

Update on the Denver 8-Hour Ozone SIP Modeling: 2006 Base Case; 2006/2010 Emissions; 2010 Ozone Projections; and Next Steps

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RAQC Board Meeting
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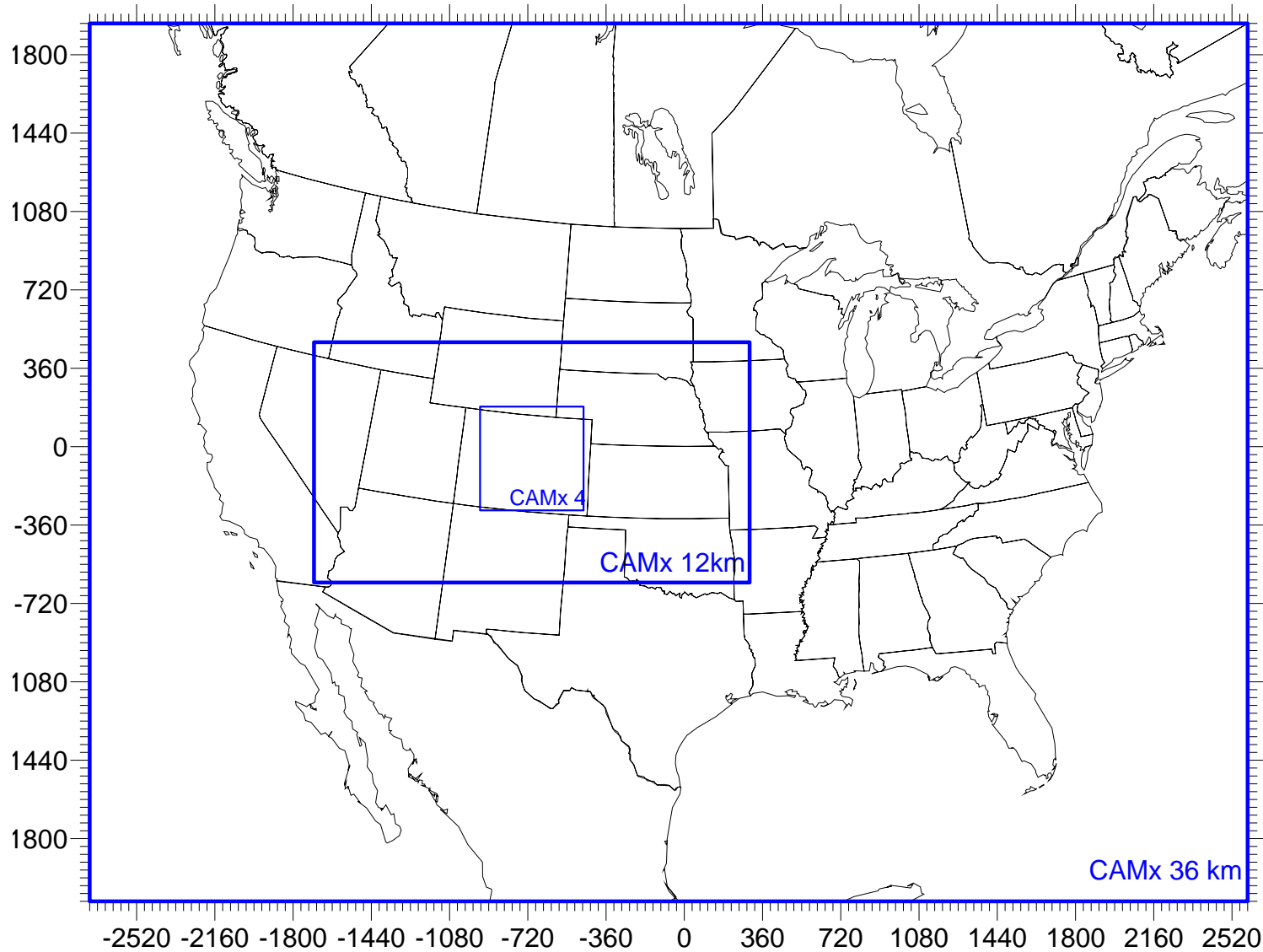
June 5, 2008

2005-2007 Fourth High Ozone (ppm)

Site Name	<u>2005</u> 4 th High 8-Hour Ozone (ppm)	<u>2006</u> 4 th High 8-Hour Ozone (ppm)	<u>2007</u> 4 th High 8-Hour Ozone (ppm)	2005- 2007 Design Value (ppm)
Welby	0.073	0.069	0.070	0.070
Highland	0.080	0.081	0.075	0.078
S. Boulder Creek	0.076	0.082	0.085	0.081
Denver – CAMP	0.051	0.062	0.057	0.056
Carriage	0.074	0.072	0.076	0.074
Chatfield State Park	0.084	0.086	0.082	0.084
USAF Academy	0.077	0.072	0.071	0.073
Manitou Springs	0.075	0.076	0.072	0.074
Arvada	0.078	0.082	0.078	0.079
Welch	0.064	0.081	0.080	0.075
Rocky Flats North	0.077	0.090	0.090	0.085
NREL	0.079	0.083	0.085	0.082
Fort Collins – West	---	0.087	0.085	---
Fort Collins	0.076	0.078	0.069	0.074
Greeley – Weld Tower	0.078	0.082	0.074	0.073

Overview of Modeling Approach

- June-July 2006 episode selected for modeling
- MM5 meteorological, SMOKE and CONCEPT (on-road mobile) emissions and CAMx photochemical models
- 36/12/4 km modeling domain
- Use projected RPO 2002 emissions for 2006/2010 modeling outside of Colorado
- Use 2006 and 2010 emissions for Colorado from CDPHE/APCD



**Modeling
Domains**

**36 km
Continental US
Domain**

**12/4 km domain
using two-way
grid nesting**

**2006 Colorado
Emissions from
CDPHE/APCD**

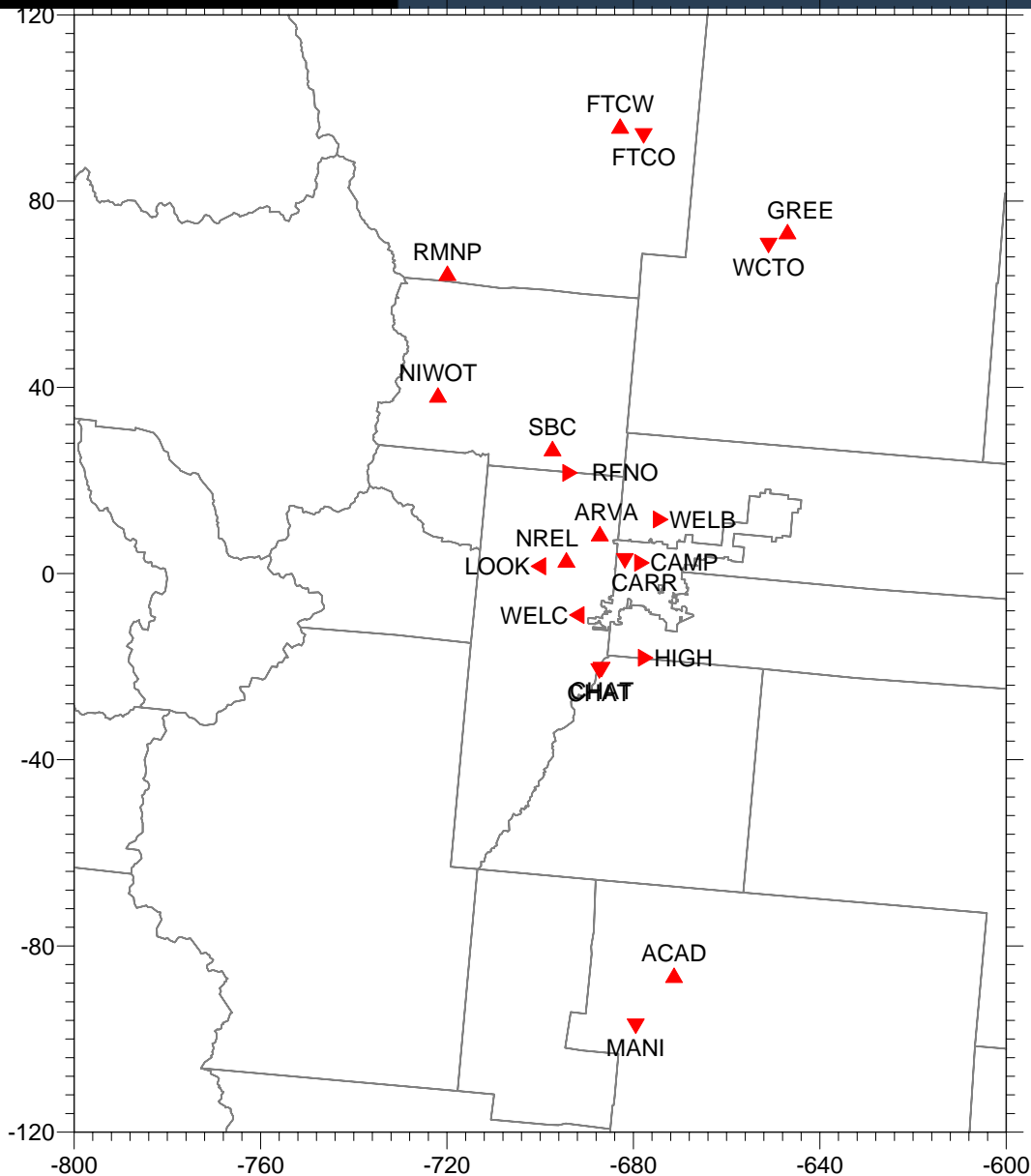
**2005 emissions
for other states
from RPOs**

Preliminary Base Case and Diagnostic Sensitivity Tests

- Preliminary 2006 emissions
- Initial model configuration
- Series of diagnostic sensitivity tests to define optimal final model configurations
- Results presented at March 4, 2008 Stakeholder Meeting and in Draft and Draft Final report on RAQC website
- Final model configurations used in final 2006 base case and 2010 base case modeling
 - Updated on-road mobile sources emissions in DMA using DRCOG linked based VMT data
 - Updated oil and gas emissions for Denver-Julesburg Basin using WRAP Phase III inventory

Model Performance Evaluation

- Model Performance Statistical Metrics
 - Bias and Error
 - Correlation
 - Model performance goals and criteria
- Graphical displays of model performance
 - Scatter Plots
 - Time Series Plots
 - Spatial maps w/ overlaid observations
 - Bugle and Soccer Plots
 - Bias/Error as function of time and concentration



Denver Ozone Monitoring Sites

Highest Monitors: DVs

RFNO: 85 ppb

CHAT: 84 ppb

NREL: 82 ppb

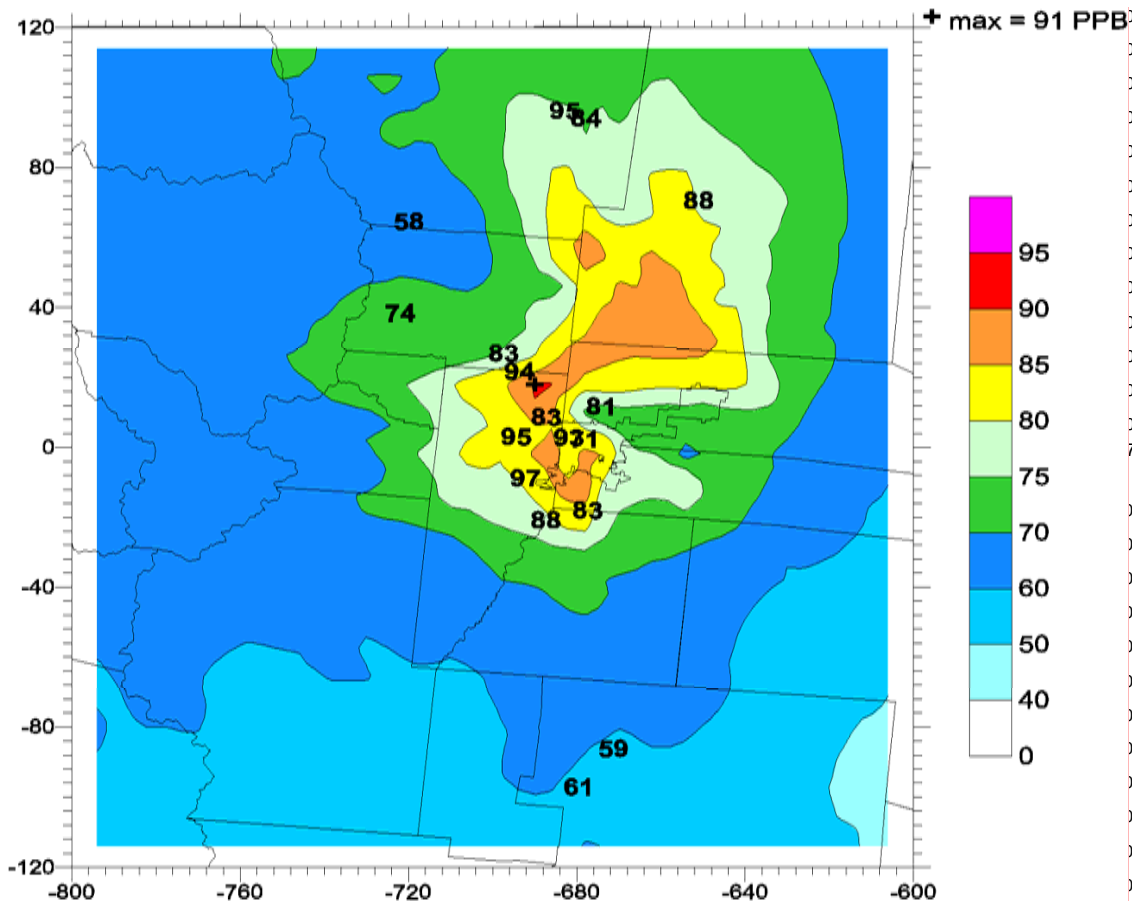
SOBC: 81 ppb

ARVA: 79 ppb

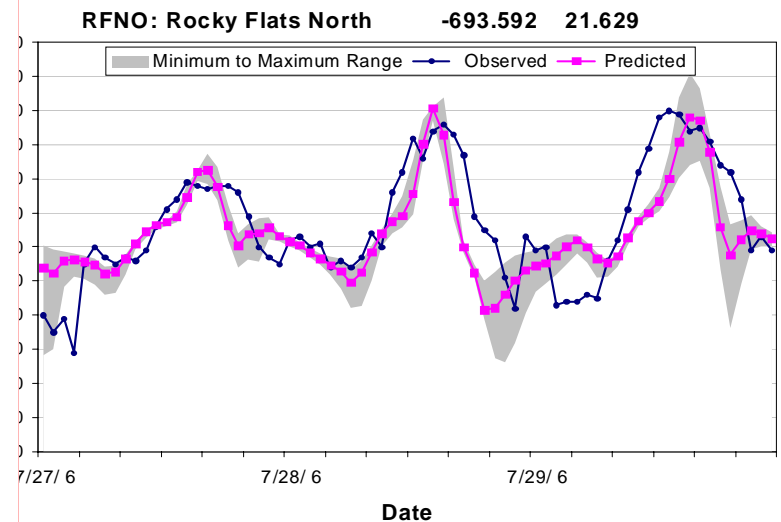
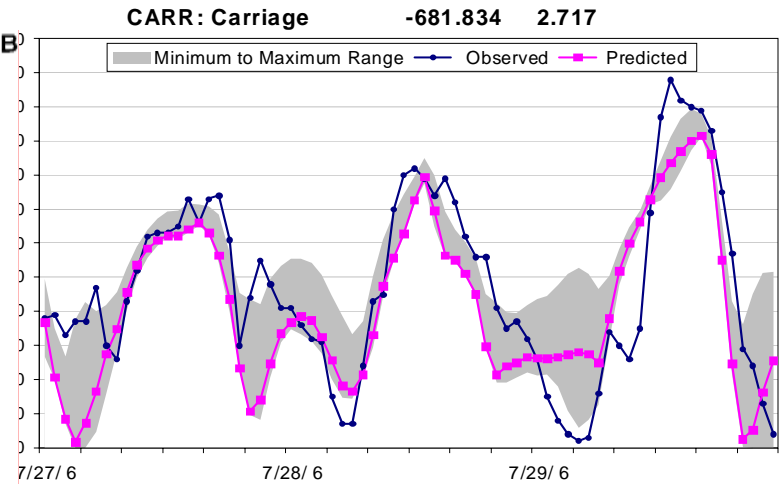
HIGH: 78 ppb

FTCW: (86 ppb)

Example Evaluation on July 29, 2006



Daily Max 8hr O3 (ppb)
Denver Base Case 4km run16.1204
July 29, 2006



Model Evaluation Conclusions

- Model Performance Variable
 - Days with good and poor ozone model performance
 - General ozone underprediction tendency
 - Ozone projection procedure will not use worst performing days when there is low predicted ozone
- Model performance achieves performance goals on almost all days
 - > 80% of the days achieves EPA's performance goals
 - Performance much better than seen in the EAC SIP
- Model appears to be suitable for evaluating control strategies
 - Further evaluation recommended (VOC species, weekend/weekday effects, etc.)
 - More refinements to model are also possible
 - Updates to meteorology, emission, etc.
 - Time and resource constraints

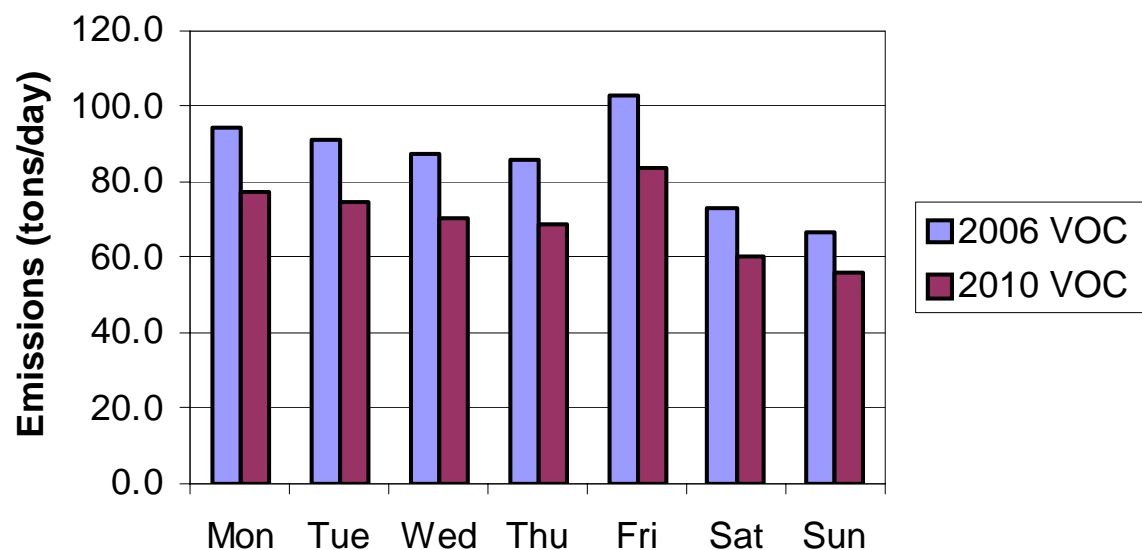
2006 Emissions

- 2006 NO_x, VOC and CO for Colorado from CDPHE/APCD
- 2006 link-based VMT for Denver NAA from DRCOG through APCD (used with CONCEPT model)
- 2006 CEM Data for NO_x and SO₂ emissions for large stationary sources (EGUs) throughout domain
- Projected 2005 emissions from 2002 State/RPO inventories outside of Colorado and for SO₂, NH₃, PM everywhere for area, mobile and non-CEM point
 - EPA MOBILE6 and NONROAD models
- MEGAN biogenic emission models using 2006 MM5 hourly meteorological data
- Day-specific 2006 wildfire data from NCAR (thanks Christine!)

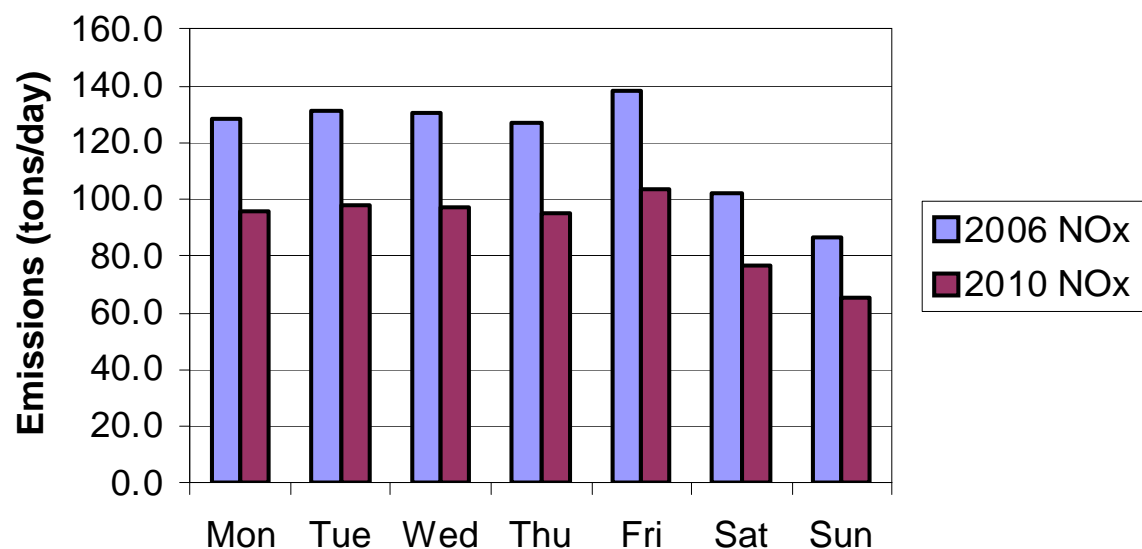
2010 Emissions

- 2010 NO_x, VOC and CO for Colorado from CDPHE/APCD
- 2010 link-based VMT for Denver NAA from DRCOG through CDPHE/APCD
 - CONCEPT emissions model uses link-based VMT, speeds, diurnally varying volumes, fleet mix and congestion adjustments
- Projected 2009 emissions from 2002 State/RPO inventories outside of Colorado
- 2006 MEGAN biogenic and Wildfire emissions (held constant)

CONCEPT June VOC Emissions



CONCEPT June NOx Emissions



Denver On-Road Mobile CONCEPT

2006-2010

VOC: -16% to -20%

NOx: -25% to -26%

CO: -17% to -19%

CONCEPT MV Molar VOC/NOx

	2006	2010
Mon	2.1	2.3
Tue	2.0	2.2
Wed	1.9	2.1
Thu	1.9	2.1
Fri	2.1	2.3
Sat	2.0	2.3
Sun	2.2	2.5

NOx Denver/NFR NAA (9-Counties)

Denver Non-attainment Area	Total Emissions (TPD)		Percent Total (%)		2010-2006 Difference	
	2006	2010	2006	2010	(TDP)	(%)
	NOx					
Area	17.7	20.2	4%	5%	2.5	14%
Oil & Gas	42.6	47.3	10%	13%	4.7	11%
EGU Point	55.6	64.1	13%	17%	8.5	15%
Fires	0.0	0.0	0%	0%	0.0	0%
Non-EGU Point	51.1	20.0	12%	5%	-31.0	-61%
Non-Road	94.2	86.5	22%	23%	-7.6	-8%
On-Road MV	167.1	139.6	39%	37%	-27.5	-16%
9-County Total	428.2	377.8	100%	100%	-50.4	-12%

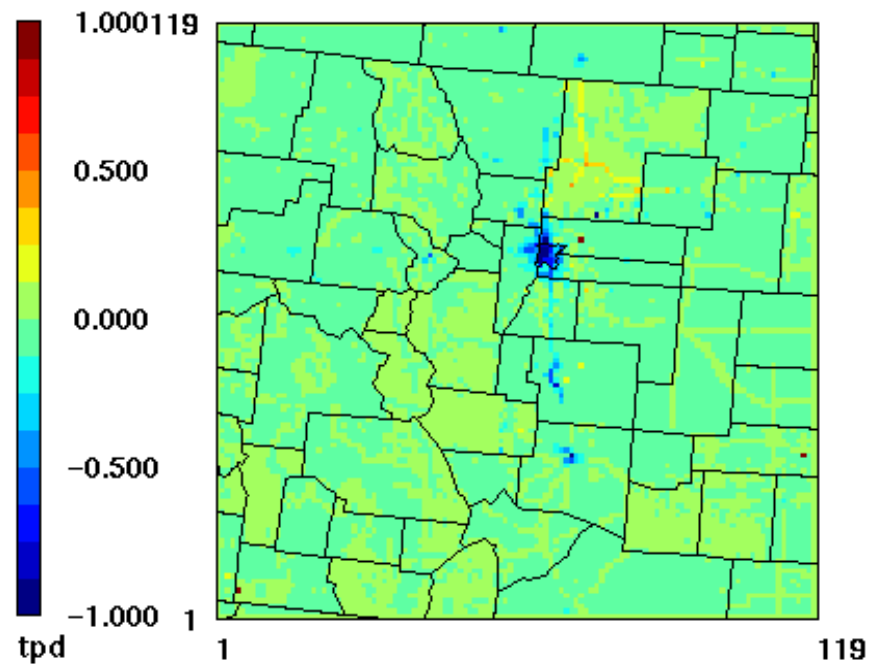
VOC Denver/NFR NAA (9-Counties)

Non-attainment Area	Total Emissions (TPD)		Total (%)		2010-2006 Difference	
	2006	2010	2006	2010	(TDP)	(%)
VOC						
Area	45.3	41.0	10%	9%	-4.4	-10%
Oil & Gas	181.6	207.6	41%	47%	25.9	14%
EGU Point	0.7	5.4	0%	1%	4.7	688%
Fires	0.0	0.0	0%	0%	0.0	0%
Non-EGU Point	42.1	37.2	9%	8%	-4.9	-12%
Non-Road	69.9	64.9	16%	15%	-5.0	-7%
On-Road MV	105.8	90.3	24%	20%	-15.5	-15%
Grid Total	445.4	446.3	100%	100%	1.0	0%

2010 – 2006 Emission Differences

NO_x 2010 – 2006

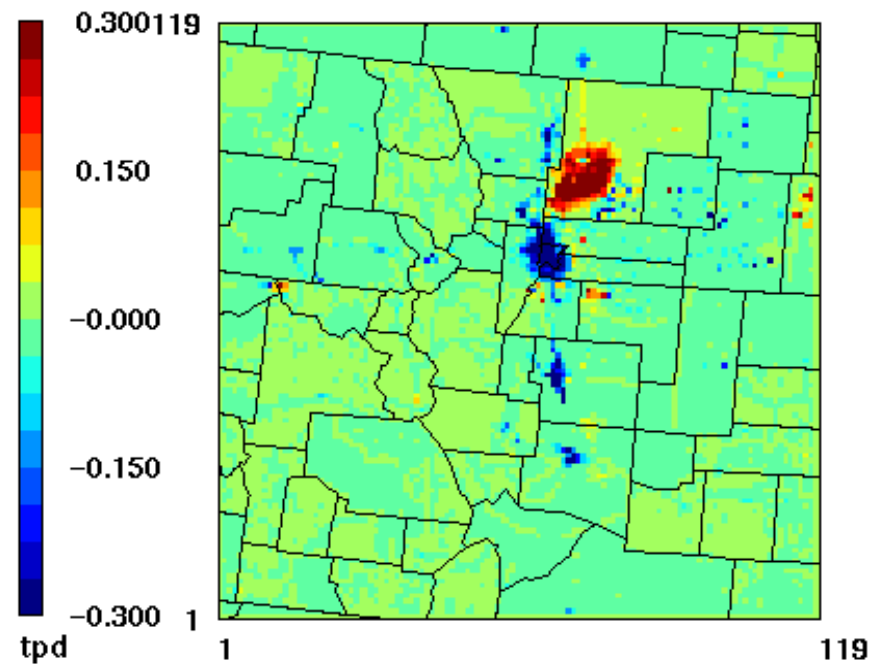
EMISSIONS
miss.NOX.surface.060615.fy2010.bin.a0, f=emiss.NOX.surface.060615.fy2006.bin.a0



June 15,2006 23:00:00
Min= -1.321 at (65,73), Max= 6.278 at (73,76)

CB05_VOC 2010–2006

EMISSIONS



June 15,2006 23:00:00
Min= -0.851 at (68,47), Max= 0.711 at (74,66)

Colorado Emissions by Source Category

2006 and 2010; 4 km Colorado Domain (TPD), June Thursday

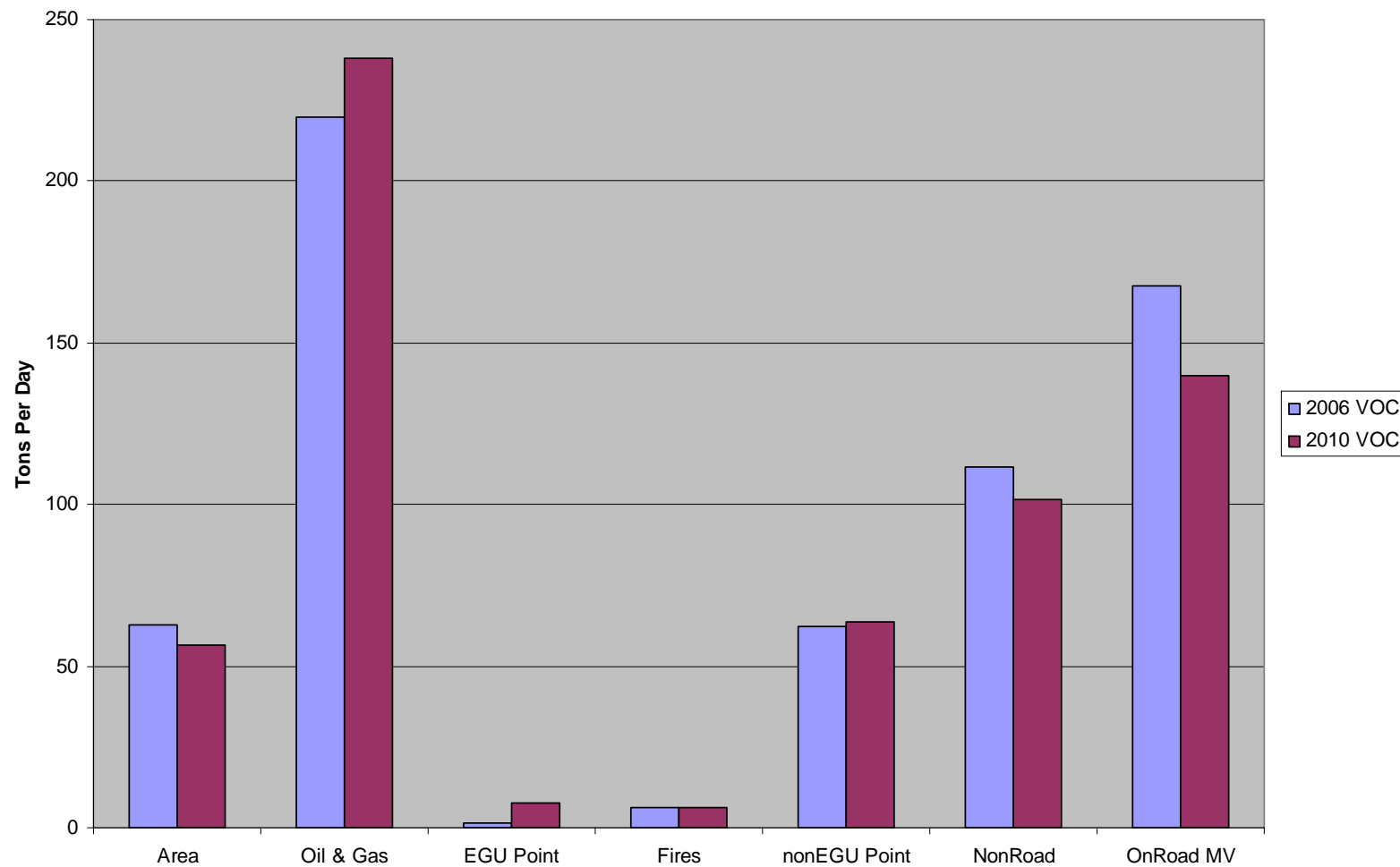
	2006			2010		
	CO	NOX	VOC	CO	NOX	VOC
Area	7.16	7.7	62.6	8.2	8.8	56.6
Oil & Gas	31.4	57.5	219.7	50.6	76.8	237.9
EGU Point	12.3	181.4	1.5	71.1	250.9	7.5
Fires	87.4	2.6	6.0	87.4	2.6	6.0
Non-EGU Point	68.0	97.3	62.5	41.0	53.2	63.5
Non-Road	1663.0	192.5	111.8	1661.6	176.9	101.5
On-Road MV	1885.2	264.5	167.6	1394.8	217.4	140
Grid Total	3754.4	803.5	631.6	3314.7	786.6	613.0

Percent Change 2006/2010

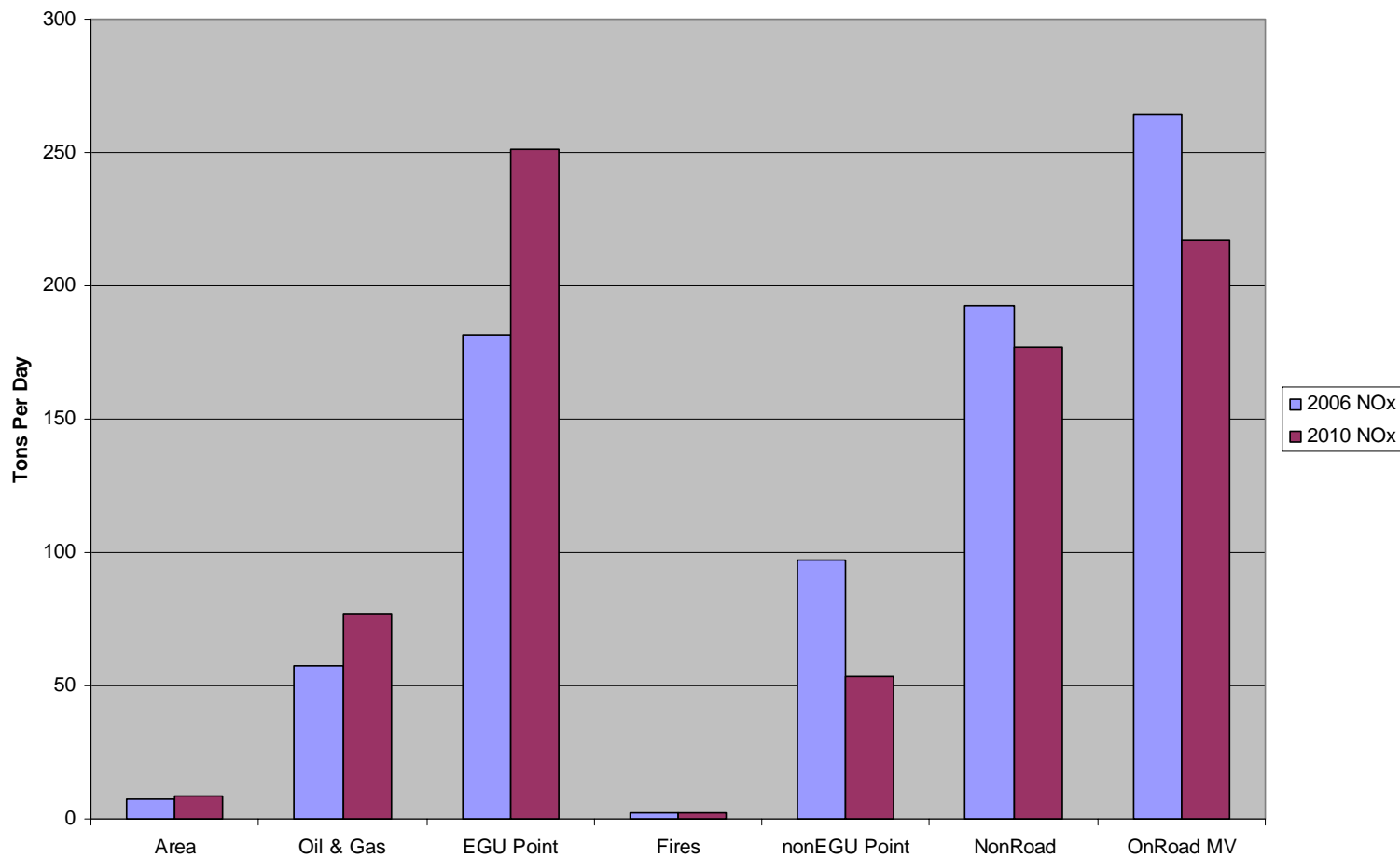
-11.7% -2.1% -2.9%

Biogenic VOC in Colorado 4 km Doman = 1,121 to 6,877 TPD

2006 vs. 2010 VOC Emissions by Major Source Category (Colorado 4 km)



2006 vs. 2010 NOx Emissions by Major Source Category (Colorado 4 km)



8-Hour Ozone Attainment Demonstration

- Model 2010 8-hour ozone Design Value projections following EPA's latest (April 2007) 8-hour ozone, PM_{2.5} and regional haze modeling guidance
 - Modeled attainment test uses the relative changes in the 2010 and 2006 modeling results to scale the observed 8-hour ozone Design Values
- In addition to a modeled ozone attainment test, EPA recommends using a weight of evidence (WOE) approach to the attainment demonstration, that includes
 - Model projected 8-hour ozone Design Values
 - Other modeling metrics showing future year ozone reductions
 - Emission and air quality trends
 - Receptor and observation based models
 - Key indicator species
- In fact, EPA guidance requires an WOE approach if the maximum model projected 8-hour ozone Design Value is between 82 and 87 ppb (85 ppb standard)

8-Hour Ozone Projection Approach

- Use the relative change in modeled ozone estimates between 2006 and 2010 to scale observed current Design Values (DVC) to obtain future year projected Design Values (DVF)
- Model derived scaling factors referred to as Relative Response Factors (RRF)
 - $RRF = \text{Modeled 2010} / \text{Modeled 2006}$
 - Taken over highest modeled ozone days near a monitor
 - $DVF = DVC \times RRF$
- Example for Chatfield (CHAT):
 - $DVC = 84 \text{ ppb}; RRF = 0.996$
 - Model estimates 0.4% reduction between 2006 and 2010)
 - $DVF = 84 \times 0.996 = 83.7 \text{ ppb}$

Percent Changes in NOx and VOC Emissions by Denver/NFR NAA County

County	NOx	VOC
Adams	-15.2	-10.5
Arapahoe	-21.7	-5.4
Boulder	-6.6	-2.7
Broomfield	-32.6	-15.7
Denver	-11.9	-12.6
Douglas	-17.9	-13.7
Jefferson	-24.7	+3.3
Larimer	-18.3	-12.2
Weld	+4.8	+24.4
Denver/NFR NAA	-11.8	+0.2

Within the Denver/NFR NAA, the total NOx reduction is -12%, whereas the total VOC reduction is 0% as the reduction in mobile VOC is compensated by increases in O&G VOC (not including biogenics)

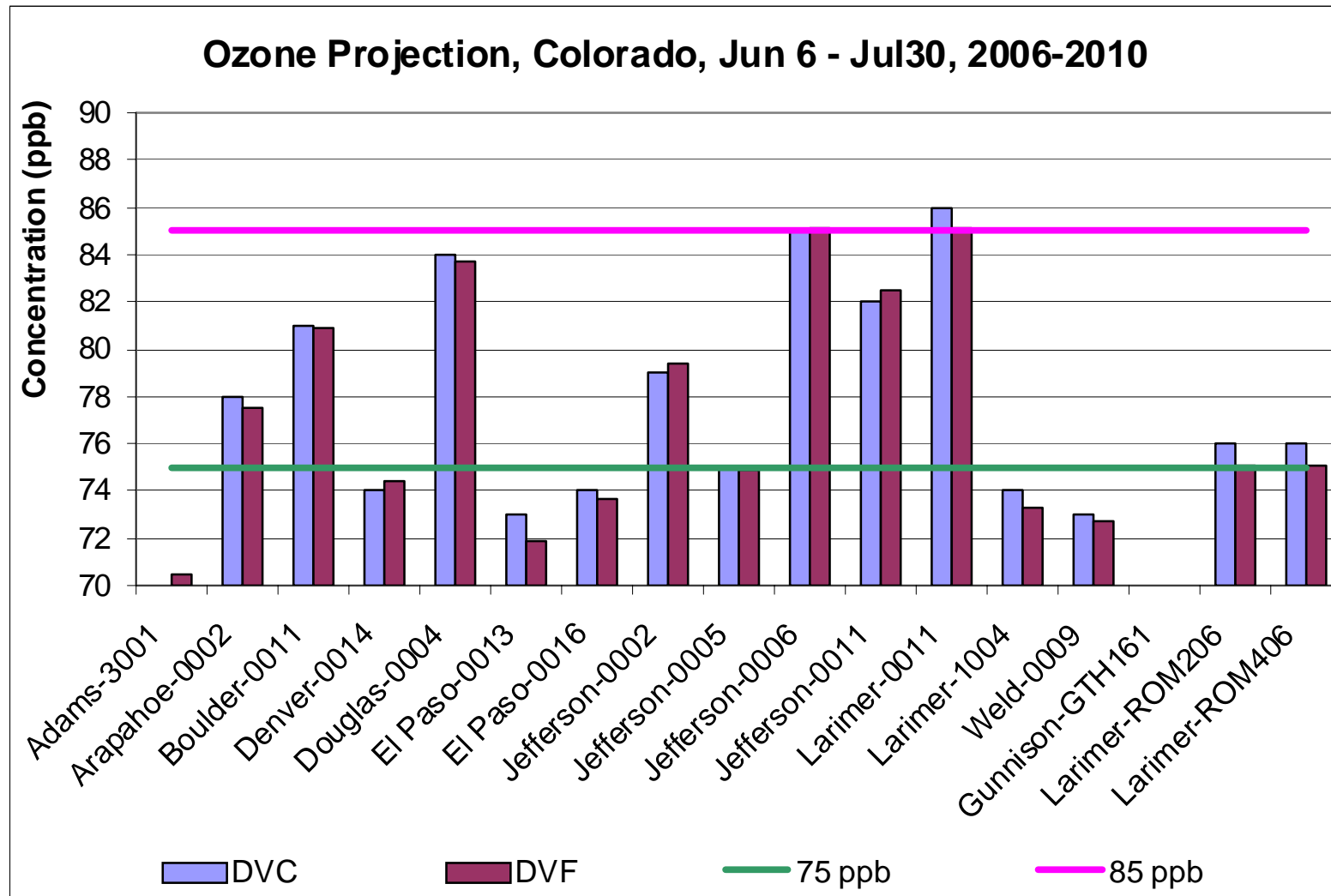
State-wide NOx and VOC is reduced, respectively, -2.1% and -2.9% (-1.9% and from -0.2% to -1.1% accounting for biogenics)

2010 8-Hour Ozone DV Projections

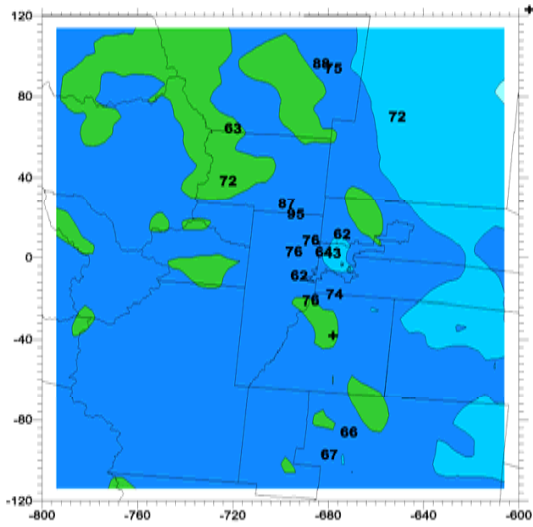
(EPA Default Approach; June 5 – July 30, 2006)

Site ID	County-Site	Name	DVC	DVF	Cutoff	#Day
80013001	Adams-3001	Welby	70	70.5	77	11
80050002	Arapahoe-0002	Highland	78	77.5	78	13
80130011	Boulder-0011	South Boulder	81	80.9	77	11
80310014	Denver-0014	Carriage	74	74.4	78	10
80350004	Douglas-0004	Chatfield	84	83.7	78	10
80410013	El Paso-0013	USAF Academy	73	71.9	74	10
80410016	El Paso-0016	Manitou	74	73.7	74	10
80590002	Jefferson-0002	Arvada	79	79.4	78	10
80590005	Jefferson-0005	Welch	75	74.9	77	11
80590006	Jefferson-0006	Rocky Flats North	85	85.1	77	11
80590011	Jefferson-0011	NREL	82	82.5	78	10
80690011	Larimer-0011	<i>Ft. Collins West</i>	86	85.1	76	10
80691004	Larimer-1004	Fort Collins South	74	73.3	76	11
81230009	Weld-0009	Weld Tower	73	72.7	75	11
GTH161	Gunnison-GTH161	Gothic	68	67.9	73	10
ROM206	Larimer-ROM206	RMNP1	76	75.1	76	10
ROM406	Larimer-ROM406	RMNP2	76	75.1	76	10

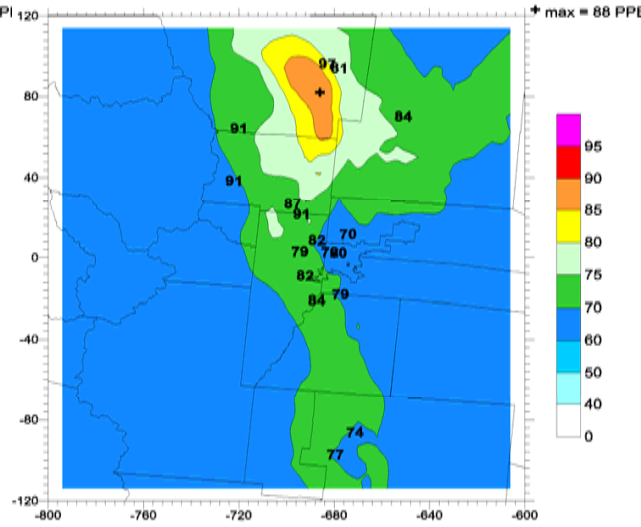
2010 8-Hour Ozone DVFs (EPA Default)



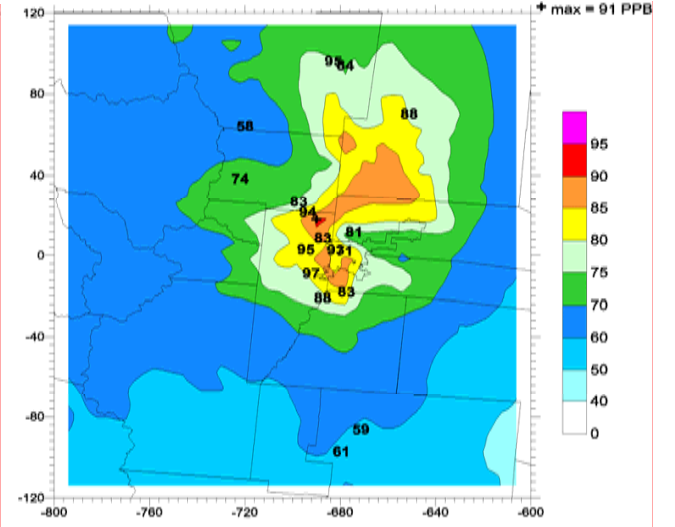
Daily Maximum 8-Hour Ozone: 2006 (top) & 2010-2006 (bottom)



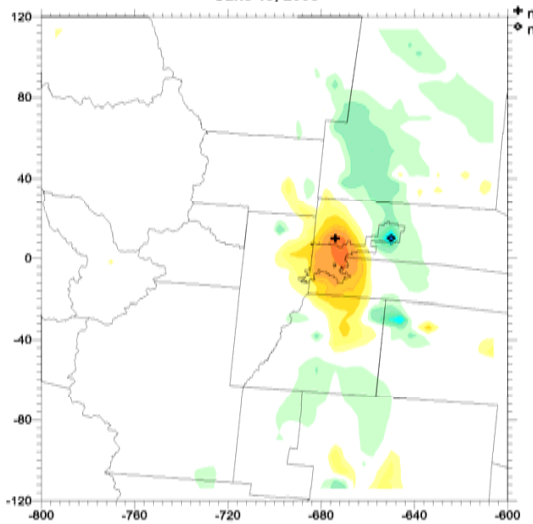
Daily Max 8hr O3 (ppb)
Denver Base Case 4km run16.1204
June 19, 2006



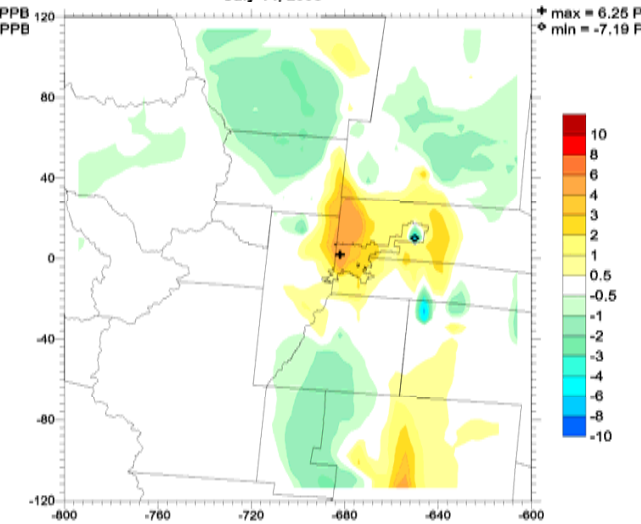
Daily Max 8hr O3 (ppb)
Denver Base Case 4km run16.1204
July 14, 2006



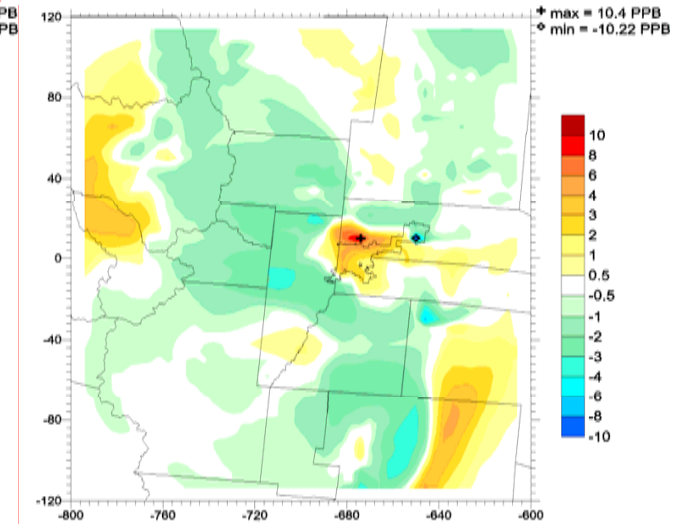
Daily Max 8hr O3 (ppb)
Denver Base Case 4km run16.1204
July 29, 2006



Difference In Daily Max 8hr O3 (ppb)
Denver Run 16: FY2010 - 2006
June 19

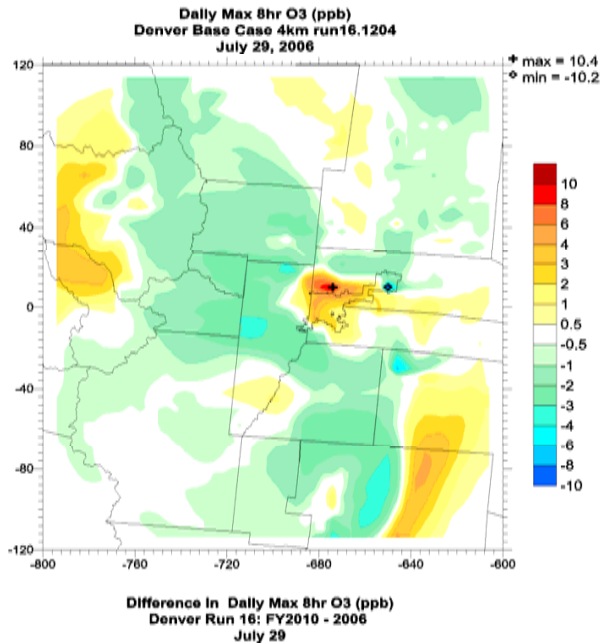
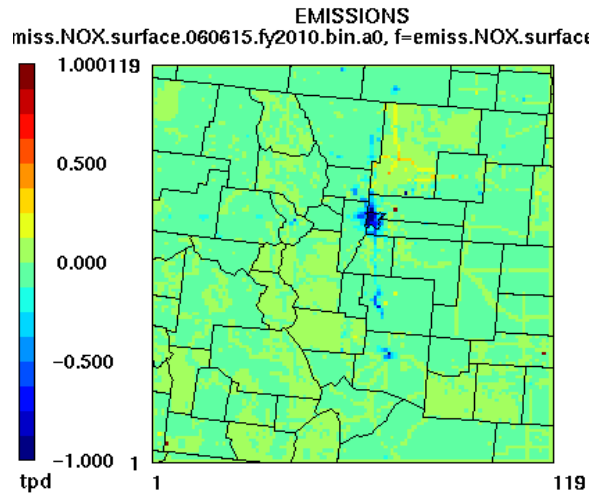
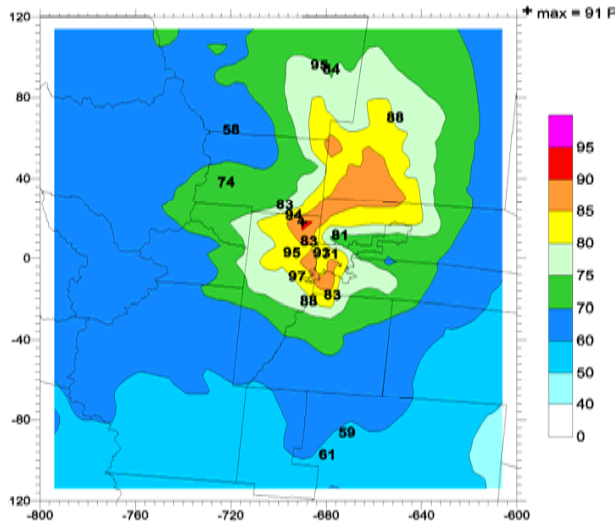


Difference In Daily Max 8hr O3 (ppb)
Denver Run 16: FY2010 - 2006
July 14

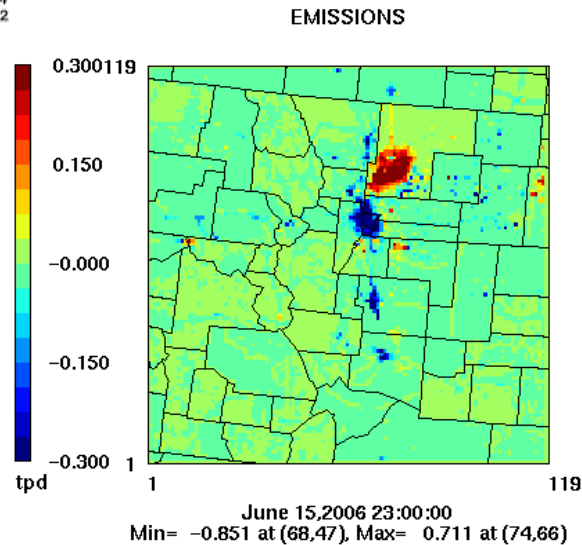


Difference In Daily Max 8hr O3 (ppb)
Denver Run 16: FY2010 - 2006
July 29

NOx 2010 - 2006



CB05_VOC 2010-2006



Hypothesis

- Ozone increases in urbanized metro Denver in area of maximum VOC and NOx reductions
- Ozone increase due to less ozone titration ($\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2$) and reduction in NOx as radical sink (less inhibition) ($\text{NO}_2 + \text{OH} \rightarrow \text{HNO}_3$)
- VOC reduction in DMA insufficient to overcome NOx disbenefits

Conclusions: 2010 Ozone Projections

- Using the EPA default projection approach, the maximum projected 2010 8-hour ozone Design Value is 85.1 ppb and occurs at both the Rocky Flats North and Ft. Collins West monitors (that started at 85 and 86 ppb, respectively)
- The next two highest projected 2010 DVs are 83.7 at Chatfield and 82.5 ppb at NREL (four values within 82-87 ppb)
- The NO_x reductions in metropolitan Denver appear to have a local adverse effect on ozone that is not sufficiently compensated for by the VOC reductions
 - Across the Denver/NFR NAA the changes in NO_x and VOC emissions between 2006 and 2010 are -12% and 0% (although in Denver and other counties getting -13% VOC reduction)

2010 Control Plan Development

- 2010 Emission Reduction Sensitivity Tests
 - Twelve (12) sensitivity tests budgeted
 - Identify sources and precursors (VOC vs. NO_x) that most efficiently reduce elevated ozone
- 2010 Ozone Source Apportionment Modeling
 - Identify source regions, categories and precursors that contribute to elevated ozone the most
 - Design to complement 2010 sensitivity tests
- 2010 Control Strategy Modeling
 - Two (2) 2010 control packages model simulations are currently budgeted
- 2020 Modeling
 - 2020 Base Case
 - Twelve (12) 2020 emission reduction sensitivity tests
 - To occur in late summer

2010 Sensitivity Tests

- Across-the-board VOC and/or NO_x emission reduction sensitivity tests for June-July, 2006 modeling period
- RAQC/CDPHE and Stakeholders proposed 12 VOC and/or NO_x emission reduction sensitivity tests to:
 - Help understand direction and magnitude of ozone changes due to reductions in VOC and/or NO_x emissions within the NAA and state-wide;
 - Aid in help defining more refined emissions control scenarios; and
 - Provide episode specific model uncertainty information that may be used later in a Weight of Evidence (WOE) analysis.

2010 Sensitivity Tests

1. 20% VOC Reduction from On-Road in NAA
2. 20% Evaporative VOC from On-Road Mobile in NAA
3. 0% Ethanol Market Penetration in NAA (on-road & non-road)
4. 20% VOC Reduction from O&G in NAA
5. 20% NOx Reduction from Point and O&G in NAA
6. 20% VOC Reduction from Non-Road in NAA
7. 20% VOC Reduction from Area in NAA
8. 20% NOx Reduction from Point and O&G in Colorado
9. 20% VOC Reduction from O&G in Colorado
10. 20% VOC & NOx Reduction from Point and O&G in Colorado
11. 20% NOx Reduction from Point and O&G in NAA and 20% NOx Reduction from Pawnee and Rawhide
12. Reduction in Biogenic VOC due to Bark Beetle Infestation

On-Road Mobile Source Sensitivity Tests

1. 20% VOC Reduction from On-Road Mobile Sources in Denver/NFR NAA
 - Sensitivity of ozone to VOC emission reductions from on-road mobile sources in Denver/NFR NAA
 - Help understand role of VOC/NO_x on ozone formation
2. 20% Evaporative VOC Reduction from On-Road Mobile Sources in Denver/NFR NAA
 - Effects of evaporative VOC control on ozone (e.g., lower RVP)
3. 0% Ethanol Market Penetration in NAA
 - Account for ethanol use in on-road and non-road mobile sources
 - Effects of ethanol fuel use on ozone

Other 2010 VOC/NOx Emission Sensitivity

4. 20% VOC Reduction from O&G in NAA
5. 20% NOx Reduction from Point and O&G in NAA
6. 20% VOC Reduction from Non-Road in NAA
7. 20% VOC Reduction from Area in NAA
 - Help map out VOC/NOx and source category specific controls within Denver/NFR NAA on ozone formation
8. 20% NOx Reduction from Point and O&G in Colorado
9. 20% VOC Reduction from O&G in Colorado
10. 20% VOC & NOx Reduction from Point and O&G in Colorado
 - Help identify effects of controls outside of Denver/NFR NAA have on ozone formation within the NAA
11. 20% NOx Reduction from Point and O&G in NAA and 20% NOx Reduction from Pawnee and Rawhide
 - Mixed NOx controls within and outside of the NAA

2010 Ozone Source Apportionment Modeling

- Perform Geographic Region and Source Category specific ozone source apportionment
 - Geographic Regions: Counties with NAA; Remainder Portions of Colorado; Groups of States.
 - Source Categories: On-Road; Non-Road; Area; Oil and Gas; EGU Point; Non-EGU Point; Biogenics+Wildfires
- Source Contributions from Source Groups
 - Identify source regions and categories that contribute to 2010 high ozone
 - Identify role of transport and contributions of NAA, remainder Colorado, nearby states, etc.
 - Designed to complement 2010 sensitivity tests

Next Steps

- Twelve 2010 Sensitivity Tests during June 2008
 - 20% Mobile VOC and 20% Mobile Evap VOC by June 18 meeting
- Source apportionment modeling during June-July 2008
- Modeling of two (2) control strategies during July-August 2008 (3 weeks from receipt of control measure packages)
- Documentation by September 2008