APPENDIX M

Evaluation of Control Strategies for the Houston Galveston Area (September 6-11 episode)

HOUSTON/GALVESTON ATTAINMENT DEMONSTRATION - PART II

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EVALUATION OF CONTROL STRATEGIES FOR THE HOUSTON GALVESTON AREA (SEPTEMBER 06-11, 1993 EPISODE)

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1. INTRODUCTION

The 1990 Federal Clean Air Act (FCAA) Amendments established five classifications for ozone nonattainment areas based on the magnitude of the monitored one-hour ozone design values, and established dates by which each classified area should attain the standard. For each nonattainment area, states must develop and submit to the U.S. Environmental Protection Agency (EPA) a State Implementation Plan (SIP) that demonstrates how the area will attain the standard by the attainment date. The EPA designated several ozone nonattainment areas in Texas and classified each.

The Houston/Galveston/Brazoria Consolidated Metropolitan Statistical Area (Brazoria, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller Counties) and Chambers County were designated as a severe ozone nonattainment area, and these counties are included in the SIP for the Houston-Galveston (HG) area. The FCAA requires that photochemical grid models be used for SIP development in severe areas. The final SIP demonstrating attainment of the ozone National Ambient Air Quality Standard (NAAQS) in Houston-Galveston was initially due November 15, 1994. Severe areas must attain the one-hour ozone NAAQS by 2007. The Beaumont-Port Arthur (BPA) area was initially designated as a serious ozone nonattainment area, and was reclassified to moderate in April 1996.

To support the 1999 SIP revision, the Comprehensive Air quality Model with extensions (CAMx) was run for two episode periods with modified future year boundary conditions and emissions projected (growth and controls on record) to the year 2007 (MCNC, 1999a; MCNC, 1999b). The future year emissions were perturbed through the introduction of various control scenarios for the September 6-11, 1993 episode and for the August 31, 1993 – September 2, 1993 episode. The same air quality and meteorological inputs previously developed for the base case simulations (MCNC, 1999c; MCNC, 1999d) were used. The CAMx results were compared to the future year base case simulations and the NAAQS.

This report deals only with the September 6-11, 1993 episode, also referred to as the Houston-Galveston (HG) episode since it is used primarily for that area but the BPA area also experienced high ozone levels during this period and results are presented for that area as well. The HG episode is also referred to as the September 8-11, 1993 episode as the majority of analyses excluded the first two simulation days.

In the following sections we describe what these emission control scenarios consist of, how they were processed for CAMx, and the results obtained. Finally, we provide a discussion of the limitations of these model applications and make recommendations for future modeling studies.

2. METHODOLOGY

2.1 INTRODUCTION

In this study, control scenarios were evaluated by simulating the air quality under that scenario with the CAMx 1.13 air quality model, comparing the simulation results to previously simulated base cases, and assessing whether the predicted air quality is sufficiently improved to represent attainment of the National Ambient Air Quality Standards (NAAQS). To carry out such control scenario modeling requires preparation of gridded emission inventory files based on the control scenario within the domain modeled as well as initial and boundary condition files reflecting air quality and emission controls outside the modeling domain. Preparation of these files is discussed in the following sections.

2.2 CONTROL SCENARIO EMISSIONS PROCESSING

Control Scenarios are implemented in the emission inventory either by processing Control Packets with the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system (Coats and Houyoux, 1996; Houyoux and Vukovich, 1998) and applied to the base emission inputs or by applying factors to the gridded, model ready emission files. The latter approach is required for applying controls to mobile source emissions because they have not been provided as raw emission inputs.

To perform these scaling operations we use the program *geocuts*, which can be applied to each anthropogenic component of the inventory (Mobile, Area/Non-Road, Elevated Point, Low Point). The *geocuts* program allows not only the scaling of individual inventory species but may be used to limit the spatial extent of controls through the use of a "mask" file. For example, a number of the scenarios call for certain controls to be applied only in the 8-County HG area, so a mask file specifying that area is used when applying the control factors. Outside the masked area the emissions remain the same.

Once control factors are applied to the individual inventory components, either by SMOKE or *geocuts*, all non-elevated emissions are merged into a single gridded emission file. Finally, the emission inventory files for each control scenario are quality assured using statistical and graphical analysis techniques. These techniques are used to verify that the magnitude and locations of emission reductions are consistent with the description of the control scenario being processed.

2.3 INITIAL AND BOUNDARY CONDITIONS

To properly represent future year initial boundary conditions, a method that reflects emission reductions both inside and outside the modeling domain must be used. The TNRCC performed regional modeling for the year 2007 with CAMx on a much larger domain than used in this study, then extracted pollutant concentrations along this studiy's boundaries for use in the control scenario modeling. Three future year scenarios were modeled on the regional domain:

1. **2007_tcas_base3** – TCAS Base3 emissions.
2. **2007_tcas_base3.050pN_cleanfuel** – TCAS Base3 emissions with 50% point source NOx emission reductions and clean fuel controls.
3. **2007_sip_call** – SIP call NOx reductions throughout the regional modeling domain.
4. **2007_tier2_tcas** – Tier 2 TCAS controls.

Table 2-1 shows the effect of each of these scenarios on ozone concentrations at the boundaries for the September 8-11, 1993 episode.

Table 2-1. Maximum Ozone Concentrations at Boundaries (ppb) for the September 8-11, 1993 Episode.

Scenario	**930908**	**930909**	**930910**	**930911**
2007_tcas_base3	125	138	157	148
2007_tcas_base3.050pN_cleanfuel	124	130	154	146
2007_sip_call	121	125	142	135
2007_tier2_tcas	121	122	142	134

Only one set of initial and boundary conditions was used with each control scenario. Table 2-3 summarizes which set of initial and boundary conditions were used with each control scenario.

Table 2-3. Summary of Initial and Boundary Conditions used with Control Scenarios.

Scenario	Episode	Initial and Boundary Conditions
2007 Base	**HG & BPA**	2007_tcas_base3
1	HG	2007_tcas_base3
2	HG	2007_tcas_base3.050pN_cleanfuel
3	HG	2007_tcas_base3
4	HG	2007_tcas_base3.050pN_cleanfuel
4a	HG	2007_sip_call
4b	HG	2007_sip_call
4c	HG	2007_sip_call
4d	HG	2007_sip_call
6	HG	2007_tcas_base3.050pN_cleanfuel
6a	HG	2007_sip_call
6b	HG	2007_sip_call
6c	HG	2007_sip_call
6d	HG	2007_sip_call
6e	HG	2007_tier2_tcas
6f	HG	2007_sip_call
7	HG	2007_tcas_base3.050pN_cleanfuel
8	HG	2007_tcas_base3.050pN_cleanfuel
8a	HG	2007_sip_call
8b	HG	2007_sip_call
8c	HG	2007_sip_call
8d	HG	2007_sip_call

3. EMISSION CONTROL SCENARIOS

3.1 INTRODUCTION

The emissions control scenarios investigated in this study were applied to the **Future Year Base Case** for the appropriate ozone episode. A total of 20 scenarios were run for the September 8-11, 1993 (Houston-Galveston) episode and one scenario was run for the September 1-2, 1993 (Beaumont-Port Arthur) episode. The future-year base-cases include the following Federal Measures (common to all scenarios). All apply nationally except as noted:

1. *On-road mobile sources*:
   - Heavy-duty diesel standards
   - Phase II reformulated gasoline (RFG) in H-G eight-county nonattainment area
   - Federal motor vehicle control program (FMVCP)
   - Texas motorists' choice inspection and maintenance (I/M) program in Harris county
   - National low emission vehicles (NLEV) standards
   - Federal low sulfur gasoline
   - Tier II vehicle emission standards

2. *Off-road mobile sources*:
   - Heavy duty diesel standards
   - Locomotive standards
   - Compression ignition standards for vehicles and equipment
   - Spark ignition standards for vehicles and equipment
   - Commercial marine vessel standards
   - Recreational marine standards

Section 3.2 describes 21 scenarios of additional control measures (beyond the federal measures above) for the Houston-Galveston episode.

3.2 SCENARIOS FOR HOUSTON-GALVESTON

Additional measures were applied to the future year base case to create seven base scenarios (1 - 4 and 6 - 8) for this episode. Six additional levels of control were defined (a, b, c, d, e and f) and applied to selected base scenarios resulting a total of 21 scenarios being investigated. Scenario 5 does not apply to this episode and refers to controls applied to the Beaumont-Port Arthur episode.

3.2.1 Overview of Control Scenarios

Scenario 1

Adds the following State Measures to the **Future Base**:

Stationary sources, eight-county nonattainment area:

- Tier II point source controls (flue-gas cleanup)

Scenario 2

Adds the following State Measures to **Scenario 1**:

Stationary sources, Texas clean air strategy (TCAS) counties (excluding H-G nonattainment counties):

- 50% reduction of all utilities (permitted and grandfathered)
- 30% reduction from remaining grandfathered sources

On-road mobile, TCAS counties (excluding H-G nonattainment counties):

- TCAS gasoline

Off-road mobile, TCAS counties (excluding H-G nonattainment counties):

- TCAS gasoline

Scenario 3

Adds the following State Measures to the **Future Base**:

Stationary Sources, eight-county nonattainment area:

- Tier III point source controls (flue-gas cleanup plus burner modification)

Adds the following Local Measures to the **Future Base**:

On-road Mobile Sources, eight-county nonattainment area:

- California RFG fuel standards
- California diesel fuel standards
- Convert transit buses to compressed natural gas or cleaner fuel
- Additional transportation control measures

Off-road Mobile Sources, eight-county nonattainment area:

- California RFG fuel standards
- California diesel standards
- California recreational vehicle standards

Area Sources

- Low NO_X standards for new water heaters and furnaces

Scenario 4

Adds the following State Measures to **Scenario 3**:

Stationary sources, Texas clean air strategy (TCAS) counties (excluding H-G nonattainment counties):

- 50% reduction of all utilities (permitted and grandfathered)
- 30% reduction from remaining grandfathered sources

On-road mobile, TCAS counties (excluding H-G nonattainment counties):

- TCAS gasoline

Off-road mobile, TCAS counties (excluding H-G nonattainment counties):

- TCAS gasoline

Scenario 6

Adds the following Local Measures to **Scenario 4**:

On-road Mobile Sources, eight-county nonattainment area:

- IM240 Inspection and Maintenance program

Scenario 7

Adds the following Local Measures to **Scenario 4**:

On-road Mobile Sources, eight-county nonattainment area:

- 55 mile/hour maximum speed limit

Scenario 8

Adds the following Local Measures to **Scenario 4**:

On-road Mobile Sources, eight-county nonattainment area:

- IM240 Inspection and Maintenance program
- 55 mile/hour maximum speed limit

3.2.2 Additional Controls

Some or all of these additional controls were applied to scenarios 4, 6, and 8:

a. Additional mobile source controls in Texas.
[Actually, this scenario is more of an update than a control scenario. It is based on new Tier II, low Sulfur reductions published by the EPA]
b. Additional non-road source controls in Texas.
c. Mobile source controls beyond those in "a".
d. Area and point source controls in offshore areas and additional non-road and area source controls in Texas.

The specific measures and the locations applied are given in Table 3-2 for point sources ("d" and "e" scenarios), Table 3-4 for mobile sources ("a" and "c" scenarios), and Table 3-5 for non-road and area sources ("b", "d" and "f" scenarios).

3.2.3 Summary of Control Scenarios

Each of the 20 control scenarios are compared to the future year base case and summarized in Table 3-1. In this table "93basA" refers to 1993 baseline emissions and "07basA" refers to 2007 baseline emissions.

Table 3-1. Summary of Control Scenarios.

Scenario	TX point source	LA point source	OS point source	TX nonroad	LA nonroad	TX area	LA area	OS area	TX mobile	LA mobile
07basA	07basA	07basA	93basA	07basA	07basA	07basA	07basA	93basA	07basA	07basA
1	***07scen1***	07basA	93basA	07basA	07basA	07basA	07basA	93basA	07basA	07basA
2	***07scen2***	07basA	93basA	***07scen2***	07basA	07basA	07basA	93basA	***07scen2***	07basA
3	***07scen3***	07basA	93basA	***07scen3***	07basA	07basA	07basA	93basA	***07scen3***	07basA
4	***07scen4***	07basA	93basA	***07scen4***	07basA	07basA	07basA	93basA	***07scen4***	07basA
4a	07scen4	07basA	93basA	07scen4	07basA	07basA	07basA	93basA	***07scen4a***	07basA
4b	07scen4	07basA	93basA	***07scen4b***	07basA	07basA	07basA	93basA	07scen4a	07basA
4c	07scen4	07basA	93basA	07scen4b	07basA	07basA	07basA	93basA	***07scen4c***	07basA
4d	07scen4	07basA	***07scen4d***	***07scen4d***	07basA	***07scen4d***	07basA	***07scen4d***	07scen4c	07basA
6	07scen4	07basA	93basA	07scen4	07basA	07basA	07basA	93basA	***07scen6***	07basA
6a	07scen4	07basA	93basA	07scen4	07basA	07basA	07basA	93basA	***07scen6a***	07basA
6b	07scen4	07basA	93basA	***07scen4b***	07basA	07basA	07basA	93basA	07scen6a	07basA
6c	07scen4	07basA	93basA	07scen4b	07basA	07basA	07basA	93basA	***07scen6c***	07basA
6d	07scen4	07basA	***07scen4d***	***07scen4d***	07basA	***07scen4d***	07basA	***07scen4d***	07scen6c	07basA
6e	***07scen6e***	07basA	93basA	07scen4b	07basA	07scen4b	07basA	93basA	07scen6c	07basA
6f	07scen6f	07basA	93basA	07scen6f	07basA	07scen4d	07basA	93basA	***07scen6e***	07basA
7	07scen4	07basA	93basA	07scen4	07basA	07basA	07basA	93basA	***07scen7***	07basA
8	07scen4	07basA	93basA	07scen4	07basA	07basA	07basA	93basA	***07scen8***	07basA
8a	07scen4	07basA	93basA	07scen4	07basA	07basA	07basA	93basA	***07scen8a***	07basA
8b	07scen4	07basA	93basA	***07scen4b***	07basA	07basA	07basA	93basA	07scen8a	07basA
8c	07scen4	07basA	93basA	07scen4b	07basA	07basA	07basA	93basA	***07scen8c***	07basA
8d	07scen4	07basA	***07scen4d***	***07scen4d***	07basA	***07scen4d***	07basA	***07scen4d***	07scen8c	07basA

Table 3-2 summarizes which areas the point source controls were applied in each scenario. For each scenario the type of control is specified for the four distinct area that point source controls were applied: 1) the 8-county HG area, 2) the 3-county BPA area, 3) the Offshore areas, and 4) the Texas Clean Air Strategy (TCAS) region.

Table 3-2. Geographical Breakdown of Point Source Control .

	Area Applied			
Scenario	**HG 8 county**	**BPA 3 county**	**Offshore**	**TCAS**
1	***TIER2***	07basA	93basA	07basA
2	TIER2	***TCAS point source controls***[1]	93basA	***TCAS point source controls***
3	***TIER3***	07basA	93basA	07basA
4	*TIER3*	***TCAS point source controls***	93basA	***TCAS point source controls***
4d	TIER3	TCAS point source controls	***89% NOX cut***	TCAS point source controls
6e	TIER3	***TIER2 Util NOX/30% Grandpa***	93basA	***TIER2 Util NOX/30% Grandpa***

1 TCAS Point source controls = 50 % NOX reduction to utilities, 30 % NOX reduction to grandfathered, non-utility sources

The areas in which mobile source control factors were applied are shown for each scenario in Table 3-3. The left half of the table provides NOx control factors by scenario and area. The right half of the table provides the VOC control factors. These factors are applied to the 2007 baseline mobile source emissions. For mobile sources, the HG non-attainment area is split between Harris County and all other counties in the area. The NOx control factors range from 0.250 (75% reduction) to 1.000 (no reduction) while the VOC control factors range from 0.220 (78% reduction) to 1.045 (4.5% increase).

Table 3-3. Mobile Source Control Factors by Region Applied.

Geographical Mobile NOX factor					*Geographical Mobile VOC factor*				
Scenario	Harris Co.	HG 7 county	BPA	TCAS	**Scenario**	Harris Co.	HG 7 county	BPA	TCAS
2	1.000	1.000	1.000	0.915	**2**	1.000	1.000	1.000	0.857
3	0.887	0.887	1.000	1.000	**3**	0.830	0.830	1.000	1.000
4	0.887	0.887	1.000	0.915	**4**	0.830	0.830	1.000	0.857
4a	0.780	0.780	0.975	0.890	**4a**	0.850	0.800	1.045	0.895
4c	0.390	0.380	0.489	0.450	**4c**	0.375	0.370	0.485	0.420
6	0.720	0.620	1.000	0.915	**6**	0.710	0.495	1.000	0.857
6a	0.635	0.545	0.975	0.890	**6a**	0.720	0.505	1.045	0.895
6c	0.315	0.270	0.489	0.450	**6c**	0.330	0.230	0.485	0.420
7	0.830	0.830	1.000	0.915	**7**	0.800	0.800	1.000	0.857
8	0.670	0.580	1.000	0.915	**8**	0.680	0.475	1.000	0.857
8a	0.590	0.510	0.975	0.890	**8a**	0.690	0.485	1.045	0.895
8c	0.295	0.250	0.489	0.450	**8c**	0.320	0.220	0.485	0.420

Table 3-4 provides an overview of the types of mobile source controls reflected in the control factors by scenario and area applied. The reference to "07basA" means 2007 baseline emissions were used in that scenario-area combination with no additional controls applied.

Table 3-4. Description of Mobile Source Controls.

	Mobile description breakdown					Mobile description breakdown			
Scenario	Harris Co.	HG 7 co.	BPA	TCAS	Scenario	Harris Co.	HG 7 co.	BPA	TCAS
2	07basA	07basA	07basA	*TCAS Gas*	6a	*Calif RFG-Diesel; Clean Buses; TCMs; IM240; LowSulf; TIER2*	*Calif RFG-Diesel; Clean Buses; TCMs; IM240; LowSulf; TIER2*	*LowSulf; TIER2*	*TCAS Gas; LowSulf; TIER2*
3	*Calif RFG-Diesel; Clean Buses; TCMs*	*Calif RFG-Diesel; Clean Buses; TCMs*	07basA	07basA	6c	*Calif RFG-Diesel; Clean Buses; TCMs; IM240; LowSulf; TIER2; Sam Max*	*Calif RFG-Diesel; Clean Buses; TCMs; IM240; LowSulf; TIER2; Sam Max*	*LowSulf; TIER2; Sam Max*	*TCAS Gas; LowSulf; TIER2; Sam Max*
4	*Calif RFG-Diesel; Clean Buses; TCMs*	*Calif RFG-Diesel; Clean Buses; TCMs*	07basA	*TCAS Gas*	7	*Calif RFG-Diesel; Clean Buses; TCMs; 55MPH*	*Calif RFG-Diesel; Clean Buses; TCMs; 55MPH*	07basA	*TCAS Gas*
4a	*Calif RFG-Diesel; Clean Buses; TCMs; LowSulf; TIER2;I/M*	*Calif RFG-Diesel; Clean Buses; TCMs; LowSulf; TIER2*	*LowSulf; TIER2*	*TCAS Gas; LowSulf; TIER2*	8	*Calif RFG-Diesel; Clean Buses; TCMs; 55MPH; IM240*	*Calif RFG-Diesel; Clean Buses; TCMs; 55MPH; IM240*	07basA	*TCAS Gas*
4c	*Calif RFG-Diesel; Clean Buses; TCMs; LowSulf; TIER2;I/M; Sam Max*	*Calif RFG-Diesel; Clean Buses; TCMs; LowSulf; TIER2; Sam Max*	*LowSulf; TIER2; Sam Max*	*TCAS Gas; LowSulf; TIER2; Sam Max*	8a	*Calif RFG-Diesel; Clean Buses; TCMs; 55MPH; IM240; LowSulf; TIER2*	*Calif RFG-Diesel; Clean Buses; TCMs; 55MPH; IM240; LowSulf; TIER2*	*LowSulf; TIER2*	*TCAS Gas; LowSulf; TIER2*
6	*Calif RFG-Diesel; Clean Buses; TCMs; IM240*	*Calif RFG-Diesel; Clean Buses; TCMs; IM240*	07basA	*TCAS Gas*	8c	*Calif RFG-Diesel; Clean Buses; TCMs; 55MPH; IM240; LowSulf; TIER2; Sam Max*	*Calif RFG-Diesel; Clean Buses; TCMs; 55MPH; IM240; LowSulf; TIER2; Sam Max*	*LowSulf; TIER2; Sam Max*	*TCAS Gas; LowSulf; TIER2; Sam Max*

Area source and non-road source controls are likewise summarized in Table 3-5. Note that area/non-road source controls were only applied in scenarios 2, 3, 4, 4b, and 4d. For each of these scenarios the type and area of control is provided. The reference to "93basA" means that emissions were not projected (grown and controlled) to 2007 levels but rather left at the 1993 baseline emission levels. Only offshore area/non-road emissions remained at 1993 levels. Again, the "07basA" means 2007 baseline emissions were used in that scenario-area combination and no additional controls were applied.

Table 3-5. Geographical Nonroad/Area-Source Breakdown.

Scenario	Area Applied		
	HG 8 county	TCAS	Offshore
2	07basA	*TCAS Gas*	93basA
3	*Calif-Diesel*	07basA	93basA
4	*Calif-Diesel*	*TCAS Gas*	93basA
4b	*Calif-Diesel; 50% NOX cut*	*TCAS Gas*	93basA
4d	*Calif-Diesel; 50% NOX cut*	*TCAS Gas; Stage I*	*50% NOX cut*
6f	*Construction Activity Shift in TX: 50% NOX cut*	*TCAS Gas; Stage I*	*93basA*

3.2.4 Emission Levels

None of the control scenarios investigated include reductions in Carbon Monoxide (CO) but the 2007 baseline emissions are provided in Table 3-5. The effect of each of the control scenarios on component and total emissions is shown in Table 3-6 (for NOx) and Table 3-7 (for VOC). These values were obtained from the model-ready gridded emission files for September 8 of the future year base case. While there are day-to-day fluctuations due to day specific environmental adjustments, these values are typical of weekday emissions during episodic conditions.

The percent reduction for each scenario relative to the anthropogenic emissions and total emissions (anthropogenic and biogenic) are given at the right side of each table. Reductions in anthropogenic NOx range from 20.1% for scenario 1 to 50.9% for scenario 8d. Biogenic NOx emissions make up 118 tons, or 4.8%, of the total NOx in the modeling domain. Reductions in anthropogenic VOC range from 0% for scenario 1 to 11.8% for scenario 8d. Biogenic VOC emissions make up 87.5% of the total VOC inventory.

Table 3-5. CO Emissions (tons per day)

Scenario	Texas Elevated Point	Louisiana Elevated Point	Offshore Elevated Point	Area & NonRoad	Mobile	Low Point	Biogenic	Total Anthro-pogenic	Anthro-pogenic Reduction	Total Emissions	Total Reduction
07basA	615	74	7	2971	2275	54	0	5996	0.0%	5996	0.0%

Table 3-5. NOx Emissions (tons per day)

Scenario	Texas Elevated Point	Louisiana Elevated Point	Offshore Elevated Point	Area & NonRoad	Mobile	Low Point	Biogenic	Total Anthro-pogenic	Anthro-pogenic Reduction	Total Emissions	Total Reduction
07basA	1078	118	32	491	458	162	118	2339	0.0%	2457	0.0%
1	622	118	32	491	458	147	118	1868	20.1%	1986	19.2%
2	462	118	32	491	446	145	118	1694	27.6%	1812	26.3%
3	594	118	32	478	424	146	118	1792	23.4%	1910	22.3%
4	434	118	32	478	416	144	118	1622	30.7%	1740	29.2%
4a	434	118	32	478	383	144	118	1589	32.1%	1707	30.5%
4b	434	118	32	374	383	144	118	1485	36.5%	1603	34.8%
4c	434	118	32	374	202	144	118	1304	44.2%	1422	42.1%
4d	434	118	4	306	202	113	118	1177	49.7%	1295	47.3%
6	434	118	32	478	363	144	118	1569	32.9%	1687	31.3%
6a	434	118	32	478	337	144	118	1543	34.0%	1661	32.4%
6b	434	118	32	374	337	144	118	1439	38.5%	1557	36.6%
6c	434	118	32	374	179	144	118	1281	45.2%	1399	43.1%
6d	434	118	4	306	179	113	118	1154	50.7%	1272	48.2%
6e	353	118	32	374	179	144	118	1200	48.7%	1318	46.4%
6f	434	118	32	374	179	144	118	1281	45.2%	1399	43.1%
7	434	118	32	478	401	144	118	1607	31.3%	1725	29.8%
8	434	118	32	478	350	144	118	1556	33.5%	1674	31.9%
8a	434	118	32	478	325	144	118	1531	34.5%	1649	32.9%
8b	434	118	32	374	325	144	118	1427	39.0%	1545	37.1%
8c	434	118	32	478	174	144	118	1380	41.0%	1498	39.0%
8d	434	118	4	306	174	113	118	1149	50.9%	1267	48.5%

Table 3-6. VOC Emissions (tons per day)

Scenario	Texas Elevated Point	Louisiana Elevated Point	Offshore Elevated Point	Area & NonRoad	Mobile	Low Point	Biogenic	Total Anthro-pogenic	Anthro-pogenic Reduction	Total Emissions	Total Reduction
07basA	153	15	18	699	267	285	10034	1437	0.0%	11471	0.0%
1	153	15	18	699	267	285	10034	1437	0.0%	11471	0.0%
2	153	15	18	694	249	285	10034	1414	1.6%	11448	0.2%
3	153	15	18	694	248	285	10034	1413	1.7%	11447	0.2%
4	153	15	18	694	230	285	10034	1395	2.9%	11429	0.4%
4a	153	15	18	694	234	285	10034	1399	2.6%	11433	0.3%
4b	153	15	18	694	234	285	10034	1399	2.6%	11433	0.3%
4c	153	15	18	694	117	285	10034	1282	10.8%	11316	1.4%
4d	153	15	18	690	117	285	10034	1278	11.1%	11312	1.4%
6	153	15	18	694	209	285	10034	1374	4.4%	11408	0.5%
6a	153	15	18	694	215	285	10034	1380	4.0%	11414	0.5%
6b	153	15	18	694	215	285	10034	1380	4.0%	11414	0.5%
6c	153	15	18	694	108	285	10034	1273	11.4%	11307	1.4%
6d	153	15	18	690	108	285	10034	1269	11.7%	11303	1.5%
6e	153	15	18	690	108	285	10034	1269	11.7%	11303	1.5%
6f	153	15	18	690	108	285	10034	1269	11.7%	11303	1.5%
7	153	15	18	694	227	285	10034	1392	3.1%	11426	0.4%
8	153	15	18	694	206	285	10034	1371	4.6%	11405	0.6%
8a	153	15	18	694	212	285	10034	1377	4.2%	11411	0.5%
8b	153	15	18	694	212	285	10034	1377	4.2%	11411	0.5%
8c	153	15	18	694	107	285	10034	1272	11.5%	11306	1.4%
8d	153	15	18	690	107	285	10034	1268	11.8%	11302	1.5%

4. RESULTS

4.1 INTRODUCTION

The CAMx simulations for these control scenarios were analyzed by statistical and graphical methods. We first calculate a series of metrics, which include the peak ozone concentration in the modeling domain for each day, the peak ozone concentration and the number of cells above the NAAQS for 1-hour ozone averages, by day, for the Houston-Galveston and Beaumont-Port Arthur non-attainment areas. The metrics are compared with the 2007 Base Case results to quantify the effectiveness of each control scenario. Finally, we generate color and gray-scale contour plots showing spatially the daily peak ozone concentrations by grid cell and the difference in daily peak ozone between the 2007 Base Case and each control scenario.

4.2 CAM-X SIMULATIONS

4.2.1 Statistical Analyses

The full set of metrics that were calculated for each scenario are provided in Appendix A. In this section some of the key metrics are presented and discussed. The daily peak ozone concentrations anywhere in the modeling domain are summarized in Table 4-1. Each of the four days presented in this table had observed ozone exceeding the NAAQS. In the 1993 Base Case simulation these peaks were under-predicted on September 8, 9, and 11. The model over-predicts on September 10. The effects of growth to the year 2007 and the introduction of federal controls are shown in the 2007 Base Case. For each control scenario of state and local controls, this table shows the predicted impact on peak ozone concentrations. While several of the scenarios show similar responses, scenario 8d, which represents the largest emission reductions, generally has the lowest ozone concentrations, although not always. Scenario 8d does result in the lowest predicted peak ozone on September 8, which had the highest observed ozone and is the hardest day to control. The location of the peak on this day is just southwest of Houston at the intersection of Harris, Brazoria, and Fort Bend counties.

Table 4-1. Domain-wide Daily Maximum 1-hr Ozone Concentrations (ppb)

SCENARIO	930908	930909	930910	930911
OBSERVED	*214.0*	*195.0*	*162.0*	*189.0*
1993 Base Case	181.9	179.7	177.8	185.7
2007 Base Case	171.1	166.0	164.9	170.6
1	171.9	162.5	163.4	165.2
2	171.3	160.4	161.8	164.2
3	170.2	160.6	161.9	160.5
4	169.6	158.4	160.3	159.6
4a	167.9	156.6	159.5	157.0
4b	159.9	147.9	153.1	146.4
4c	146.7	134.7	141.3	140.3
4d	146.7	134.6	136.7	140.2
6	167.9	155.9	158.6	155.4
6a	166.0	154.1	157.1	153.1
6b	155.9	143.4	148.4	141.0
6c	143.7	131.7	141.1	140.3
6d	143.7	131.6	136.1	140.2
6e	143.4	130.4	138.4	139.6
6f	138.4	127.2	139.2	139.8
7	169.2	157.7	160.0	158.3
8	167.3	155.2	157.8	154.2
8a	165.2	153.3	156.2	151.9
8b	154.4	142.0	146.7	140.3
8c	142.9	130.8	141.1	140.3
8d	142.9	130.8	136.1	140.2

The daily peak ozone concentrations and the number of cells with concentrations above 124 ppb (areal exposure) for the eight-county Houston-Galveston non-attainment area are provided in Tables 4-2 and 4-3. These tables also include September 6 and 7, which were "ramp up" days and not normally used in the analysis of control strategies due to the uncertainties associated with initial conditions. They are presented here to demonstrate their lack of significance since most control scenarios investigated reduce concentrations on these days to below the NAAQS. From these tables we see results that are very similar to those based on the domain-wide peak ozone concentrations.

Table 4-2. Daily Peak Ozone (ppb) for the 8-county Houston-Galveston non-attainment area by date and control scenario.

	Date (YYMMDD)					
Scenario	930906	930907	930908	930909	930910	930911
1	61	129	171	162	163	165
2	59	129	171	160	161	164
3	61	126	170	160	161	160
4	59	125	169	158	160	159
4a	54	122	167	156	159	156
4b	54	111	159	147	153	146
4c	54	109	146	134	136	130
4d	54	107	146	134	136	130
6	59	121	167	155	158	155
6a	54	118	165	154	157	153
6b	54	110	155	143	148	141
6c	54	109	143	131	132	127
6d	54	107	143	131	132	126
6e	54	108	143	130	132	126
6f	54	108	138	127	130	123
7	59	124	169	157	160	158
8	59	120	167	155	157	154
8a	54	117	165	153	156	151
8b	54	110	154	142	146	139
8c	54	109	142	130	131	125
8d	54	107	142	130	131	125

Table 4-3. Number of Cells in the 8-county Houston-Galveston non-attainment area with concentrations greater than 124 ppb by date and control scenario.

	Date (YYMMDD)					
Scenario	930906	930907	930908	930909	930910	930911
1	0	23	284	182	330	252
2	0	21	283	157	298	248
3	0	8	260	161	261	233
4	0	6	254	136	238	225
4a	0	0	234	124	214	213
4b	0	0	161	88	122	159
4c	0	0	77	40	36	42
4d	0	0	73	40	33	40
6	0	0	233	123	192	207
6a	0	0	219	114	172	195
6b	0	0	131	70	83	122
6c	0	0	63	31	22	16
6d	0	0	57	31	19	13
6e	0	0	61	28	22	10
6f	0	0	50	12	12	0
7	0	1	249	133	227	222
8	0	0	230	121	182	200
8a	0	0	211	109	162	190
8b	0	0	120	66	77	110
8c	0	0	58	31	22	7
8d	0	0	54	31	19	5

4.2.2 Graphical Analyses

The graphical analyses of the 20 control scenarios investigated are presented in the next 40 pages with each figure representing a single scenario and covering two pages and presented in order beginning with scenario 1 and ending with scenario 8d. The first page of each figure is the "a" part of the figure and covers September 8 and 9. The second page of each figure is the "b" part of the figure and covers September 10 and 11. Each page has four plots on it with the daily maximum ground level ozone concentrations for the scenario presented on the left side and the corresponding difference plot showing the change in ozone from the 2007 base case. The daily maximum ozone plots show concentrations in five gray shades, with areas exceeding the NAAQS in black. On the difference plots the negative values represent decreases in ozone due to the control scenario and are separated into four gray shades:

- White – Little or no change (within 5 ppb of the2007 base case)
- Light Gray – 5 to 15 ppb decreases
- Medium Gray – Decreases in excess of 15 ppb
- Black – Increases of more than 5 ppb ("disbenefit" areas)

While there are obviously differences in the magnitudes of peak ozone, and some differences in the where the peaks are and where benefits are seen between scenarios, there are many similarities that should be discussed. First, none of the scenarios run for this episode predict attainment of the NAAQS for the HG area. Second, there are several "features" in the ozone patterns that should be explored in the context of base case model performance and the meteorological inputs to CAMx. In preparation for further discussion and exploration, we will describe here, the ozone patterns seen for scenario 8d. We choose this scenario because it represents one of the highest level of controls simulated in this study and allows us to focus on those areas with ozone concentrations still above the NAAQS. The following descriptions are in reference to Figures 4-21a and 4-21b.

September 8^{th}

In Figure 4-21a (upper-left) we see four distinct peak areas that exceed the NAAQS:

1. Southwest of Houston at the intersection of Harris, Fort Bend, and Brazoria counties,
2. just offshore of Galveston county,
3. immediately Southeast of Beaumont, and
4. on the Eastern boundary, just North of Lake Charles, LA.

The areas of greatest reduction (more than 15 ppb) are generally associated within the regions of highest ozone and extend over a broad region including the HG and BPA non-attainment areas and offshore regions adjacent to these areas. The peak ozone area in Louisiana shows little or no benefit from this control scenario, which is expected considering that no additional controls are applied in Louisiana and the Eastern boundary is predominately an inflow boundary on this day. The inflow is evident in the peak ozone plot as an area of moderate ozone (76-92 ppb) extending from the boundary into Texas and the adjacent offshore areas.

September 9th

On September 9 (Figure 4-21a, lower-left) we see lower ozone level but the general areas of high ozone are similar. The only area exceeding the NAAQS is South of Houston on the Harris-Galveston county line. A secondary peak is predicted offshore of Galveston county. Instead of separate peaks near Beaumont and Lake Charles, we see the same broad area of elevated ozone but with the peak in Louisiana, midway between Beaumont and Lake Charles. Again, most of the modeling domain sees some reduction in ozone with the largest reductions in the same areas as on the preceding day. The area with benefits greater than 15 ppb in the offshore areas is almost twice as large as on September 8th.

September 10th

Once again (Figure 4-21b, upper-left) we see the same general areas with elevated ozone. The peaks are slightly shifted to the Northeast near HG and slightly shifted to the South near Beaumont and Lake Charles. On this day we see a new peak area offshore and further South of Beaumont. This offshore peak is surrounded by the largest single area that exceeds the NAAQS on this or any other day of the episode. The difference plot (upper-right) for this day shows the same general areas of benefit with the exception of an area of reduced benefit (or possibly disbenefit) in the region offshore of Galveston County.

September 11th

On September 11 (Figure 4-21b, lower-left) we see the peak areas shifted to the North of Houston, Beaumont, and Lake Charles respectively. While not exceeding the NAAQS in the offshore areas, there remain moderate levels of ozone, which is likely carry-over from the previous day. Again, benefits are generally seen throughout the domain. However, the maximum benefits are concentrated in a region extending 75 to 120 kilometers either side of a line running from Northwest to Southeast through Houston. The benefits offshore are less than on previous days, which is consistent with the more pronounced onshore flow this day. We also see a distinct disbenefit (13 ppb maximum increase) area over Houston on this day. If moderate ozone concentrations offshore (carry-over) are being transported onshore in the absence of fresh emissions to produce new ozone in the plume, the ozone would be titrated as it moved over NOx rich emission areas. It is for this reason that this particular day sees the most pronounced disbenefit, although this disbenefit does not affect the areas exceeding the NAAQS.

5. DISCUSSION

None of the control scenarios modeled for the Houston Galveston area were sufficient to model attainment of the NAAQS on all episode days. Based on the directional guidance simulations performed for the HG area (MCNC, 1999e), it is not unexpected that the control scenarios investigated did not lead to modeled attainment of the NAAQS in that area. The directional guidance simulations indicated that the peak would only drop to 161 ppb on September 8th with 50 percent NOx control. Adding 50 percent VOC control to the 50 percent NOx control only reduced the peak to 155 ppb. We would expect some reductions in ozone due to the reduced boundary conditions but even those reductions were not large and some boundary cells remained at or above the NAAQS.

The areas that appear to be the most resistant to controls include the region immediately downwind of the Houston and Beaumont metropolitan areas, the areas immediately offshore of the HG and BPA areas, and the Lake Charles area of Louisiana. Based on a review of the meteorological fields for this episode and animations of ozone and its precursors for the 1993 base case, we suspect that the peaks in the eastern portion of the domain (BPA, BPA-Offshore, and LA) are significantly influenced by boundary conditions. The zero initial/boundary condition simulations performed as a part of the base case model performance evaluation tends to confirm this and also implies that the effects of the eastern boundary conditions extend to the HG and adjacent offshore areas.

In our review of meteorological inputs to the September 8-11 episode we noticed two features that may have bearing on the resistance of the HG area (onshore and offshore). First, the peaks that are seen just downwind of Houston are associated with an area of convergence and stagnation in the surface wind fields. The second feature involves an offshore wind speed minimum that appears to be inducing the injection of ozone aloft into the surface layer along the coast.

In the first feature, the stagnation areas are associated with areas where wind monitors are clustered and this leads us to believe that the assimilation of wind observations is inducing the stagnation area in the SAI Mesoscale Model (SAIMM) used to prepare the meteorological inputs. Without knowing more about the characteristics of the wind monitoring sites we can not say whether or not these data are appropriate for assimilation into the mesoscale meteorological model. However, we do suspect that this assimilation process is resulting in the improper placement and extent of the convergence zone.

September 8th provides a good example of the problem. On this day the modeled area of stagnation is centered of the intersection of Harris, Brazoria and Fort Bend counties. This area is close enough to the central Houston area to have high NOx level. Normally we would expect an area with levels of NOx this high to be titrating ozone, but in this case we model the domain-wide peak there. The high NOx concentrations are verified by the fact that in the directional guidance simulations, there is a disbenefit to NOx reductions in that area. We suspect that the high ozone in the region is due to convergence of NOx from Houston to the east and biogenic VOC seen in Brazoria County to the South and Fort Bend County to the West. When we refer back to the model performance evaluation for this episode we note that the Croquet site in southern Harris County is located in this area and that the ozone peak at this site is over-predicted by 50 ppb on this day. We believe that this ozone peak may be artificially enhanced because of the simulated meteorology and may be easier to control in reality than the model implies. Further investigations would be needed to confirm this.

The second feature involves an extended area of low wind speeds centered over an offshore wind observation. As with the first feature, we suspect that this area of low wind speeds is being induced through data assimilation in the SAIMM. When the wind flow is onshore this creates an area of divergence between the observation site and the shoreline, resulting in vertical transport of ozone from layers aloft to the surface. This injection of ozone from aloft appears to be at least partially responsible for the persistent offshore ozone peaks. This type of transport mechanism has been previously observed. However, if this phenomenon is over-estimated because of the data assimilation, the offshore ozone concentrations may be over-estimated as well.

6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Twenty one different emission control scenarios were processed with the SMOKE and simulated with CAMx for the September 6-11, 1993 COAST episode. None of those simulations demonstrated attainment of the NAAQS in the Houston-Galveston area. For this episode, the maximum emission reduction modeled included a 50.5 percent anthropogenic NOx and 11.8 percent anthropogenic VOC reduction. Based on direction guidance simulations done previously, we might expect that NOx reductions on the order of 75 percent might be required to reach attainment.

From an analysis of boundary conditions, model performance, and the meteorological inputs to CAMx, it appears that high ozone areas that are the most resistant to emission control may be significantly, and possibly excessively, influenced by the boundary conditions derived from regional CAMx modeling and the meteorological inputs derived from SAIMM simulations. As a result, it may be easier to attain the NAAQS in reality than implied by this modeling study.

7. REFERENCES

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