ENVIRON

April 27, 2012

FINAL TECHNICAL MEMORANDUM No. 5: FIRE EMISSIONS

To: Tom Moore, Western Regional Air Partnership (WRAP)

From: Ralph Morris and Edward Tai, ENVIRON International Corporation
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Subject: Wildfires, Prescribed Burns and Agricultural Burning Emissions

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INTRODUCTION

ENVIRON International Corporation (ENVIRON), Alpine Geophysics, LLC (Alpine) and the University of North Carolina (UNC) at Chapel Hill Institute for Environment are performing the West-wide Jump Start Air Quality Modeling Study (WestJumpAQMS) managed by the Western Governors' Association (WGA). WestJumpAQMS is setting up the CAMx and CMAQ photochemical grid models for the 2008 calendar year (plus spin up days for the end of December 2007) on a 36 km CONUS, 12 km WESTUS and several 4 km Inter-Mountain West domains. The WestJumpAQMS Team are currently compiling emissions to be used for the 2008 base case modeling, with the 2008 National Emissions Inventory (NEI) being a major data source. Thirteen Technical Memorandums discussing the sources of the 2008 emissions by major source sector are being prepared as part of the WestJumpAQMS:

1. Point Sources including Electrical Generating Units (EGUs) and Non-EGUs;
2. Area plus Non-Road Mobile Sources;
3. On-Road Mobile Sources that will be based on MOVES;
4. Oil and Gas Sources;
5. Fires Emissions including wildfire, prescribed burns and agricultural burning;
6. Fugitive Dust Sources;
7. Off-Shore Shipping Sources;
8. Ammonia Emissions;
9. Biogenic Emissions;
10. Eastern USA Emissions;

11. Mexico/Canada;

12. Sea Salt and Lightening Emissions; and

13. Emissions Modeling Parameters including spatial surrogates, temporal adjustment parameters and chemical (VOC and PM) speciation profiles.

This document is final version of Technical Memorandum Number 5 that discusses the approach to be used for developing 2008 emissions for fires. In particular, this Memorandum describes the source data considered for WestJumpAQMS and how the emissions associated with wildfires, prescribed burns and agricultural burning will be treated in the air quality modeling. Fire emissions due to home heating and recreation (e.g., wood stoves and fireplaces), trash burning and biomass fueled boilers are not addressed in this Memorandum. They will be addressed under Technical Memorandum No. 2: Area and Non-Road Mobile Emissions Sources and will be based on the 2008 National Emissions Inventory (NEI).

FIRE EMISSIONS SOURCES

Emissions from fires are important ozone and $PM_{2.5}$ precursors and can obscure visibility. Procedures for developing fire emissions inventories have been undergoing development and improvements. To address regional haze State Implementation Plans (SIPs) for the western States, the Western Regional Air Partnership (WRAP) Fire Emissions Joint Forum (FEJF) went through four Phases of fire emissions development:

- Phase I developed an initial 2002 fire emissions database for actual fires and the western U.S.
  - http://www.wrapair.org/forums/fejf/tasks/FEJFtask7PhaseI.html
- Phase II developed a more refined actual fire emissions inventory for 2002 and the western U.S.
  - http://www.wrapair.org/forums/fejf/tasks/FEJFtask7PhaseII.html
- Phase III and IV developed fire emission inventories for 2000 through 2004 as well as an "average" fire emissions inventory for the 2000-2004 baseline that had locational characteristics of the 2002 fire emissions.
  - http://www.wrapair.org/forums/fejf/tasks/FEJFtask7Phase3-4.html
- The final Phase of the WRAP FETJ work effort was the compilation of fire emissions for the five Regional Planning Organizations.
  - http://www.wrapair.org/forums/fejf/tasks/FEJFtask7InterRPO.html

WRAP classified fire emissions as either wildfires (WF), prescribed burns (Rx) or agricultural burning (Ag). In some cases, subclasses of fire definition within each of these three major fire classifications are prescribed. Given that the goal of the regional haze rule was natural visibility conditions by 2064 and the importance of wildfires on natural visibility conditions for the worst days, the distinction of natural and man-made fires was a critical operational classification scheme for regional haze planning purposes.

WRAP continues to track fire emissions in the western U.S. through the Fire Emissions Tracking System (http://wrapfets.org/).

SOURCES OF 2008 FIRE EMISSIONS

The Joint Fire Science Program (JFSP) is funding the Deterministic and Empirical Assessment of Smoke's Contribution to Ozone (DEASCO3[1]) study that, among other things, will develop a 2008 fire emissions inventory using techniques learned through the WRAP fire emissions development effort, FETS and other efforts. The DEASCO3 study is led by the Western Governors Association (WGA) with Air Sciences and ENVIRON as Subcontractors and includes several collaborators from the USFS, NPS and FWS. The DEASCO3 2008 fire emissions inventory will identify the fire emission by their major types (WF, Rx and Ag) be the most comprehensive and accurate fire emissions inventory available for 2008 and is ideal for use in the WestJumpAQMS. However, currently it is not scheduled for completion until approximately June 2012 so would not be available for the initial WestJumpAQMS photochemical modeling runs.

Thus, an interim 2008 fire emissions inventory will be needed for the initial WestJumpAQMS photochemical model simulations. There are two main alternatives available:

- The Fire INventory from NCAR (FINN[2]) is derived from analysis of fire locations determined by satellite-borne detectors. The MODerate-resolution Imaging Spectroradiometer (MODIS) instruments fly aboard two polar-orbiting satellites, Terra, and Aqua. These two satellites orbit the Earth, traveling from pole to pole while the earth rotates beneath them; a given area of the Earth will have an overpass from Terra and Aqua approximately twice a day. MODIS instruments detect fires as thermal anomalies (i.e. hot spots seen against a cooler background) at a spatial resolution of about 1 kilometer. Fire emissions derived from the MODIS data include NOx, CO, VOC and PM species, along with other compounds (e.g., Hg). The FINN fire emissions inventory development is described by Wiedinmyer and co-workers (2006) and Friedli and Wiedinmyer (2008) as well as other publications[3].

- The Satellite Mapping Automated Reanalysis Tool for Fire Incident Reconciliation (SMARTFIRE[4]) is an algorithm and database system that operate within a geographic information system (GIS) framework. SMARTFIRE combines multiple sources of fire information and reconciles them into a unified GIS database. It reconciles fire data from space-borne sensors and ground-based reports, thus drawing on the strengths of both data types while avoiding double-counting. SMARTFIRE and its outputs were designed with the BlueSky Framework[5] in mind, though the Framework can be run without

1 http://www.wrapair2.org/pdf/JSFP_DEASCO3_TechnicalProposal_November19_2010.pdf
2 http://bai.acd.ucar.edu/Data/fire/
3 http://www.atmos-chem-phys.net/11/4039/2011/acp-11-4039-2011.pdf
4 http://getbluesky.org/smartfire/
5 http://blueskyframework.org/

SMARTFIRE data. In addition, SMARTFIRE can be useful for purposes beyond its original role of providing fire inputs to the Framework.

The FINN fires may be biased low since if the satellite instruments cannot "see" the ground (e.g., there are clouds present), then they won't detect the fires. However, some concerns have been raised that the SMARTFIRE may overstate fire emissions. Since the SMARTFIRE emissions use the Blue Sky Framework, which is not a specific algorithm, it is difficult to determine what was used. Appendix A compares the FINN and SMARTFIRE emissions for 2008 and a 12 km WESTUS domain and a 4 km Colorado/Denver domain. The SMARTFIRE emissions were obtained from the 2008 NEI V1.5. A couple of observations are as follows:

- SMARTFIRE/BlueSky estimates higher fire emissions that are somewhat higher for NO_X but much higher for SO_2, VOC and CO.
- SMARTFIRE/BlueSky is missing fire emissions in Canada, which may be important for the northern WRAP states.
- SMARTFIRE/BlueSky does not include coarse PM emissions.

Given that ultimately the DEASCO3 fire emissions will be used in the WestJumpAQMS the selection of either the FINN or SMARTFIRE emissions for the initial modeling is not as critical as it might be otherwise. We are recommending use of the FINN fire emissions for the initial modeling because of the following:

- FINN is more complete spatially.
- FINN has more complete species.
- SMARTFIRE may overestimate fire emissions that would confound the initial model evaluation.
- FINN is better documented.

FINN EMISSIONS PROCESSING

How the DEASCO3 emissions will be processed will remain to be seen and will be based on the recommendations from the DEASCO3 study. For the FINN processing, we use a modified versions of the Emissions Processing System (EPS) that has incorporated the WRAP fire plume rise and diurnal allocation estimates.

Spatial Allocation

The FINN database includes daily fire emissions at a 1 km by 1 km resolution. The location of each fire is re-projected to the CAMx domain projection and is treated as a point source. Points that are within 5 km of one another are assumed to be part of the same fire. The size of the fire is later used to estimate the vertical plume distribution of emissions.

Temporal Allocation

The WRAP fire emissions temporal diurnal profile is used within EPS3 to allocate the daily FINN fire emissions throughout the day. All fires are assumed to have the same diurnal profile, as shown in Figure 1. This diurnal profile has much greater fire emissions during the day than at night. Appendix A includes additional examples showing the diurnal distribution of the fire emissions.

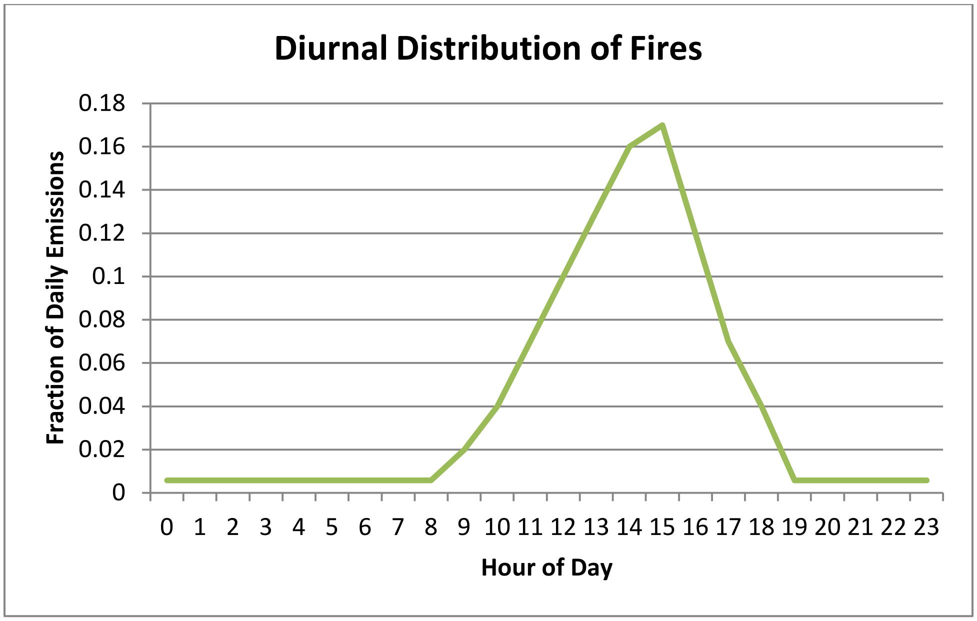


Figure 1. Diurnal profile of fire emissions from WRAP.

Plume Rise

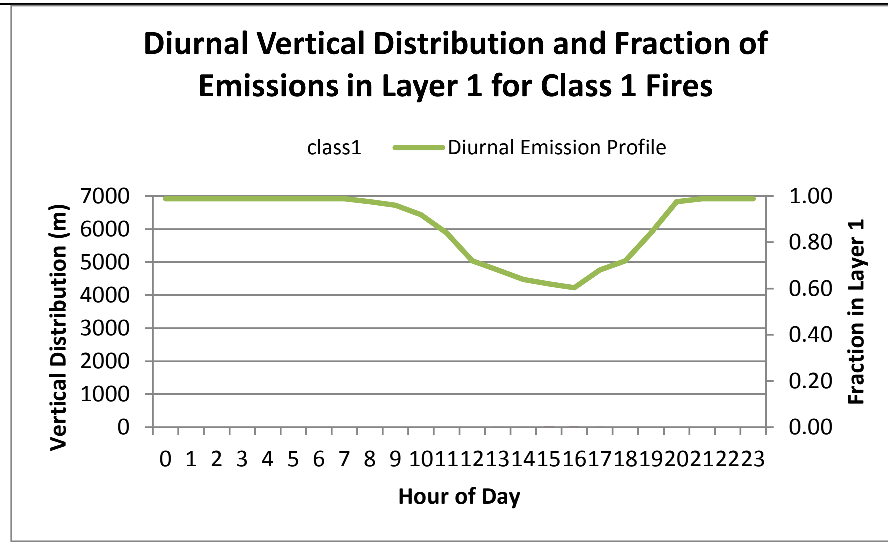
The WRAP methodology incorporated into EPS3 is used to determine the top and bottom of each fire plume and the fraction of emissions that goes into the lowest model layer. In this method, fires are assigned to one of five classes based on virtual acreage, which depends on the fire size and the amount of fuel available to be burned. Parameters are assigned to each fire size class to calculate the hourly plume top and bottom and fraction of emissions to be placed in layer 1. Figure 2 displays the diurnal profiles for each fire size class. The top left shows the five fire size classes; the rest of the figure displays red bars representing the vertical distribution of the plume for each hour of the day (keyed off left axis) and a green line representing the fraction of emissions to be assigned to layer 1 (keyed off right axis).

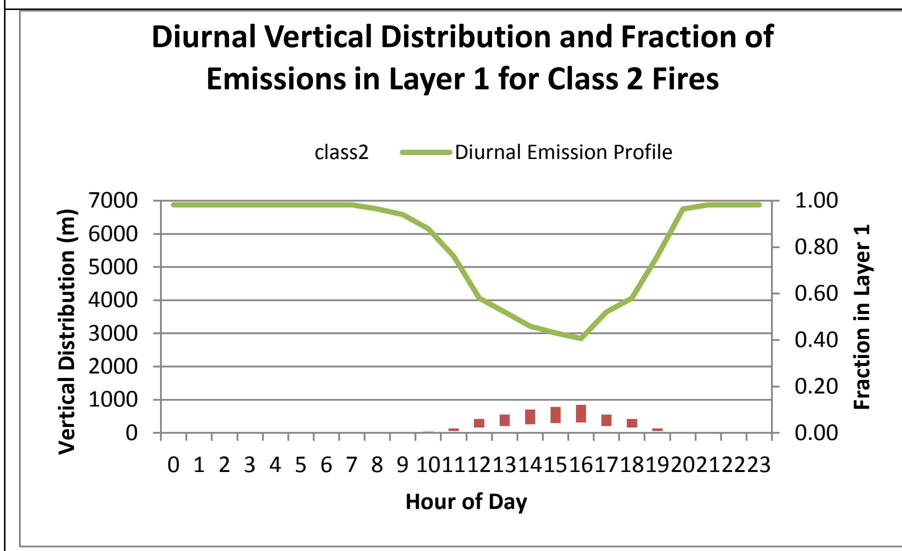
EPS3 then generates multiple point sources at the center of each vertical layer that contains part of the plume and allocates the emissions (after removing the fraction in layer 1) based on the depth of the plume within each layer. All fire points are flagged so that there will be no additional plume rise calculation in CAMx.

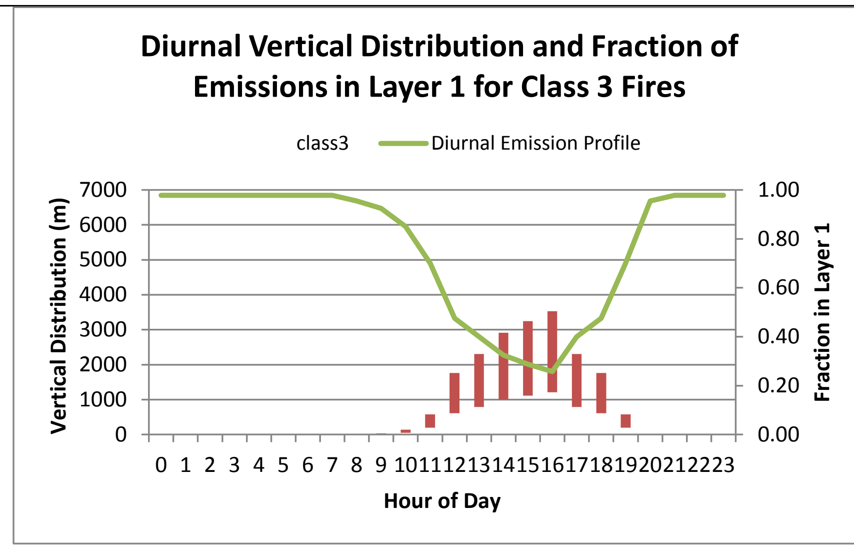
The FINN dataset does not contain the biomass burned information needed to compute the virtual acreage that is used to classify the fire type (see Figure 2). However, before NCAR named the inventory FINN, they provided unspeciated MODIS satellite-based fire datasets in 1 km resolution which included biomass information. Using an older set of 2005 MODIS fire data that included biomass burn data for each fire across the RPO 36 km domain, virtual areas of each fire were computed. Fires within 5 km of one another were assumed to be part of the same fire so their virtual acreages were summed together. Fires not associated with any other fire points were assumed to burn in only 50% of the 1 km by 1 km pixel. Figure 3 displays a scatterplot of the virtual acreage and NOx emissions. Each pair shows the NOx and virtual area from a stand-alone fire point, or the sum of all NOx and virtual areas from fire points that are grouped together. The trend line shows a strong linear relationship between NOx emissions and the virtual area with a R^2 value of 0.96 and a slope of 24.8 virtual acres per ton of NOx emitted. This 24.8 ratio is assumed to be applicable to the FINN dataset and is used to compute the virtual acreage.

The WRAP methodology was originally structured based on the first layer being 38 m thick; the WestJumpAQMS layer 1 depth is only 24 m. To account for the smaller depth, the surface emissions that came from the fraction in layer 1 were scaled by 0.63 (24/38) and were assigned to the second layer in the point source file.

Class	Virtual Acreage
1	< 10
2	10 – 100
3	100 – 1000
4	1000 – 5000
5	>= 5000







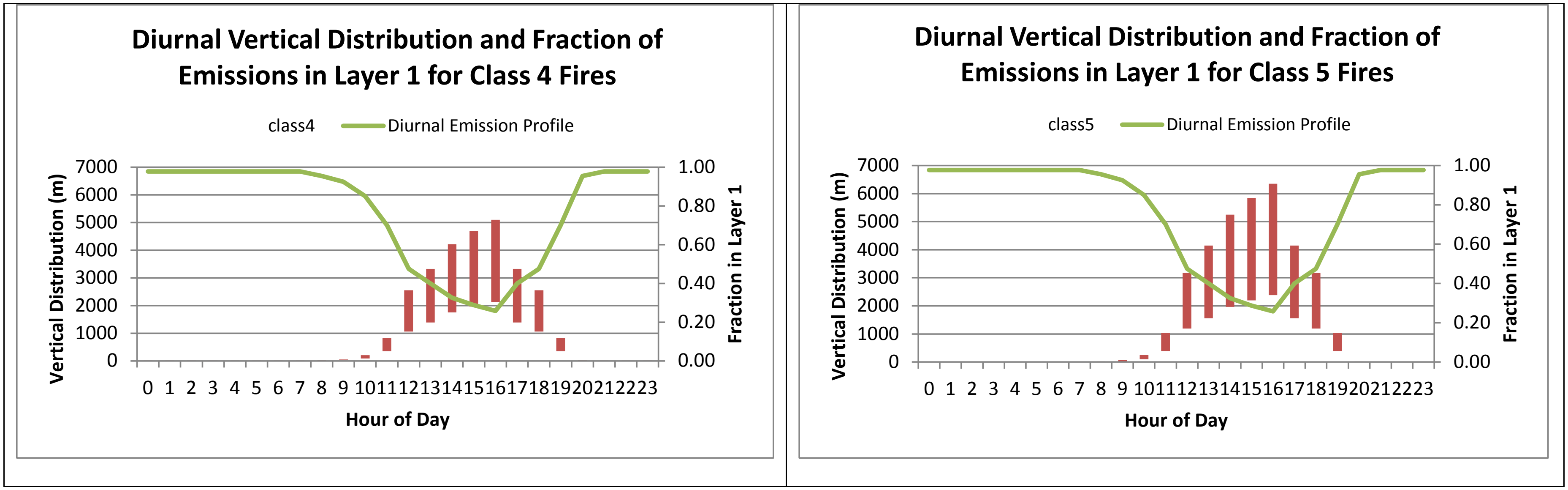


Figure 2. Diurnal profiles of the vertical distribution of emissions in the five fire classes showing the fraction of fire emissions injected into the first layer (green line, right axis) and plume top and bottom (red bars, left axis) that defines the vertical layers for the injection of the remainder of the fire emissions.

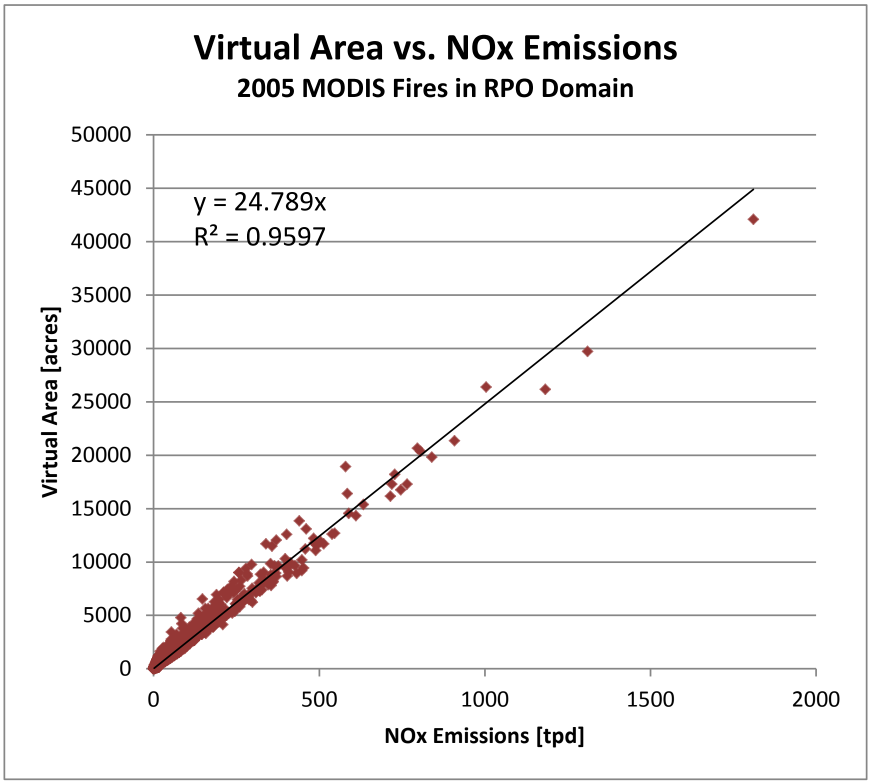


Figure 3. Relationship between the virtual area and NOx fire emissions in the 2005 MODIS fire dataset

Chemical Speciation

The FINN database comes speciated to either MOZART, GEOS-Chem, or SAPRC-99 species. A land cover type was set to each fire point to determine the type of fuel burned and speciation profile assigned to each fire. The FINN data with MOZART species were downloaded and remapped to CB6 speciation for CAMx using the mapping profile shown in Table 1. Particulate speciation was not as detailed as for the VOCs, so default WRAP profiles for wildfires were used to estimate the sulfate, nitrate, and fine primary particulate emissions.

Table 1. Mapping of fire emissions in MOZART-4 speciation to CAMx CB6

CAMx CB6	Fire emissions speciated to MOZART-4
NO	NO
NO2	NO2
CO	CO
FORM	CH2O
ALD2	CH3CHO
ALDX	GLYALD
ETOH	C2H5OH
MEOH	CH3OH
ETHA	C2H6
AACD	CH3COOH
FACD	HCOOH
PAR	C3H6 + 1.7BIGENE + 5 BIGALK + 1.5 C3H8 + 3 MEK + C2H2 + 3 HYAC
ACET	3 CH3COCH3
KET	MEK
ETH	C2H4
OLE	C3H6 + 1.0 BIGENE
IOLE	0 BIGENE
ISOP	ISOP
ISPD	MACR + MVK
TERP	C10H16
TOL	0.3 TOLUENE
XYL	0.1 TOLUENE
CRES	CRESOL
OPEN	BIGALD
MGLY	CH3COCHO
SO2	SO2
NH3	NH3
TOLA	0.3 TOLUENE
XYLA	0.1 TOLUENE
ISP	ISOP
TRP	C10H16
NR	C2H2 + 1.5C3H8 + 0.5TOLUENE + 0.3BIGENE
CH4	CH4
BENZ	0.6 TOLUENE
HCN	HCN
CH3CN	CH3CN

CPRM	PM10-PM25
POA	OC
PEC	BC
FPRM	68 % of (PM25 - OC - BC)
PSO4	29 % of (PM25 -OC - BC)
PNO3	3 % of (PM25 - OC - BC)

Quality Assurance

Quality assurance (QA) will be performed following the emissions quality assurance protocol developed during WRAP (Adelman, 2004[6]). These procedures include systematic procedures for:

- Modeling QA – accuracy assurance and problem identification.
- System QA – software and data tracking.
- Documentation – tracking QA issues, recording the QA process and report writing.

An emissions QA checklist is developed that delineates each step of the QA process and allows a systematic approach to the QA process to assure critical steps are not overlooked. The completed QA checklists and templates include:

- Model configuration settings.
- Inventory file log.
- Ancillary input file log.
- Model execution log.

A series of QA products are produced that are compared to other studies and the expected outcomes:

- Spatial plots of emissions by source category.
- Annual time series plots of emissions for subregions.
- Diurnal time series plots.
- Daily vertical profile plots.

The emissions QA officer is required to generate, review and distribute the QA products to the modeling team and buy off on the results prior to execution of the air quality model.

6 http://www.epa.gov/ttnchie1/conference/ei13/qaqc/adelman_pres.pdf

Input Emissions Summaries

Detailed spatial plots and summary tables of the initial FINN fire emissions will be prepared and distributed when they are processed by the EPS emissions model as part of the WestJumpAQMS. Summaries of the DEASCO3 fire emissions will also be distributed when they generated.

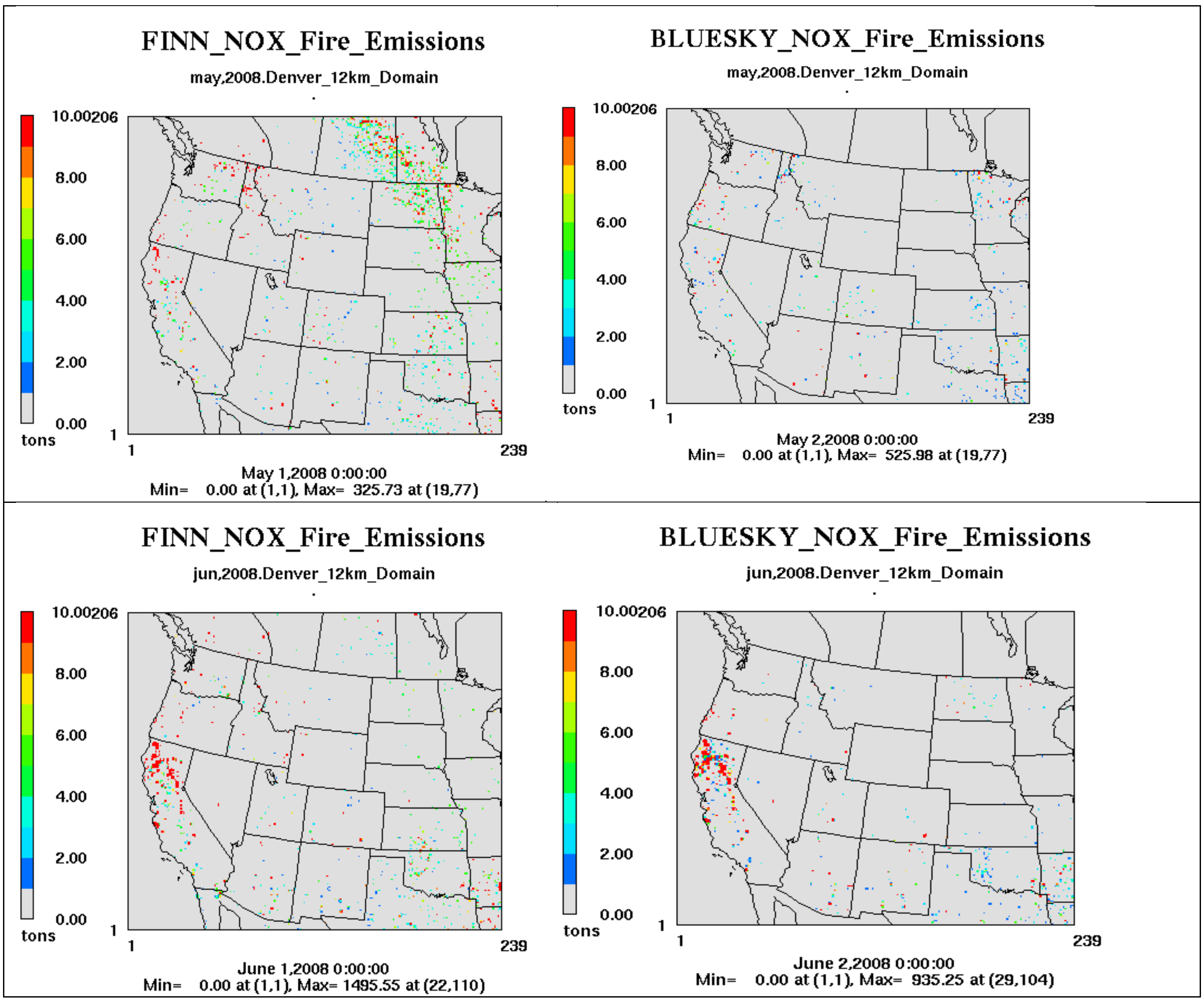
APPENDIX A

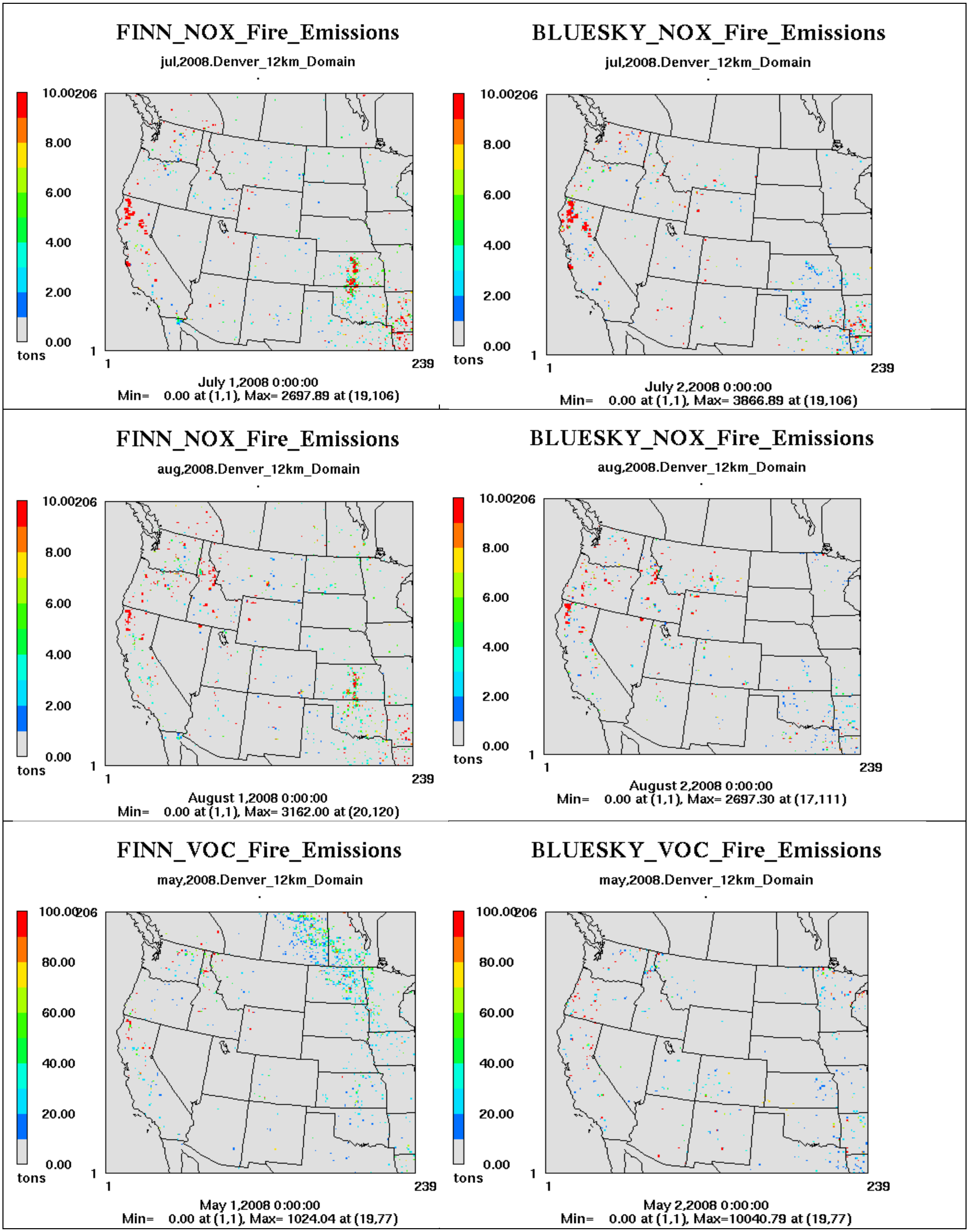
Comparison of SMARTFIRE/BlueSky and FINN Fire Emissions for a 12 km Western U.S. Domain and a 4 km Colorado/Denver Domain

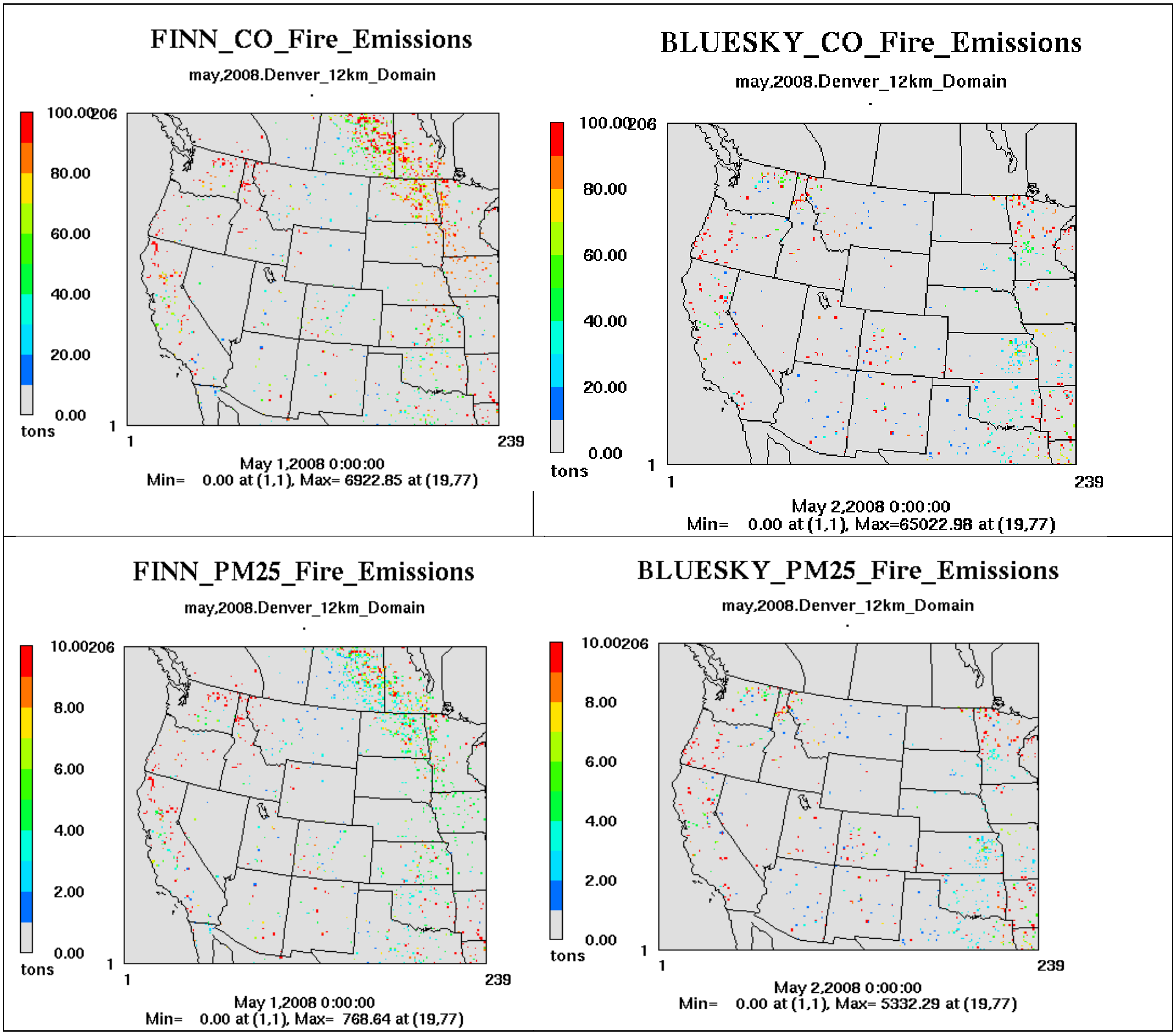
FINN vs. Bluesky fire emissions.

Plots contain the following:

- PAVE plots of monthly NOx, VOC, CO, PM25, and SO2 fire emissions in the Denver 12km domain
- Time series of total emissions by day in the 12km domain
- PAVE plots of monthly NOx, VOC, CO, PM25, and SO2 fire emissions in Colorado (Denver 4km domain)
- Time series of total emissions by day in Colorado
- Focus on the Las Animas County (SE Colorado) fire from June 10-16, 2008.
    - Hourly time series of NOx emissions
    - Hourly vertical distribution of emissions




FINN_NOX_Fire_Emissions
jul,2008.Denver_12km_Domain
10.00
8.00
6.00
4.00
2.00
0.00
tons
206
1
1
239
July 1,2008 0:00:00
Min= 0.00 at (1,1), Max= 2697.89 at (19,106)
BLUESKY_NOX_Fire_Emissions
jul,2008.Denver_12km_Domain
10.00
8.00
6.00
4.00
2.00
0.00
tons
206
1
1
239
July 2,2008 0:00:00
Min= 0.00 at (1,1), Max= 3866.89 at (19,106)
FINN_NOX_Fire_Emissions
aug,2008.Denver_12km_Domain
10.00
8.00
6.00
4.00
2.00
0.00
tons
206
1
1
239
August 1,2008 0:00:00
Min= 0.00 at (1,1), Max= 3162.00 at (20,120)
BLUESKY_NOX_Fire_Emissions
aug,2008.Denver_12km_Domain
10.00
8.00
6.00
4.00
2.00
0.00
tons
206
1
1
239
August 2,2008 0:00:00
Min= 0.00 at (1,1), Max= 2697.30 at (17,111)
FINN_VOC_Fire_Emissions
may,2008.Denver_12km_Domain
100.00
80.00
60.00
40.00
20.00
0.00
tons
206
1
1
239
May 1,2008 0:00:00
Min= 0.00 at (1,1), Max= 1024.04 at (19,77)
BLUESKY_VOC_Fire_Emissions
may,2008.Denver_12km_Domain
100.00
80.00
60.00
40.00
20.00
0.00
tons
206
1
1
239
May 2,2008 0:00:00
Min= 0.00 at (1,1), Max=10040.79 at (19,77)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80.00
60.00
40.00
20.00
0.00
tons
1
1
239
May 1,2008 0:00:00
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BLUESKY_CO_Fire_Emissions
may,2008.Denver_12km_Domain
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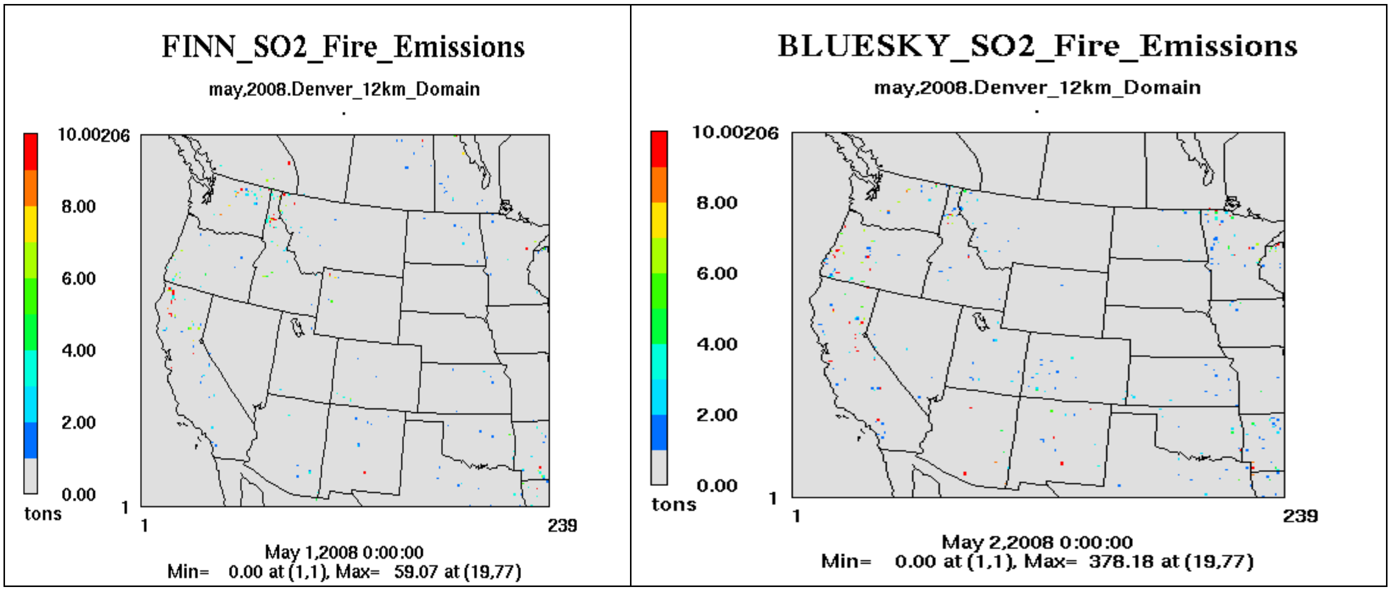
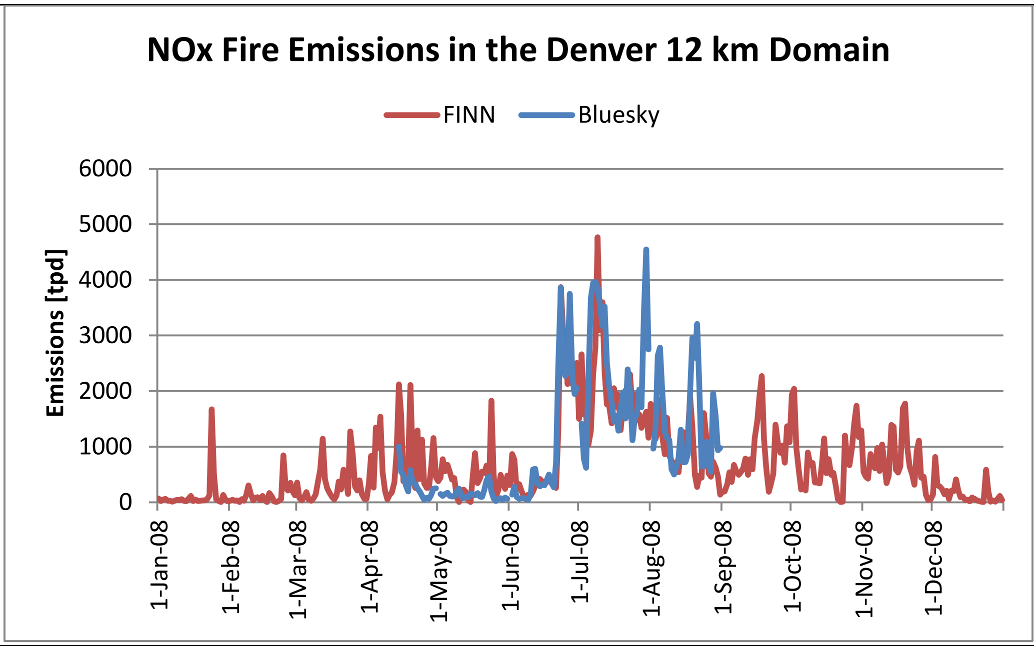
80.00
60.00
40.00
20.00
0.00
tons
1
1
239
May 2,2008 0:00:00
Min= 0.00 at (1,1), Max=65022.98 at (19,77)
FINN_PM25_Fire_Emissions
may,2008.Denver_12km_Domain
10.00206
8.00
6.00
4.00
2.00
0.00
tons
1
1
239
May 1,2008 0:00:00
Min= 0.00 at (1,1), Max= 768.64 at (19,77)
BLUESKY_PM25_Fire_Emissions
may,2008.Denver_12km_Domain
10.00206
8.00
6.00
4.00
2.00
0.00
tons
1
1
239
May 2,2008 0:00:00
Min= 0.00 at (1,1), Max= 5332.29 at (19,77)



12km spatial comparison notes:

- May. FINN has large area of small emissions in Saskatchewan, Manitoba, and the Dakotas that is not evident in Bluesky.
- May. FINN has more fires and/or higher emissions in northern California and Washington
- June. Spatial distribution seemed to agree, but Bluesky had higher emissions across North Dakota while FINN had more in Washington and Kansas
- July and August. Generally good agreement in the west. FINN had more emissions in a north-south line across the middle of Kansas


NOx Fire Emissions in the Denver 12 km Domain
FINN
Bluesky
Emissions [tpd]
6000
5000
4000
3000
2000
1000
0
1-Jan-08
1-Feb-08
1-Mar-08
1-Apr-08
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1-Jun-08
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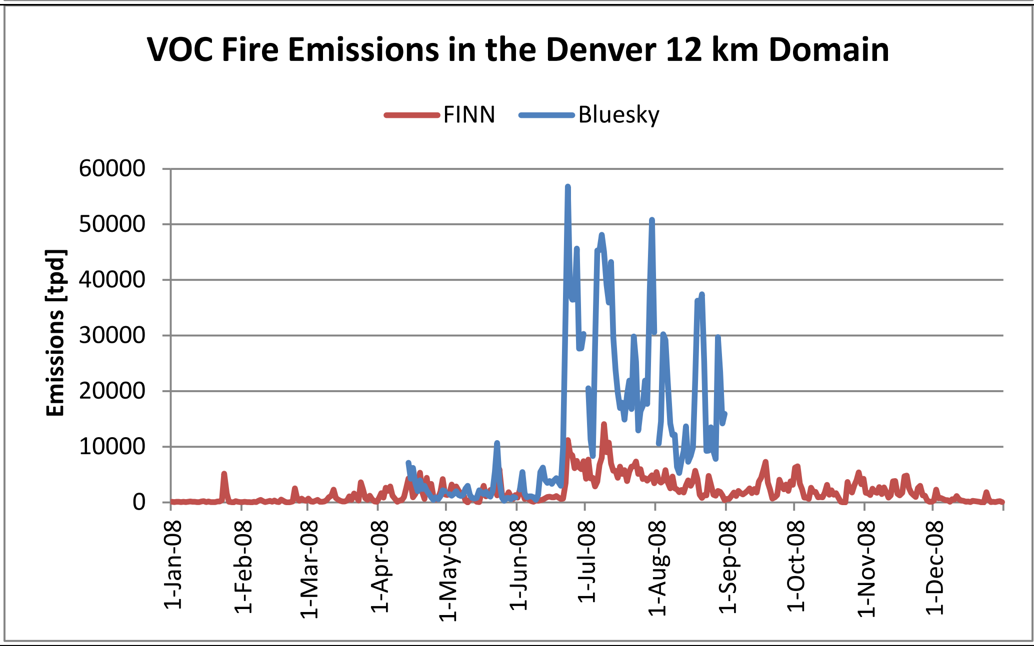
1-Oct-08
1-Nov-08
1-Dec-08


VOC Fire Emissions in the Denver 12 km Domain
FINN
Bluesky
Emissions [tpd]
60000
50000
40000
30000
20000
10000
0
1-Jan-08
1-Feb-08
1-Mar-08
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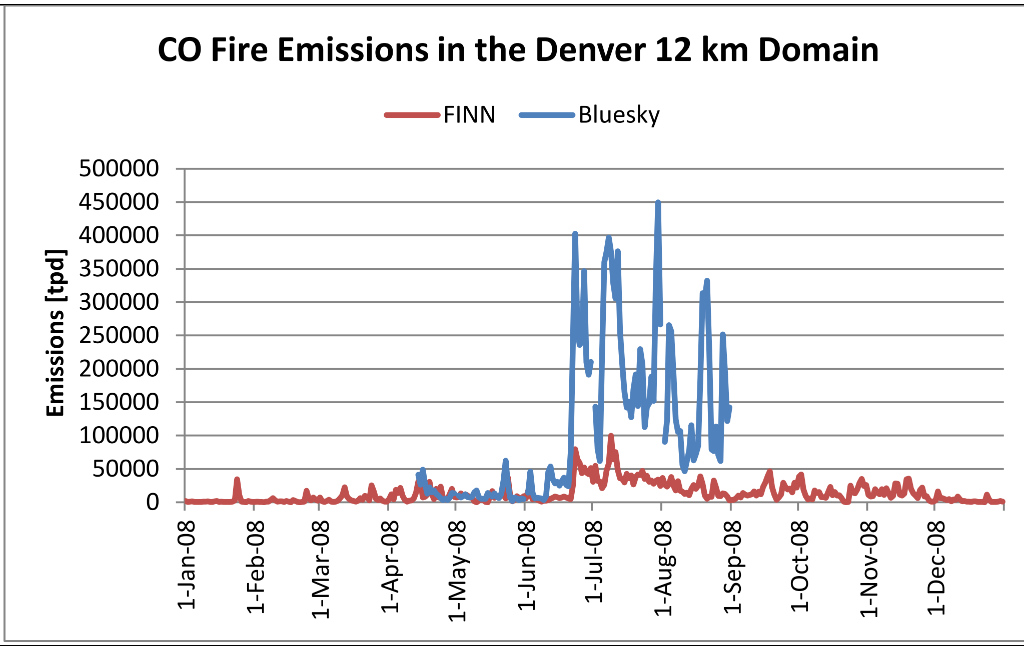
1-Nov-08
1-Dec-08


CO Fire Emissions in the Denver 12 km Domain
FINN
Bluesky
Emissions [tpd]
500000
450000
400000
350000
300000
250000
200000
150000
100000
50000
0
1-Jan-08
1-Feb-08
1-Mar-08
1-Apr-08
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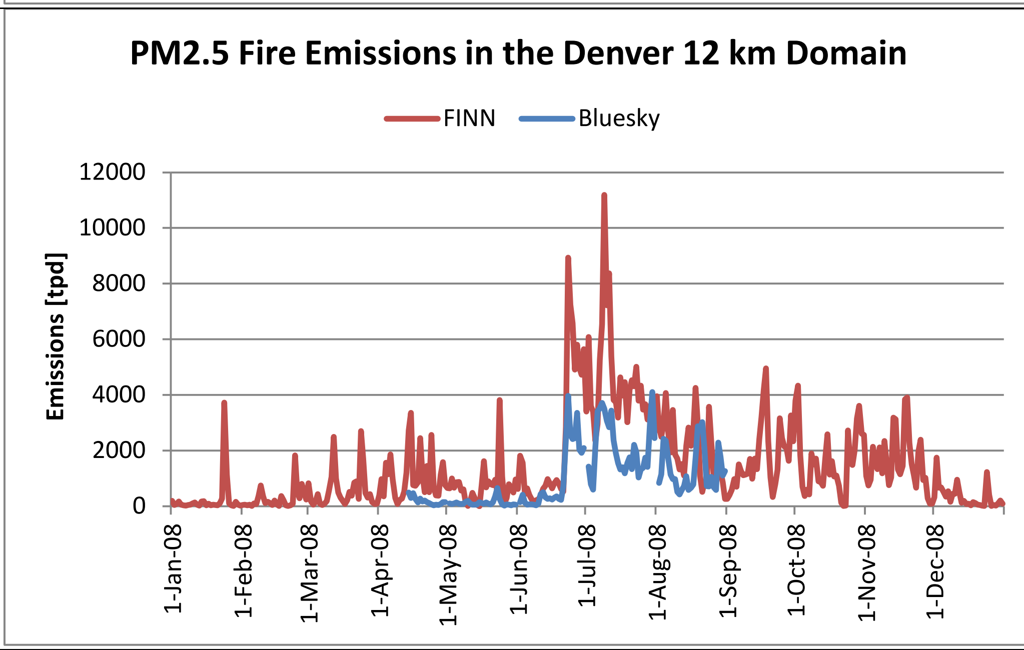
1-Nov-08
1-Dec-08


PM2.5 Fire Emissions in the Denver 12 km Domain
FINN
Bluesky
Emissions [tpd]
12000
10000
8000
6000
4000
2000
0
1-Jan-08
1-Feb-08
1-Mar-08
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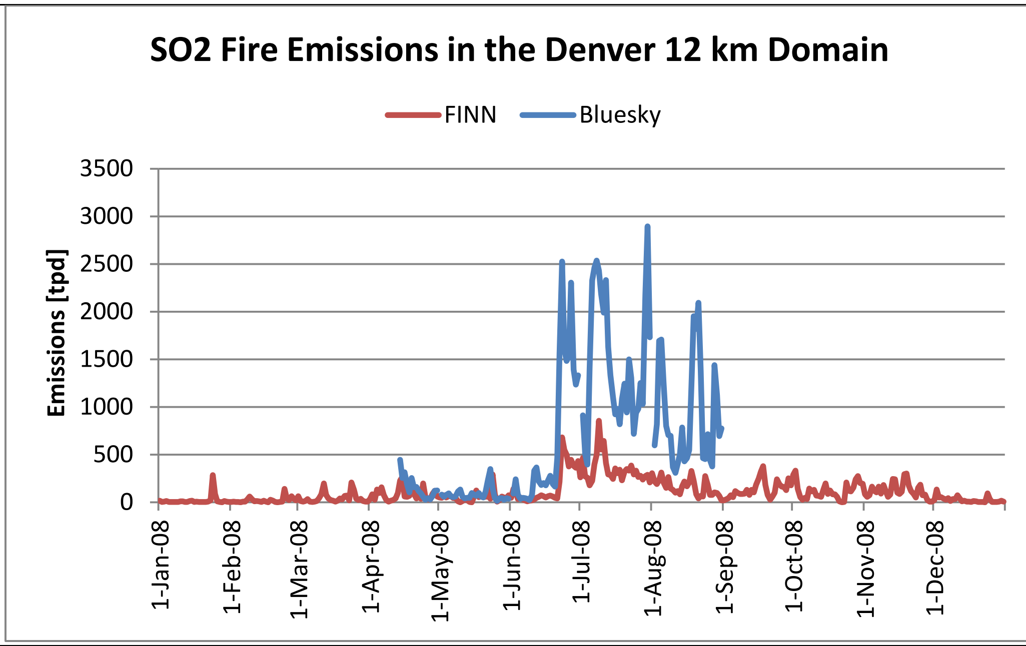
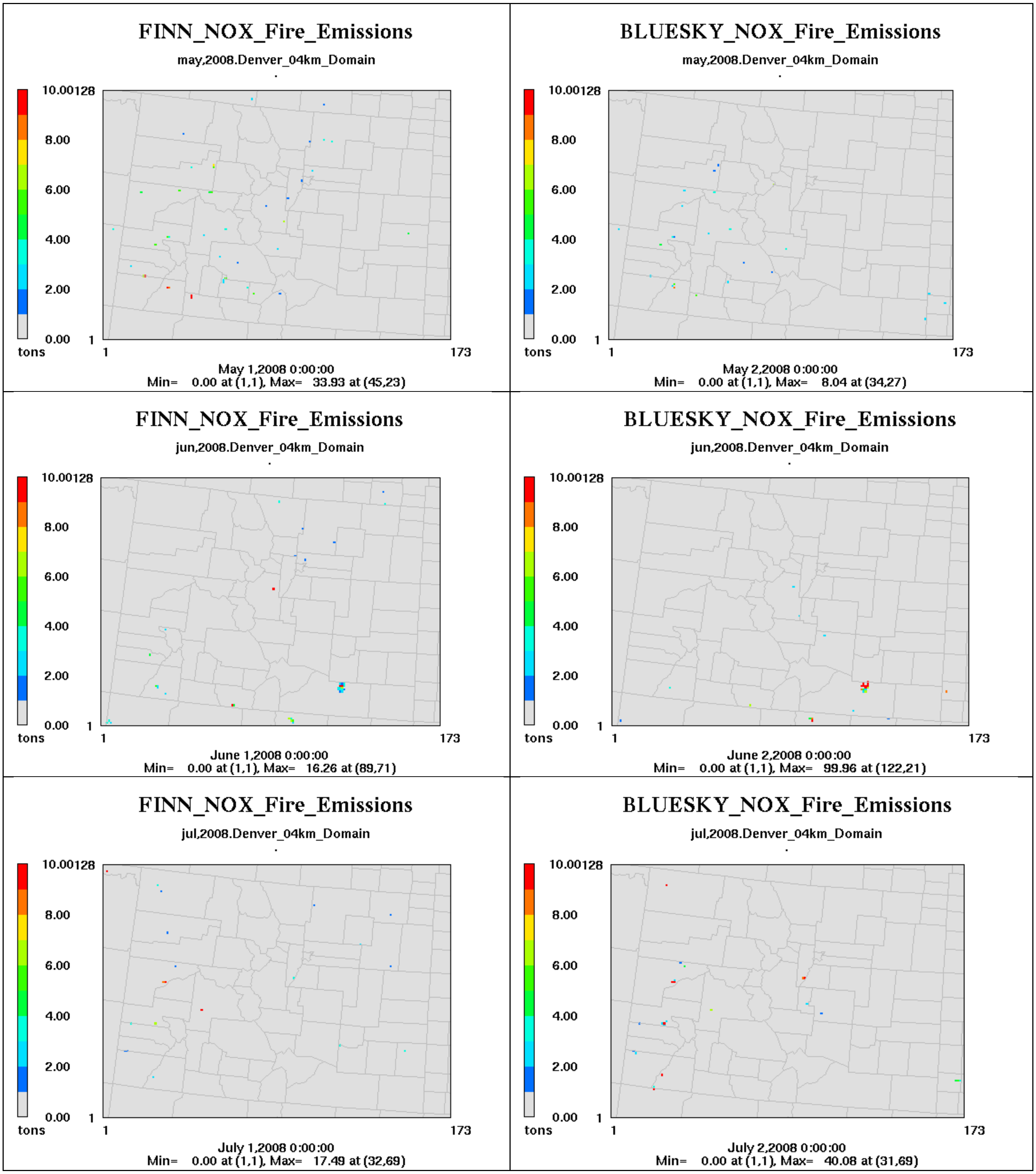
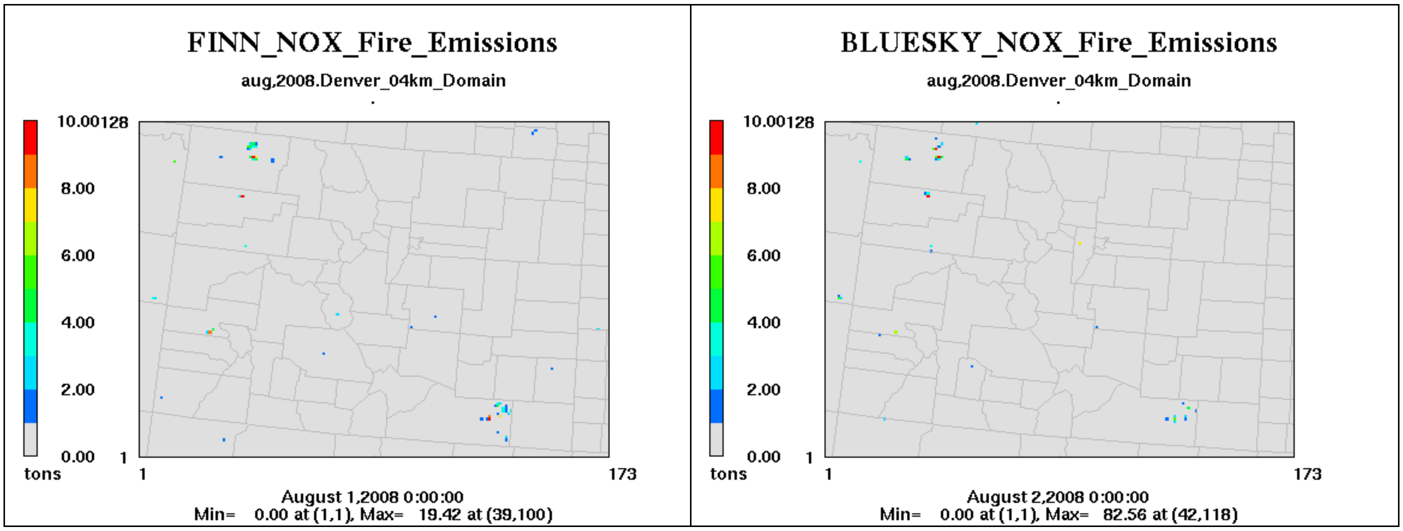
1-Nov-08
1-Dec-08



Time series notes (12km domain):

- Bluesky fire emissions were only processed for May through August for this comparison
- NOx totals were in a similar range
- VOC, CO, and SO2 were much higher in Bluesky emissions while PM2.5 was lower
- Emissions of all species jumped beginning in mid-June in both FINN and Bluesky


FINN_NOX_Fire_Emissions
may,2008.Denver_04km_Domain
10.00128
8.00
6.00
4.00
2.00
0.00
tons
1
173
May 1,2008 0:00:00
Min= 0.00 at (1,1), Max= 33.93 at (45,23)
BLUESKY_NOX_Fire_Emissions
may,2008.Denver_04km_Domain
May 2,2008 0:00:00
Min= 0.00 at (1,1), Max= 8.04 at (34,27)
FINN_NOX_Fire_Emissions
jun,2008.Denver_04km_Domain
June 1,2008 0:00:00
Min= 0.00 at (1,1), Max= 16.26 at (89,71)
BLUESKY_NOX_Fire_Emissions
jun,2008.Denver_04km_Domain
June 2,2008 0:00:00
Min= 0.00 at (1,1), Max= 99.96 at (122,21)
FINN_NOX_Fire_Emissions
jul,2008.Denver_04km_Domain
July 1,2008 0:00:00
Min= 0.00 at (1,1), Max= 17.49 at (32,69)
BLUESKY_NOX_Fire_Emissions
jul,2008.Denver_04km_Domain
July 2,2008 0:00:00
Min= 0.00 at (1,1), Max= 40.08 at (31,69)

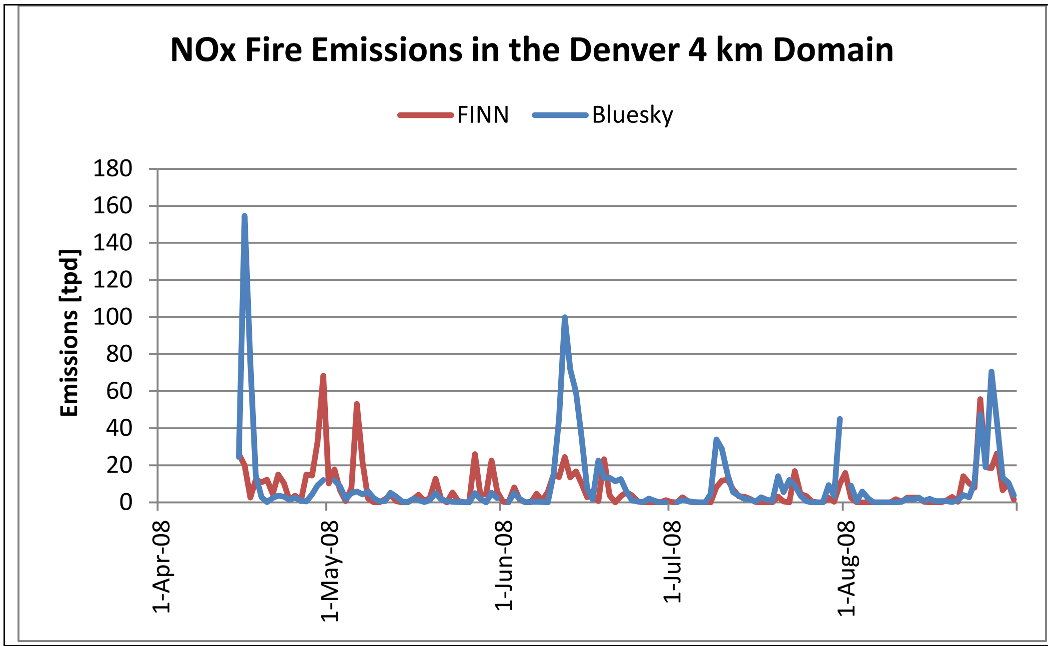


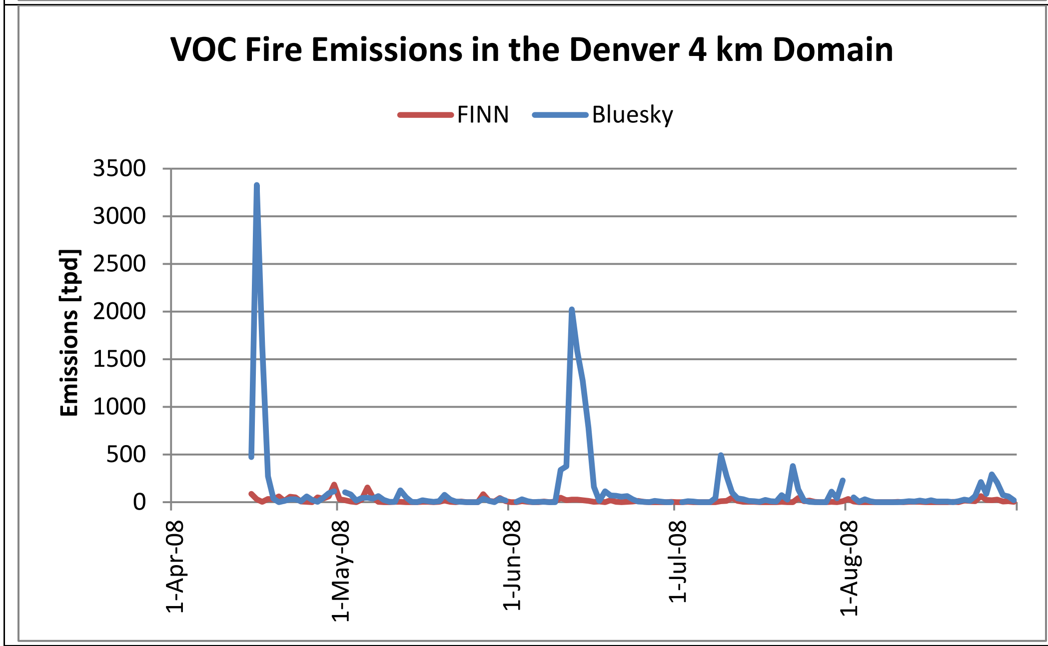
Colorado fire spatial plot notes:

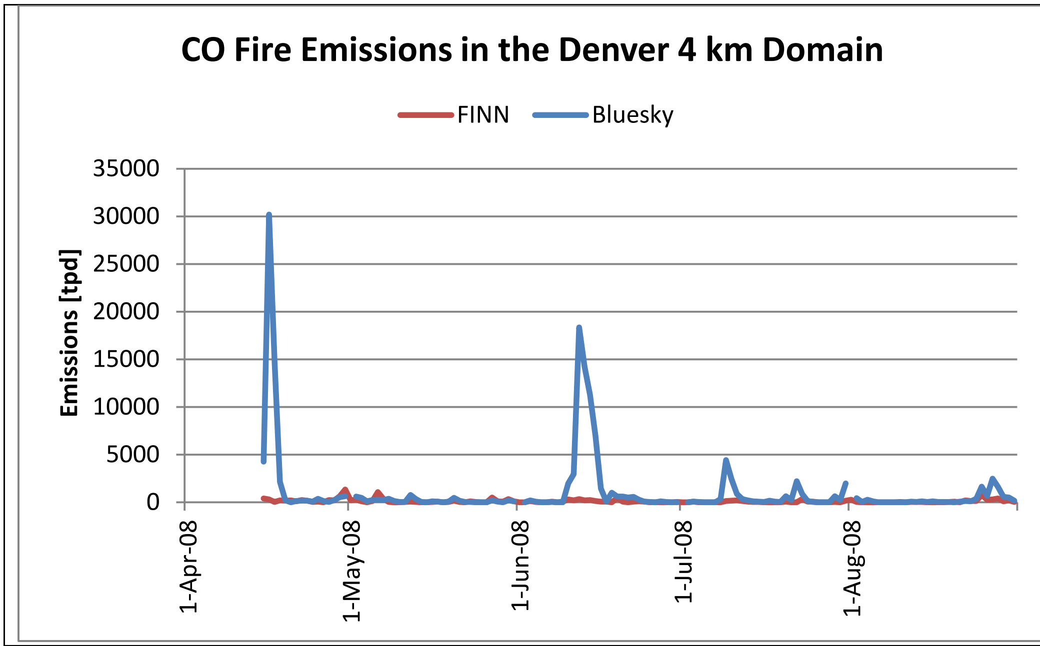
Both FINN and Bluesky identified 3 of the largest fires: June in Las Animas County, August in Moffat County (NW Colorado) and eastern Las Animas County

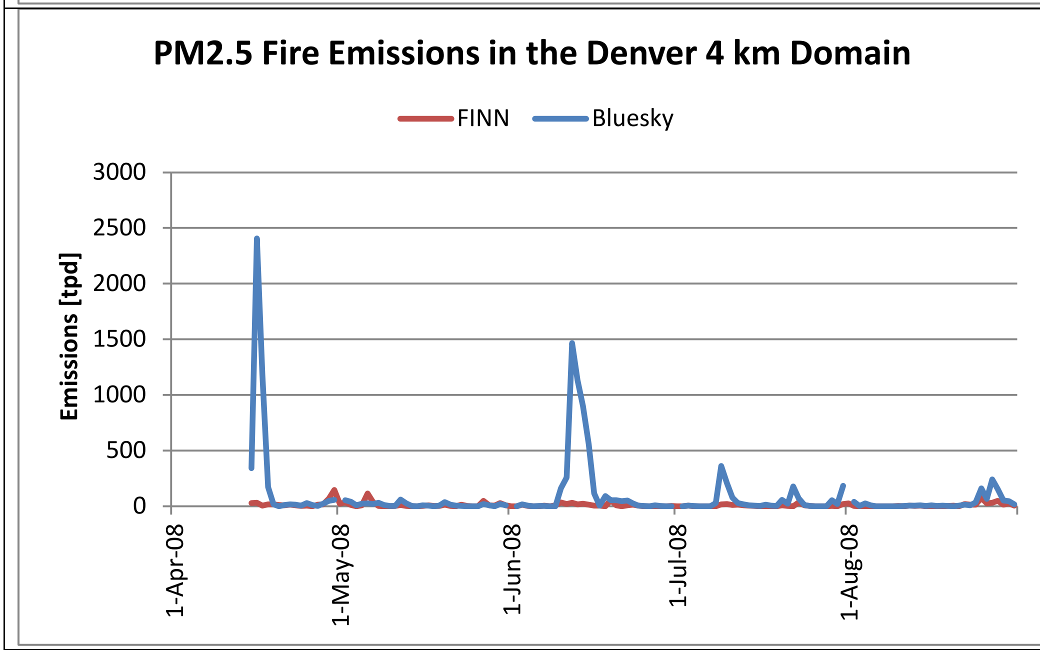
- Bluesky identified more fires in western Colorado than FINN (or FINN detected these fires as well, but had much smaller emissions).

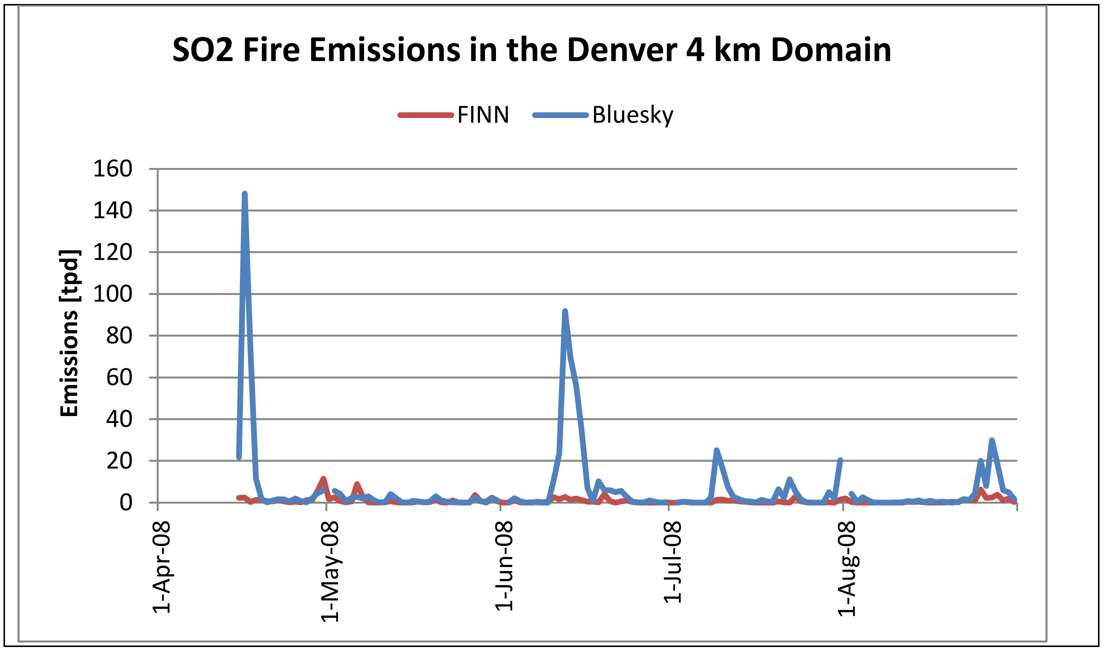
•


NOx Fire Emissions in the Denver 4 km Domain
FINN
Bluesky
Emissions [tpd]
180
160
140
120
100
80
60
40
20
0
1-Apr-08
1-May-08
1-Jun-08
1-Jul-08
1-Aug-08


VOC Fire Emissions in the Denver 4 km Domain
FINN
Bluesky
Emissions [tpd]
3500
3000
2500
2000
1500
1000
500
0
1-Apr-08
1-May-08
1-Jun-08
1-Jul-08
1-Aug-08


CO Fire Emissions in the Denver 4 km Domain
FINN
Bluesky
Emissions [tpd]
35000
30000
25000
20000
15000
10000
5000
0
1-Apr-08
1-May-08
1-Jun-08
1-Jul-08
1-Aug-08

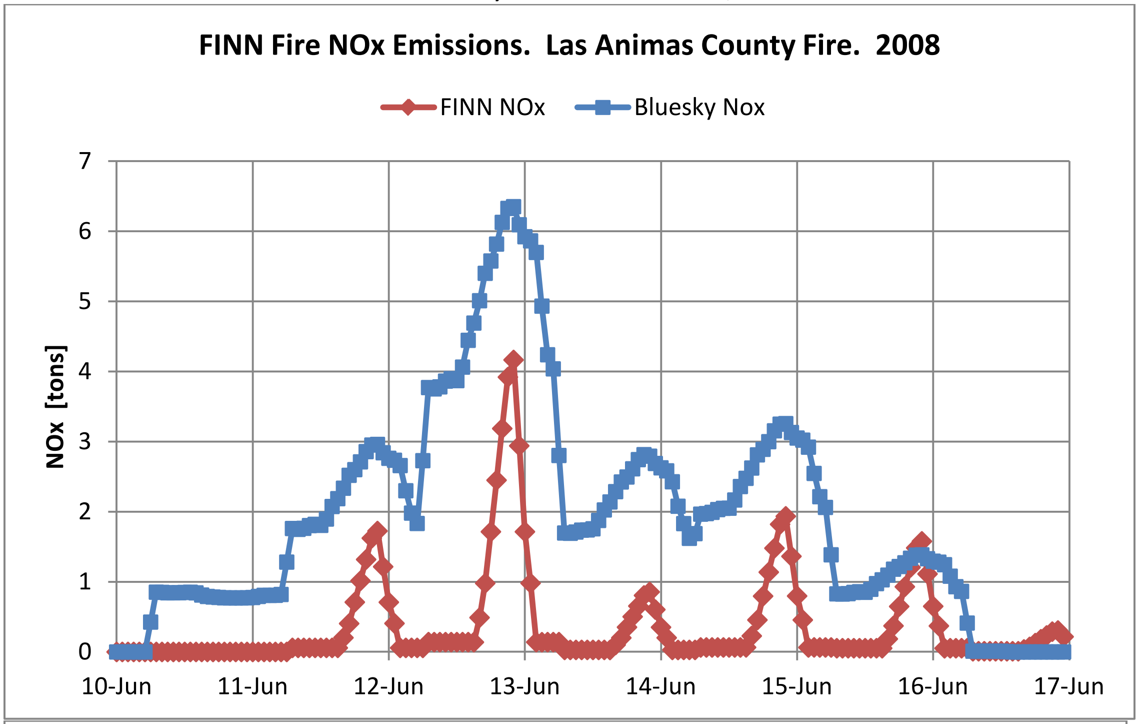

PM2.5 Fire Emissions in the Denver 4 km Domain
FINN
Bluesky
Emissions [tpd]
3000
2500
2000
1500
1000
500
0
1-Apr-08
1-May-08
1-Jun-08
1-Jul-08
1-Aug-08

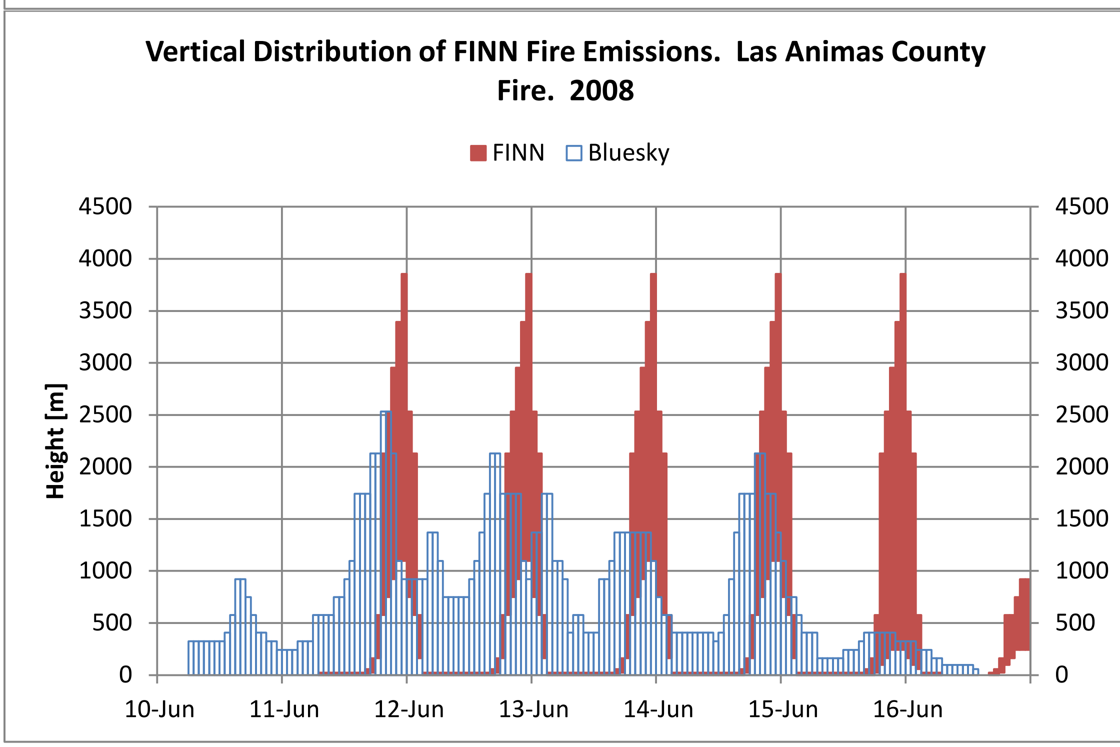


4km time series notes:

- Bluesky emissions were higher than FINN for most species, especially for large fires, but NOx was more comparable.
- Ignoring the April spike since it is in a spinup period, both FINN and Bluesky emissions spiked for the Las Animas County fire, but Bluesky was significantly higher for all species.

More details of the Las Animas County Fire. June 10-16, 2008.





Hourly temporal and vertical distribution findings at the Las Animas County fire

- Bluesky emissions for this fire were higher during most hours. Both emit the most in the mid afternoon
- Bluesky's diurnal distribution is spread out over more hours whereas FINN (WRAP profile) emphasizes emissions in the midday

- Bluesky's vertical distribution is lower than FINN (WRAP profile) in the daytime (when emissions are highest), but have a higher vertical distribution at night.
- Bluesky detected this fire beginning June 10. FINN started on June 11.