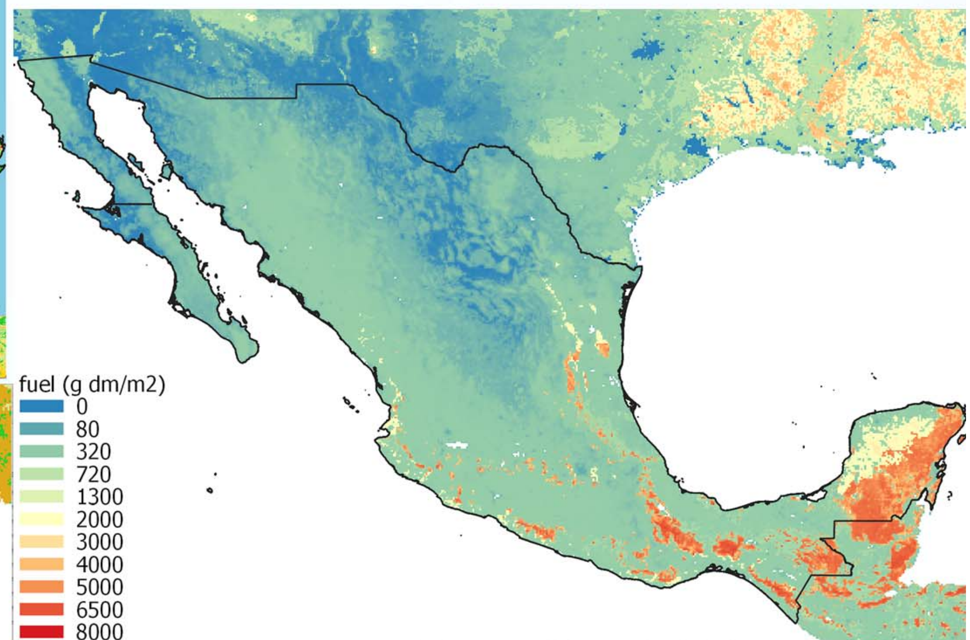


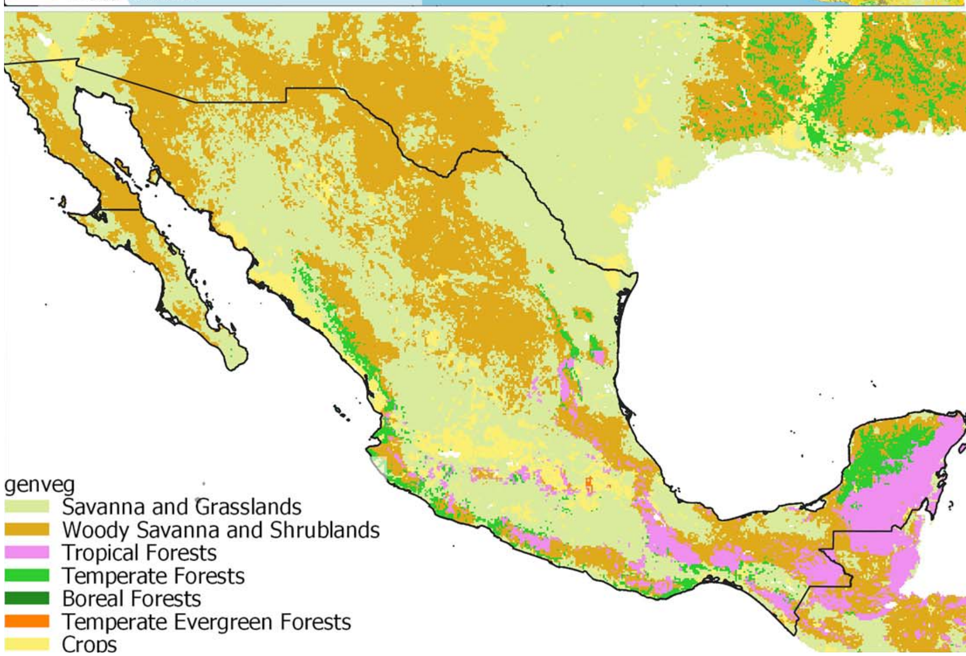




Land Cover and Fuel Loading in Mexico







VIIRS Active Fire Products: Screening for Non-Fires Sources

Type Type attributed to thermal anomaly:

0 = presumed vegetation fire
1 = active volcano
2 = other static land source
3 = offshore detection (includes all detections over water)

IGBP to FINN land Cover Mapping

IGBP Land Cover			IIQQ#P dsslqj			
IG	Ghvfulswlrq		odw#?5618	5618083	odw#A#83	
4	hyhujuhhq# qhhgdndi# iruhvw		9	9	8	
5	hyhujuhhq# eurdgdndi# iruhvw		6	7	7	
6	ghflgxrxv# qhhgdndi# iruhvw		7	7	8	
7	ghflgxrxv# eurdgdndi# iruhvw		7	7	7	
8	p l{hg#iruhvw		6	7	8	
9	forvh# vkuxeodqgv	5				
:	rshq# vkuxeodqgv	5				
;	zrrg|# vdydqqd	5				
<	vdydqqd	4				
43	judvvodqg	4				
44	shup dqhqw# z hwodqg	4				
45	fursodqg	<				
46	xuedq					ghshqgv#rq#wuhh#fryhu/#?73# @A#4/#73093#@A#5/#A93#@A# +6/7/8/#ghsgqh rq#odwlwxgh,
47	furs2qdwxudo p rvdlf	4				
48	vqrz2lfh					
49	eduuhq	4				

IIQQ#IG	Fdwhjru|
4	judvvodqg
5	vkuxeodqg
6	wurslfdo# iruhvw
7	whp shudwh# iruhvw
8	eruhdo# iruhvw
9	Hyhujuhhq# iruhvw
<	furs

HYSPLIT Results Ground Validation

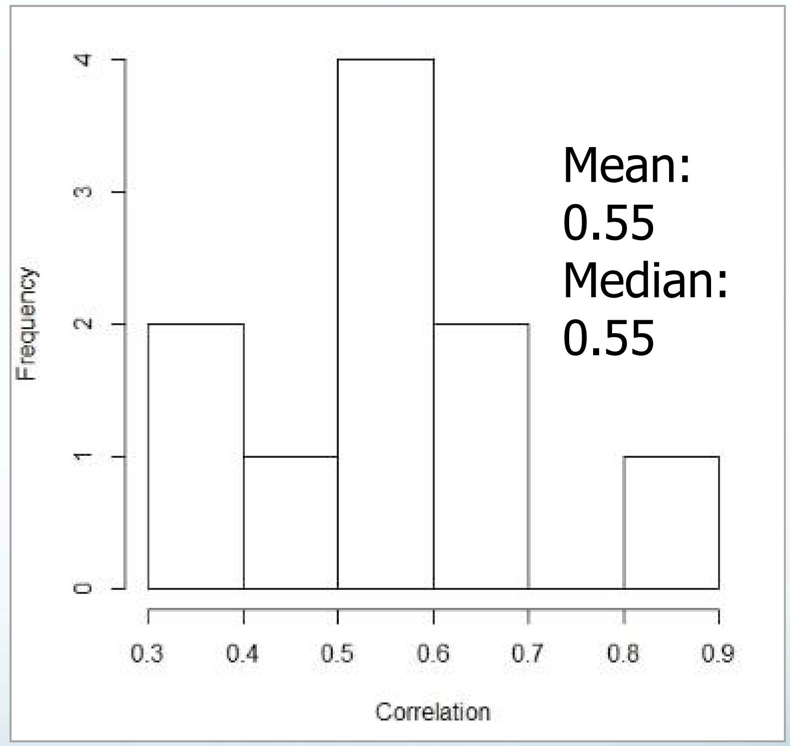
- Xvh#Wrwdo#Fduerq#+WF,#dv#d#sur{|#iru#EE# sruwlrq#ri#SP 518 ehfdxvh#zlogiluh#SP #lv# frpsulvhg#ri#xs#wr#;3(#RF#+Fodunh#hw#do1/# 533:>#XV#HSD#UKU#Jxlgdqfh/#5349># PfFoxuh#dqg#Mdiih/#534;,

- Wrwdo#Fduerq#fdq#eh#fdofxodwhg#xvlqj#HF# dqg#RF#frqfhqwudwlrqv

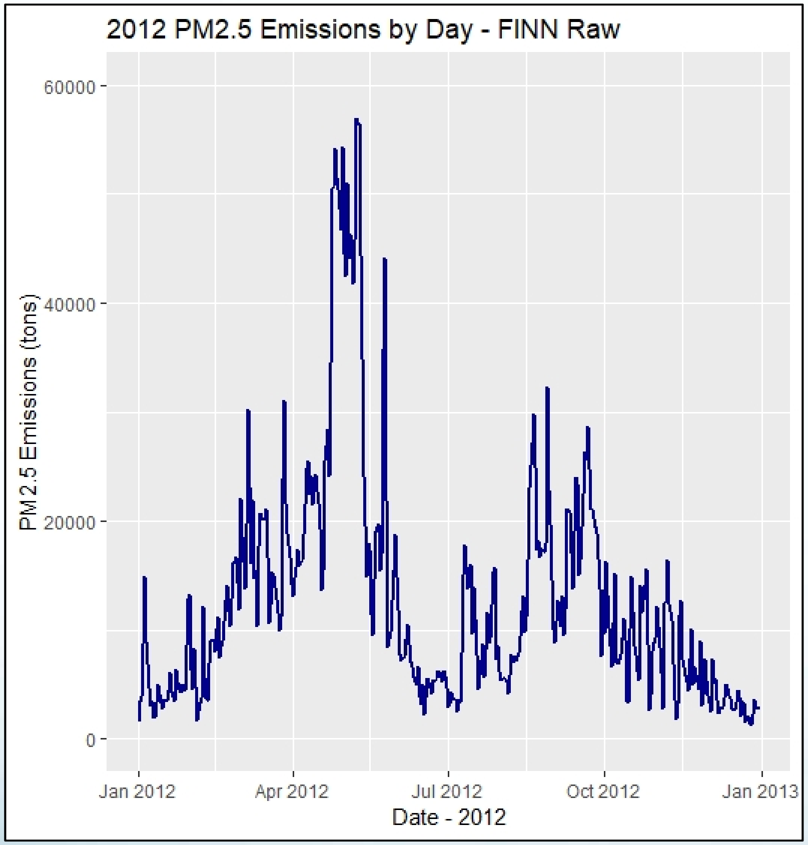
  WF#@#HF#.#41;-RF,

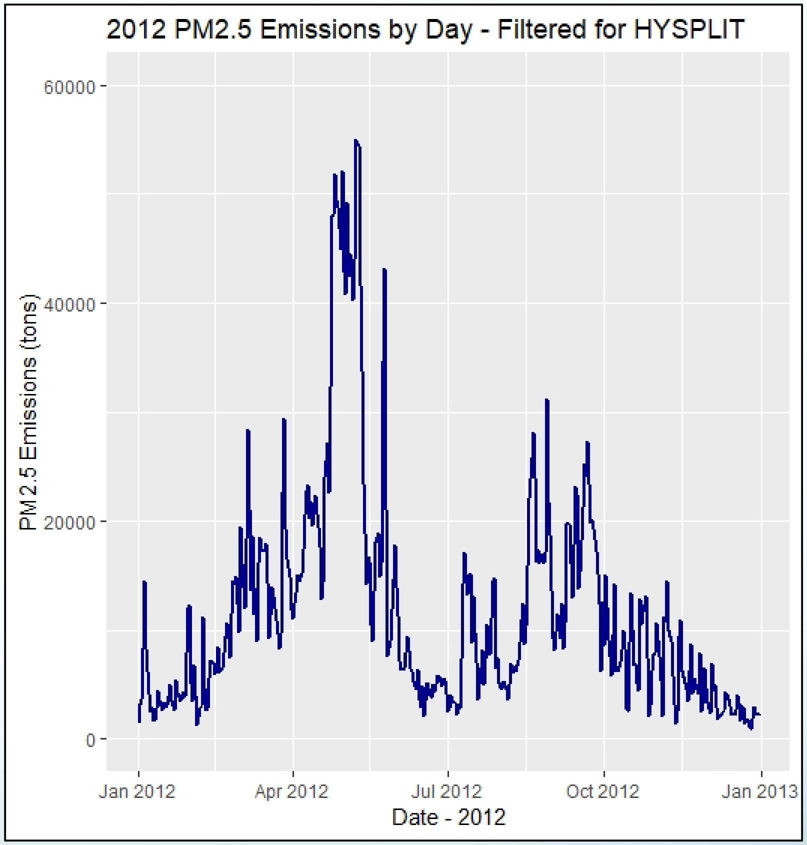
- 43#LPSURYH#vlwhv#durxqg#Wh{dv/#lqfoxglqj# QP/#RN/#DU/#dqg#OD

- Fdofxodwh#Shduvrq#fruuhodwlrq#ehwzhhq# K\VSOLW#fdofxodwhg#dqg#LPSURYH#iru# vxpphu#5345

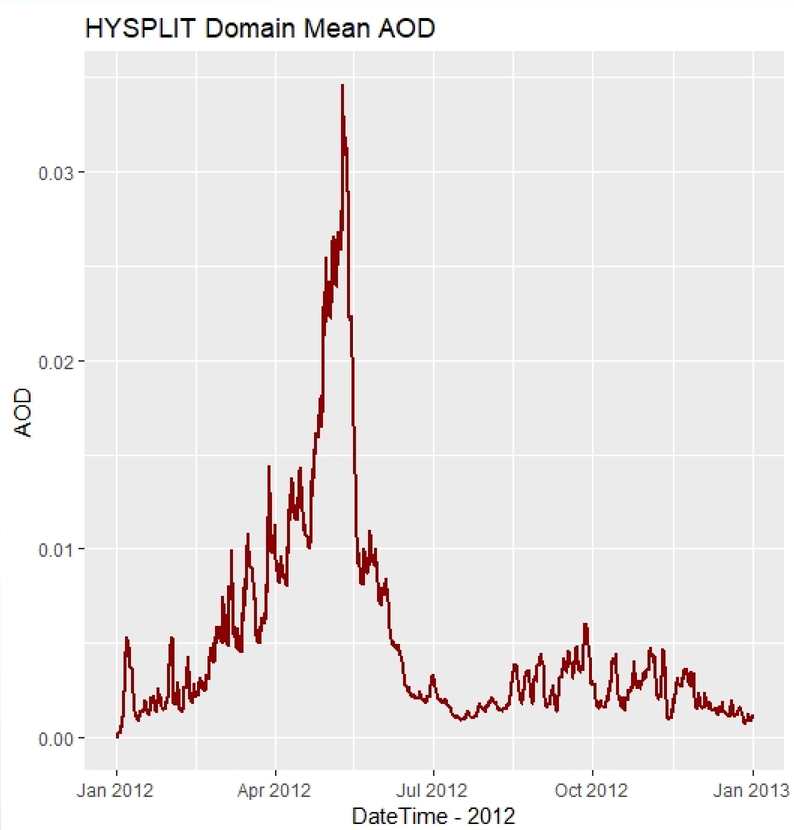


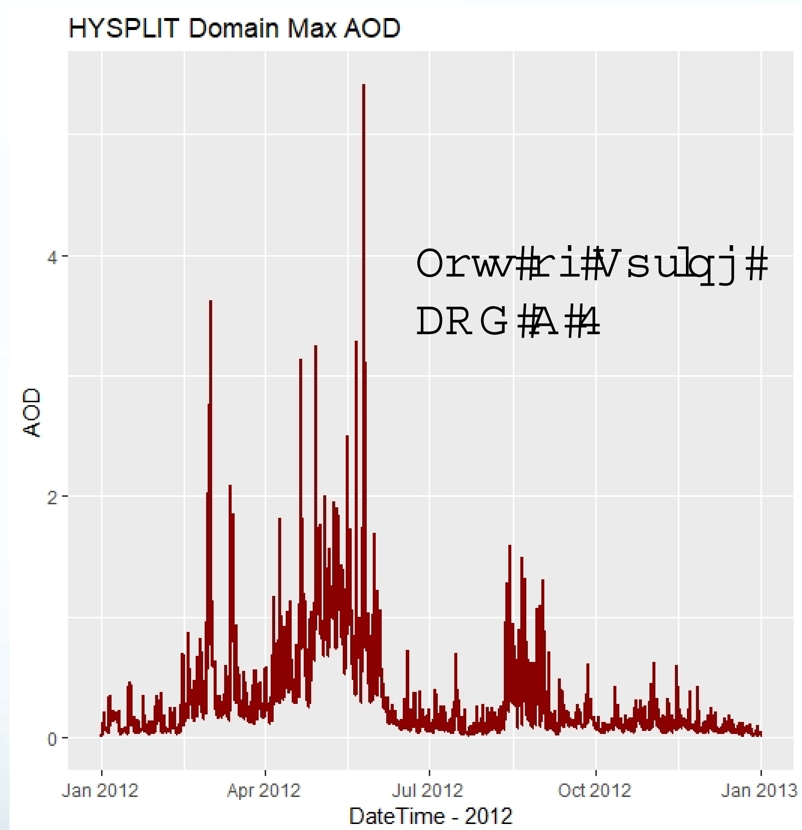
2012 Emissions Time Series





HYSPLIT Domain AOD





Orw#ri#Vsulqj#
DRG#A#4

DRG#Fdofxodwhg#iurp#IP SURYH#5#Htq