Summary of the Revised Denver 2010 8-Hour Ozone Projections and Sensitivity Test Modeling Results

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July 9, 2008
Revised DRAFT: July 11, 2008

INTRODUCTION

In December 2002, the Denver region entered into an 8-hour ozone Early Action Compact (EAC) with the U.S. Environmental Protection Agency (EPA) that allowed them to defer designating the area as nonattainment for the 8-hour ozone National Ambient Air Quality Standard (NAAQS) until 2007, provided they submit a State Implementation Plan (SIP) by March 2004. In November 2007 the Denver area was designated nonattainment of the 8-hour ozone NAAQS due to a measured 8-hour ozone Design Value from 2005-2007 of 85 ppb at the Rocky Flats North monitoring site that violated the current 8-hour ozone NAAQS (0.08 ppm), which requires the Denver area to submit a revised 8-hour ozone SIP that demonstrates the region will attain the 0.08 ppm 8-hour ozone NAAQS by 2010..

ENVIRON International Corporation and Alpine Geophysics, LLC were retained by the Denver Regional Air Quality Council (RAQC) to perform the photochemical modeling necessary to develop such an 8-hour ozone SIP. Important milestone events related to those activities to date are as follows:

- A Modeling Protocol was prepared, dated November 28 2007, that describes how the MM5 meteorological, SMOKE and CONCEPT emissions and CAMx photochemical grid models will be applied to demonstrate attainment of the 8-hour ozone NAAQS by 2010 (http://ozoneaware.org/documents/DraftFinalProtocolDenver8-HourOzoneNov282007.pdf).
- Reports on the MM5 meteorological modeling (http://ozoneaware.org/documents/MM5_Eval_DENSIP_Feb25_2008.pdf) and the preliminary CAMx photochemical modeling (http://ozoneaware.org/documents/Prelim_Ozone_Eval_Denver_SIP_Feb27_2008.pdf) of the June-July 2006 ozone episode were prepared, distributed in February 2008 and discussed at a March 4, 2006 stakeholders meeting.
- On March 12, 2008 EPA promulgates a new lower 8-hour ozone NAAQS of 0.075 ppm (75 ppb) that will need to be addressed in a 2013 8-hour ozone SIP.
- A report documented the preliminary CAMx model evaluation, diagnostic testing and identification of optimal model configuration was completed on May 13, 2007

(http://www.ozoneaware.org/documents/Denver_ozone_preliminary_MPE_May13_2008.pdf).

- Draft final 2006 base case modeling results and model performance evaluation and preliminary 2010 8-hour ozone projections were presented at a June 4 stakeholders and June 5 RAQC Board meetings.

The 2006 and 2010 emissions for Colorado provided to the ENVIRON/Alpine modeling team and used in the 2006/2010 modeling results presented at the June 4-5, 2008 meetings contained some errors that have been corrected. Thus, this document contains updated 2006 and 2010 modeling and 2010 8-hour ozone projections. These updated modeling databases were used to perform a series of 2010 emission sensitivity tests that are reported on below. The updated 2006 emissions did not substantially change the model performance evaluation, so the reader is referred to the previous presentations and reports to assess the performance of the model. A report documenting the final model performance evaluation is in preparation.

REVISED MODELING RESULTS

Below we present the results of the revised emissions and photochemical modeling that was conducted using the corrected 2006/2010 emissions during June-July 2008.

Updated 2006/2010 Emissions

Table 1 displays the updated 2006 and 2010 VOC and NOx emissions for the 9-county Denver nonattainment area (NAA). From 2006 to 2010 the VOC emissions are projected to be reduced -3% across the NAA with the largest decrease in on-road mobile sources (-21%) and the largest increase in oil and gas (O&G) sources (+9%). More reductions are seen in NOx emission across the NAA (-10%) that is primarily due to reductions in on-road mobile sources (-27%).

Table 1a. Revised 2006 and 2010 VOC emissions for the 9-county Denver NAA.

Non-attainment Area	Total Emissions (TPD)		Total (%)		2010-2006 Difference	
	2006	2010	2006	2010	(TDP)	(%)
	VOC					
Area	55.6	47.9	12.3	10.9	-7.680	-13.8
Oil & Gas	189.6	207.4	41.9	47.0	17.790	9.4
EGU Point	0.7	1.6	0.2	0.4	0.917	134.1
Fires	0.0	0.0	0.0	0.0	0.000	0.0
Non-EGU Point	31.4	35.5	6.9	8.0	4.054	12.9
Non-Road	69.9	64.9	15.4	14.7	-4.954	-7.1
On-Road MV	105.8	83.8	23.3	19.0	-21.985	-20.8
Total	452.9	441.1	100.0	100.0	-11.859	-2.6

Table 1b. Revised 2006 and 2010 NOx emissions for the 9-county Denver NAA.

Non-attainment Area	Total Emissions (TPD)		Total (%)		2010-2006 Difference	
	2006	2010	2006	2010	(TDP)	(%)
	NOX					
Area	17.7	18.9	4.4	5.2	1.242	7.0
Oil & Gas	42.5	49.9	10.6	13.7	7.423	17.5
EGU Point	55.6	58.5	13.8	16.1	2.887	5.2
Fires	0.0	0.0	0.0	0.0	0.000	0.0
Non-EGU Point	25.5	27.5	6.3	7.6	1.955	7.7
Non-Road	94.2	86.5	23.4	23.8	-7.649	-8.1
On-Road MV	167.1	121.8	41.5	33.5	-45.284	-27.1
Total	402.5	363.1	100.0	100.0	-39.427	-9.8

2010 8-Hour Ozone Projections

The EPA Modeled Attainment Test Software (MATS) was used with the revised 2006 and 2010 base case 4 km CAMx modeling results to project 2010 8-hour ozone Design Values (DVs) at monitoring sites in the Denver NAA. EPA's April 15, 2007 Modeling Guidance has specific recommended procedures for projecting 8-hour ozone DVs. These procedures use the modeling results in a relative fashion using relative response factors (RRFs) to scale the observed base year 8-hour ozone Design Values (DVB) to obtain future year projected 8-hour ozone Design Values (DVF). EPA's recommended procedures were followed with one exception. EPA recommends averaging three years of 8-hour ozone DVs that straddle the modeling year (2006), which would be 8-hour ozone DVs from the 2004-2006, 2005-2007 and 2006-2008 periods. As 2008 data do not yet exist, then for the Denver 2010 8-hour ozone projections we are using the 2005-2007 8-hour ozone Design Values as the base year Design Value (DVB) for all sites but one. The Fort Collins West monitoring site started monitoring in 2006, so its base year Design Values is based on an average of the fourth highest 8-hour ozone concentrations from just two years of data (2006-2007). These procedures have been documented in the Modeling Protocol and presentations to the stakeholder group and agreed to by EPA Region VIII.

Table 2 presents the base year 8-hour ozone Design Values (DVB) and 2010 projected 8-hour ozone Design Values for monitoring sites in the Denver NAA using the updated 2006 and 2010 base case modeling results. EPA guidance recommends projecting the future year 8-hour ozone Design Values to the nearest tenth of a ppb and then truncating the values for comparisons with the NAAQS to determine whether they pass (84 ppb or lower) or fail (85 ppb or higher) the modeled attainment test. Thus, two projected DVFs are presented in Table 2, one that includes the projected value to the nearest tenth of a ppb, and one that truncates the value as recommended by EPA. The 2010 8-hour ozone Design Values at all monitoring sites in the Denver NAA are projected to pass the modeled attainment test with projected values of 84 ppb or less. There are two monitoring sites with DVBs above the 8-hour ozone NAAQS, 85 ppb at Rocky Flats

North and 86 ppb at Fort Collins West. These two monitoring sites are projected to have 2010 8-hour ozone Design Values of 84 ppb (84.6 and 84.9 ppb, respectively).

EPA guidance requires that a weight of evidence (WOE) attainment demonstration be performed if there are any projected future year Design Values between 82-87 ppb. The current Denver 8-hour ozone Design Value projections for the 2010 base case has 4 monitoring sites that fall within the 82-87 ppb WOE range, so additional WOE analysis will be needed.

Table 2. Base year (DVB) and 2010 projected (DVF) 8-hour ozone Design Values using the updated 2006 and 2010 modeling results.

			DVB	DVF (ppb)	
Site ID	**Site Name**	**County**	**(ppb)**	**w/tenths**	**EPA**
80013001	Welby	Adams	70	70.2	70
80050002	Highland	Arapahoe	78	77.3	77
80130011	S. Boulder Creek	Boulder	81	80.6	80
80310002	Denver - CAMP	Denver	56	56.1	56
80310014	Carriage	Denver	74	74.0	74
80350004	Chatfield	Douglas	84	83.1	83
80410013	USAF Academy	El Paso	73	72.0	72
80410016	Manitou Springs	El Paso	74	73.8	73
80590002	Arvada	Jefferson	79	79.0	79
80590005	Welch	Jefferson	75	74.5	74
80590006	Rocky Flats North	Jefferson	85	84.6	84
80590011	NREL	Jefferson	82	82.1	82
80690011	Fort Collins - West	Larimer	86	84.9	84
80691004	Fort Collins	Larimer	74	73.0	73
81230009	Greeley - WeldTow	Weld	73	72.7	72
GTH161	Gunnison	Gunnison	68	67.9	67
ROM206	Larimer	Larimer	76	75.0	75
ROM406	Larimer	Larimer	76	75.0	75
MATS: http://www.epa.gov/scram001/modelingapps_mats.htm					

2010 Sensitivity Modeling Results

Sixteen (16) 2010 sensitivity tests were conducted that reduced emissions from the 2010 base case levels. These sensitivity tests examined mainly VOC and/or NOx emissions reductions in either the 9-county Denver nonattainment area (NAA) or across all of Colorado. These 2010 sensitivity tests were as follows:

- Sens01 – 20% reduction in VOC emissions from on-road mobile sources in the NAA;
- Sens02 – Reduction in on-road mobile sources VOC emissions (accomplished by reducing RVP to 7.0 psi with ethanol market penetration of 85% at 8.0 psi –net reduction 0.8 psi);
- Sens03 – 0% ethanol market penetration.

- Sens04 – 20% reduction in VOC emissions from oil and gas (O&G) sources in the NAA;
- Sens04B – 20% reduction in VOC and NOx emissions from O&G sources in the NAA;
- Sens04C – 20% reduction in VOC and 30% reduction in NOx from O&G sources in the NAA (achieves an equivalent tonnage of VOC and NOx emission reductions);
- Sens04D – 40% reduction in VOC emissions from O&G emissions in the NAA;
- Sens05 – 20% reduction in NOx emissions from point and O&G sources in the NAA;
- Sens06 – 20% reduction in VOC emissions from non-road mobile sources in the NAA;
- Sens07 – 20% reduction in VOC emissions from area sources in the NAA;
- Sens08 – 20% reduction in NOx emissions from point and O&G sources in Colorado;
- Sens09 – 20% reduction in VOC emissions from O&G sources in Colorado;
- Sens10 – 20% reduction in VOC and NOx emissions from point and O&G sources in Colorado;
- Sens11 – 20% reduction in NOx emissions from point and O&G sources in the NAA plus 20% reduction in NOx emissions from Pawnee EGUs;
- Sens12A – Effects of increase in bark beetle infestation between 2006 and 2010 on biogenic emissions; and
- Sens12B – Effects of bark beetle infestation in 2010 versus no infestation.

Table 3 summarizes the results of the 2010 sensitivity tests and includes the VOC and NOx emission reductions in the Denver NAA and the reduction in the projected 2010 8-hour ozone Design Values at the key Rocky Flats North (RFNO) and Fort Collins West (FTCW) monitoring sites. The EPA MATS tool provides 8-hour ozone Design Value projections to the nearest tenth of a ppb. Consequently, it is difficult to see some differences in the effects of sensitivity tests whose modeled ozone changes are small and may not influence the RFNO or FTCW monitors on the days used in the ozone projections.

Spatial maps of daily maximum 8-hour ozone concentrations and their differences for July 14 and July 29 are shown in Figure 1. These are two of the highest observed and predicted ozone days during the June-July 2006 modeling period. The spatial maps help explain the sensitivity tests.

The 20% reduction in on-road mobile source VOC emissions sensitivity test (Sens01) results in a -0.1 ppb reduction in the projected 8-hour ozone DVs at both the RFNO and FTCW monitoring sites. The area of ozone reductions is rooted to and spreads a little way downwind of the Denver metropolitan area (Figure 1). When lower RVP gasoline (Sens02) is used in the NAA (7 psi) projected ozone is also reduced by -0.1 ppb, but the area of reduction is much smaller than in Sens01 owing to much less VOC controls. And

the zero ethanol penetration sensitivity test has very little effect on the ozone concentrations and no change in the projected DVs from the 2010 base case.

Sens04 and Sens04D examine a 20% and 40% reduction in VOC emissions from O&G in the NAA, which results in ozone reductions in Weld County, and 0.0 and -0.2 ppb reductions in the projected DVs at RFNO and FTCW monitors, respectively. There are not many days when the ozone reductions from the O&G VOC controls in Weld County are transported over the RFNO monitor during the June-July 2006 modeling episode.

Sens04B and Sens04C examine reductions in both VOC and NOx emissions from area, point, non-road and O&G sources in the NAA. The larger amounts of VOC and NOx controls produces greater reductions in the projected 2010 DVs at RFNO (-0.5 and -0.7 ppb) and FTCW (-1.1 and -1.6 ppb). The ozone difference plots in Figure 1 show ozone increases in metropolitan Denver on July 14th, but much less ozone increase on July 29, suggesting that the VOC- versus NOx-limited ozone formation characteristics on July 14 (Friday) and July 29 (Saturday) are quite different.

The 20% NOx control on point and O&G sources in the NAA (Sens05) results in modest reductions in the 2010 projected DVs at RFNO (-0.2 ppb) and FTCW (-0.5 ppb). The 20% non-road mobile VOC (Sens06) and 20% area VOC (Sens07) have little effect on the 8-hour ozone projections.

20% control of NOx from point and O&G sources state-wide (Sens08) reduces the 2010 projected DVs at RFNO and FTCW by -0.2 and -0.7 ppb, respectively. Whereas adding an additional 20% VOC control on point and O&G sources state-wide to Sens08 (Sens10) reduces the projected 8-hour ozone DVs at the two monitors by only an additional -0.1 ppb each. By looking at the differences between Sens10 and Sens08 (Figure 1) sensitivity simulation we see that the state-wide NOx reductions are much more effective at reducing ozone in the Denver NAA than the state-wide VOC reductions.

According to the Sens09 modeling results, extending the 20% VOC controls from just the NAA (Sens04) to all of Colorado (Sens09) has no affect on the projected DV at RFNO, and reduces it at FTCW by an additional -0.1 ppb. However, the difference plots for Sens09 don't look correct and these sensitivity results should be viewed with caution.

Sens11 was suppose to add 20% NOx reductions at the Pawnee and Rawhide EGUs to Sens05 that examined 20% NOx control to point and O&G in the NAA. However, it turned out that the grid cell definition of the Denver NAA used in developing the emissions sensitivity reduction input files included one of the EGUs so reductions in NOx emissions at one of the EGUs was also included in Sens05. Sens11 produced the same ozone reductions at the two key monitors as Sens05.

The results of the two bark beetle infestation sensitivity tests (Sens12A and Sens12B) are still being analyzed.

Preliminary Findings from 2010 Sensitivity Tests

The results of the sensitivity tests are still being analyzed and interpreted. But the preliminary results suggest that regional NOx controls are one of the most effective strategies for reducing ozone in the Denver NAA. Local NOx controls can also be effective; although they do appear to have adverse effects in the downtown metropolitan area whose ozone increases can impact downwind monitors depending on the wind direction. Regional VOC controls outside of the NAA have little benefits in reducing ozone in the NAA. Local VOC controls appear to have some ozone benefits and no adverse effects, but their benefits do not appear to be as great as the NOx controls.

One difference in the current and EAC ozone modeling is the sensitivity of the ozone at RFNO monitor to O&G VOC controls. During the EAC modeling, there were several key days during the June-July 2002 episode when emissions from the O&G developments in Weld County were advected over the RFNO monitor. During the current June-July 2006 modeling such events are much less frequent. However, there are many days during the current episode when the air masses from Weld County impact the FTCW monitor.

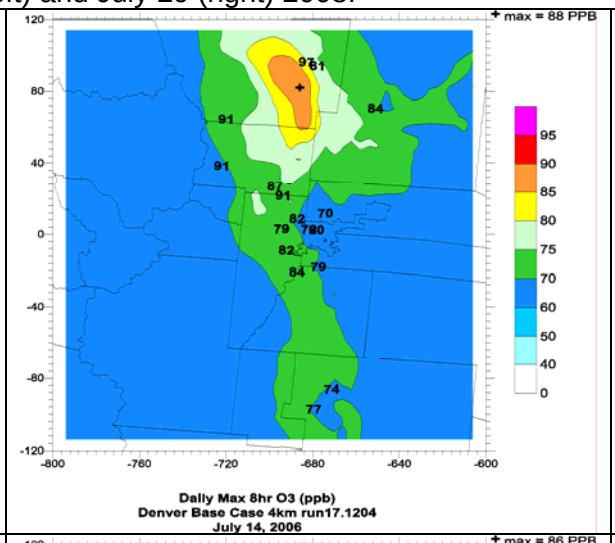
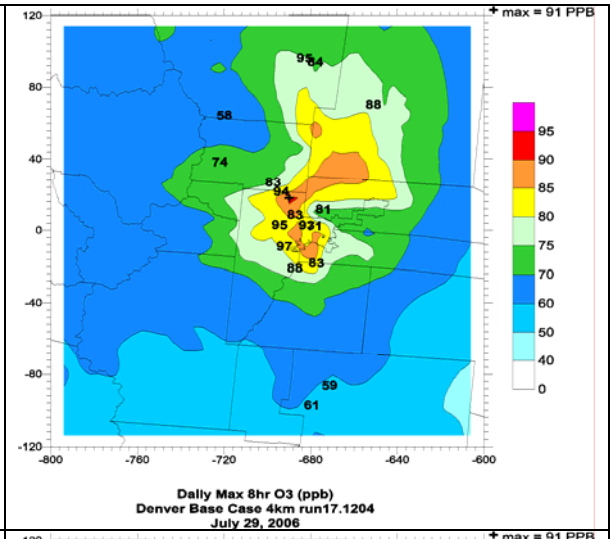
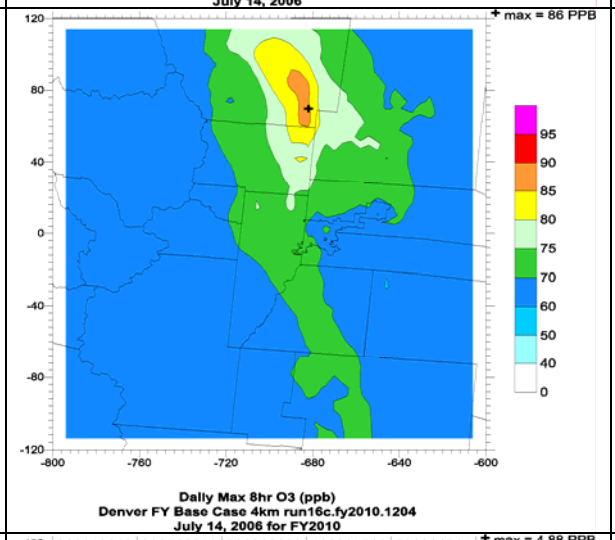
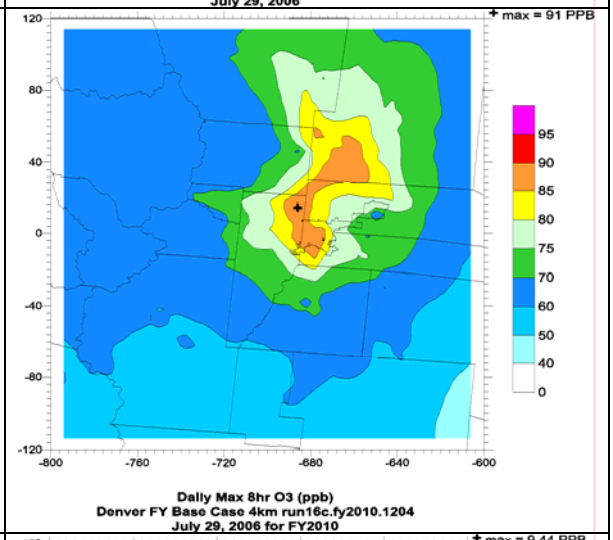
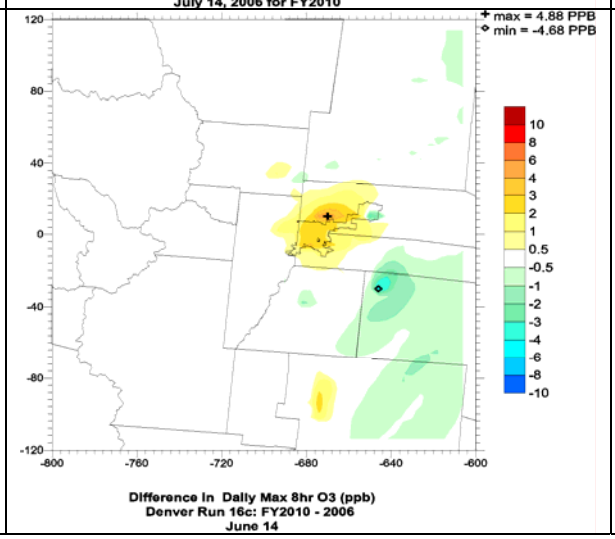
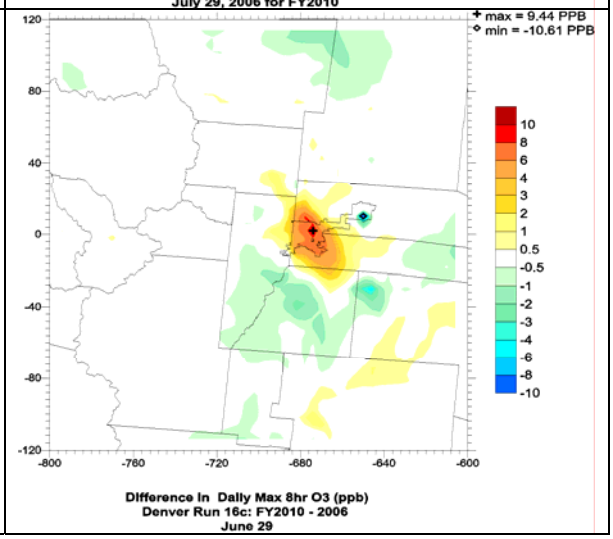
The modeling results should be interpreted while accounting for data analysis and the Conceptual Model of ozone formation in the Denver NAA and at the key monitors. As the modeling results have their own uncertainties and limitations, they should not be the sole basis for making emission control decisions.

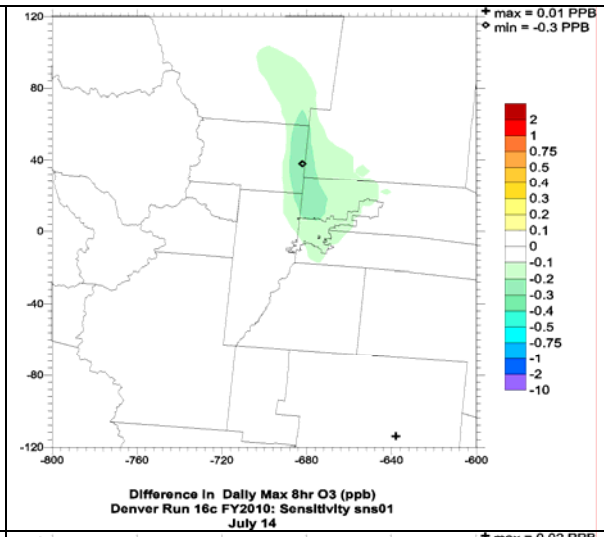
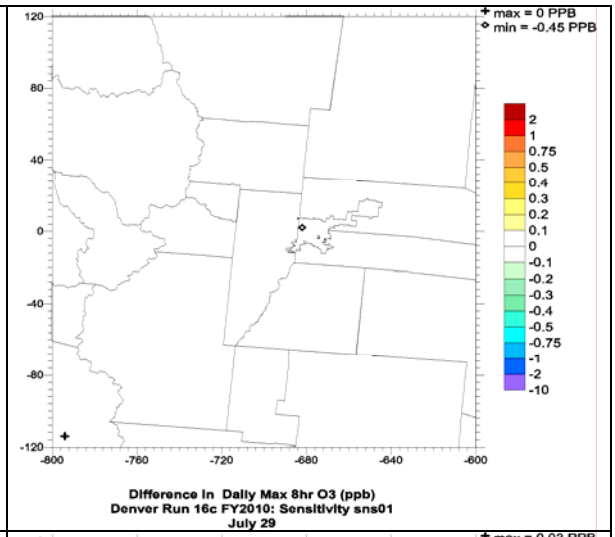
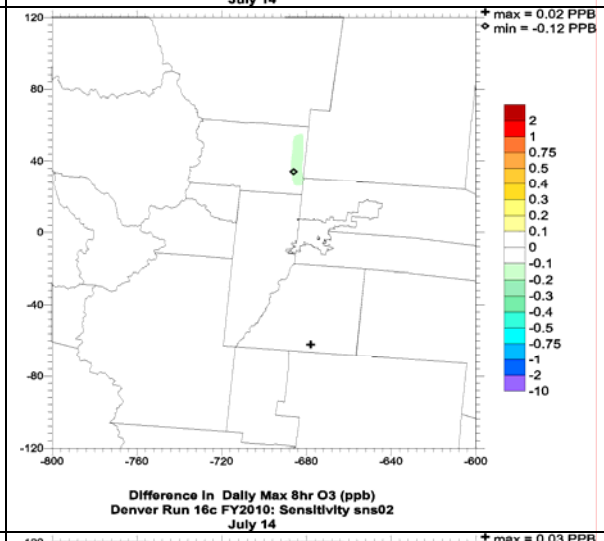
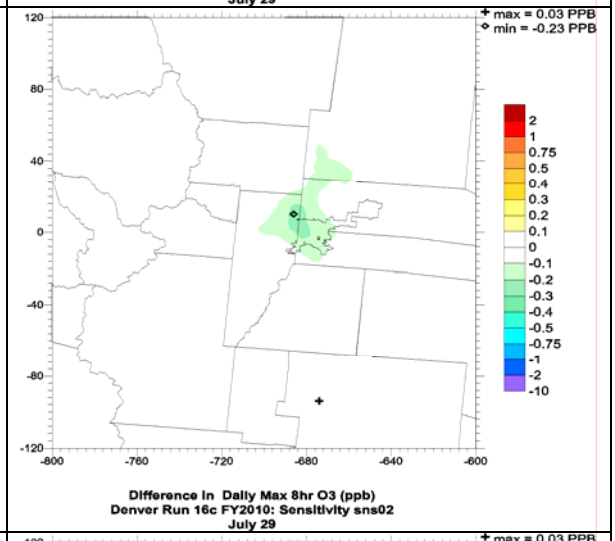
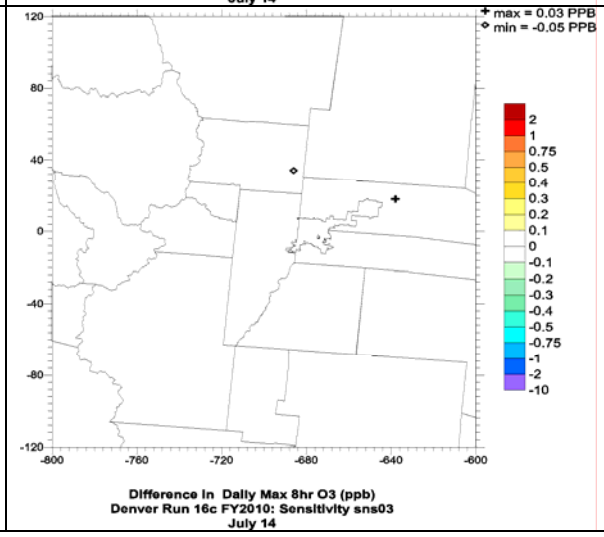
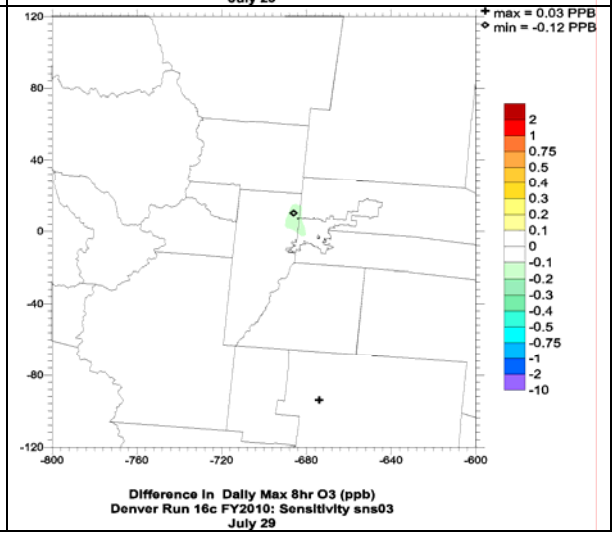
Table 3. Summary of the Denver 2010 sensitivity test modeling results.

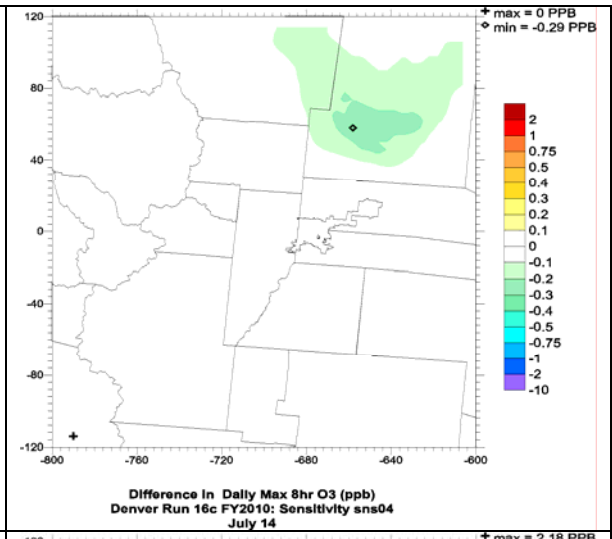
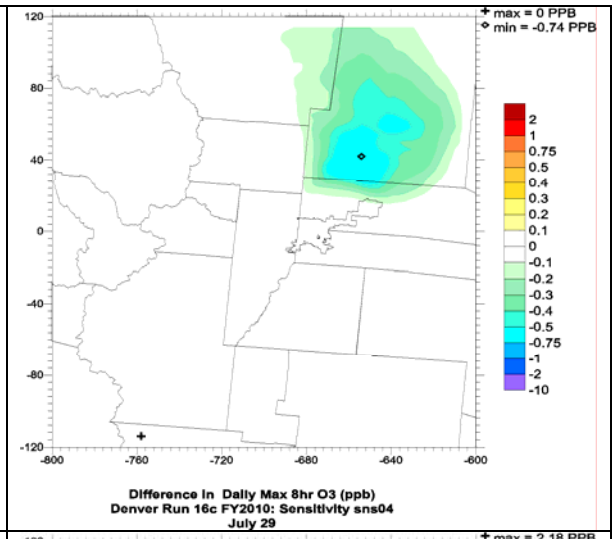
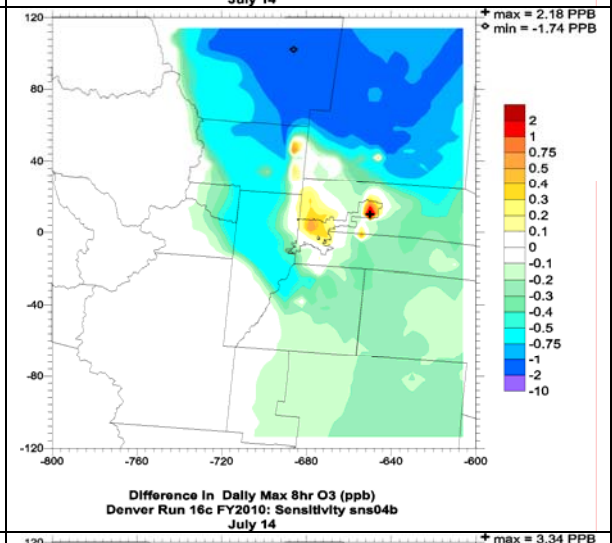
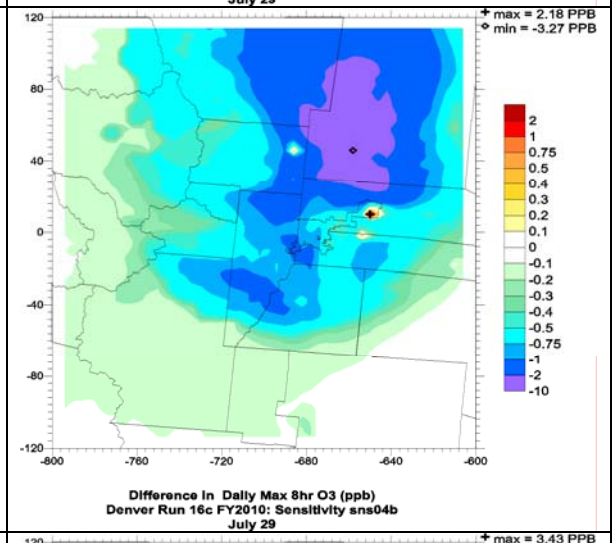
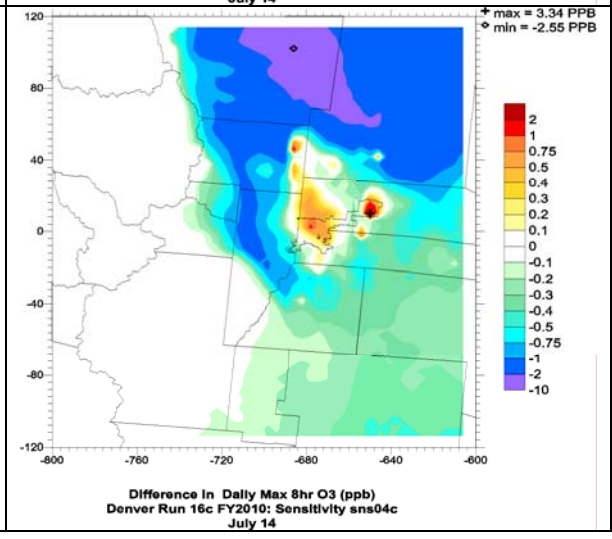
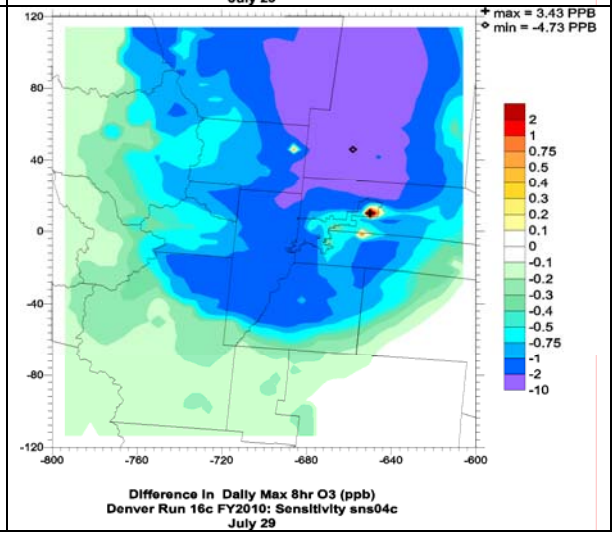
		Emissions (TPD)*		% Anthro (%)*		Ozone (ppb)	
Test	**Description**	**VOC**	**NOx**	**VOC**	**NOx**	**RFNO**	**FTCW**
DVB	Current Year 8-Hour Ozone Design Value					85.0	86.0
2010 Base	2010 Base Case	-11.8	-39.4	-2.6%	-10.0%	84.6	84.9
2010 Sns01	20% VOC On-Road in NAA	-16.8	0.0	-3.8%	0.0%	-0.1	-0.1
2010 Sns02	Evap VOC On-Road in NAA (7 psi RVP)	-4.7	-0.2	-1.1%	0.0%	-0.1	-0.1
2010 Sns03	0% Ethanol in NAA (+45 TPD CO)	-2.4	0.0	-0.5%	0.0%	0.0	0.0
2010 Sns04	20% VOC O&G in NAA	-41.5	0.0	-9.4%	0.0%	0.0	-0.1
2010 Sns04B	20% VOC & NOx Area, Point, Non-Road and O&G in NAA	-71.7	-48.3	-16.2%	-13.3%	-0.5	-1.1
2010 Sns04C	20% VOC & 30% NOx Area, Point, Non-Road and O&G in NAA	-71.7	-72.4	-16.2%	-20.0%	-0.7	-1.6
2010 Sns04D	40% VOC O&G in NAA	-83.0	0.0	-18.8%	0.0%	0.0	-0.2
2010 Sns05	20% NOx Point & O&G in NAA	0.0	-27.2	0.0%	-7.5%	-0.2	-0.5
2010 Sns06	20% VOC Non-Road in NAA	-13.0	0.0	-2.9%	0.0%	-0.1	-0.1
2010 Sns07	20% VOC Area in NAA	-9.6	0.0	-2.2%	0.0%	0.0	0.0
2010 Sns08	20% NOx Point & O&G in Colorado	0.0	-27.2	0.0%	-7.5%	-0.2	-0.7
2010 Sns09	20% VOC O&G in Colorado	-41.5	0.0	-9.4%	0.0%	0.0	-0.2
2010 Sns10	20% VOC & NOx Point & O&G in CO	-48.9	-27.2	-11.1%	-7.5%	-0.3	-0.8
2010 Sns11	20% NOx Point & O&G in NAA + 20% NOx Pawnee & Rawhide	0.0	-27.2	0.0%	-7.5%	-0.2	-0.5

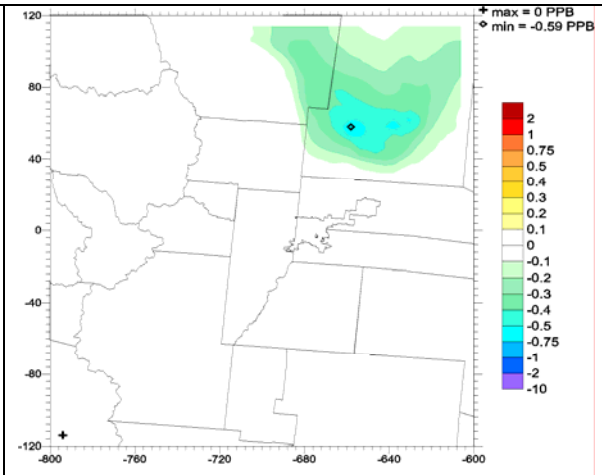
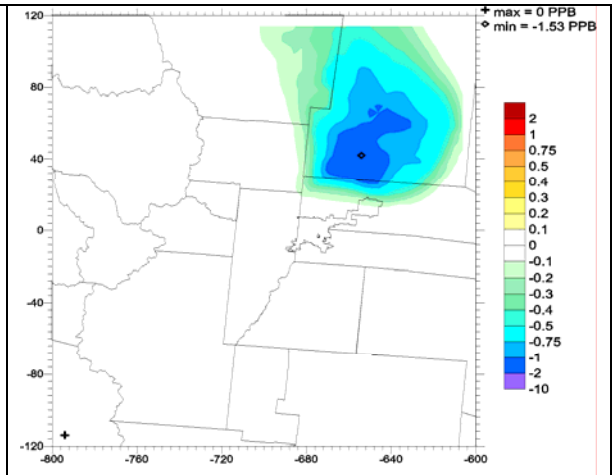
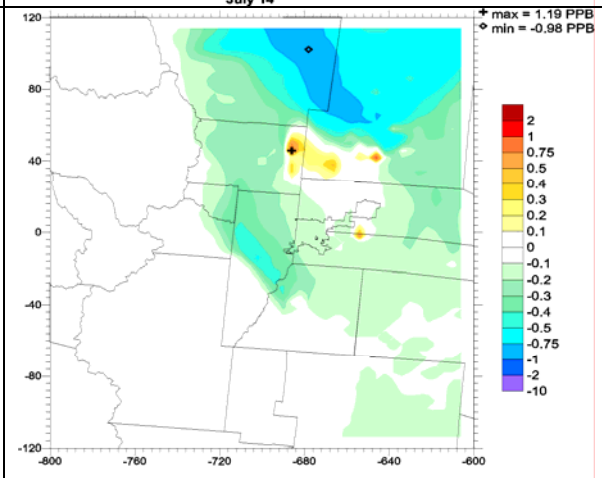
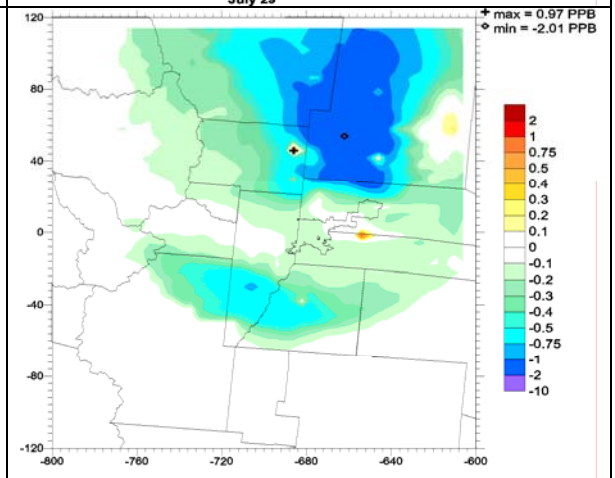
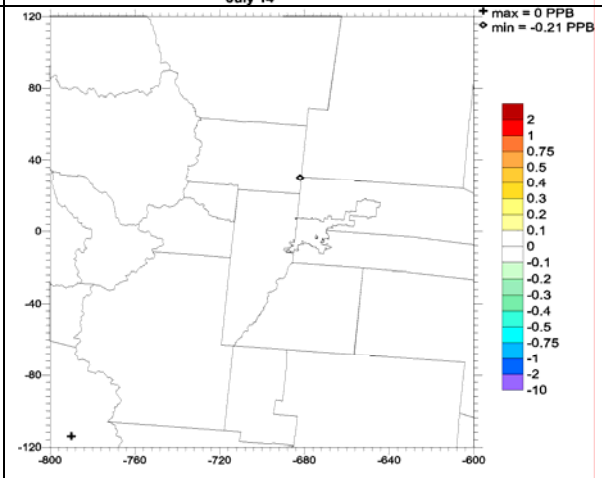
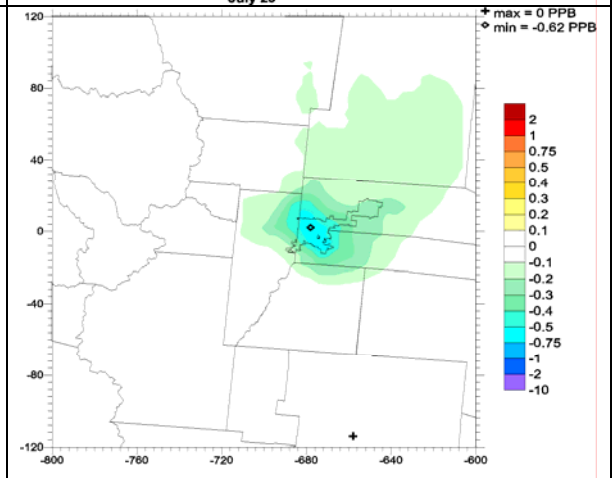
* 2010 Base Case emission reductions from 2006 levels, all other emission reductions from 2010 Base Case. Emission reductions just for Denver NAA anthropogenic emissions.

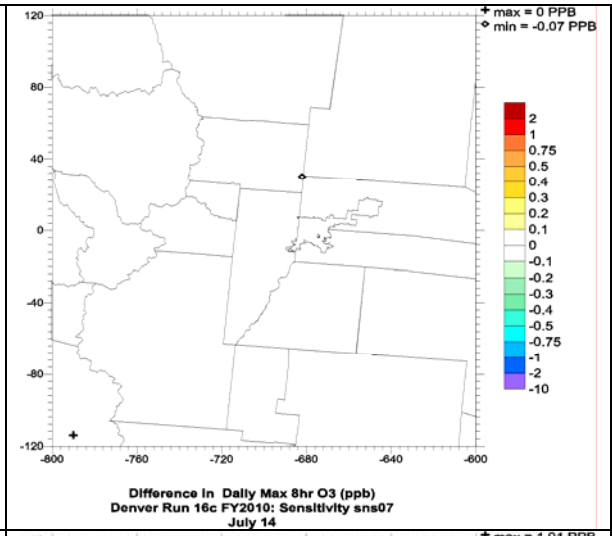
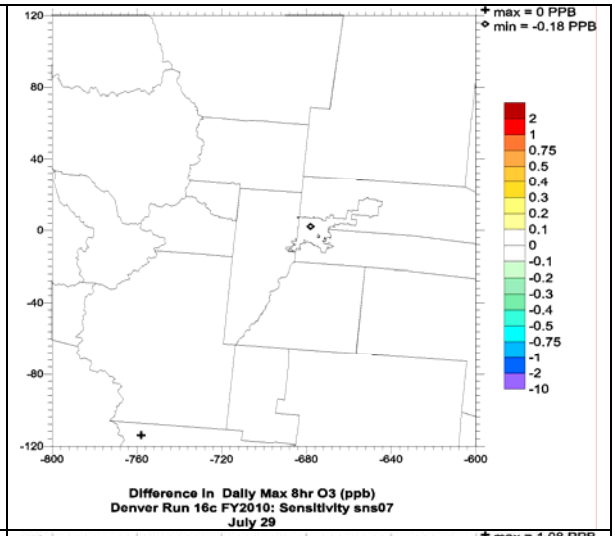
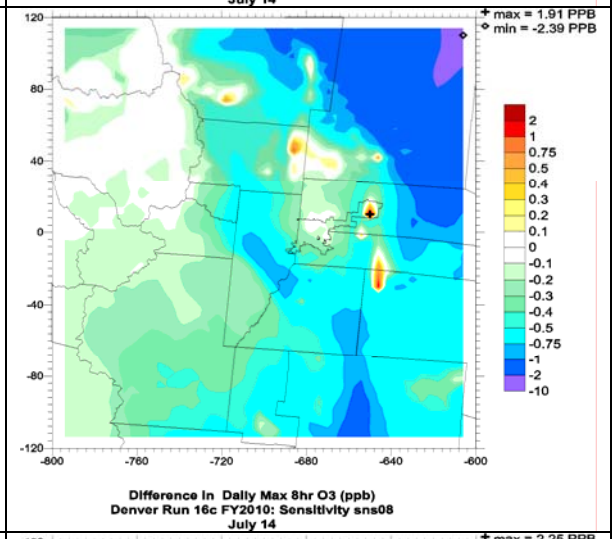
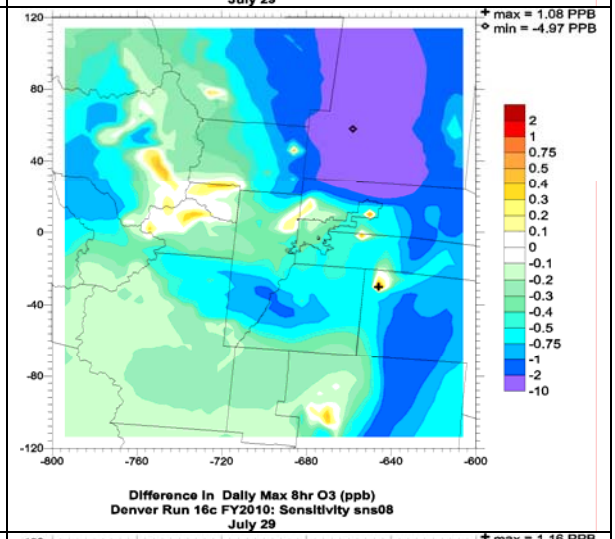
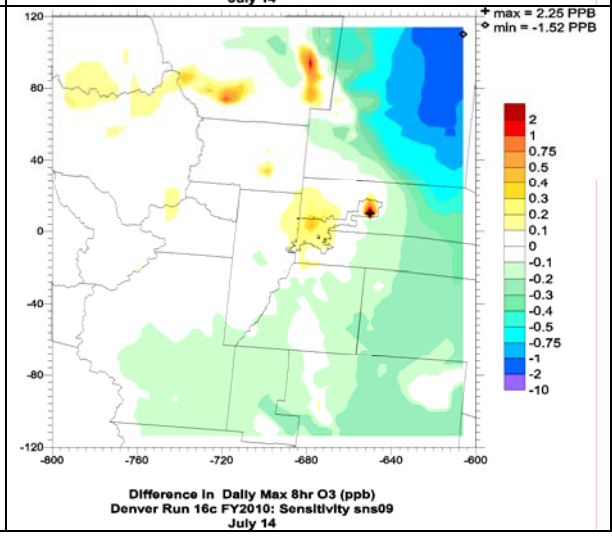
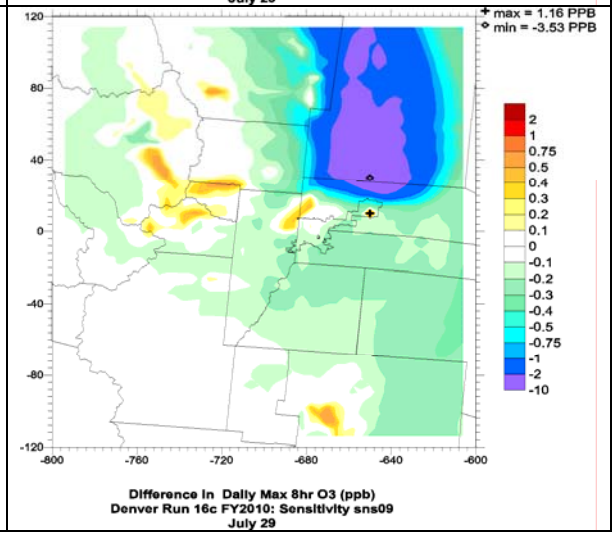
Figure 1. 2006 and 2010 base case and difference in estimated daily maximum 8-hour ozone concentrations (ppb) between 2010 sensitivity test and 2010 base case on July 14 (left) and July 29 (right) 2008.

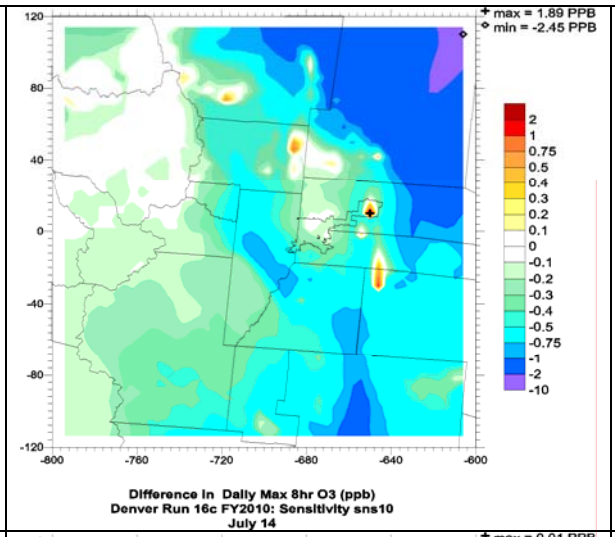
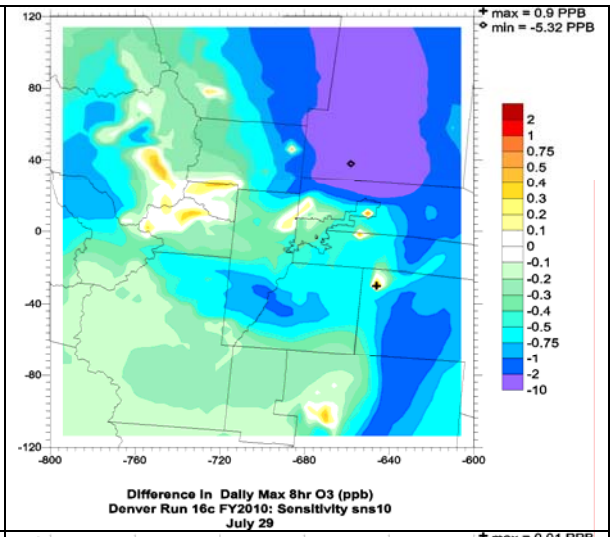
2006 Base Case Run17		
2010 Base Case		
2010-2006 Base Case		

Sens01 20% VOC On-Road Mobile NAA		
Sens02 Evap VOC OnRd 7 psi NAA		
Sens03 0% EtOH NAA		

Sens04 20% VOC O&G NAA		
Sens04B 20% VOC & NOx Area Point Non- Road O&G NAA		
Sens04C 20% VOC 30% NOx Area Point Non- Road O&G NAA		

Sens04D 40% VOC O&G NAA		
Sens05 20% NOx Point O&G NAA		
Sens06 20% VOC NonRd NAA		

Sens07 20% VOC Area NAA		
Sens08 20% NOx Point Area CO		
Sens09 20% VOC O&G CO		

Sens10 20% VOC 20% NOx Point O&G CO		
Sens10-Sens08 20% VOC Point O&G CO