Final Report

ADDITIONAL SENSITIVITY ANALYSES OF THE SEPTEMBER 8-11, 1993 OZONE EPISODE

Work Order No. 31984-22
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1. INTRODUCTION

TNRCC is responsible for developing a State Implementation Plan (SIP) for ozone in Houston/Galveston and Beaumont/Port-Arthur (HGBPA) ozone nonattainment areas (the Houston area). The TNRCC's SIP relies upon photochemical modeling to relate atmospheric ozone concentrations to emission levels for ozone precursors. The most recent modeling was performed using the Comprehensive Air Quality Model with extensions (CAMx) version 2.03 for the December, 2000 SIP revision and considered emissions of volatile organic compounds (VOCs), nitrogen oxides (NOx) and carbon monoxide. Since then a number of new features have been implemented in the CAMx modeling system, in particular, flexi-nesting and chlorine chemistry. Recent studies (ENVIRON, 2001; Tanaka, 2000) have suggested that reactive chlorine compounds may play a significant role in ozone formation in the Houston atmosphere, while the use of the flexi-nesting features of the CAMx model may be able to provide significant model performance improvements for the Houston area. In addition, during the summer of 2000 the Texas Air Quality Study (TexAQS) was conducted to collect atmospheric measurements of ozone and ozone precursors in order to further support atmospheric computer modeling of the Houston area as well as to better characterize industrial precursor emissions within the area. The impacts on simulated ozone concentrations due to these new features of the CAMx model as well as the analysis of future year alternative emission scenarios have been investigated and documented previously using the SAIMM meteorological fields (ENVIRON, 2002; 2002a). The purpose of the current study is to apply the CAMx model to the 8-11 September, 1993 ozone episode using alternative meteorological fields and to evaluate model performance under alternative emission scenarios. In addition, the modeling effort will focus on the determination of alternative VOC emission reductions that would be required to compensate for relaxing the NOx reductions currently implemented in the future year Strategy I8a.

OBJECTIVES

The overall objectives of this study are as follows:

1. Apply the CAMx model to the 8-11 September, 1993 ozone episode and evaluate model performance using the latest meteorological fields developed by Tremback and Cram (2002) using the Penn State/NCAR Mesoscale Meteorological Model, Version 5 (MM5). The MM5 meteorology has technical advantages of being developed with a state-of-the-science model and having very high (1.33-km) grid resolution in the Galveston Bay Area. A model performance evaluation using the statistical and graphical analyses recommended by EPA Guidance will be conducted and the modeling results and model performance are compared with that obtained using the SAIMM meteorological data.

2. Perform sensitivity analyses in order to assess model performance under alternative emissions scenarios. The various alternative emission scenarios are developed to reflect a realistic estimate of industrial VOC emission levels consistent with the TexAQS analysis. Adjustments to the industrial VOC emission inventory are made based on the TexAQS Special Inventory and upset/maintenance reports compiled from EPA Region 12 databases to characterize the types of non-routine emissions that are known to occur in the industrial areas. The alternative emission scenarios were developed based on TNRCC recommendations.

3. Determine whether less stringent industrial NOx emission reductions in the 2007 Strategy I8a scenario could be compensated by greater reductions in 2007 industrial VOC emissions.

2. MODELING DATABASES AND MODEL CONFIGURATION

This section of the report documents the Houston ozone modeling databases that were utilized, the CAMx model configuration and options used to perform the emission sensitivity simulations, and the implementation of the CAMx model.

CAMx MODELING DATABASES

The TNRCC has developed CAMx modeling databases for ozone episodes that occurred in 1993 during the COAST field study. The episode periods are September 6-11 and August 16-20, 1993. Several concerns have been raised about the performance of modeling using these databases, and the TNRCC did not use the August episode in the HGBPA SIPs (the TNRCC is currently developing new modeling episodes). The TNRCC has also performed Houston modeling over a much larger area referred to as the SuperCOAST domain. The modeling performed for the current study utilizes the SuperCOAST domain with an inner 2-way nested 4-km grid which is the same as the 4-km grid used in the original COAST domain. In addition, a high-resolution 1.33-km flexi-nested grid is included to better simulate the relatively high density of point source emissions within the industrial areas along the Houston Ship Channel and Galveston Bay. The area covered by the CAMx model for the SuperCOAST domain is shown in Figure 2-1. The domain has an outer 16-km grid with inner 2-way nested 4-km and 1.33-km grids. The grid is defined in UTM zone 15 coordinates and has 8 vertical layers between the surface and 3.03 km. with a surface layer 20 meters deep. Figure 2-2 displays the location of the 1.33-km grid within the 4-km HGBPA grid. Note that previous studies have used the 1.33-km grid with CAMx flexi-nesting to interpolate meteorology from the 4-km to 1.33-km, but in this study 1.33-km meteorology was explicitly generated by the MM5 model.

The COAST domain meteorological fields for both the August and September 1993 episodes were developed using the SAIMM hydrostatic meteorological model with data assimilation (Kessler and Douglas, 1992). SAIMM was applied with relatively strong assimilation of wind data in an attempt "nudge" the model into reproducing the timing and magnitude of the land/sea breezes (Lolk et al., 1995). This has raised some concerns that the strength of the nudging may have compromised the consistency of the meteorological fields (Yocke et al., 1996). Numerous recent studies have developed alternate meteorological fields for the September Episode using other mesoscale meteorological models and horizontal resolutions (Emery et al., 2001; Tremback and Emery, 2001) and CAMx model performance evaluations using these alternative meteorological fields have been performed and documented (Tesche and McNally, 2001). The CAMx 1993 base case model simulations and future year emission sensitivity simulations using the SAIMM meteorological fields have been documented previously (ENVIRON, 2002).

In early 2002, ENVIRON and ATMET completed high resolution meteorological simulations of the September 1993 COAST ozone episode for the TNRCC (Tremback and Cram, 2002). The model simulations utilized the Penn State/NCAR Mesoscale Meteorological Model, Version 5 (MM5) and included a 1.33-km high resolution nested grid domain over the Houston Ship Channel and Galveston Bay. Numerous simulations were performed to assess the sensitivity to model configuration and performance optimization. The current study investigates the CAMx model performance and future year emission sensitivity analyses using the MM5 meteorological fields developed as part of the ENVIRON/ATMET study. A detailed description and analysis of the MM5 simulations, including model configuration, options and model performance evaluation can be found in Tremback and Cram (2002). The MM5 run denoted "new_4b" by Tremback and Cram (2002) was used to develop CAMx input files for this study. CAMx was run in a UTM

Zone 15 coordinate system to match the available emission inventories, and so MM5 meteorological fields were translated from their native Lambert Conformal grid to the CAMx UTM grid using ENVIRON's MM5CAMx software.

The base case emission inventories were developed by the TNRCC and have undergone continual upgrades to include the latest information with the September episode inventories being the most updated as it continues to be used for SIP modeling. A discussion of the various components of the inventories, including data sources and development methodologies is presented in the final report for a previous TNRCC sponsored project: Sensitivity Analyses of the September 8-11, 1993 Ozone Episode, Work Order NO. 31984-19, TNRCC Umbrella Contract NO. 582-0-31984 (ENVIRON, 2002). Boundary and initial conditions were developed by the TNRCC using methods developed in Yocke et al., 1996.

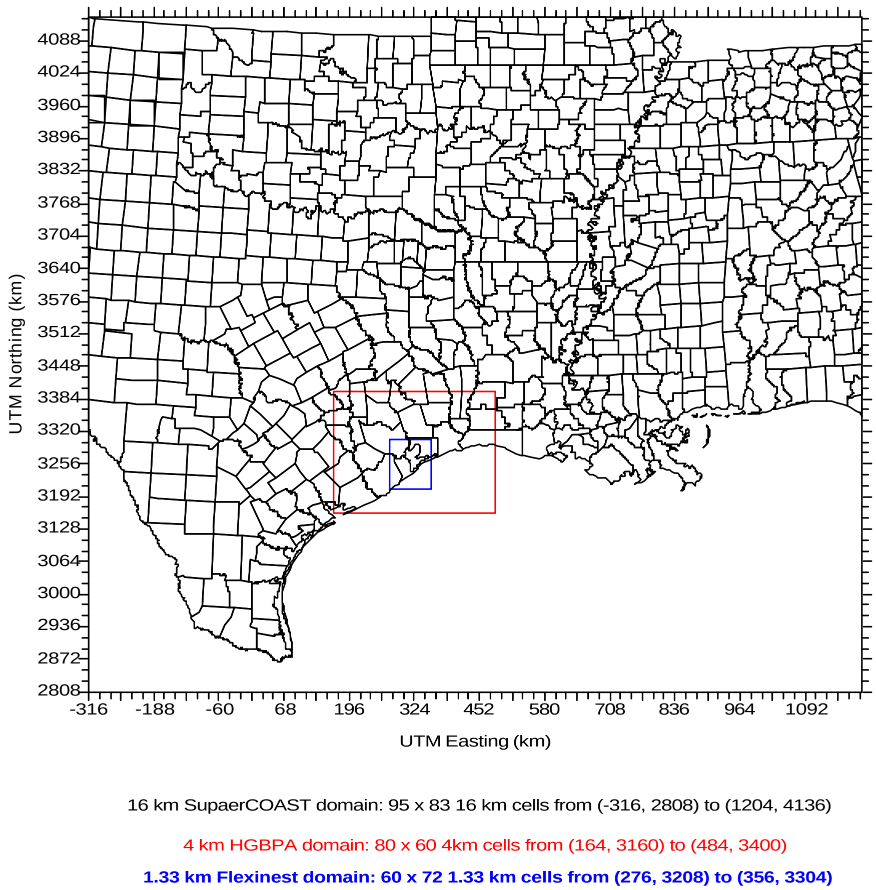

Figure 2-1. Map of the SuperCOAST domain showing the location of the 4-km HGBPA and 1.33 km domains.

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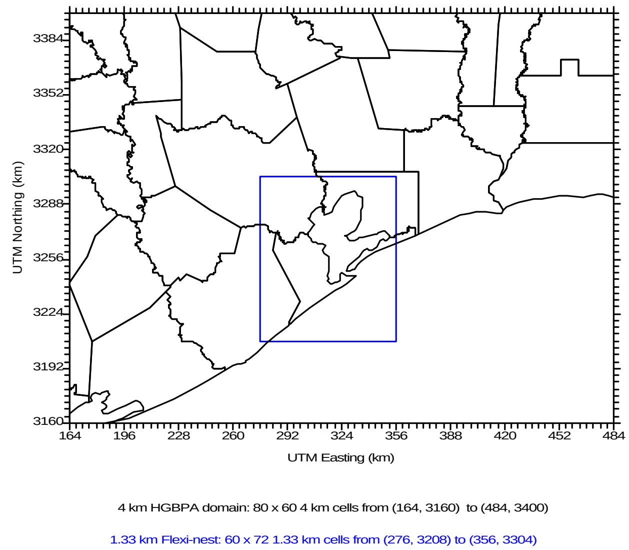


Figure 2-2. Map of the 4-km HGBPA domain showing the location of the 1.33-km grid.

CAMx MODEL CONFIGURATION

The TNRCC SIP modeling simulations for the 1993 ozone episodes were performed using the Comprehensive Air Quality Model with extensions (CAMx) version 1.13. Under Work Order No. 31984-19 (ENVIRON, 2002) ENVIRON investigated the sensitivity of the simulation results to model version and configurations for both the 1993 base case and future year 2007 base case. The results of these sensitivity simulations are documented in ENVIRON (2002). This study led to the recommendation to use version 3.01 of the CAMx model for further emission sensitivity simulations. The model configuration makes use of the updated chlorine chemistry and includes the 1.33-km Houston nested grid domain. In order to adequately simulate the interaction of NOx and VOC emission within the industrial area within and around the Houston Ship Channel and Galveston Bay, the Plume-in-Grid treatment of large NOx sources should not be implemented. Finally, the advection scheme used in the simulations should be the Piecewise Parabolic Method (PPM) in order to minimize the overly diffusive effects seen with the Smolarkiewicz solver. Thus, the starting point for the emission sensitivity simulations documented herein is the CAMx version 3.01 with chlorine chemistry including the 1.33-km nested grid, the PPM advection scheme and no Plume-in-Grid treatment of elevated point source emissions.

3. EMISSION SCENARIOS

As was the case with the previous study (ENVIRON, 2002b), an objective of the current study was to perform various emission sensitivity analyses and to assess model performance under alternative emission scenarios for the September 1993 base year ozone episode using the latest MM5 meteorology including the high resolution 1.33km nested grid. For the future year Strategy I8a scenario, an investigation of greater industrial VOC emission reductions required to compensate for lesser industrial NOx emission reductions contained in the final 2000 SIP was also conducted. The alternative emission scenarios examined the effect of increased emissions of volatile organic compound from industrial sources (industrial VOC, or IVOC), both continuously and episodically. The specific emission adjustment were made in consultation with TNRCC staff and were intended to approximate realistic levels of VOC emissions consistent with the results of the Texas Air Quality Study of 2000 (TexAQS 2000). In addition, from an analysis of the TexAQS Special Inventory and upset/maintenance reports, a number of episodic upset emission scenarios were developed and examined in order to evaluate the effects of non-routine emissions occurring within the industrial areas around the Houston Ship Channel and Galveston Bay.

The alternative emission scenarios focused on the HGBPA 4-km nested grid of the modeling domain as this region encompasses the urban areas within and around Houston, as well as the Ship Channel and Galveston Bay. As noted in earlier studies, due to the use of model-ready emission inventory data files, it was not possible to specifically identify individual sources as either industrial or non-industrial. Therefore, for the purposes of the present study, industrial sources are defined simply as all point sources, both elevated and low level. The development of the alternative emission scenarios were accomplished using the EPS2 utility processors to apply appropriate adjustment factors to the elevated and low level NOx and/or VOC emissions.

All alternative emission scenarios considered involved adjustments to industrial VOC and olefins within the 8-county Houston-Galveston area only and excluded shipping emissions. In the case of future year scenarios, the emission adjustments considered both existing and new sources for the purpose of adjusting NOx emission levels from the 90% reductions in the SIP. Figure 3-1 displays the 8-county Houston-Galveston region within which emission adjustments were performed. The specific procedures used for developing the emission sensitivity scenarios are documented in ENVIRON, 2002b.

This section of the report summarizes the alternative emission scenarios for both the 1993 base year and future year 2007 Strategy I8a to be applied for the September 1993 SuperCOAST CAMx ozone air quality modeling.

1993 BASE YEAR EMISSION SCENARIOS

As noted above, the objective of the current task was to evaluate model performance under various alternative emission scenarios involving continuous and episodic industrial VOC (IVOC) emission increases. To provide some reference with respect to the NOx and VOC emissions levels within and outside the HGBPA 4-km grid, Table 3-1 presents a summary of existing emissions in the September 1993 base year emission inventory.

Table 3-1. NOx and VOC 1993 Base Year Emission Summaries within and outside the HGBPA 4-km Domain.

HGBPA 4-km Domain. Emission Component	Inside 4-km Domain (tpd)	Outside 4-km Domain (tpd)
Elevated Point NOx	989	6283
Low Level Point NOx	45	--
Area/Mobile/Biogenic NOx	845	9478 (incl. low level points)
Elevated Point VOC	172	1174
Low Level Point VOC	427	--
Area/Mobile/Biogenic VOC	4039	68559 (incl. low level points)

The emission adjustments considered increases in total VOC as well as industrial light olefins (IOLE, represented by modeled species ETH and OLE), both separately and in combination with each other. In consultation with TNRCC staff, the sensitivity scenarios for continuous IVOC emission increases identified for evaluation are presented in Table 3-2. These scenarios were conducted to determine a more realistic level of VOC emissions consistent with findings of the TexAQS. Each of these scenarios was simulated using the CAMx air quality model and the resulting model performance was evaluated with respect to EPA guidance on acceptable model performance.

Table 3-2. Summary of 1993 Base Year Alternative Industrial VOC Emission Scenarios

Scenario Name	IVOC Increase (%)[1]	IOLE Increase (%)
200ole.200voc	100	100
300ole.300voc	200	200
400ole.100voc	0	300
600ole.100voc	0	500
800ole.100voc	0	700
1000ole.100voc	0	900

[1] Emission adjustments are multiplicative, i.e., IVOC increases are applied in addition to IOLE increases.

The above scenarios were developed through application of the appropriate adjustment factors using the emission processing utilities, MRGUAM and PTSCOR for low level and elevated point sources, respectively.

A number of experimental episodic emission scenarios were also examined. Based on consultations with the TNRCC project manager, a hypothetical VOC upset condition occurring several hours upwind of the peak observed concentrations on Sept. 8 was selected to evaluate the effects of episodic VOC emission increases on model performance. The release point was chosen as 303.637 km Easting, 3292.915 km Northing, UTM Zone 15, which corresponds to a location near Baytown at the mouth of the Houston Ship Channel.

The specific location was chosen based on an examination of model wind back trajectories ending at Smith Point and Seabrook at around mid-day September 8, 1993. In order to ensure that the upset emissions were released within the lowest model layer, the emissions were added to the low-level component emissions data file. Table 3-3 summarizes the upset scenario simulated.

Table 3-3. Summary of Upset Emission Scenario., UPSET1C

Scenario Name	Emission release (magnitude and species)	Release duration (start and end time, Sept. 8, 1993)
UPSET1C	5000 lb/hr Propylene (OLE+PAR)	5 am – 11 am

2007 FUTURE YEAR EMISSION SCENARIOS

The objective of the 2007 Strategy I8a emission sensitivity scenarios was to investigate the potential for offsetting the adopted reduction in point source NOx with reductions in industrial VOC emissions. In addition, the effects of the alternative VOC emission scenarios performed for the 1993 Base year simulations were considered for the 2007 Strategy I8a emission scenarios.

In order to accomplish this task, the industrial NOx emission for the I8a scenario were first increased by a factor of 2 to approximate the NOx emission levels with 80% rather than 90% reduction applied to industrial sources. A series of emission scenarios were then developed with varying reductions in industrial VOC emission levels. The CAMx model was then applied to determine the extent to which the modeled ozone concentrations could be reduced to the Strategy I8a levels through reduction of industrial VOC emissions. As noted above, the procedures used to develop the emission scenarios were subsequently refined to apply only within the 8-county region with appropriate treatment of sources not subject to controls.

For reference, Table 3-4 presents to VOC and NOx emission totals within and outside the HGBPA 4-km modeling domain. Table 3-5 provides a summary of the industrial NOx and VOC/OLE emission reduction scenarios considered. Note that the “80nox.*ole” scenarios represent the 2007 future year emission levels without the SIP adopted NOx reductions and represent the starting point for the investigation of potential VOC/OLE reduction scenarios to compensate for the proposed NOx reductions. Of note is the “80nox00ole” scenario, which corresponds to the maximum potential industrial olefin emission reductions.

Table 3-4. NOx and VOC Strategy I8a Emission Summaries within and outside the HCBPA 4-km Domain.

4-dm Domain.HGBPA 4-km Domain. Emission Component	Inside 4-km Domain (tpd)	Outside 4-km Domain (tpd)
Elevated Point NOx	300	4150
Low Level Point NOx	18	--
Area/Mobile/Biogenic NOx	506	8465 (incl. low level points)
Elevated Point VOC	50	860
Low Level Point VOC	220	--
Area/Mobile/Biogenic NOx	3851	67805 (incl. low level points)

Table 3-5. Summary of 2007 Strategy I8a Emission Scenarios

Scenario Name	INOx Increase (%)	IVOC Increase (%)	IOLE Increase (%)
i8a base	0	0	0
i8a 200ole.200voc	0	100	100
i8a 600ole.100voc	0	0	500
i8a 1000ole.100voc	0	0	900
80nox.1000ole	100	0	900
80nox.800ole	100	0	700
80nox.600ole	100	0	500
80nox.500ole	100	0	400
80nox.400ole	100	0	300
80nox.300ole	100	0	200
80nox.200ole	100	0	100
80nox.100ole	100	0	0
80nox.00ole	100	0	-100
85nox.1000ole	50	0	900
85nox.800ole	50	0	700
85nox.600ole	50	0	500
85nox.500ole	50	0	400
85nox.400ole	50	0	300
85nox.300ole	50	0	200
85nox.200ole	50	0	100
85nox.100ole	50	0	0
85nox.00ole	50	0	-100

Each of the above alternative emission scenarios were simulated using Version 3.01 of the CAMx air quality model, configured as discussed above in Section 2.

Identification of the "Shipping Sources"

The refinement of the future year alternative emission scenarios involved the identification of shipping emissions (which were treated as "pseudo-stacks" in the inventory), accounting for new sources not subject to controls and the restriction of the emission adjustments to the 8-county Houston-Galveston area.

Ships were located by matching "stack parameters" in the 2007 shipping "AFS" file to stack parameters in the model ready elevated point source file. This means matching sources based on location. Locations were considered a match when they agreed to within 10 meters. The 10-meter tolerance is necessary to account for the limits of representing these locations as 4-byte real binary numbers plus several conversions between binary and ASCII format.

Figure 3-1 shows the location of elevated sources identified as ships. They follow the ship channel and intra-coastal waterway, as expected.

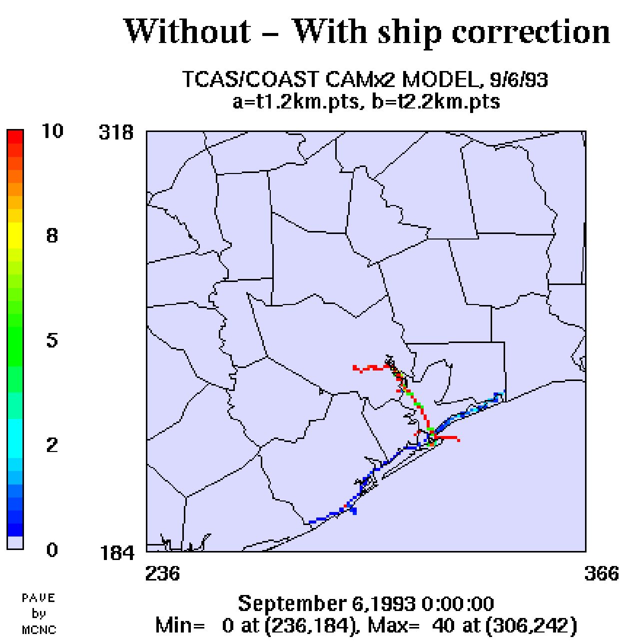


Figure 3-1. Location of shipping emission sources.

Scaling Emissions from "Industrial Sources"

Emissions from industrial sources were identified as follows:

- Elevated points within a 4 km resolution mask of the 8-county Houston-Galveston area that were not ships
- Low level points within a 4 km resolution mask of the 8-county Houston-Galveston area.

The 4-km resolution mask of the 8-county Houston-Galveston area was provided by the TNRCC.

Emissions from the "INOx" sources were "doubled" by multiplying by a factor of 1.78 to account for new sources not subject to control. The factor of 1.78 was obtained through consideration of the industrial NOx emission levels in the i8 Strategy within the 8-county area and the NOx emission levels from new sources. The i8 Strategy contained 103 tons of industrial NOx in the 8-county area, of which 23 tons were from new sources. Therefore, to multiply the controlled sources by 2 we multiply all industrial sources by the following: [2 x (103-23) + 23]/103 = 1.78. Ships and sources outside the 8-county mask were not doubled and appear in green. In the detail of the ship channel area, some 2-km grid cells contain both ships and INOx sources and appear yellow/orange.

The increase in NOx emissions between the i8 base inventory and the inventory with "doubled" industrial NOx emissions was 71 tons. This means that the base inventory had (71/0.78) = 91 tons of INOx. The shipping emissions amount to 39 tons of NOx.

Based on model performance results of the 1993 base year VOC emission adjustment scenarios, and through consultation with the TNRCC, two acceptable alternative IOLE emission scenarios were selected for further analysis. The Strategy I8a inventory was adjusted to reflect the increased industrial olefin emission levels within the 8-county region. The resulting scenarios were then simulated with CAMx to provide a reference for subsequent emission reduction scenarios. Two series of simulations were then undertaken; one with the industrial NOx emissions at 80% reduction levels from the base year and one with the industrial NOx emissions at 85% reductions levels from the 1993 base levels. Air quality model simulations were performed with each of these NOx reduction scenarios for varying levels of industrial olefin emission reductions to determine the potential for compensating NOx reductions in the future year with industrial olefin emission reductions. The scenarios chosen for further analysis include the 6x IOLE and 10x IOLE alternative emission scenarios. Table 3-7 summarizes the industrial olefin and VOC emissions within the 4-km HGBPA modeling domain for both the 1993 base year and 2007 future year with adjusted (6xOLE) and unadjusted emission levels. Emissions of NOx for the 2007 I8a levels (90% reduction), the 85% and 80% reduction levels amount to 91 tpd, 126 tpd, and 162 tpd, respectively.

Table 3-7. Summary of industrial emissions for the 1993 and 2007 alternative emission scenarios (tpd).

Pollutant	1993 Base Elevated Points	1993 Base Low Level Points	1993 6 x OLE Elevated Points	1993 6 x OLE Low Level Points	2007 Ia8 Elevated Points	2007 Base Low Level Points	2007 6 x OLE Elevated Points	2007 6 x OLE Low Level Points
VOC	101	265	190.5	421	35.3	116	74.9	201
OLE	9.1	14.6	54.6	87.6	4.6	8.8	27.5	52.8
ETH	8.8	16.6	52.8	99.6	3.5	8.2	20.1	49.2

4. BASE YEAR MODELING RESULTS

The results of the emission sensitivity scenarios for the 1993 base year utilizing the MM5 meteorology are presented and discussed in this section.

1993 BASE YEAR MODEL PERFORMANCE EVALUATION

Version 3.01 of the CAMx air quality model was applied to the September 6-11, 1993 ozone episode using the model domain and configuration described in Section 2. The latest MM5 meteorological data fields were used including the high-resolution 1.33-km nested grid domain. The modeling results were examined and evaluated with respect to the spatial distribution of simulated daily maximum 1-hour ozone concentrations and model performance evaluation criteria as defined by EPA guidance. A comparison with the CAMx modeling results obtained using the SAIMM meteorological fields was also conducted. In addition to the base year base case simulation, a series of enhanced industrial VOC and olefins emission scenarios were simulated for the 1993 base year.

Figure 4-1 displays the spatial distribution of daily maximum 1-hour ozone for the 1993 base case within the HGBPA 4-km modeling grid. The model performance statistical measures for each scenario are presented in Table 4-1, which also shows the peak modeled ozone concentration within the 4-km HGBPA domain. These data were compiled based on results at 1.33-km horizontal resolution (i.e., each 4-km grid cell contains the aggregate of 9 1.33-km cells in the area of the 1.33-km grid).

Table 4-1 displays the model performance statistical measures obtained for both the SAIMM base case simulation and the base case simulation with the MM5 new4b simulation results. Also presented in Table 4-1 are the model performance statistics for the CAMx simulations with enhanced industrial olefin and VOC emissions presented in Table 3-5. Except for the unpaired peak accuracy metric, the September 8th episode day for the simulation using the MM5 meteorology meets the performance goals with respect to EPA guidance. The rest of the simulation days show large under-estimations of the observed ozone concentrations within the 4-km HGBPA domain.

Displays of the spatial distribution of the daily maximum 1-hour ozone concentrations are shown in the Figure 4-1 for the 1993 base case using the MM5_new4b meteorology. The corresponding displays for the SAIMM meteorology are shown in Figure 4-3 for reference. Clearly, the model is grossly under-estimating peak ozone concentrations for the September 10th and 11th simulation days. For both the September 8th and 9th simulation days, while the peak ozone concentrations are considerably lower than the SAIMM simulations, the spatial patterns are seen to be similar. Elevated ozone concentrations for both cases are occur within the Houston urban area and Galveston Bay and extending offshore on the 8th of September. The September 9th simulation day shows high ozone concentrations primarily within the Houston/Galveston Bay area with a region of elevated concentrations also occurring just northeast of Beaumont/Port Arthur region. The last two days of the simulation (Sept. 10th and 11th) exhibit gross under-estimations of predicted daily maximum 1-hour ozone throughout the region.

Time series plots displayed in Figure 4-3 illustrate the 1993 base case model performance for the MM5 meteorology. In general, while the 8th and 9th of September replicate the observed ozone concentration at many monitors, the 10th and 11th simulation days are consistently under-estimating the hourly ozone concentrations within the Houston-Galveston Bay area.

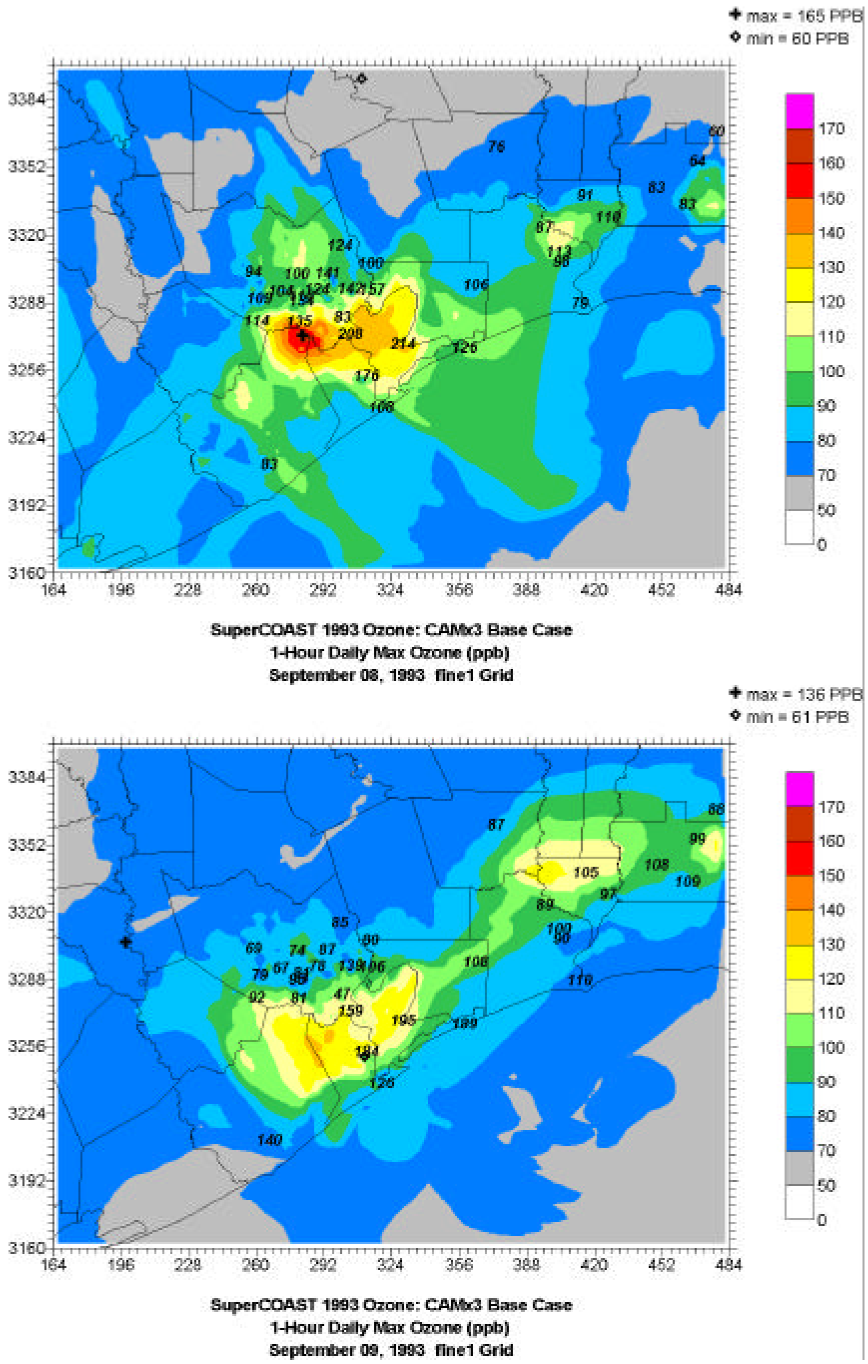
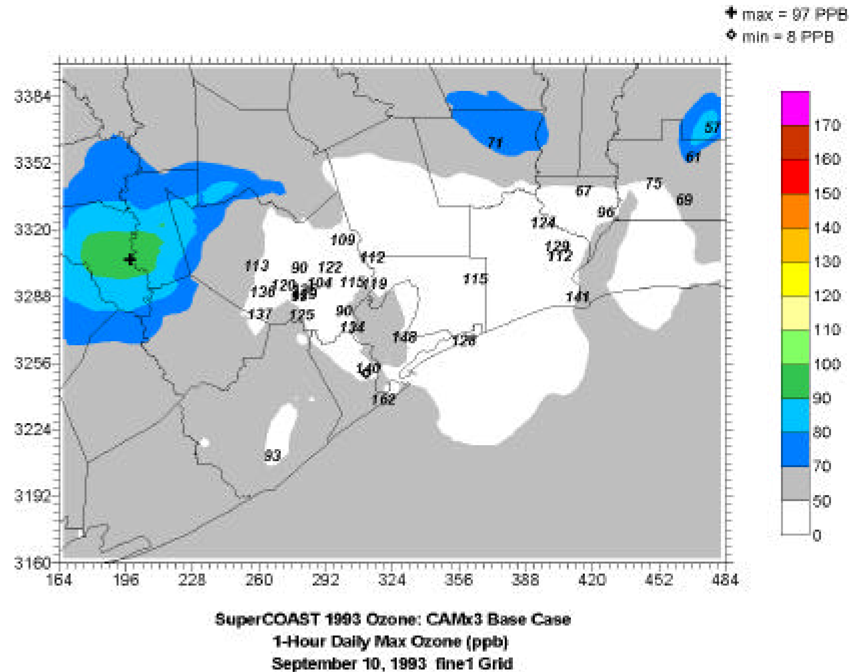


Figure 4-1. Daily maximum ozone concentrations for 1993 Base Case with MM5 meteorology.



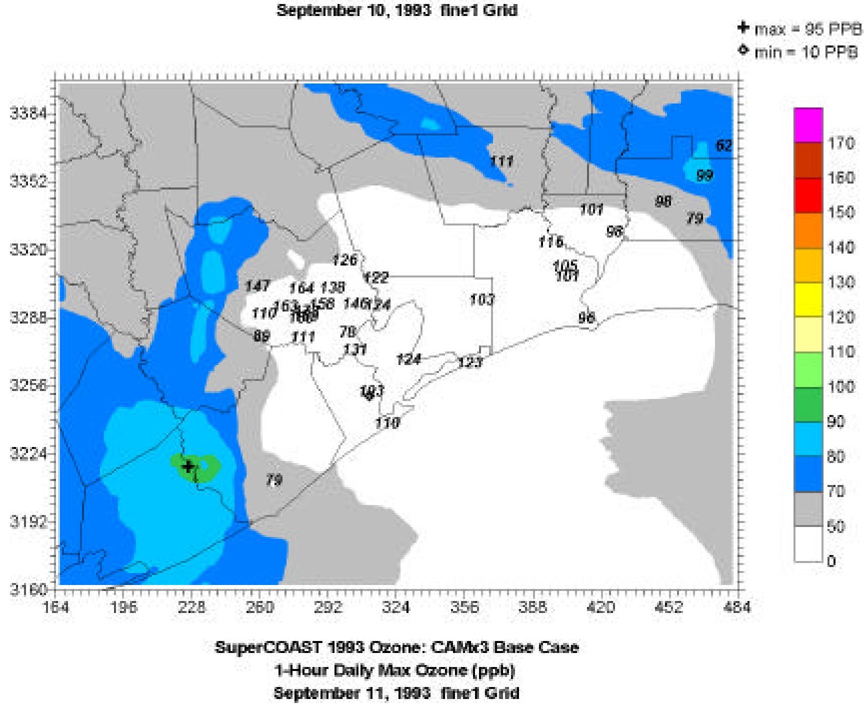


Figure 4-1 (continued). Daily maximum ozone concentrations for 1993 Base Case with MM5 meteorology.

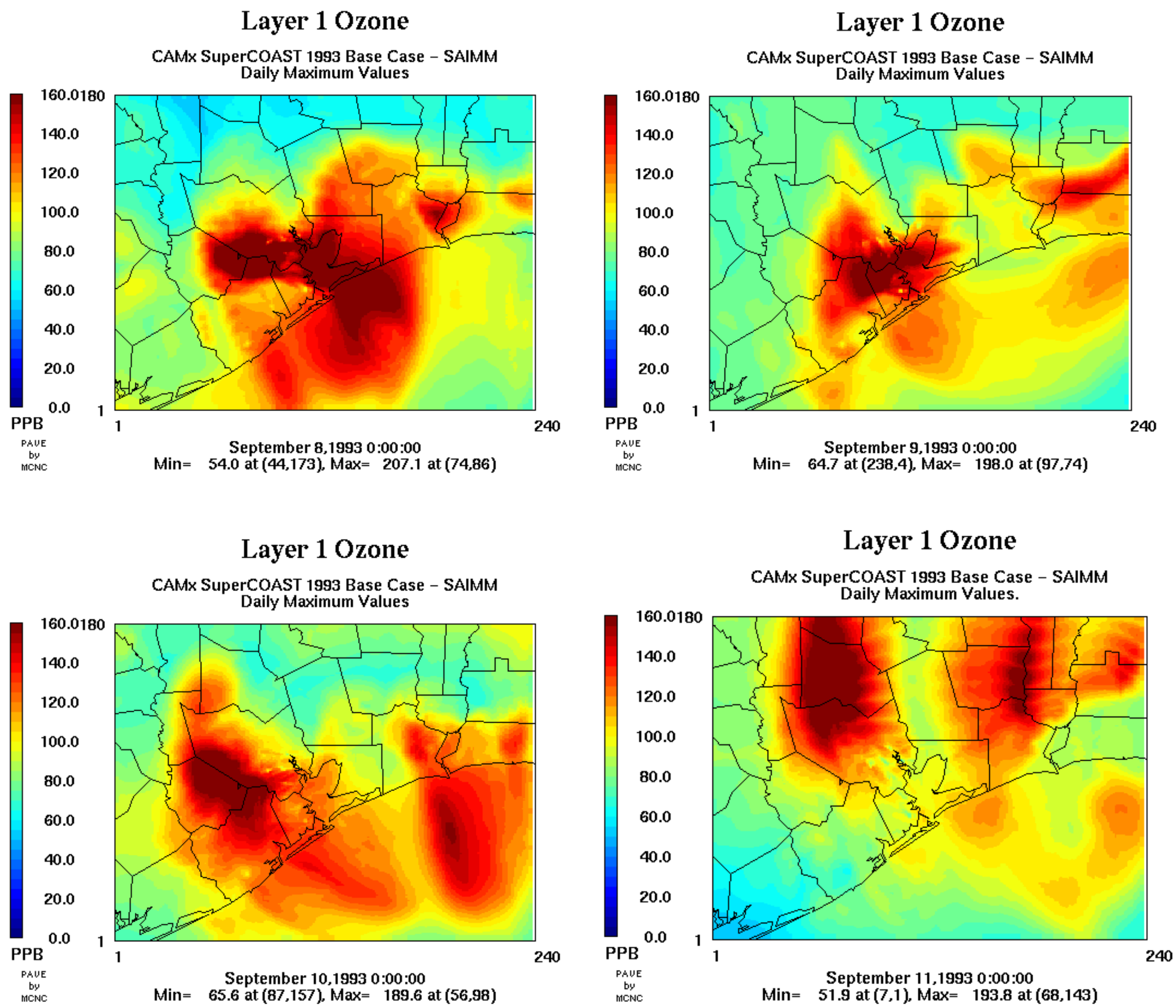


Figure 4-2. Daily Maximum ozone concentrations (ppb) on the HGBPA 4-km domain with SAIMM meteorology.

Table 4-1. CAMx Model Evaluation Statistics for the 8-11 September 1993 Episode on 4-km HGBPA Domain.

Performance Attribute	EPA Goal	8 Sept	9 Sept	10 Sept	11 Sept
Maximum Observed Concentration (ppb)		214.0	195.0	162.0	189.0
Maximum Modeled Conc. (ppb)					
SAIMM		207.1	198.0	189.6	193.8
MM5_new4b		165.5	136.3	96.6	94.7
MM5_new4b;200ole.200voc		178.3	142.5	102.1	96.9
MM5_new4b;300ole.300voc		198.4	150.3	110.3	116.3
MM5_new4b;400ole.100voc		175.3	141.7	96.5	96.8
MM5_new4b;600ole.100voc		181.3	144.8	98.0	98.1
MM5_new4b;800ole.100voc		192.4	147.7	99.3	99.3
MM5_new4b;1000ole.100voc		204.5	150.5	100.7	60.9
Accuracy of Unpaired Peak (%)	<"20%				
SAIMM		-3.2	1.5	17.1	2.5
MM5_new4b		-22.7	-30.1	-40.4	-49.9
MM5_new4b;200ole.200voc		-16.7	-26.9	-37.0	-48.7
MM5_new4b;300ole.300voc		-7.3	-22.9	-31.9	-38.5
MM5_new4b;400ole.100voc		-18.1	-27.4	-40.4	-48.8
MM5_new4b;600ole.100voc		-15.3	-25.7	-39.5	-48.1
MM5_new4b;800ole.100voc		-10.1	-24.3	-38.7	-47.4
MM5_new4b;1000ole.100voc		-4.4	-22.8	-37.9	-20.9
Mean Normalized Bias (%)	<"15%				
SAIMM		7.1	5.3	-10.1	0.7
MM5_new4b		-10.0	-17.6	-67.2	-59.0
MM5_new4b;200ole.200voc		-6.8	-14.9	-60.7	-51.9
MM5_new4b;300ole.300voc		-3.0	-12.8	-59.0	-50.3
MM5_new4b;400ole.100voc		-7.2	-16.2	-66.8	-58.2
MM5_new4b;600ole.100voc		-5.5	-15.2	-66.5	-57.6
MM5_new4b;800ole.100voc		-4.0	-14.4	-66.3	-56.9
MM5_new4b;1000ole.100voc		-2.5	-13.5	-66.0	-59.5
Mean Normalized Gross Error (%)	<"35%				
SAIMM		25.4	27.4	25.7	21.4
MM5_new4b		17.5	24.7	67.2	59.3
MM5_new4b;200ole.200voc		16.6	23.6	60.9	52.4
MM5_new4b;300ole.300voc		16.3	23.8	59.1	51.5
MM5_new4b;400ole.100voc		16.8	24.6	67.0	58.5
MM5_new4b;600ole.100voc		16.6	24.6	66.7	57.9
MM5_new4b;800ole.100voc		16.6	24.6	66.4	57.3
MM5_new4b;1000ole.100voc		16.6	24.7	66.1	59.5

SuperCOAST September 8-11, 1993 -- 4-km Grid

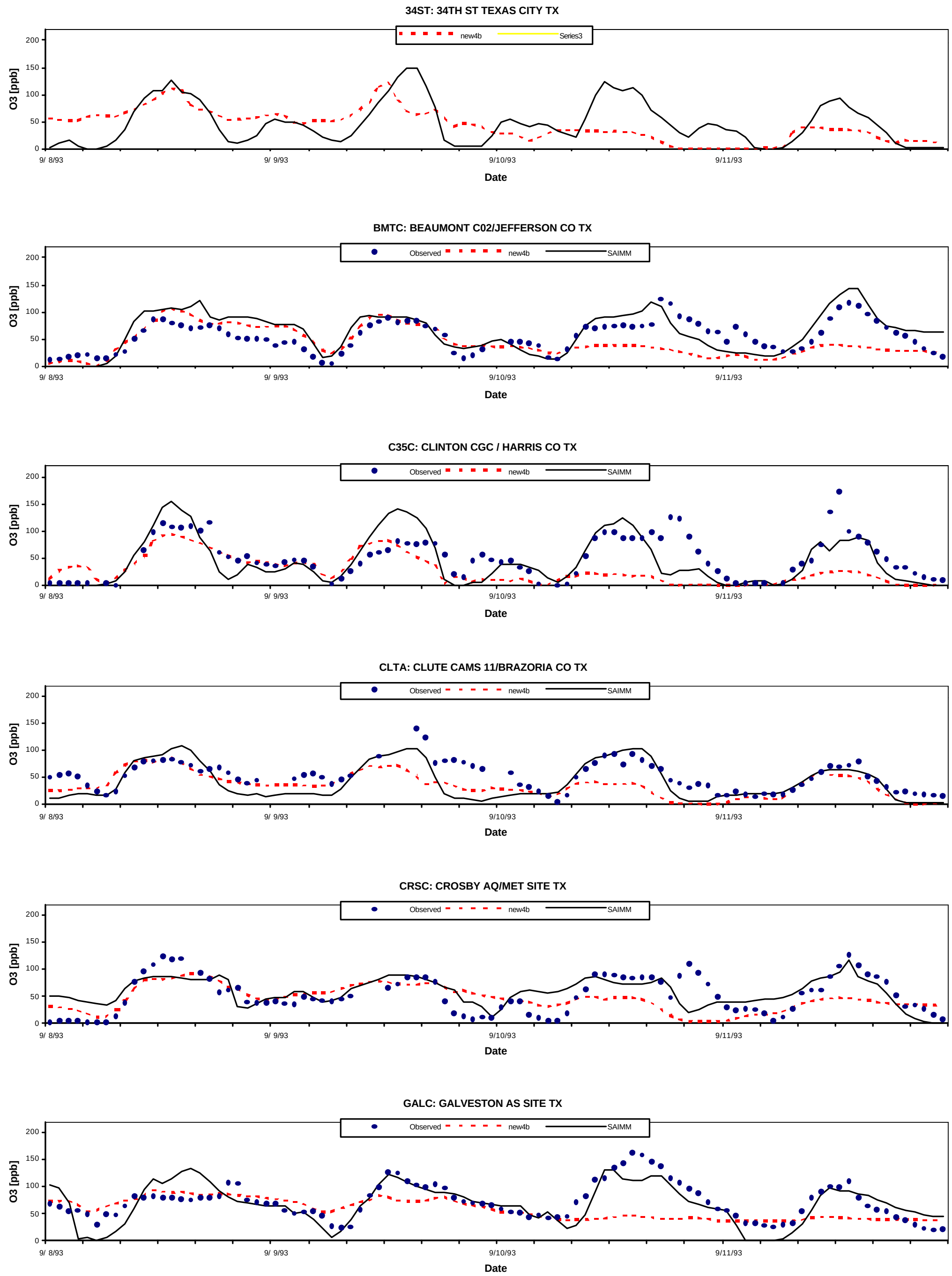


Figure 4-3. Time series plots of MM5 and SAIMM simulations.

SuperCOAST September 8-11, 1993 -- 4-km Grid

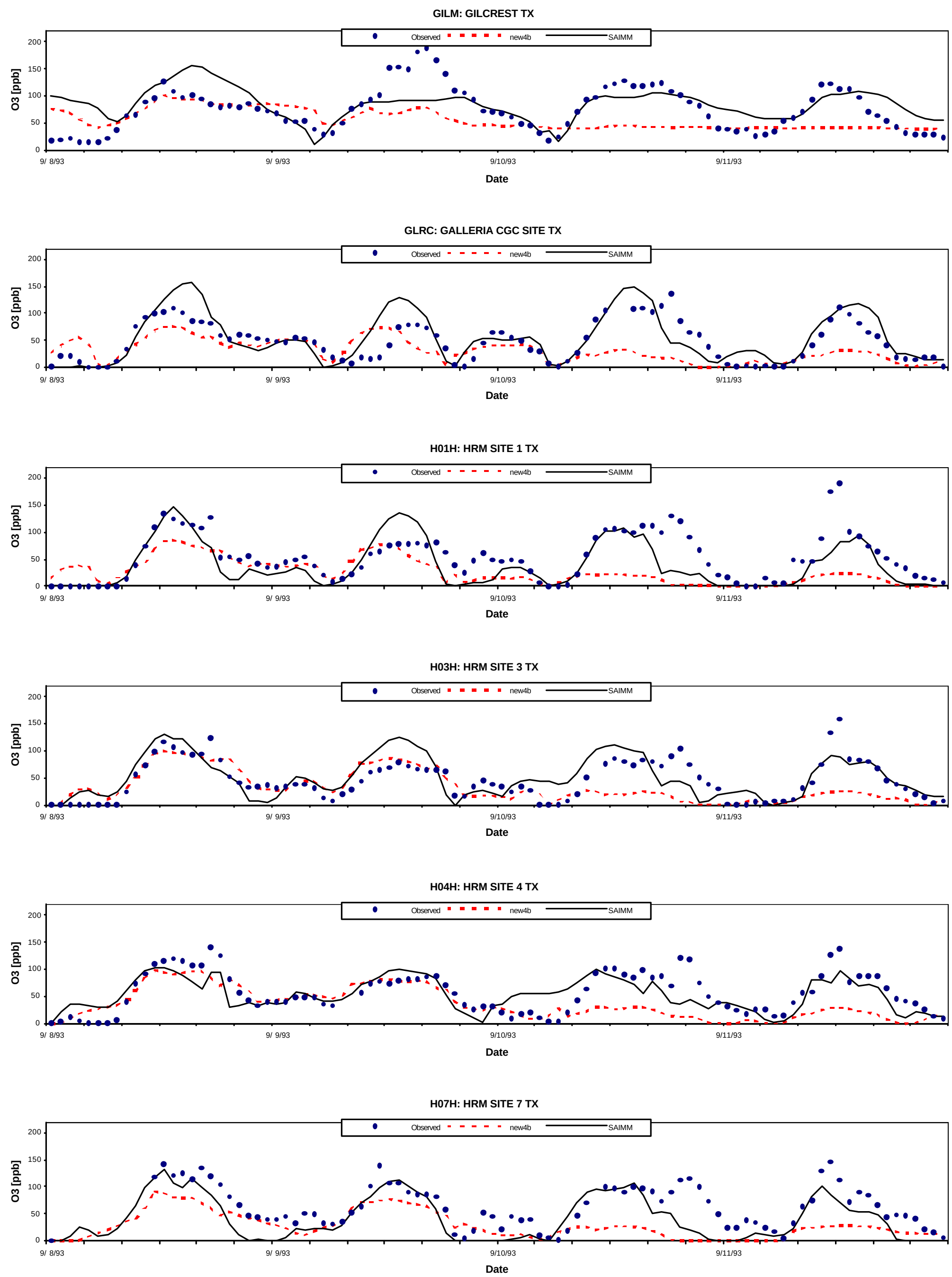


Figure 4-3. (continued). Time series plots of MM5 and SAIMM simulations.

SuperCOAST September 8-11, 1993 -- 4-km Grid

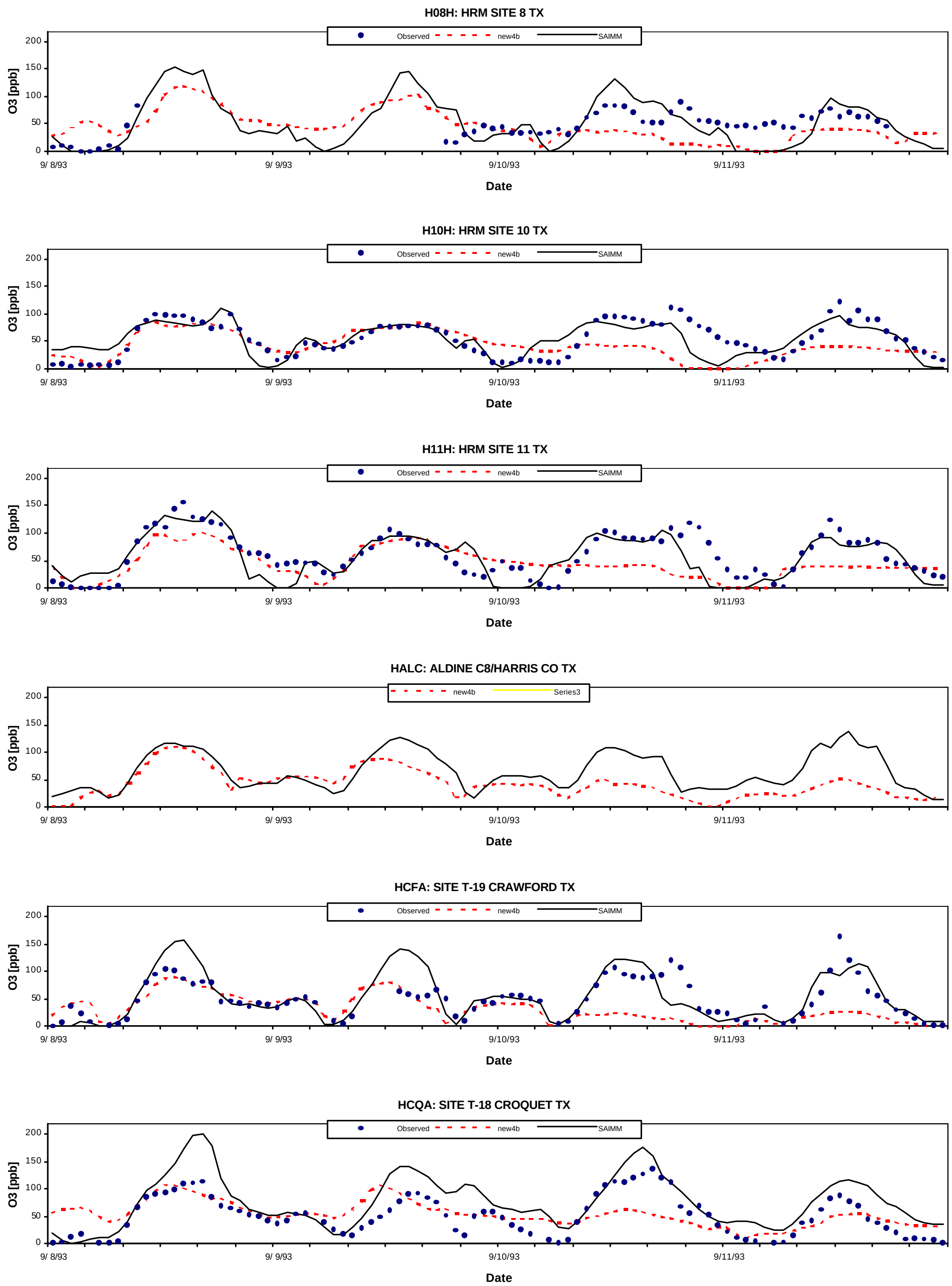


Figure 4-3. (continued). Time series plots of MM5 and SAIMM simulations.

SuperCOAST September 8-11, 1993 -- 4-km Grid

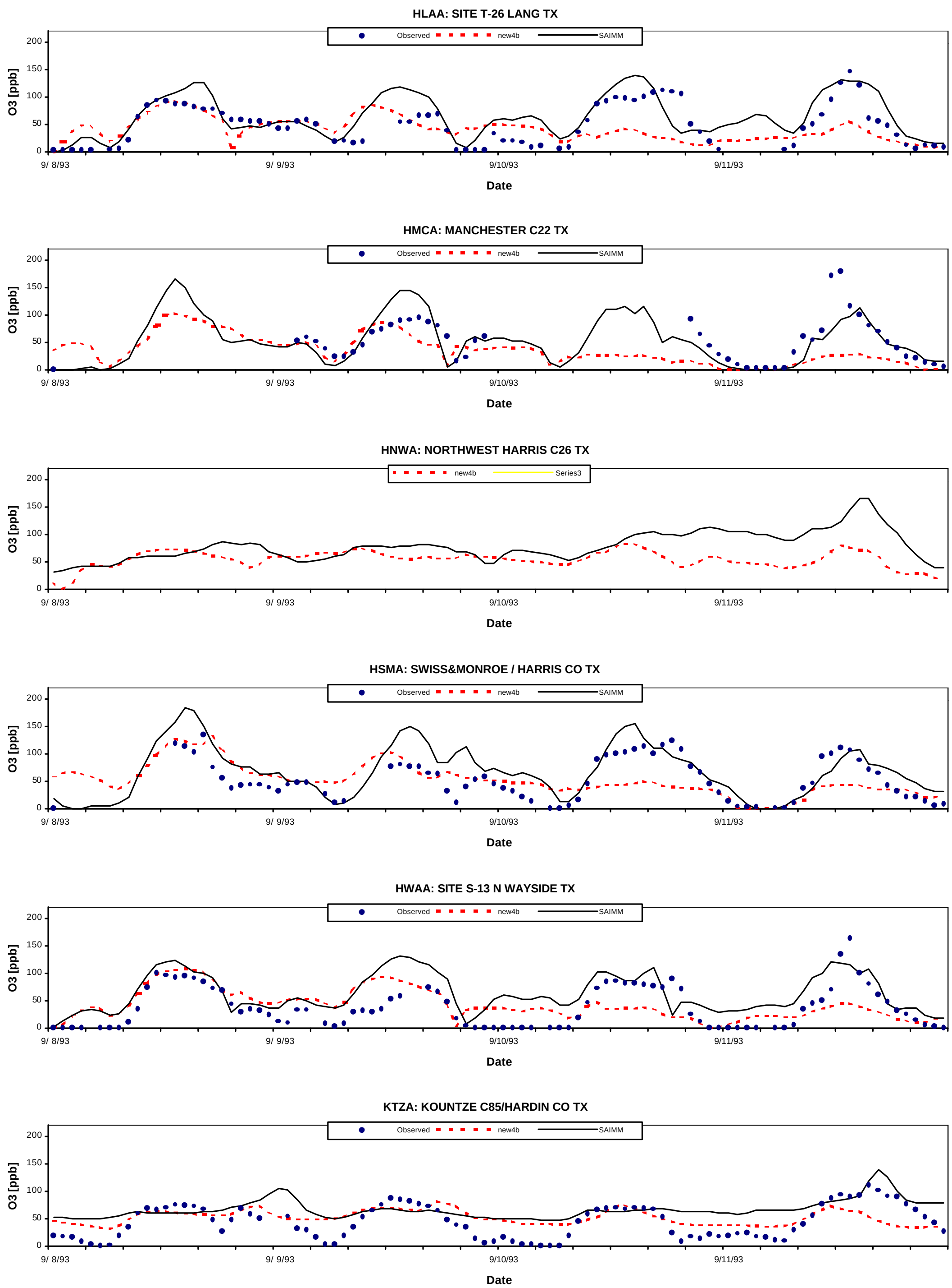


Figure 4-3. (continued). Time series plots of MM5 and SAIMM simulations.

SuperCOAST September 8-11, 1993 -- 4-km Grid

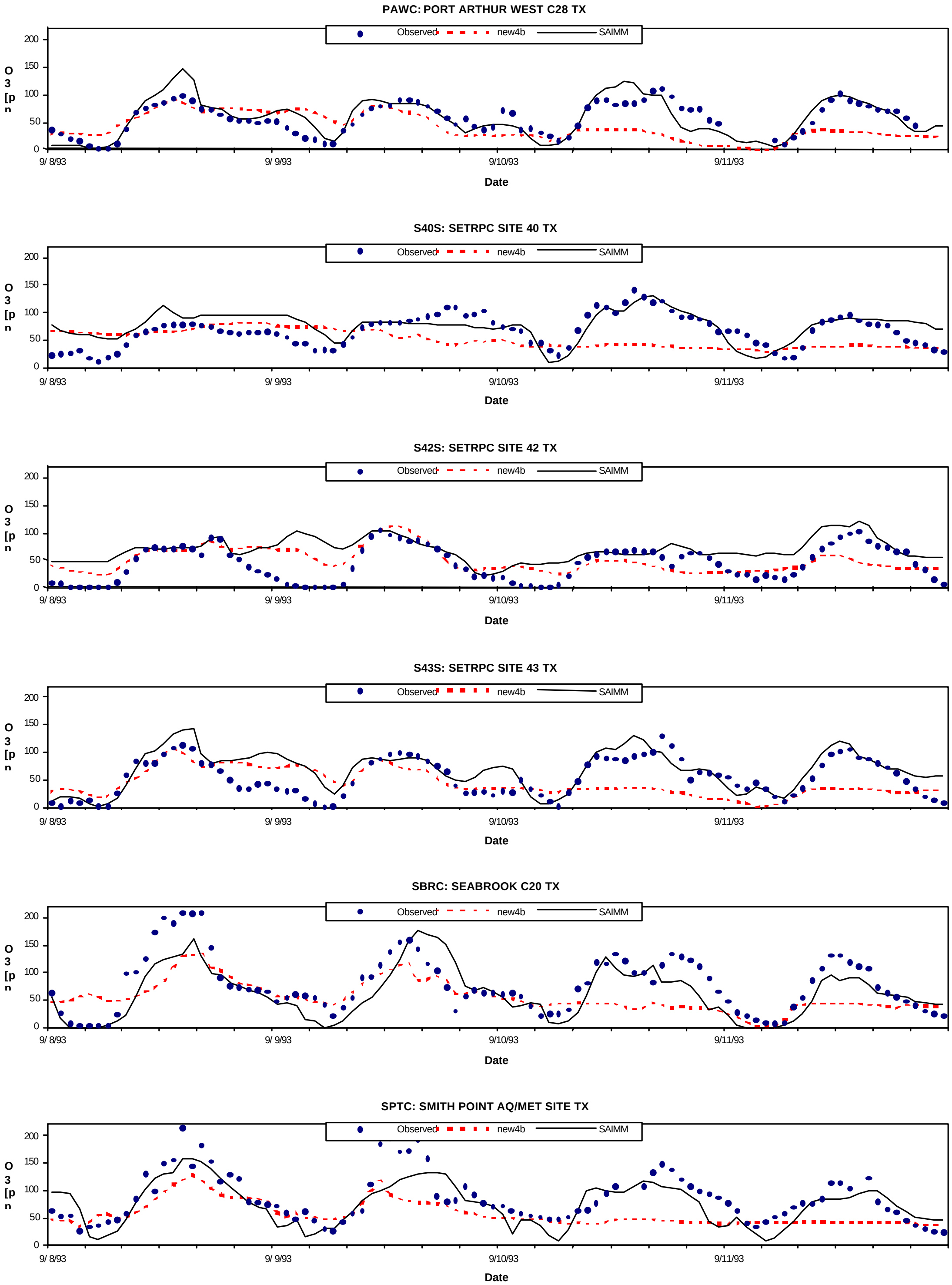


Figure 4-3. (continued). Time series plots of MM5 and SAIMM simulations.

SuperCOAST September 8-11, 1993 -- 4-km Grid

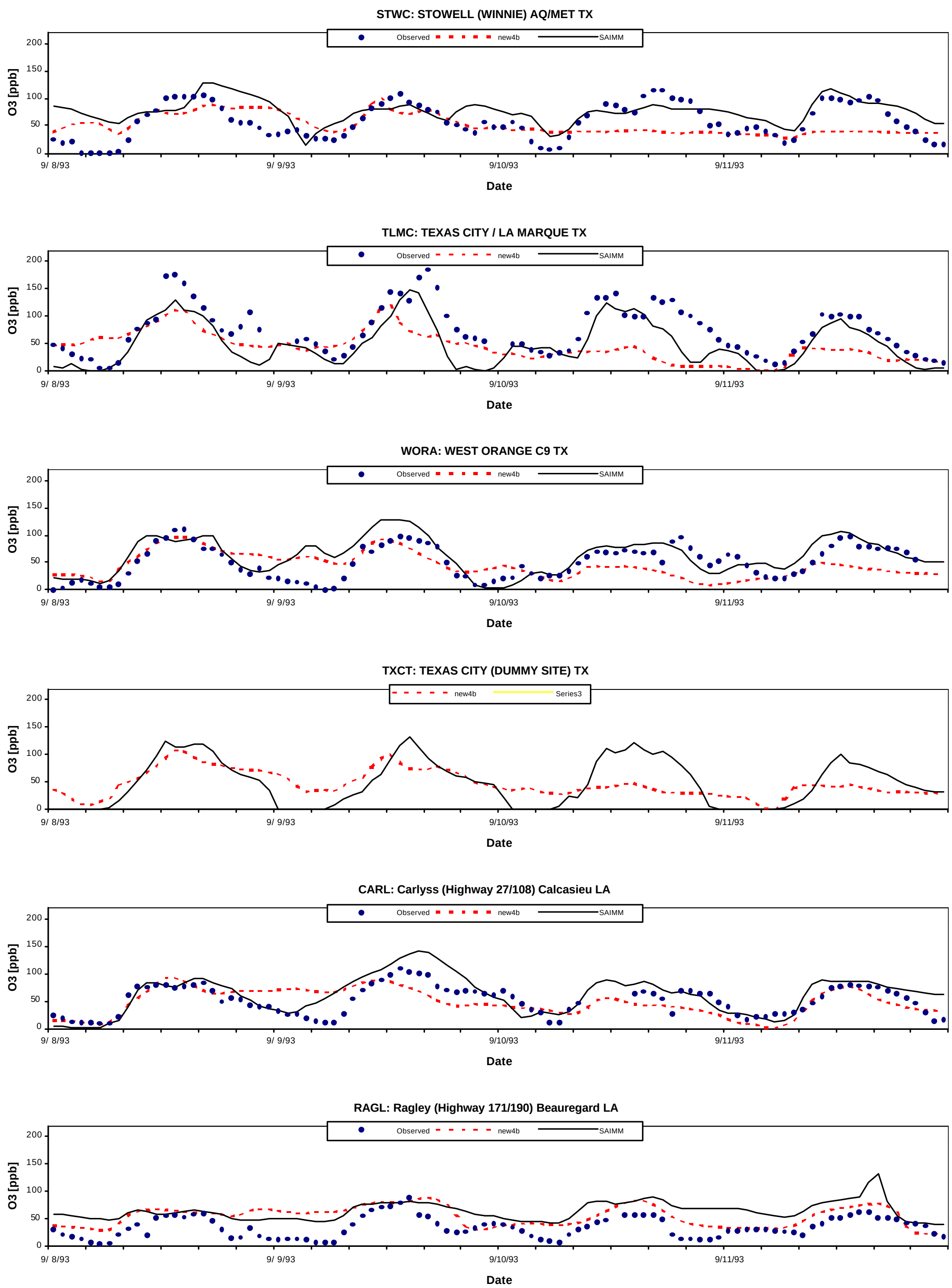


Figure 4-3. (continued). Time series plots of MM5 and SAIMM simulations.

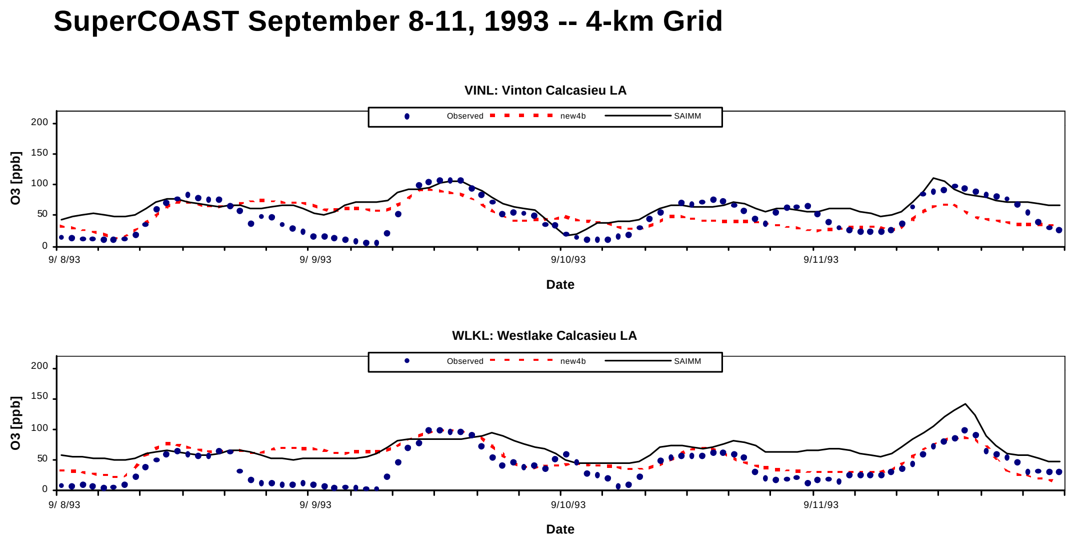


Figure 4-3. (concluded) Time series plots of MM5 and SAIMM simulations.

The low predicted ozone on the 9th and 10th of September for the 1993 base case prompted a closer examination of the MM5 meteorology data fields. An examination of the PBL depths in the 4-km and 1.33-km modeling domains showed relatively little, if any, significant variation in the PBL heights between mid-day and nighttime on these days. In addition, the presence of increased convective activity and cloud cover appears to have suppressed the development of the boundary layer and thus resulted in minimal turbulent mixing. These findings were expected based on the MM5 performance problems described in Tremback and Cram (2002). The impacts of cloud cover and the PBL depths on the modeled results were investigated to provide an understanding of the possible sources of the gross under-predictions of the simulations with the MM5 meteorology. Spatial plots of the cloud optical depth and PBL heights for September 9th are displayed in Figure 4-4. The presence of clouds and convective activity southwest of Galveston Bay is seen to result in local suppression of the PBL heights. Figure 4-5 displays the extent of cloud cover within the 1.33-km Houston/Galveston Bay domain and shows the major cause for the reduced PBL heights and resulting turbulent mixing within the region.

Displays of the PBL heights for the 4-km and 1.33-km modeling domains at mid-day for each episode day are presented in Figure 4-6. On the 8th and 9th of September the deep boundary layer closely follows the coast line, including the Galveston Bay area and drops off quickly over the water as would be expected. Increased cloud cover and convective activity in the area on the 10th and 11th of September is seen to lead to the collapse of the PBL across the Houston/Galveston Bay area. While the display in Figure 4-6 illustrates conditions at 2:00pm, the situation persists throughout most of the daylight hours on both days leading to the extremely low predicted ozone concentrations.

The excessive cloud cover developed by the MM5 simulation on September 10th and 11th suppresses the ozone formation throughout the Houston/Galveston area by reducing vertical mixing, lowering temperatures and attenuating photolysis rates. Because of the, the MM5-based CAMx simulations for September 10th and 11th are considered un-usable. Causes for the excessive cloudiness in MM5 were discussed by Tremback and Cram (2002).

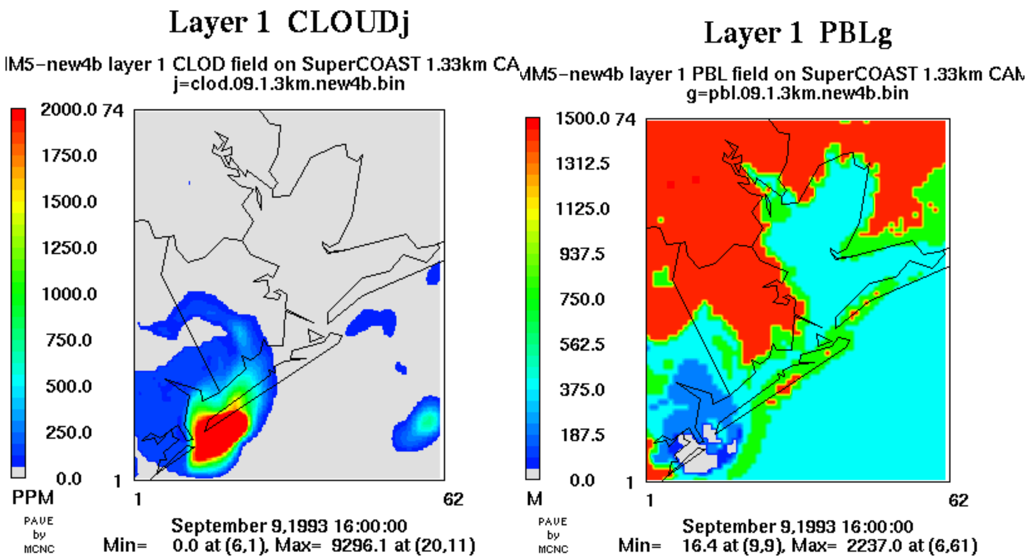


Figure 4-4. Cloud optical depth (dimensionless) and PBL heights (m) at 16:00 on September 9th based on MM5 meteorology.

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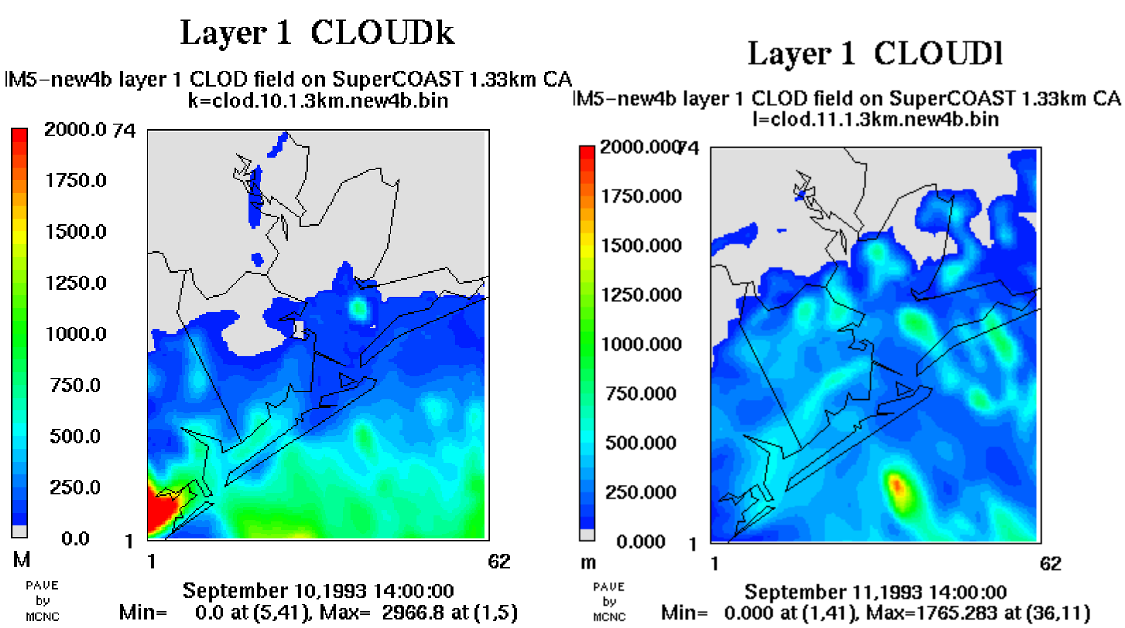


Figure 4-5. Cloud optical depths (dimensionless) in the 1.33-km domain at 14:00 on September 10th and 11th based on MM5 meteorology.

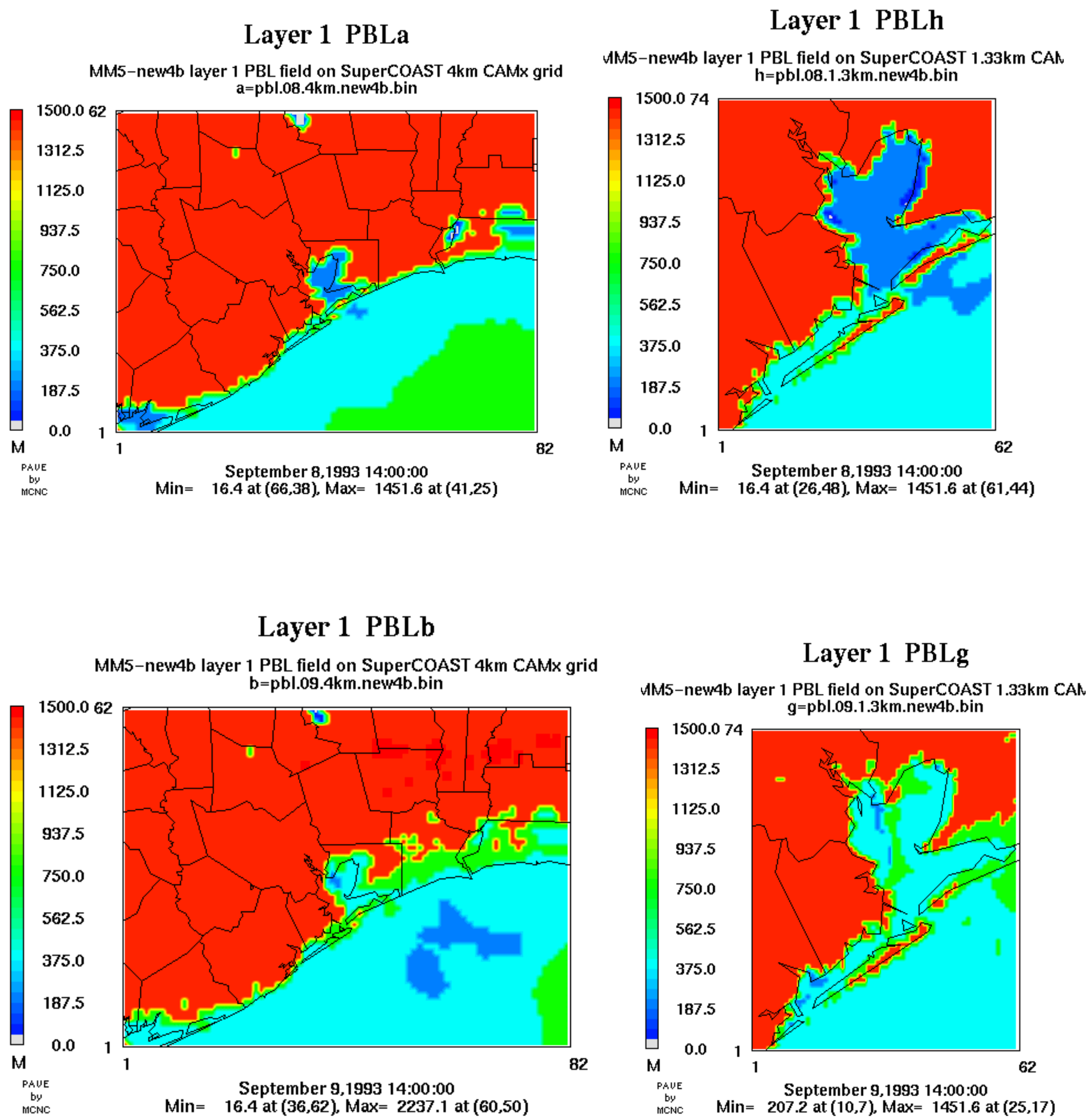


Figure 4-6. PBL heights (m) at 14:00 on September 8th and 9th within the 4-km and 1.33-km modeling domains based on MM5 meteorology.

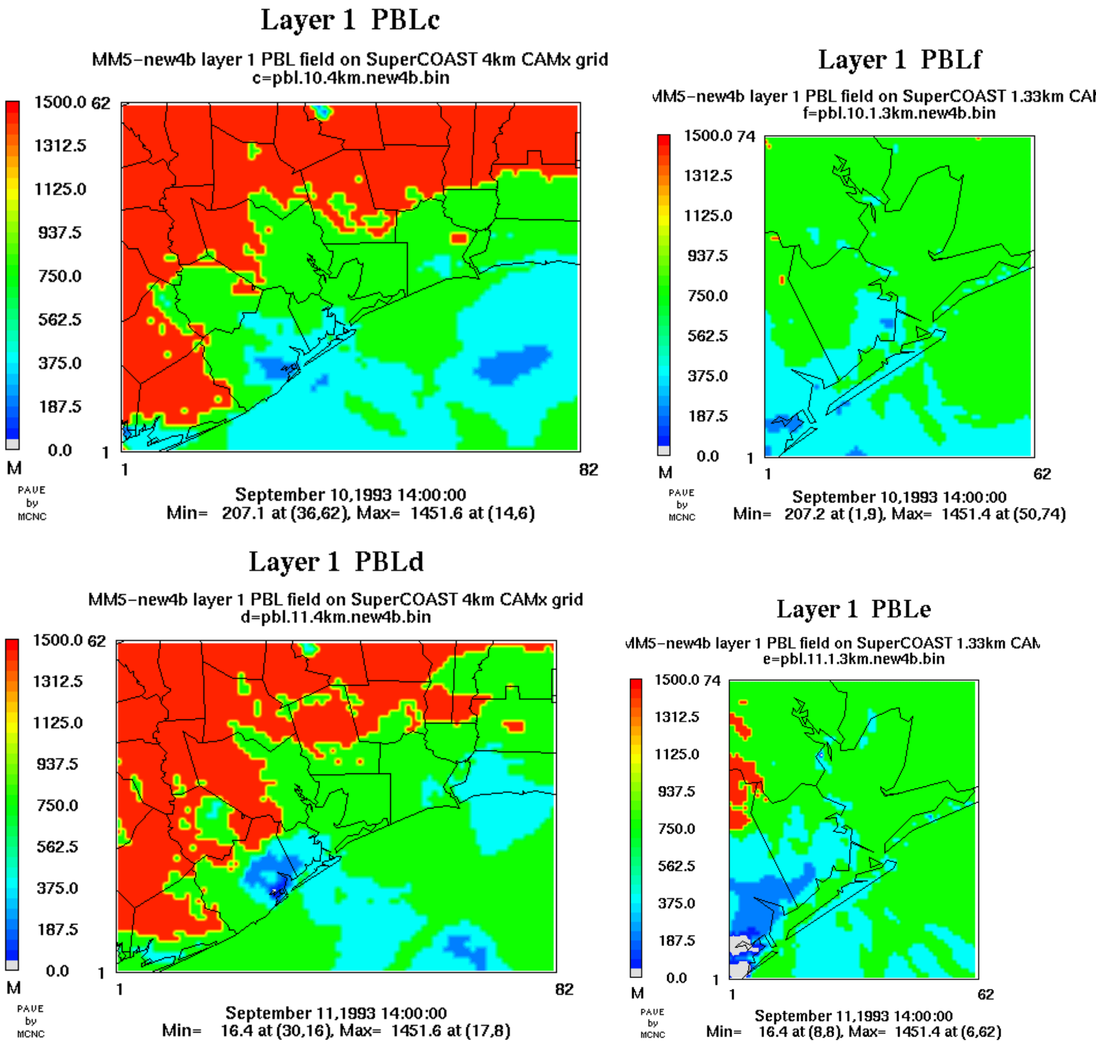


Figure 4-6 (continued). PBL heights (m) at 14:00 on September 8th and 9th within the 4-km and 1.33-km modeling domains based on MM5 meteorology.

In order to quantify the effect of increased VOC emissions on the modeled ozone concentrations an analysis was conducted to evaluate the potential for ozone production under each emission scenario. The analysis focused on the maximum rate of ozone production from hour to hour within the 1.33-km high-resolution nested grid domain. The peak rate of ozone production was defined as the maximum difference from hour to hour of the average ozone concentrations anywhere within the 1.33-km grid. The effects of enhanced VOC emission on the ozone production rate for each of the 1993 base year sensitivity simulations are presented in Table 4-2.

Table 4-2. Ozone production rates (ppb/hr) within the HGBPA domain with MM5 meteorology.

Scenario	Sept. 8, 1993	Sept. 9, 1993	Sept 10, 1993	Sept 11, 1993
Base Case	43.97	37.94	25.24	34.36
200ole.200voc	53.09	40.21	28.52	43.62
300ole.300voc	65.06	42.85	29.10	63.95
400ole.100voc	56.61	40.07	25.54	34.43
600ole.100voc	63.01	41.45	25.75	34.47
800ole.100voc	66.72	42.71	25.96	34.51
1000ole.100voc	67.88	43.86	26.17	-

The results of the 2xVOC/2xOLE alternative emission scenario are presented in Figure 4-6 which displays the daily maximum 1-hour ozone concentrations in the 4-km HGBPA domain for each day of the simulation. The results show spatial distributions of daily maximum ozone concentration similar to the base case although the magnitudes are somewhat higher. The spatial distributions of daily maximum ozone concentrations for the 3xVOC/3xOLE scenario are displayed in Figure 4-7. As in the base case, the 10th and 11th of September shows extremely low ozone concentrations and therefore these two simulations days were dropped from further analysis.

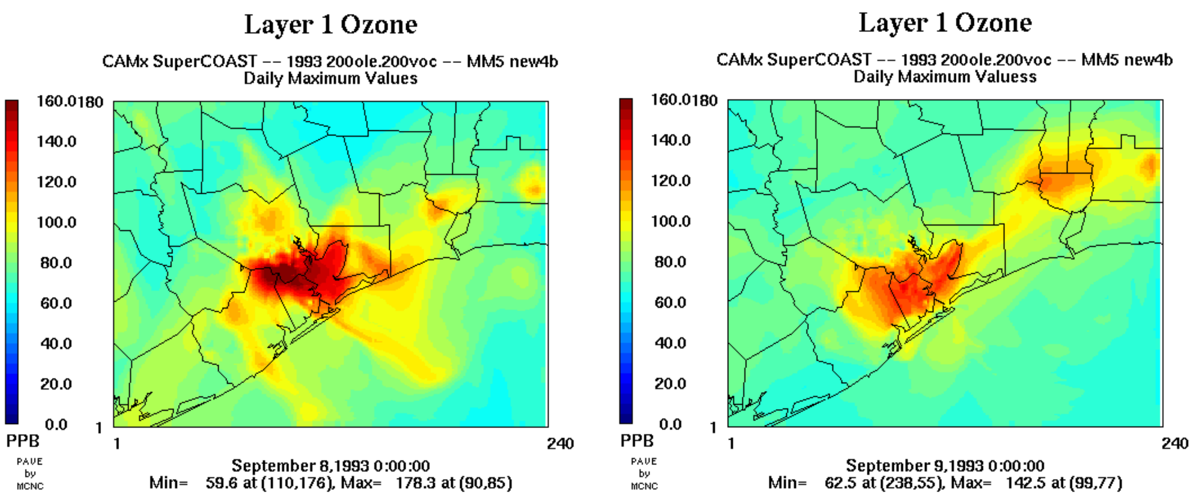


Figure 4-7. Daily maximum ozone concentrations for 1993 200ole.200voc scenario.

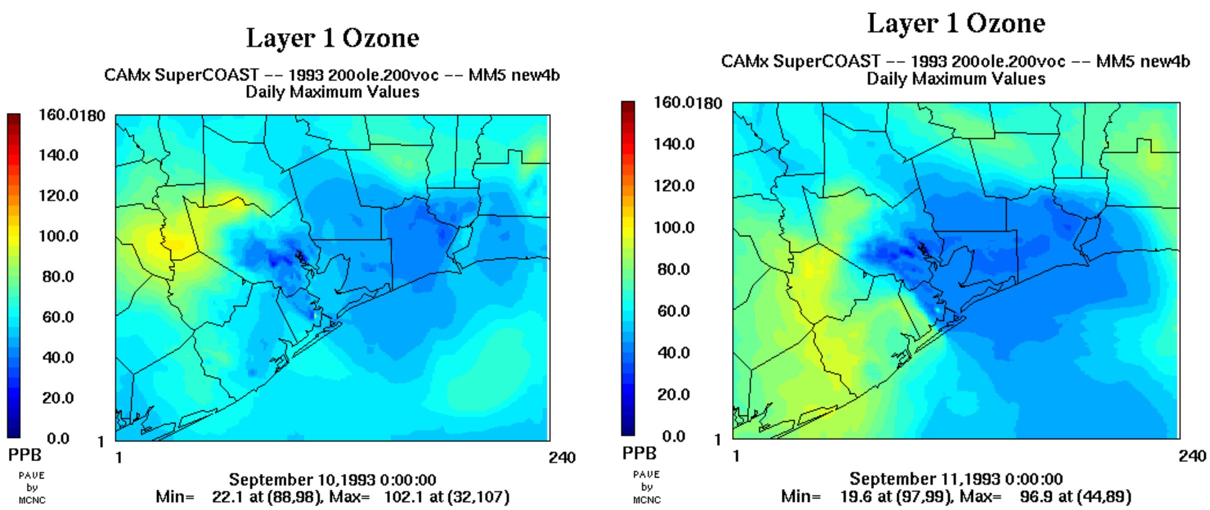


Figure 4-7 (continued). Daily maximum ozone concentrations for 1993 200ole.200voc scenario.

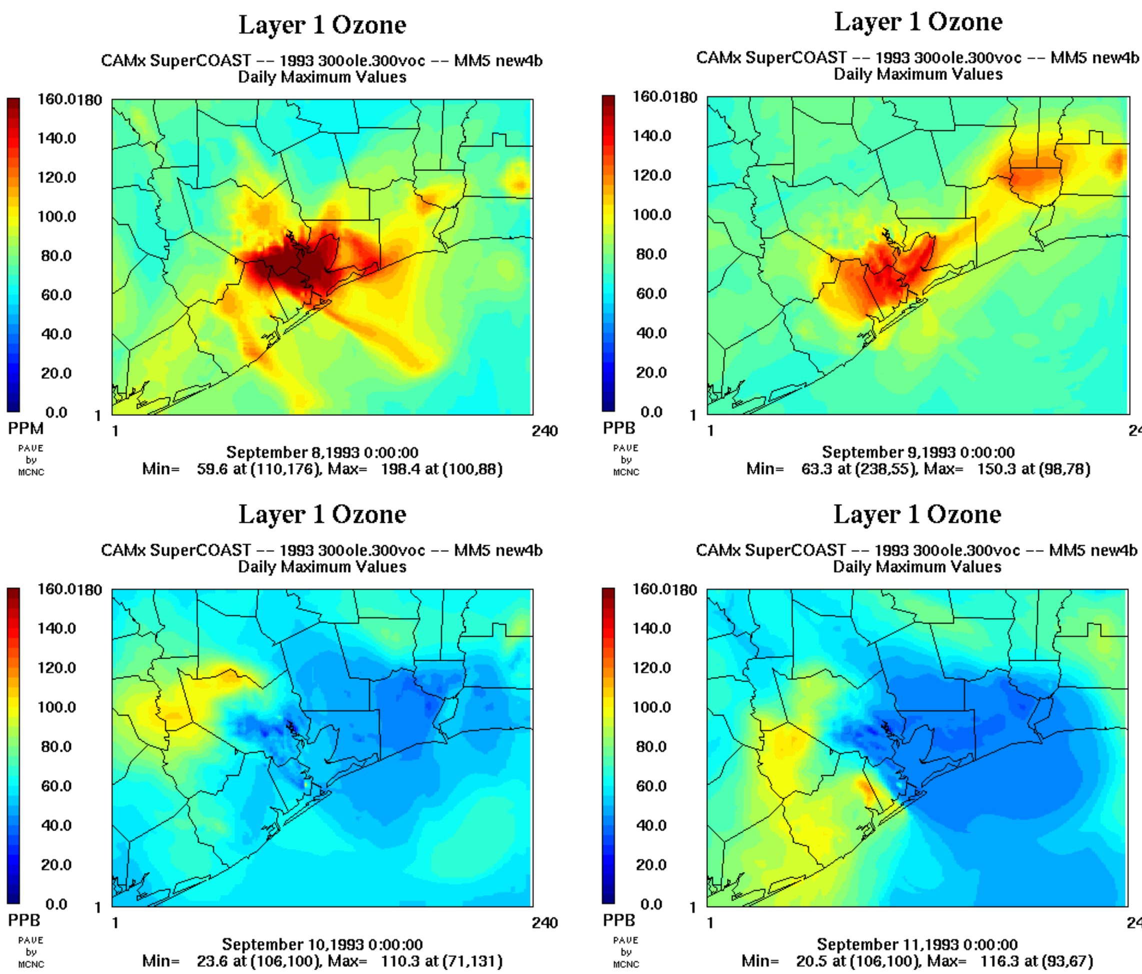
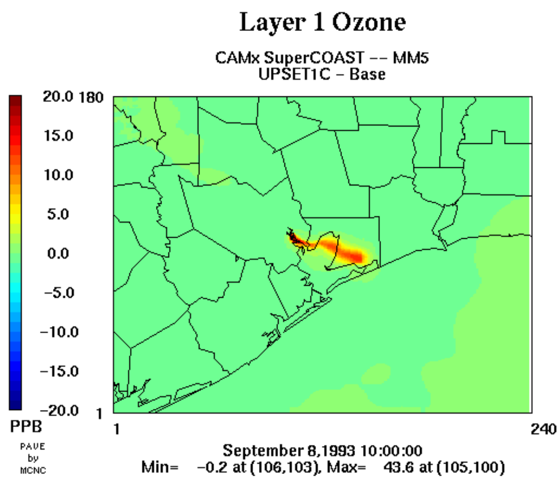
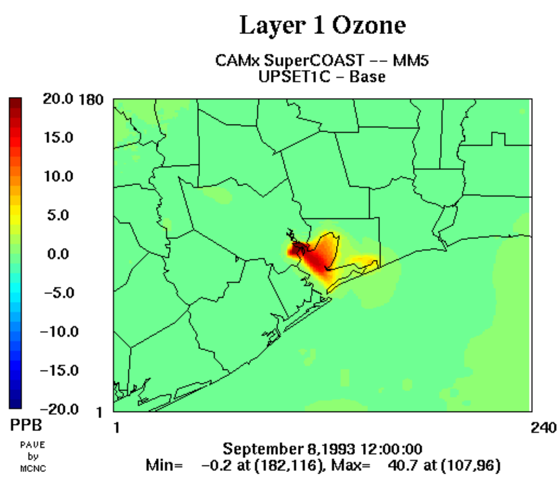


Figure 4-8. Daily maximum ozone concentrations for 1993 300ole.300voc scenario.

The effect of episodic VOC emission increases on the model performance were also investigated and are displayed in Figure 4-9. Displayed are the difference in simulated ozone concentrations between the UPSET1C scenario and the base case at 10:00 am, 12 noon and 2:00 pm on September 8, 1993. Figure 4-10 displays the difference in daily peak ozone concentrations. The impact on the daily peak ozone is seen to be a considerable increase (~24 ppb) highly localized around the ship channel in the area of the emission release. The effects at Seabrook and Smith Point are illustrated in the difference isopleths in Figure 4-9, as well as in Figure 4-11, which displays time series for these two monitor locations. These results illustrate the capability of the CAMx model and associated databases to provide plausible ozone increases due to episodic, or non-routine, emission releases within the Houston-Galveston Bay area. Comparing with the corresponding results with the SAIMM meteorology shows considerable differences. In the case of SAIMM meteorology, the ozone plume from the upset release point extends directly out across Galveston Bay, impacting both Seabrook and Smith Point. The MM5 meteorology results in a more diffuse plume extending slightly northeast of Galveston Bay with less impact at both Smith Point and Seabrook, and a more widespread impact throughout the Galveston Bay throughout the day.

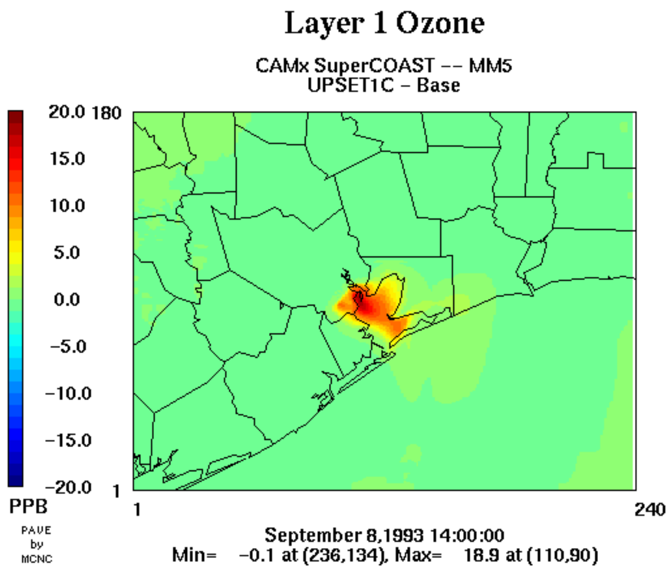


Ozone impacts at 10 am on 8 September 1993 due to UPSET1C scenario.



Ozone impacts at 12 noon on 8 September 1993 due to UPSET1C scenario.

Figure 4-9. Ozone impacts due to the UPSET1C episodic emission scenario.



Ozone impacts at 2 pm on 8 September 1993 due to UPSET1C scenario.

Figure 4-9 (continued). Ozone impacts due to the UPSET1C episodic emission scenario.

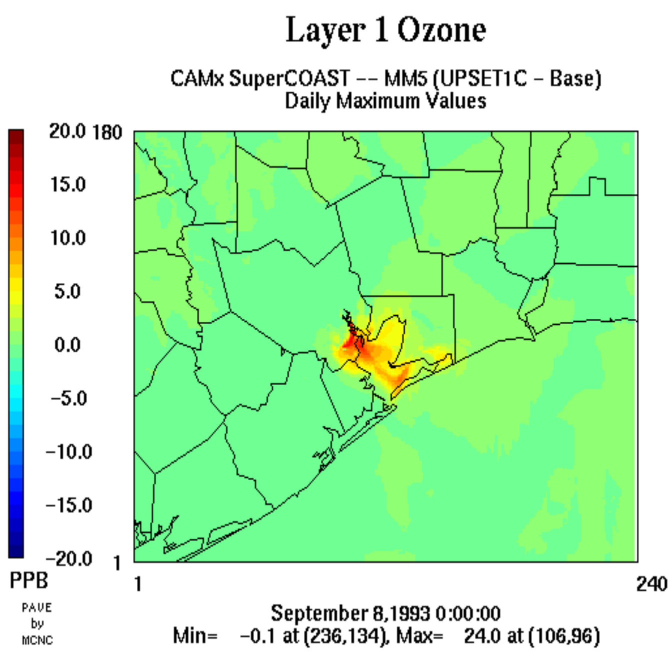


Figure 4-10. Daily maximum ozone impacts due to the UPSET1C episodic emission scenario.

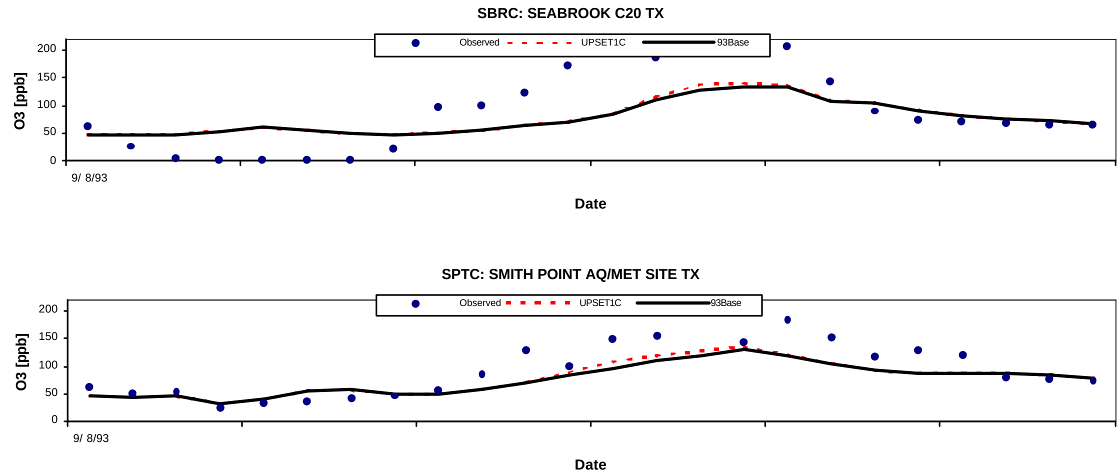


Figure 4-11. Times series plot for Seabrook and Smith Point; Base case (solid line) and UPSET1C (dashed line).

Finally, a series of emission enhancement scenarios were run with increases in industrial olefins alone, at a variety of increased emission levels. The results are presented in Figure 4-12 through Figure 4-15 which display the daily maximum 1-hour ozone concentrations for each emission scenario. The resulting model performance statistics were presented in Table 4-1.

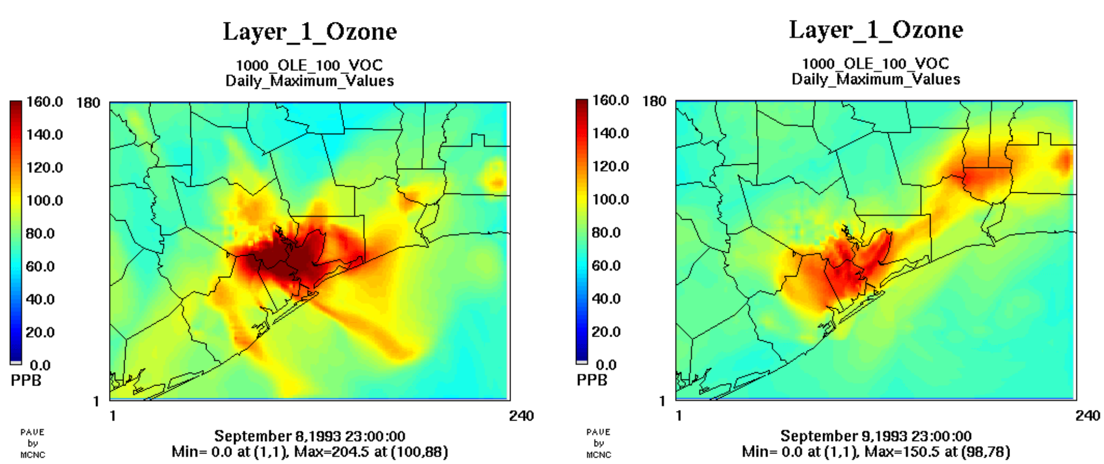


Figure 4-12. Daily maximum ozone concentrations for 1993 1000ole.100voc scenario.

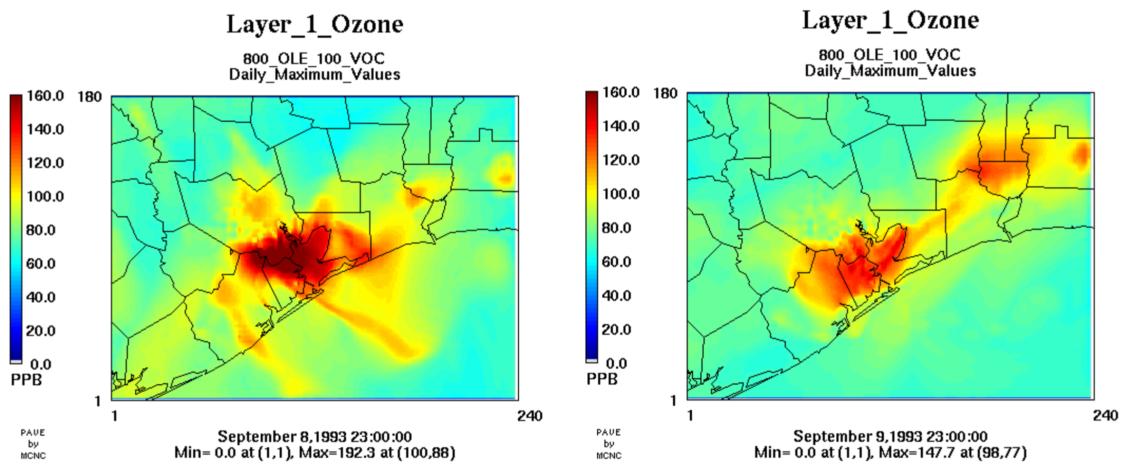


Figure 4-13. Daily maximum ozone concentrations for 1993 800ole.100voc scenario.

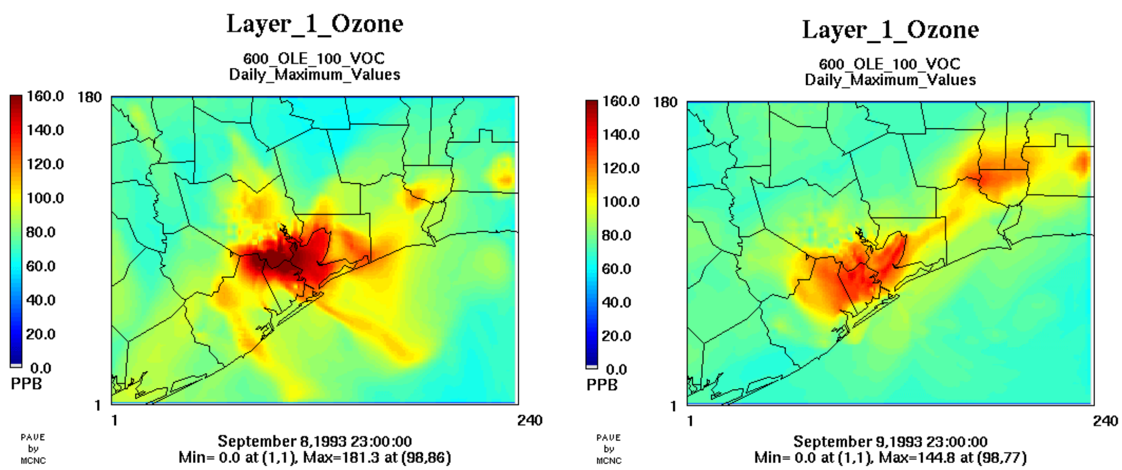


Figure 4-14. Daily maximum ozone concentrations for 1993 600ole.100voc scenario.

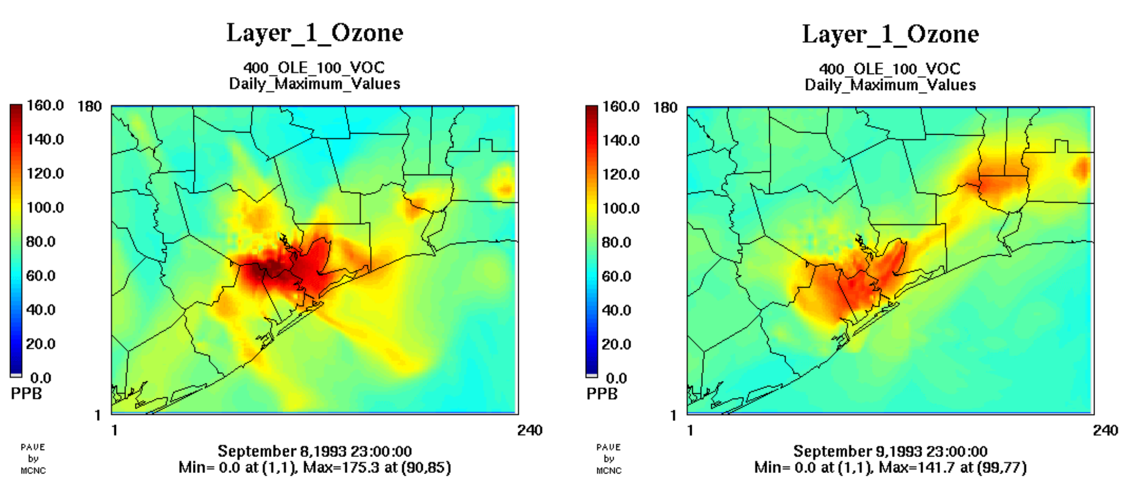


Figure 4-15. Daily maximum ozone concentrations for 1993 400ole.100voc scenario.

5. FUTURE YEAR MODELING RESULTS

2007 FUTURE YEAR SCENARIOS

Each of the emission scenarios developed for future year 2007were simulated using version 3.01 of the CAMx air quality model and the model domain and configuration described in Section 2. The modeling results were examined and evaluated with respect to the spatial distribution of simulated daily maximum 1-hour ozone concentrations and the impacts of each emission scenario on the daily maximum 1-hour ozone concentrations. The modeling results were also investigated to determine the necessary level of industrial olefin emission reductions required to compensate for industrial NOx emission reductions.

Figure 5-1 displays the spatial distribution of daily maximum 1-hour ozone for the 2007 Strategy I8a scenario within the HGBPA 4-km modeling grid. Based on the results of the 1993 base year alternative emission scenarios, the 6xOLE and 10xOLE scenarios were chosen for further analysis in the 2007 future year airquality simulations. Figure 5-2 and Figure 5-3 display the spatial distribution of daily maximum 1-hour ozone concentrations for the 6xOLE and 10xOLE scenarios, respectively. In both of these scenarios, shipping emissions and new sources not subject to future year controls were taken into consideration as described in Section 3. In addition, emission adjustments were confined to the 8-county Houston-Galveston area. The daily peak 1-hour ozone concentrations in the 4-km HGBPA domain for all future year emission scenarios are presented in Table 5-1. As noted in Section 4, due to the poor model performance obtained for the September 10th and 11th episode days, the future year modeling analyses are presented only for the 8th and 9th of September.

Table 5-1. Daily maximum ozone concentrations (ppb) for preliminary future year 2007 scenarios.

Scenario Name	Sept. 8	Sept. 9
i8a base	124.8	106.1
i8a 200ole.200voc	126.8	107.7
i8a 600ole.100voc	127.3	108.2
i8a 1000ole.100voc	134.4	109.6
80nox.1000ole	144.6	115.8
80nox.800ole	139.9	113.3
80nox.600ole	135.6	112.4
80nox.500ole	133.3	111.9
80nox.400ole	130.7	111.5
80nox.300ole	129.4	110.9
80nox.200ole	128.6	110.5
80nox.100ole	127.7	109.9
80nox.00ole	126.8	109.4
85nox.1000ole	140.5	113.1
85nox.800ole	136.2	111.3
85nox.600ole	131.7	110.5
85nox.500ole	129.7	110.1
85nox.400ole	128.3	109.6
85nox.300ole	127.5	109.2
85nox.200ole	126.8	108.7
85nox.100ole	126.2	108.2
85nox.00ole	125.6	107.7

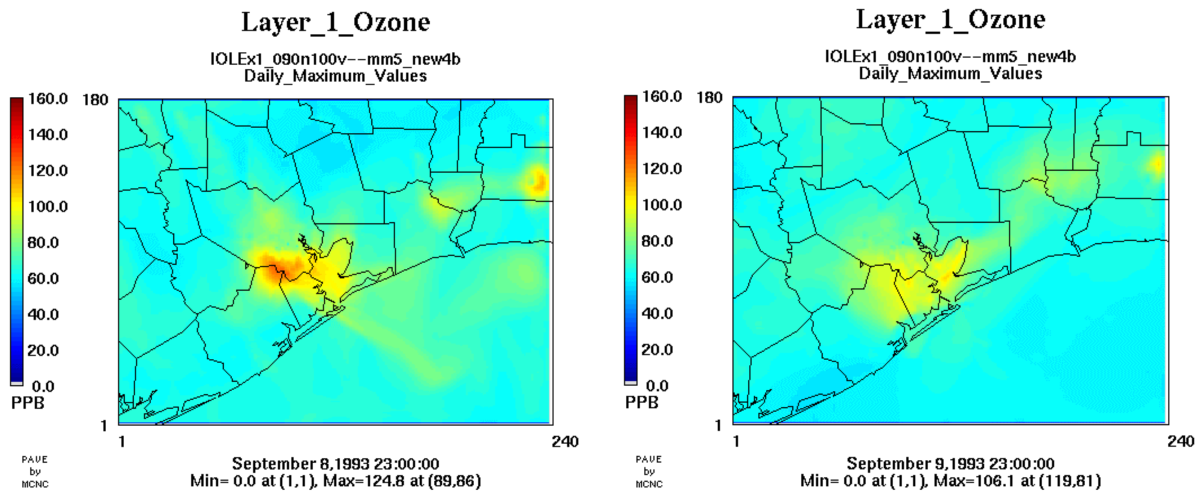


Figure 5-1. Daily maximum 1-hour ozone concentrations for the 2007 future year base case with MM5 meteorology.

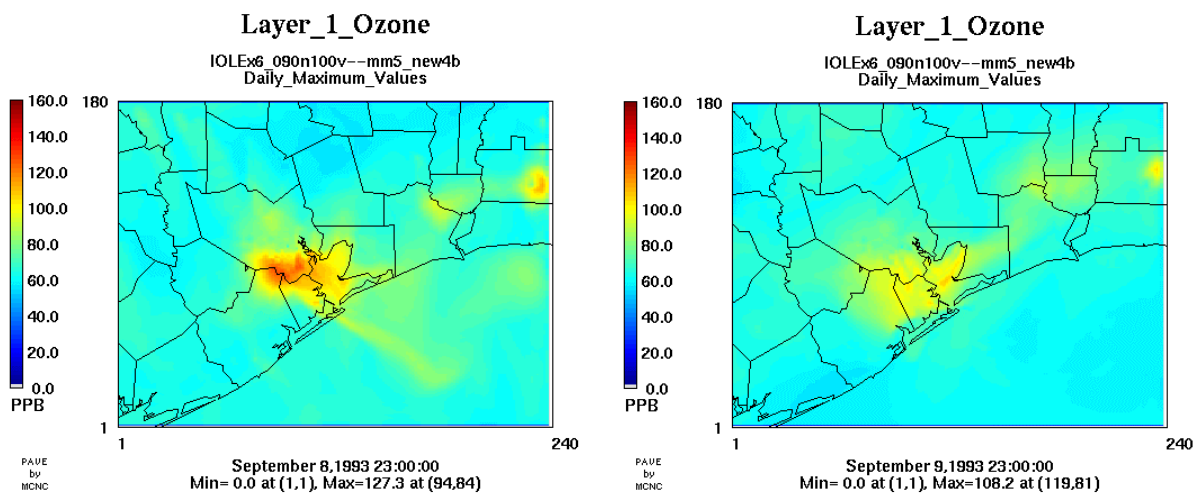


Figure 5-2. Daily maximum 1-hour ozone concentrations for the 2007 future year 6xOLE emission scenario with MM5 meteorology.

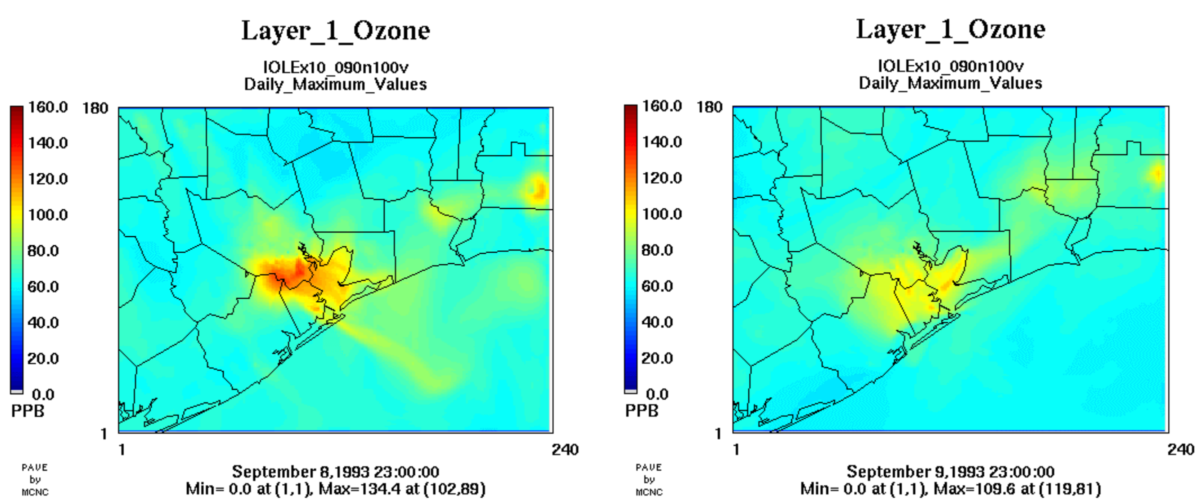


Figure 5-3. Daily maximum 1-hour ozone concentrations for the 2007 future year 10xOLE emission scenario with MM5 meteorology.

A comparison of the 2007 I8a Strategy simulation results obtained with the MM5 meteorology with the corresponding results obtained using the SAIMM meteorology reveals somewhat similar spatial distributions of daily maximum 1-hour ozone concentrations although the magnitude of elevated ozone concentrations is considerably lower using the MM5 meteorology. In addition, the large region of elevated ozone concentrations offshore obtained with the SAIMM fields is not as evident in the case of MM5 meteorology. The results of the 6xOLE and 10xOLE are consistent with expectations showing similar spatial distribution patterns with higher peak ozone concentrations.

Strategy I8a includes 90% reductions in industrial NOx emissions from the 2007 base case levels. There is interest in determining whether less stringent NOx reductions (80% or 85%) could be compensated by greater reductions in 2007 industrial VOC emissions. Thus, a series of emission scenarios were conducted beginning with the 6xOLE emission level at 80% and 85% reduced NOx emission levels from the 2007 Strategy I8a scenario. After increasing the industrial NOx emission from the 2007 Strategy I8a levels, the olefin emissions were incrementally decreased to determine a compensation level of emissions required to obtain equivalent results as the 2007 Strategy I8a. A similar series of emission scenarios beginning with the 10xOLE emission levels was also conducted. The spatial distribution of daily maximum 1-hour ozone concentrations and corresponding spatial differences in daily maximum 1-hour ozone concentrations for selected olefin emission levels are displayed in Figure 5-4 through Figure 5-10 for the 80% industrial NOx emission levels. Figures 5-11 through Figure 5-16 display the corresponding results at the 85% industrial NOx reduction level. The full set of simulation results for both emission reduction series are presented in Appendix A for completeness. Due to the poor model performance on the 10th and 11th of September using the MM5 meteorological fields, only the September 8th and 9th episode days have been included in the present analysis.

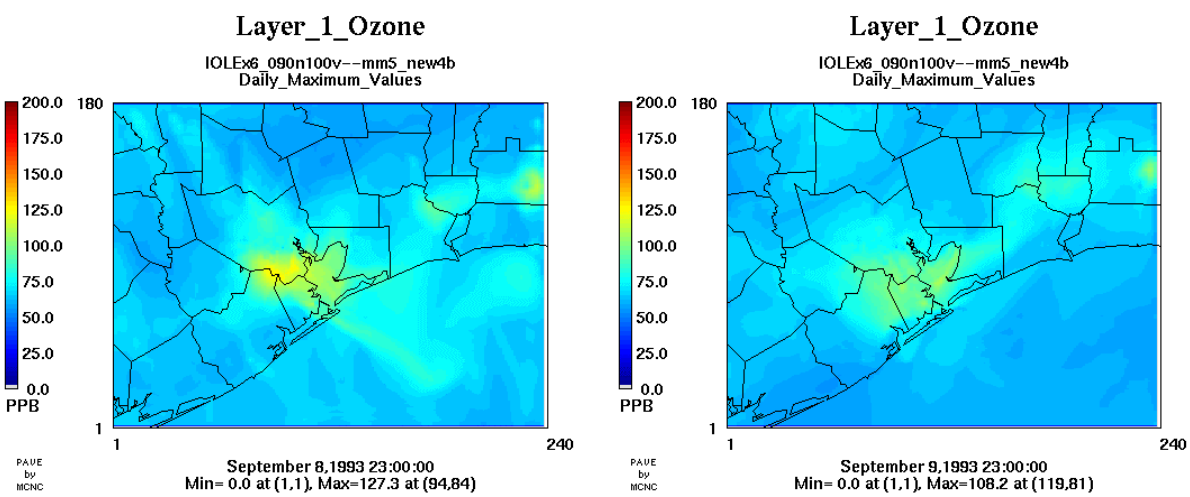


Figure 5-4. Daily maximum ozone concentrations for future year 2007 at 6x industrial olefins and Strategy I8a NOx emission levels.

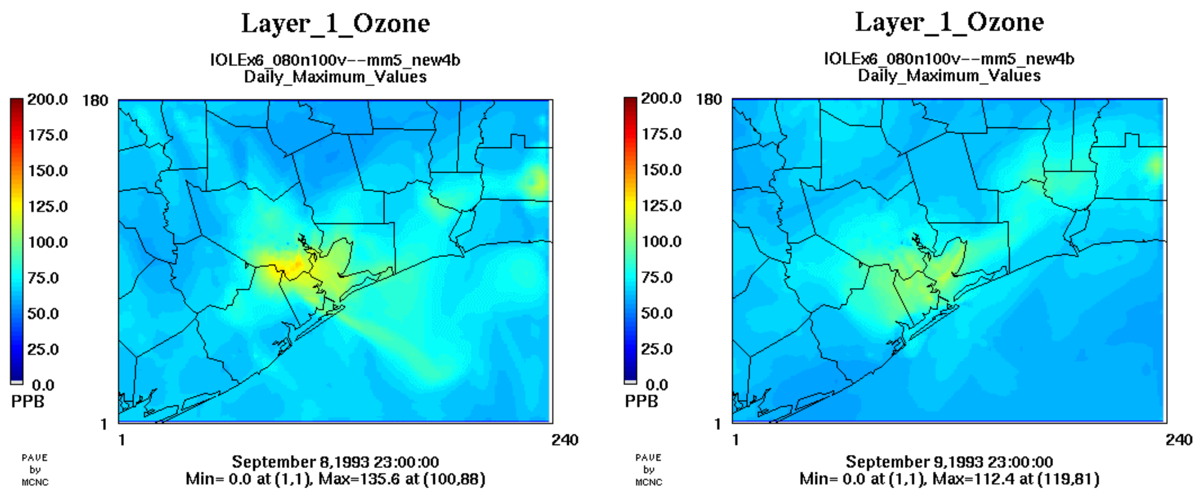


Figure 5-5. Daily maximum ozone concentrations for future year 2007 at 6x industrial olefins and double Strategy I8a NOx emission levels (80% reduction).

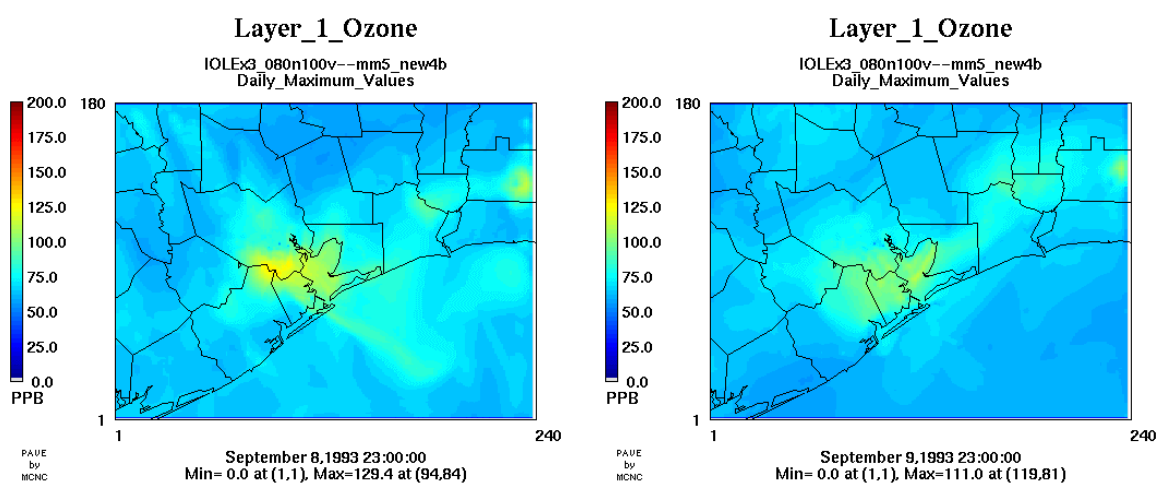


Figure 5-6. Daily maximum ozone concentrations for future year 2007 at 3x industrial olefins and double Strategy I8a NOx emission levels (80% reduction).

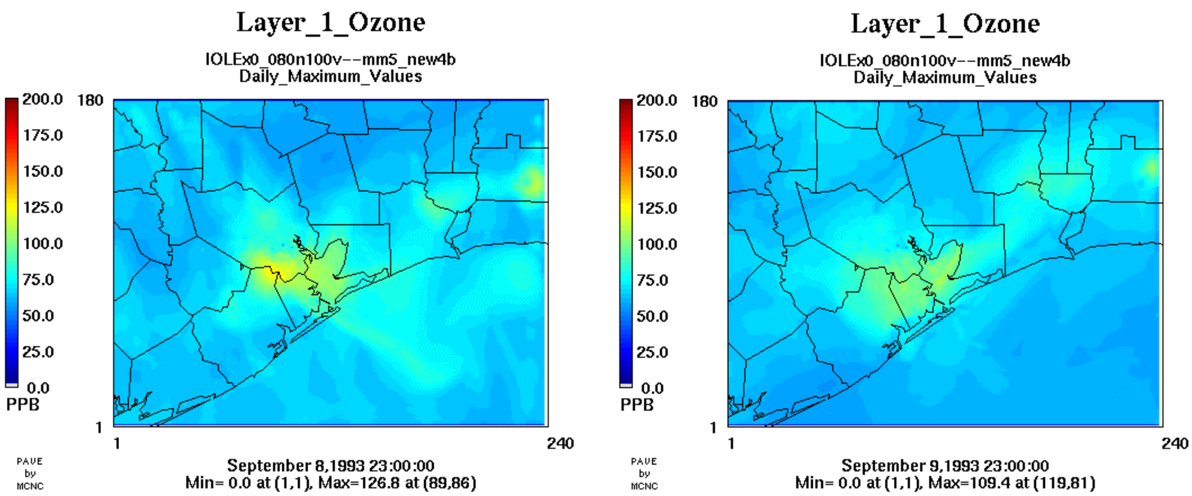


Figure 5-7. Daily maximum ozone concentrations for future year 2007 with zero industrial olefin emissions and double Strategy I8a NOx emission levels (80% reduction).

Figure 5-8 illustrates the effects of "doubled" industrial NOx emissions (i.e., 80% reduction from base levels) on the 2007 future year simulation results with 6xOLE emissions levels. Increasing NOx emissions within the 8-county region result in increased ozone concentrations throughout the Houston/Galveston Bay area and extending offshore on the 8th of September. The results for the 9th of September display more localized ozone increases primarily within the ship channel area. Small localized ozone decreases are also evident. The effects of "doubled" industrial NOx and a 50% decrease in industrial olefin emissions are displayed in Figure 5-9. On both the September 8th and 9th episode days, localized ozone decreases are realized while broad regions of ozone increases are still present. The greatest reduction in ozone concentrations under this scenario amounts to approximately 13 ppb and 16 ppb on September 8th and 9th, respectively. Figure 5-10 illustrates the effect of doubled industrial NOx and 100% reduction in industrial olefin emissions. This case represents the maximum potential ozone reductions achievable for this alternative emission scenario. Results for the 85% industrial NOx emission reduction level are similar with respect to the spatial distributions although the magnitude of possible ozone reductions is slightly larger.

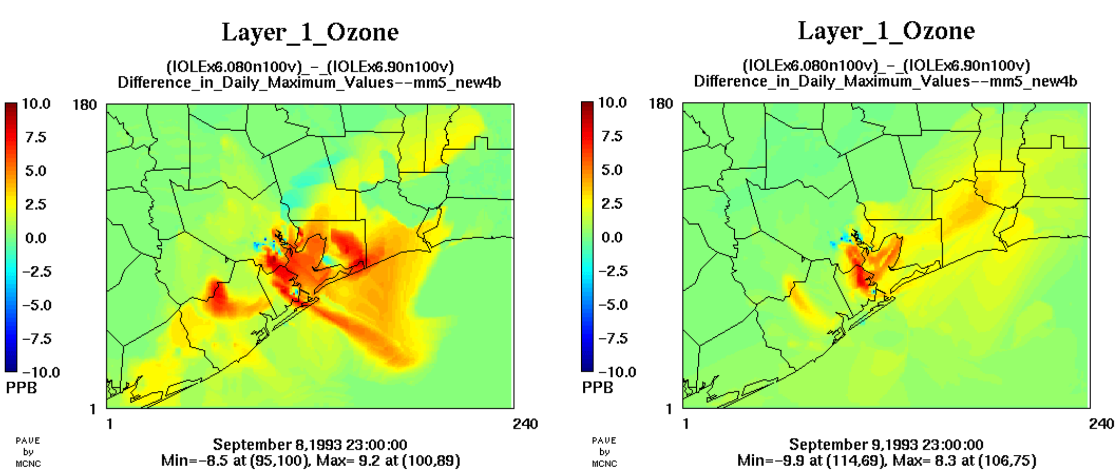


Figure 5-8. Effects of doubled industrial NOx emissions on daily maximum ozone concentrations for future year 2007.

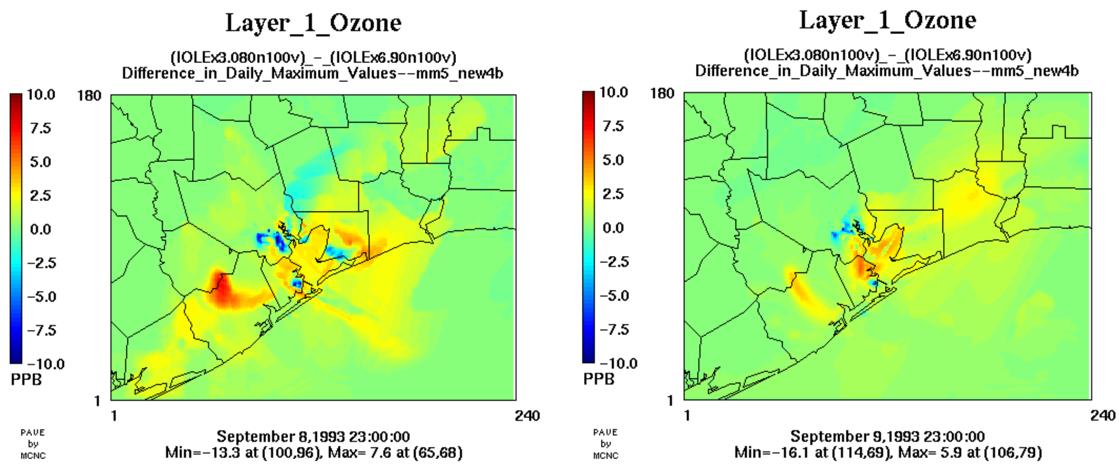


Figure 5-9. Effects of doubled industrial NOx emissions and 50% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

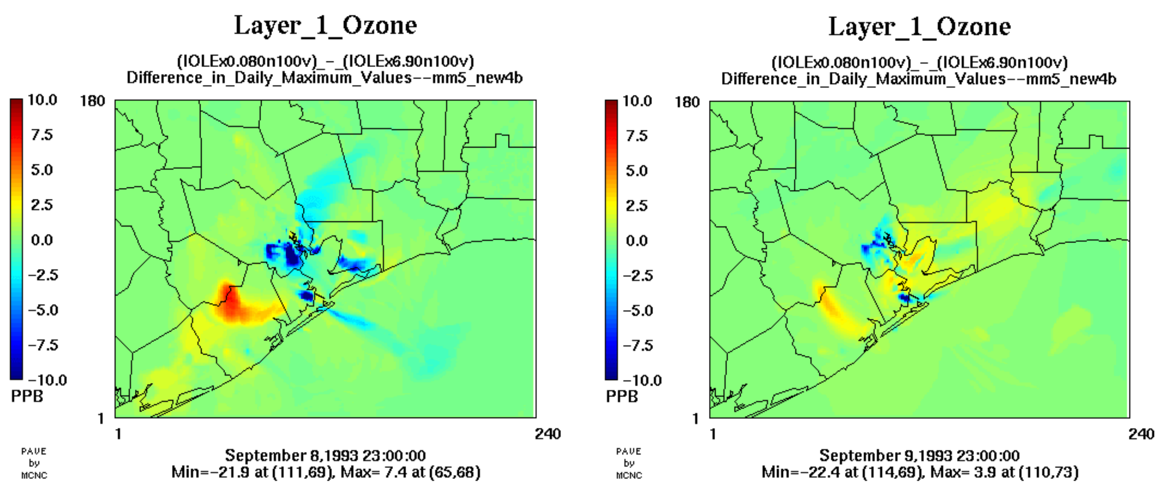


Figure 5-10. Maximum potential ozone reductions from the doubled Strategy i8a NOx emission levels (80% reduction) resulting from 100% reduction of industrial olefin emissions.

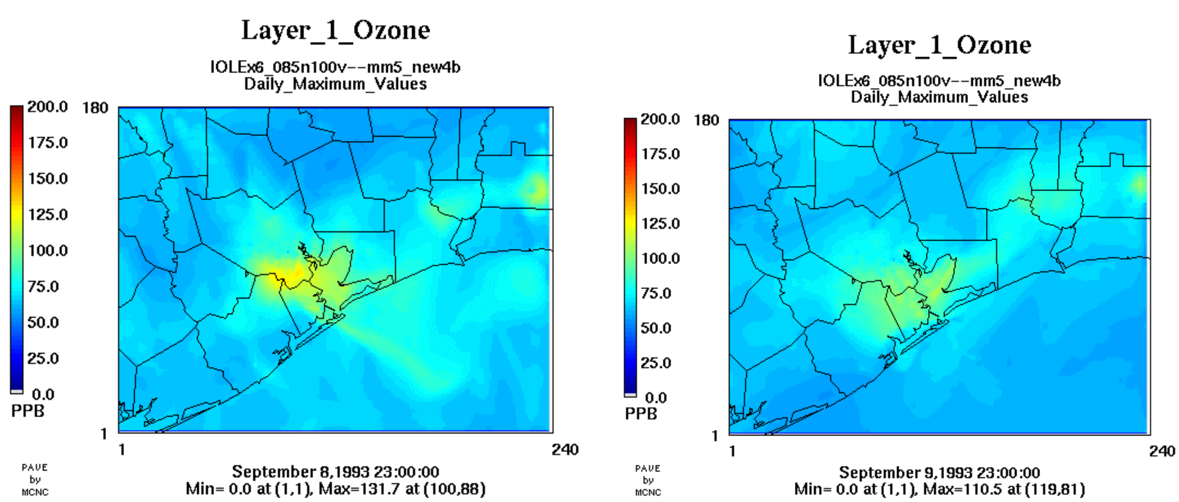


Figure 5-11. Daily maximum ozone concentrations for future year 2007 at 6x industrial olefins and 150% Strategy I8a NOx emission levels (85% reduction).

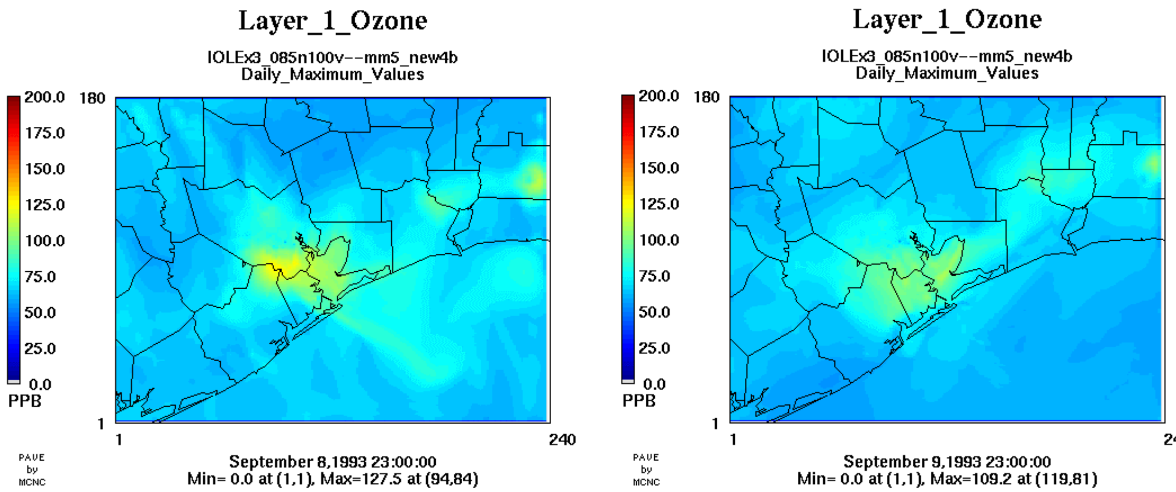


Figure 5-12. Daily maximum ozone concentrations for future year 2007 at 3x industrial olefins and 150% Strategy I8a NOx emission levels (85% reduction).

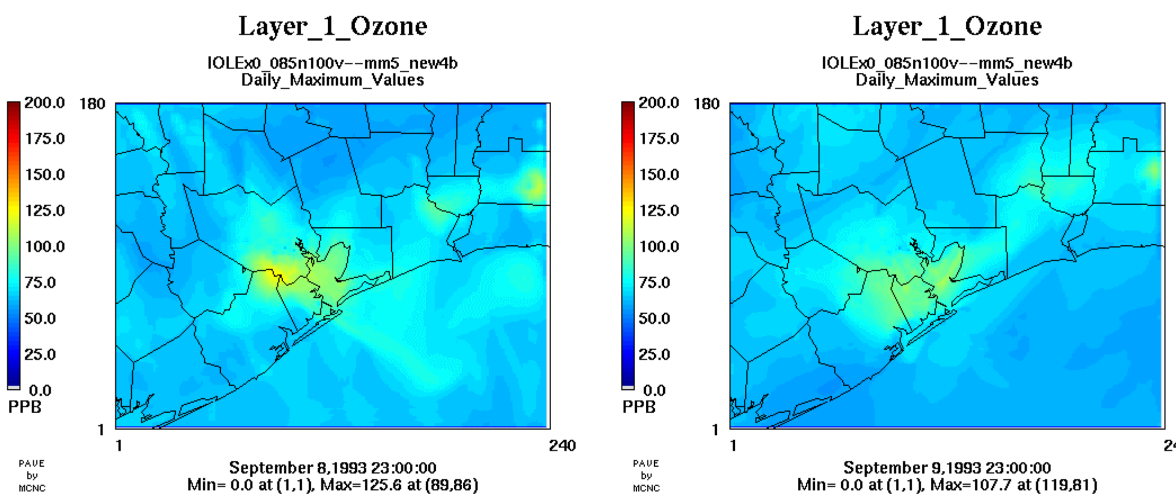


Figure 5-13. Daily maximum ozone concentrations for future year 2007 with zero industrial olefin emissions and 150% Strategy I8a NOx emission levels (85% reduction).

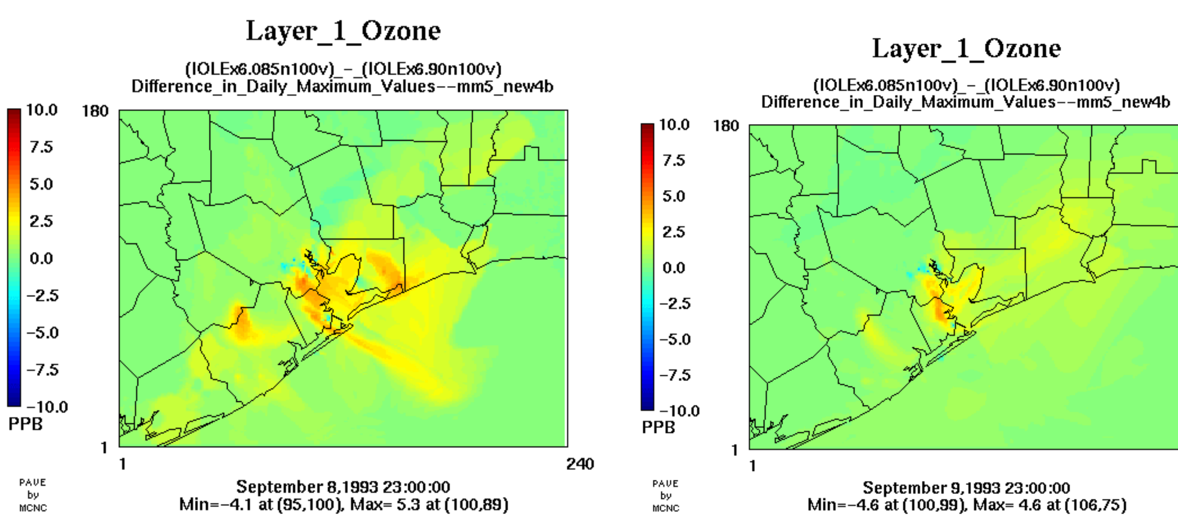


Figure 5-14. Effects of 150% industrial NOx emissions on daily maximum ozone concentrations for future year 2007.

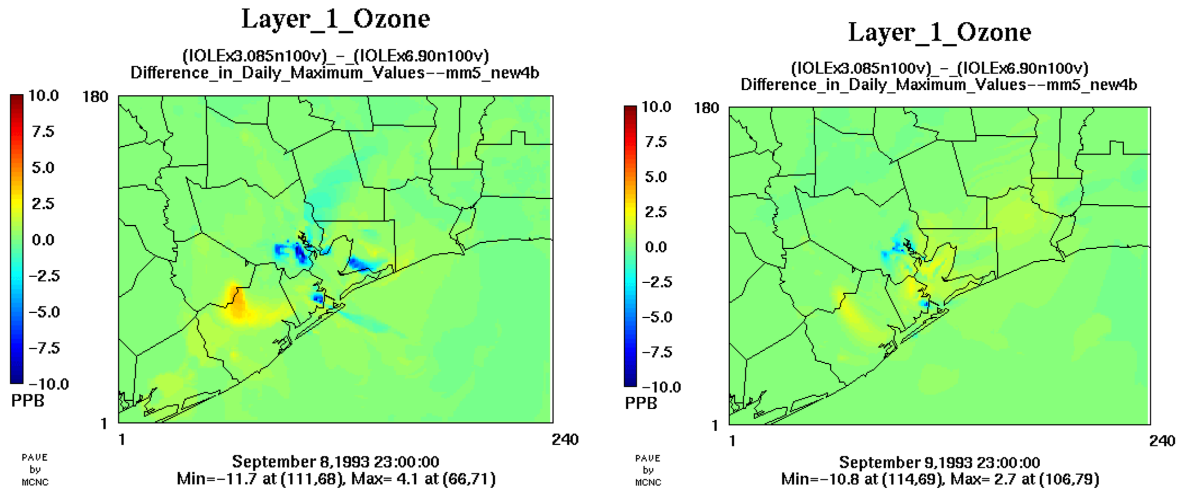


Figure 5-15. Effects of 150% industrial NOx emissions and 50% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

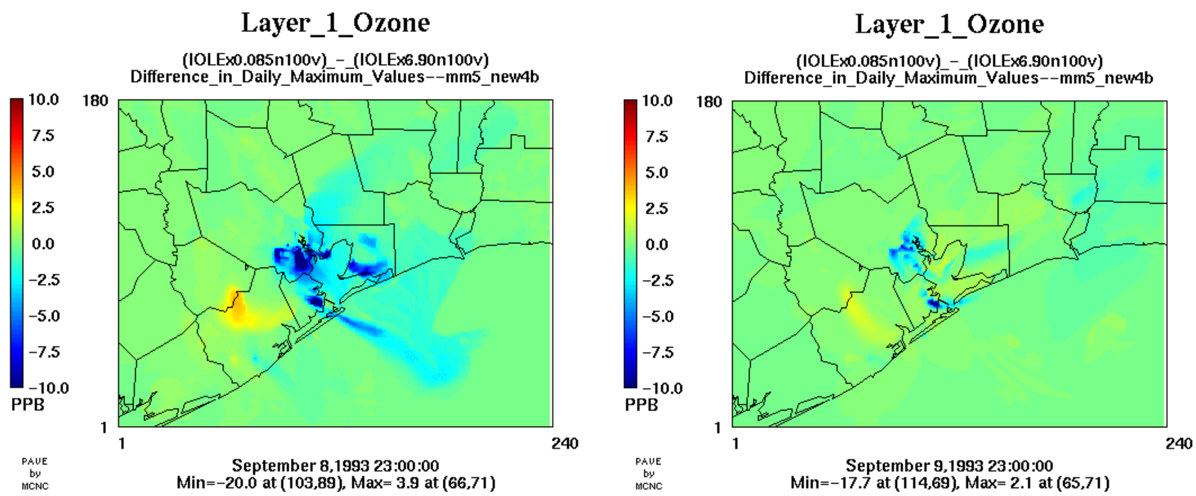


Figure 5-16. Maximum potential ozone reductions from the 150% Strategy i8a NOx emission levels (85% reduction) resulting from 100% reduction of industrial olefin emissions.

Tables 5-2 and 5-3 present a quantitative analysis of the sensitivity scenarios investigated in this study. In Tables 5-2 and 5-3 the 90nox.600ole simulation represents the peak ozone concentration value which must be matched through reductions in industrial olefin (IOLE) emission levels. The 80nox.600ole simulation values provide the starting point for olefin emission reductions. The highlighted values in the Tables give the closest match obtained for the reduction scenarios considered. The necessary levels of olefin emission reductions required to compensate for industrial NOx emission reductions is seen to vary depending on the episode day. For example, on the September 8th episode day, doubling the industrial NOx emissions increases the peak ozone concentration in the 4-km HGBPA domain from 127.3 ppb to 135.6 ppb. Subsequent reduction of IOLE emission levels to zero brings the peak ozone level down to 126.8 ppb. At the 1xOLE emission level the peak on the 8th is approximately 127.1 ppb. Therefore, for this day, increased industrial NOx emission in the future year control case can be compensated for with an approximately 85% reduction in industrial olefin emissions. The analysis for the September 9th simulation day is similar, although for this day a 100% reduction in IOLE emission levels brings the ozone peak only to 109.4 ppb, slightly above the target value of 108.2 ppb.

Table 5-2. INOx/IOLE Equivalence at the 80% NOx emissions level

Date/ Time	90nox 6ole	80nox 6ole	80nox 5ole	80nox 4ole	80nox 3ole	80nox 2ole	80nox 1ole	80nox 0ole
9/8 Max	127.3	135.6	133.3	130.7	129.4	128.6	127.7	126.8
9/9 Max	108.2	112.4	111.9	111.5	110.9	110.5	109.9	109.4

Repeating the analysis for the 85% NOx emission level scenarios gives the following IOLE emission reductions necessary for each day: ~50% on September 8th; and ~85% on September 9th.

Table 5-3. INOx/IOLE Equivalence at the 85% NOx emissions level

Date/ Time	90nox 6ole	85nox 6ole	85nox 5ole	85nox 4ole	85nox 3ole	85nox 2ole	85nox 1ole	85nox 0ole
9/8 Max	127.3	131.7	129.7	128.3	127.5	126.8	126.2	125.6
9/9 Max	108.2	110.5	110.1	109.6	109.2	108.7	108.2	107.7

Figure 5-17 and 5-18 display these relations graphically and provide a means for interpolating the results to other industrial olefin emission reduction levels that lie between the levels modeled. These figures display the modeled peak ozone concentration as a function of the industrial olefin emission reduction levels for each day of the simulation. Also shown are the target peak ozone levels, i.e., the peak ozone concentrations resulting from the model simulations with 90% NOx emission reduction and 6xIOLE emissions. The intersection of the curves gives the required level of IOLE emission reductions to compensate for the increased industrial NOx emission reductions for each day of the episode. The response of the modeled ozone peaks due to industrial olefin emission reductions can be seen to depend on the episode day.

Similar results for the 10xOLE sensitivity analyses are presented in Tables 5-4 and Table 5-5 and Figures 5-19 and 5-20. As was the case for the 6xOLE series, the industrial olefin emission reductions required to compensate for the increased industrial NOx emissions varies for each day of the simulation.

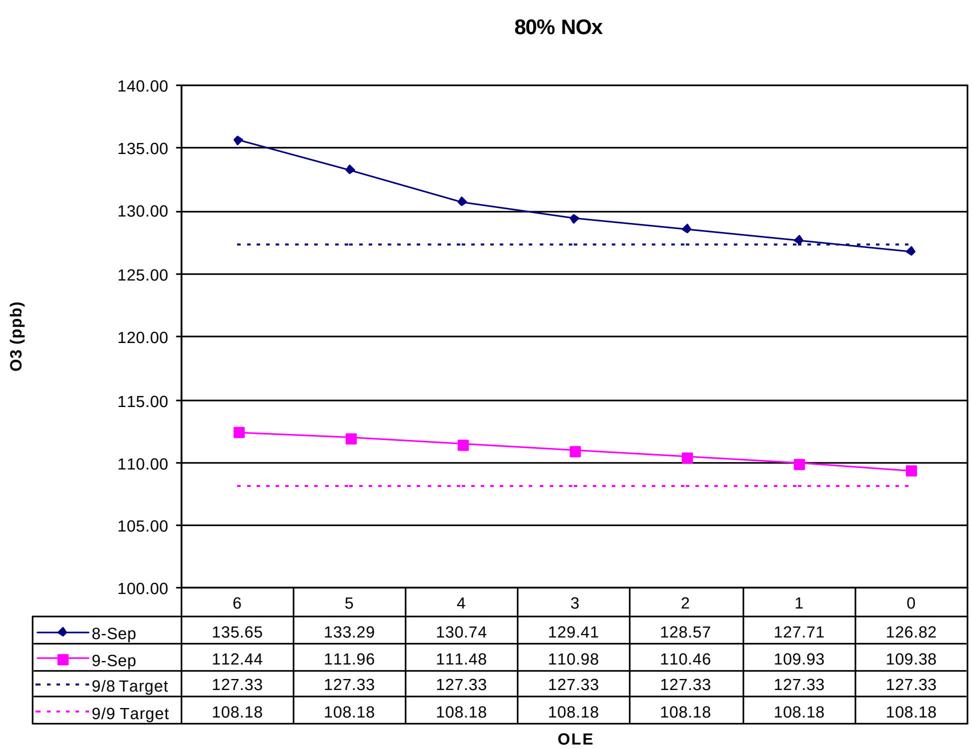
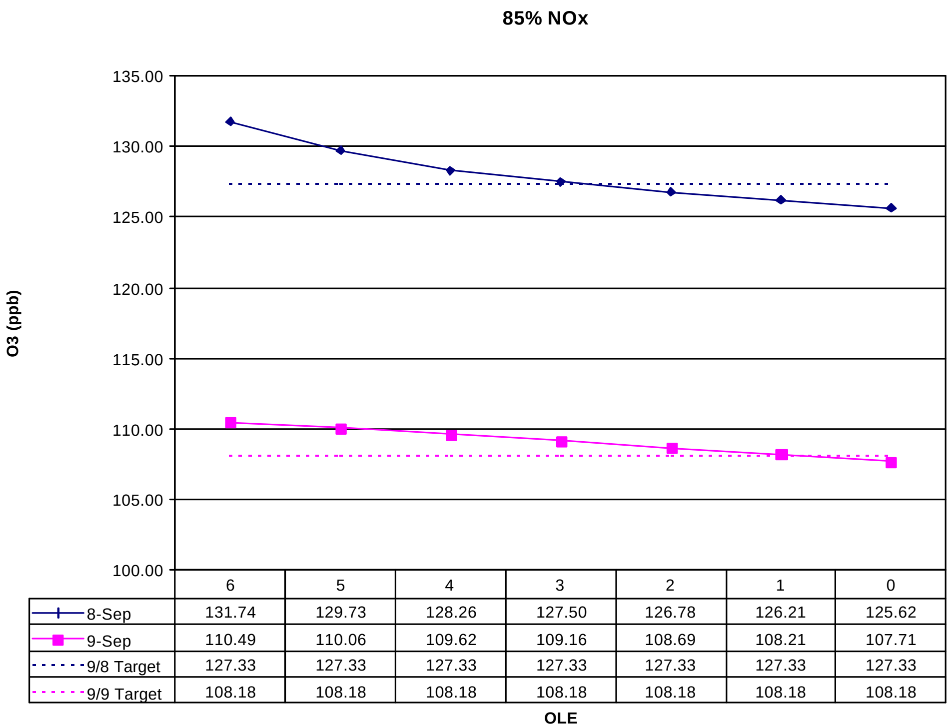


Figure 5-17. Graphical representation of INOx/IOLE equivalency for the 80% INOx series.



	6	5	4	3	2	1	0
8-Sep	131.74	129.73	128.26	127.50	126.78	126.21	125.62
9-Sep	110.49	110.06	109.62	109.16	108.69	108.21	107.71
9/8 Target	127.33	127.33	127.33	127.33	127.33	127.33	127.33
9/9 Target	108.18	108.18	108.18	108.18	108.18	108.18	108.18

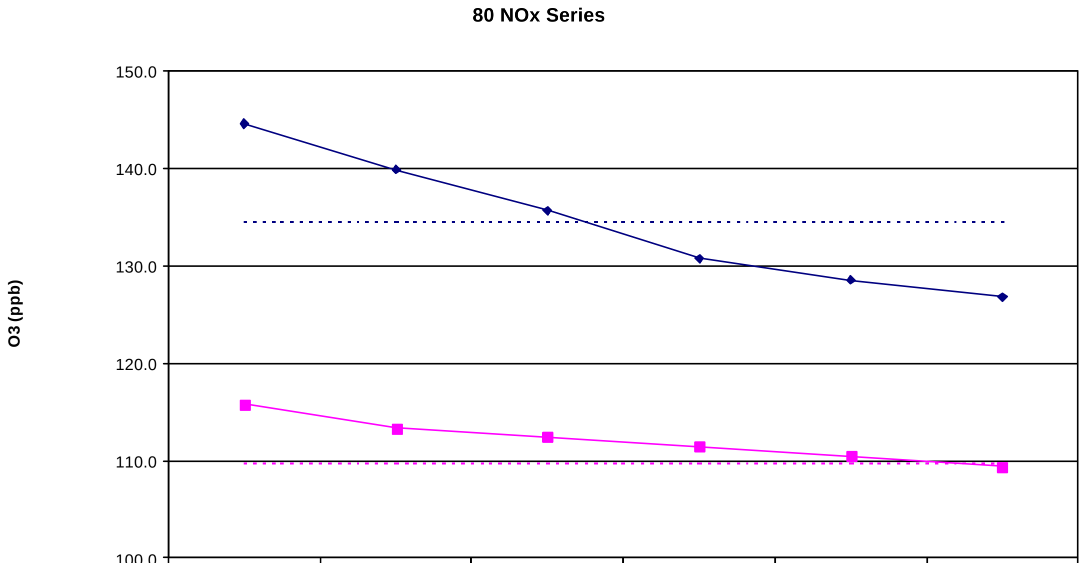
Figure 5-18. Graphical representation of INOx/IOLE equivalency for the 85% INOx series.

Table 5-4. INOx/IOLE Equivalence at the 80% NOx emissions level

Date/ Time	90nox 10ole	80nox 10ole	80nox 8ole	80nox 6ole	80nox 4ole	80nox 2ole	80nox 0ole
9/8 Max	134.4	144.6	139.9	135.6	130.7	128.6	126.8
9/9 Max	109.6	115.8	113.3	112.4	111.5	110.5	109.4

Table 5-5 INOx/IOLE Equivalence at the 85% NOx emissions level

Date/ Time	90nox 10ole	85nox 10ole	85nox 8ole	85nox 6ole	85nox 4ole	85nox 2ole	85nox 0ole
9/8 Max	134.4	140.5	136.2	131.7	128.3	126.8	125.6
9/9 Max	109.6	113.1	111.3	110.5	109.6	108.7	107.7



	10	8	6	4	2	0
8-Sep	144.58	139.87	135.65	130.74	128.57	126.82
9-Sep	115.77	113.34	112.44	111.48	110.46	109.38
9/8 Target	134.44	134.44	134.44	134.44	134.44	134.44
9/9 Target	109.63	109.63	109.63	109.63	109.63	109.63

Figure 5-19. Graphical representation of INOx/IOLE equivalency for the 10xOLE 85% INOx series
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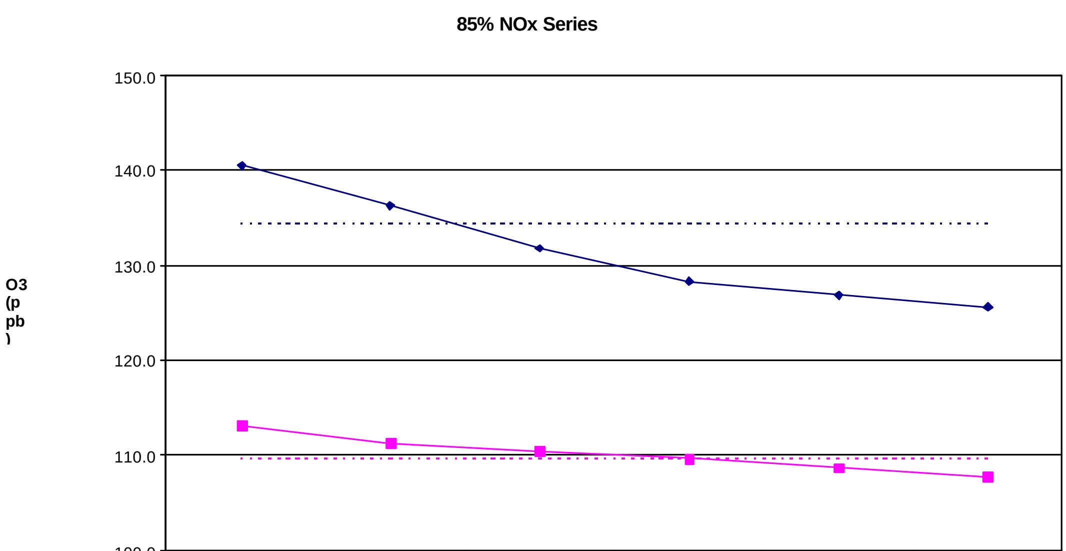

	10	8	6	4	2	0
8-Sep	140.47	136.19	131.74	128.26	126.78	125.62
9-Sep	113.12	111.31	110.49	109.62	108.69	107.71
9/8 Target	134.44	134.44	134.44	134.44	134.44	134.44
9/9 Target	109.63	109.63	109.63	109.63	109.63	109.63

Figure 5-20. Graphical representation of INOx/IOLE equivalency for the 10xOLE 85% INOx series.

6. SUMMARY

The CAMx air quality model was applied to the September 8-11, 1993 ozone episode on the SuperCOAST domain. High resolution MM5 meteorological fields developed by Tremback and Cram (2002) were used with version 3.01 of the CAMx model including chlorine chemistry. A high resolution 1.33-km nested modeling grid over the Houston Ship Channel and Galveston Bay was included. As documented previously (ENVIRON, 2002), this model version and configuration provided acceptable model performance. The response of the model to emission scenarios used by the TNRCC for control strategy evaluation was determined to be consistent with the response obtained using the same model version (2.03) and configuration as used in the development of the December 2000 SIP.

Emission sensitivity simulations were conducted to assess model performance under various alternative emission scenarios selected to reflect a more realistic estimate of VOC emission levels consistent with the 2000 TexAQS analysis. An episodic emission scenario was also developed to characterize the types of non-routine emission levels known to occur in the industrial areas around Houston and model simulations performed to assess the sensitivity of model performance to these emission adjustments.

Future year 2007 control simulations were conducted under various alternative industrial VOC emission scenarios. Industrial VOC emission adjustments were developed within an 8-county Houston-Galveston region with appropriate consideration given for sources not subject to future year controls. A series of future year emission scenarios were conducted to evaluate the potential of alternative VOC emission reductions to compensate for NOx emission reductions currently implemented in the future year 2007 Strategy i8a SIP simulations.

A number of summary conclusions can be drawn from the model simulations performed for this study:

- The MM5-based simulations included high resolution 1.33-km meteorology within the Galveston Bay area and thus no flexi-nesting features were required for the meteorology. However, the area source emissions data was still interpolated to the 1.33-km fine grid modeling domain.

- The resulting model performance was acceptable at many monitoring sites on the 8th and 9th of September, although there was a tendency to under-predict the highest ozone levels in the Galveston Bay area.

- Very poor model performance was achieved on the 10th and 11th on September primarily due to excessive cloudiness in the MM5 meteorology. These model performance problems were expected based on the MM5 performance evaluation for these episode days.

- Increasing olefin and/or VOC emission from industrial sources increased predicted ozone levels in the Galveston Bay area on September 8th and 9th, improving the model performance. Based on these ozone performance improvements, the 6xOLE and 10xOLE emission scenarios were selected for further analysis and evaluation.
- The hypothetical “upset scenario” was modeled by releasing olefin emission in the ship channel area. The resulting ozone increases within the ship channel area demonstrate that the modeling system is capable of producing locally elevated ozone levels in response episodic releases of reactive VOCs.

- An analysis of the alternative emission scenarios for the future year control case demonstrate the response of the modeling system to varying industrial NOx and VOC control strategies. Model response is shown to vary depending on the episode day. The potential for compensating NOx emission reductions with appropriate industrial olefin (IOLE) emission reductions has been shown to be theoretically possible for some episode days at the 80% NOx emission levels with varying IOLE emission reductions, albeit extremely large emission reductions in most cases. For the 85% NOx emission reduction levels, compensation potential again varies by day and compensating NOx emission reductions with IOLE emission reductions would be possible at a number of industrial olefin emission levels. In general, based on the results of the sensitivity simulations, increased NOx emissions results in broad regions of ozone concentration increases while reductions in industrial olefin emissions produce more localized ozone reductions.

Given the limitations inherent with the sensitivity modeling performed for this study, it would be advantageous to consider various refinements to the sensitivity simulations. Because the alternative emission scenarios have been developed based on model-ready data, the identification and adjustments for industrial sources were based on the assumption that all point source emission are due to industrial sources. While this may be true for the majority of sources, a more refined analysis based on raw inventory data is likely to provide a more realistic representation of the impacts due modeled ozone concentrations due to the various future year control strategies. In addition, the refinement of the olefin and VOC emission scenarios with respect to varying either pollutant independently or in combination with other industrial VOC emission components may provide additional insight to the results presented here.

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APPENDIX A

Simulation Results for the Future Year
Alternative Emission Scenarios

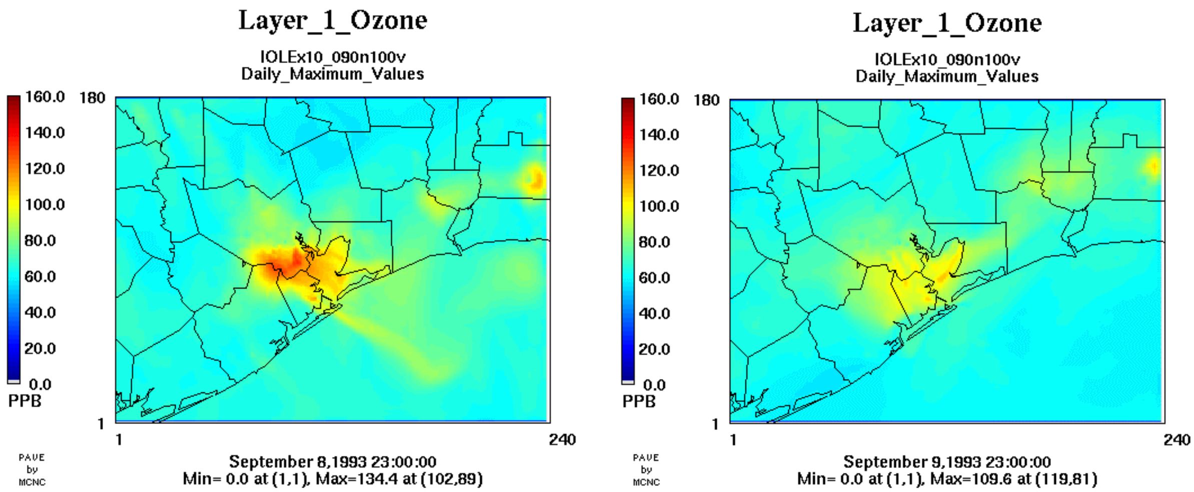

Figure A-1. Daily maximum ozone concentrations for future year 2007 at 10x industrial olefin emission levels.

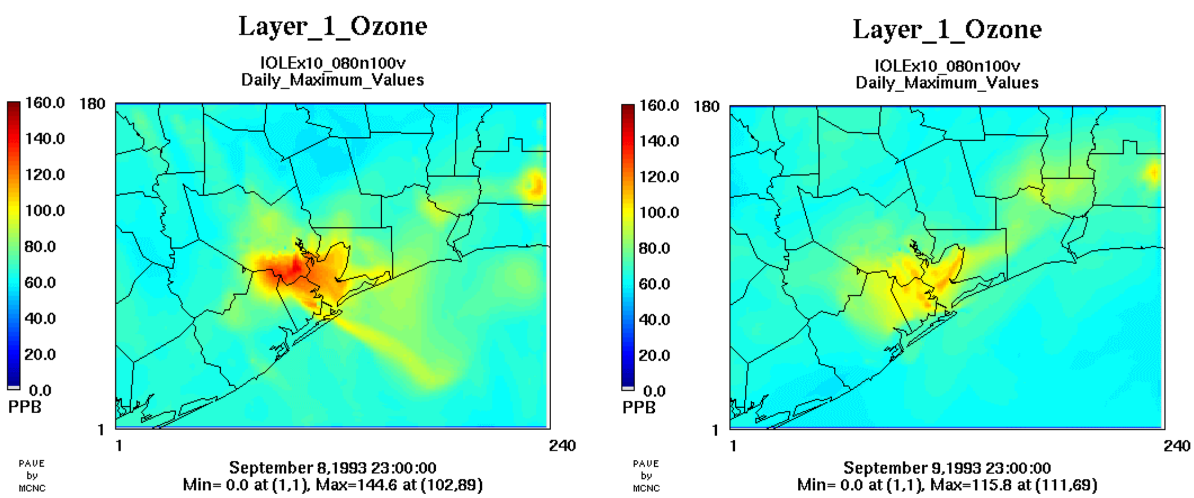

Figure A-2. Daily maximum ozone concentrations for future year 2007 at 10x industrial olefins and double Strategy I8a NOx emission levels (80% reduction).

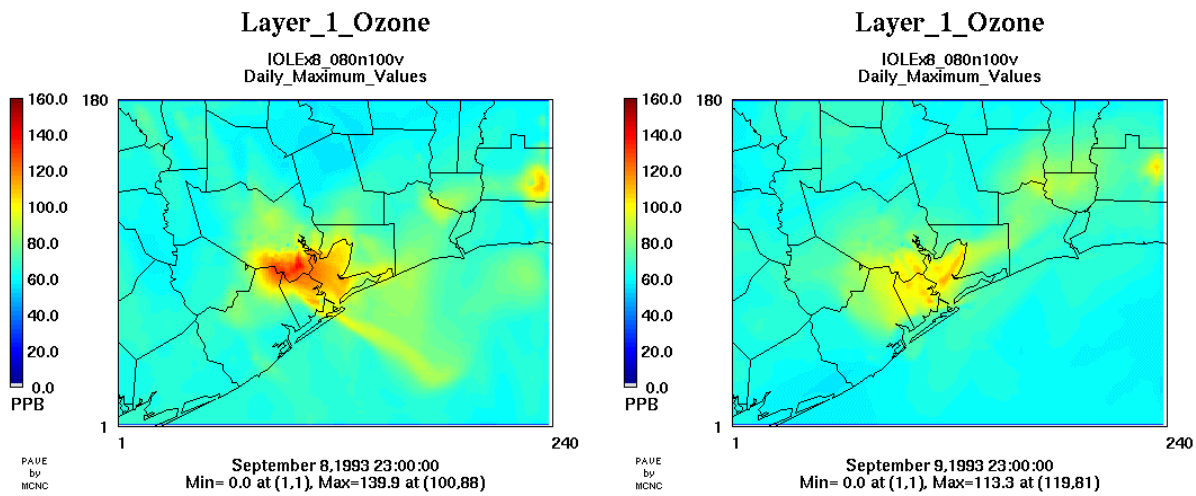

Figure A-3. Daily maximum ozone concentrations for future year 2007 at 8x industrial olefins and double Strategy I8a NOx emission levels (80% reduction).

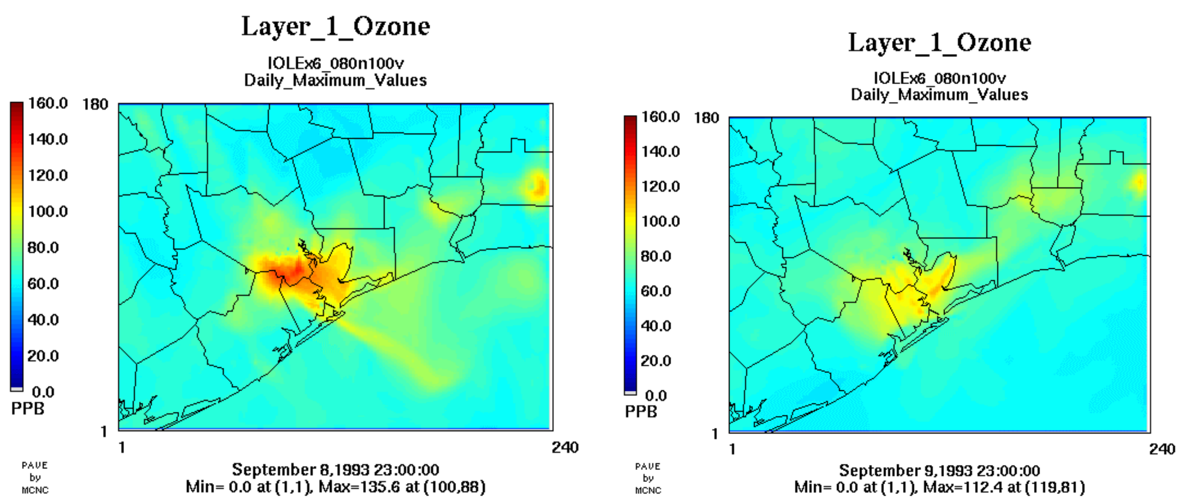

Figure A-4. Daily maximum ozone concentrations for future year 2007 at 6x industrial olefins and double Strategy I8a NOx emission levels (80% reduction).

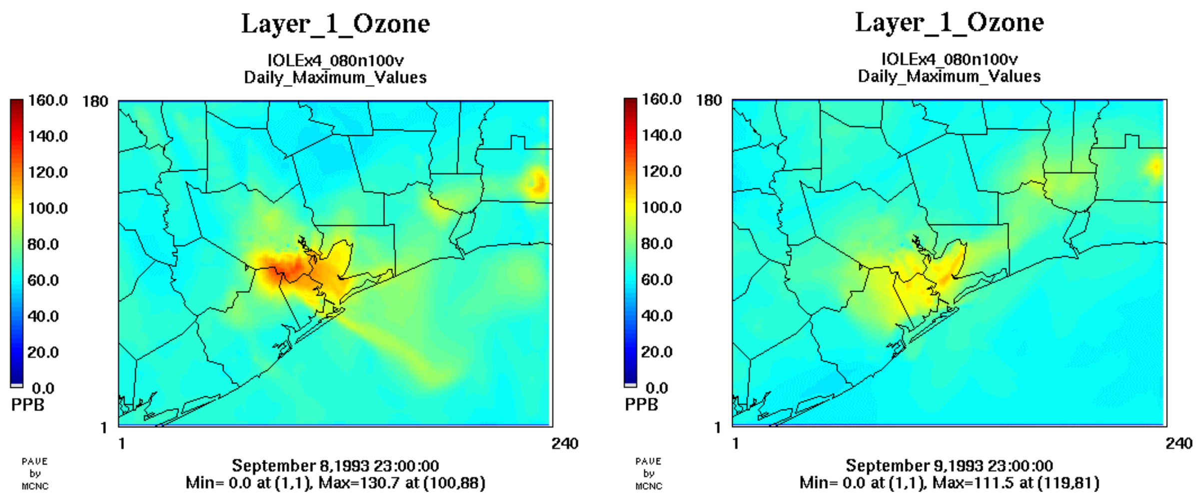

Figure A-5. Daily maximum ozone concentrations for future year 2007 at 4x industrial olefins and double Strategy I8a NOx emission levels (80% reduction).

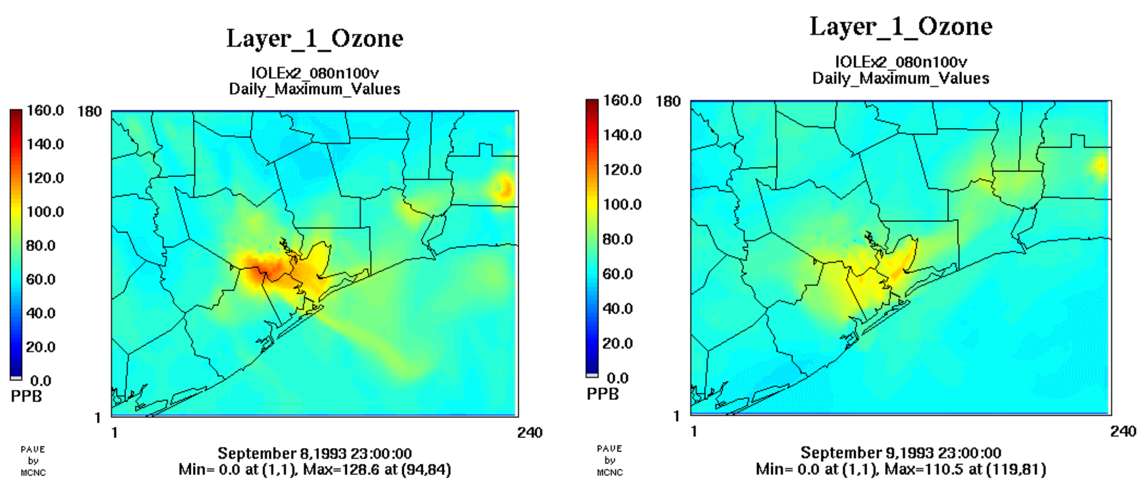

Figure A-6. Daily maximum ozone concentrations for future year 2007 at 2x industrial olefins and double Strategy I8a NOx emission levels (80% reduction).

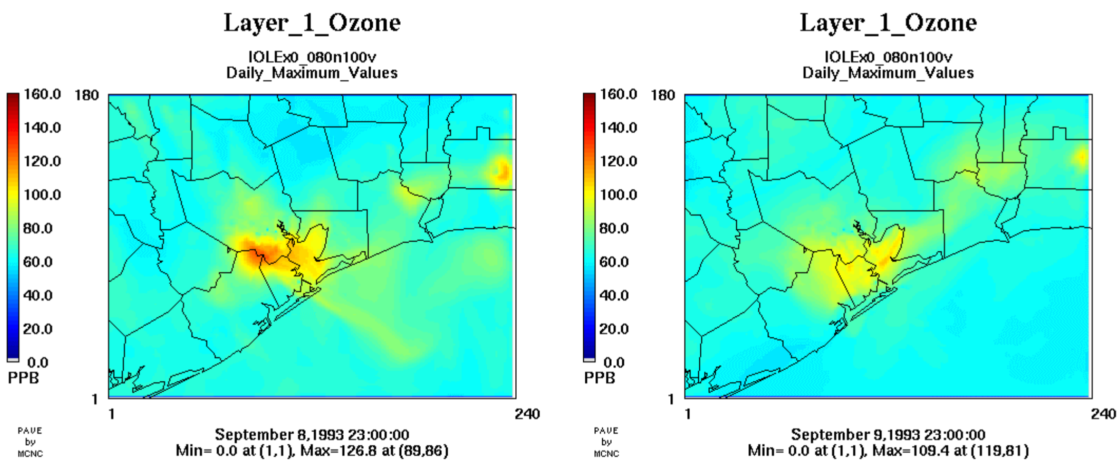

Figure A-7. Daily maximum ozone concentrations for future year 2007 at 0x industrial olefins and double Strategy I8a NOx emission levels (80% reduction).

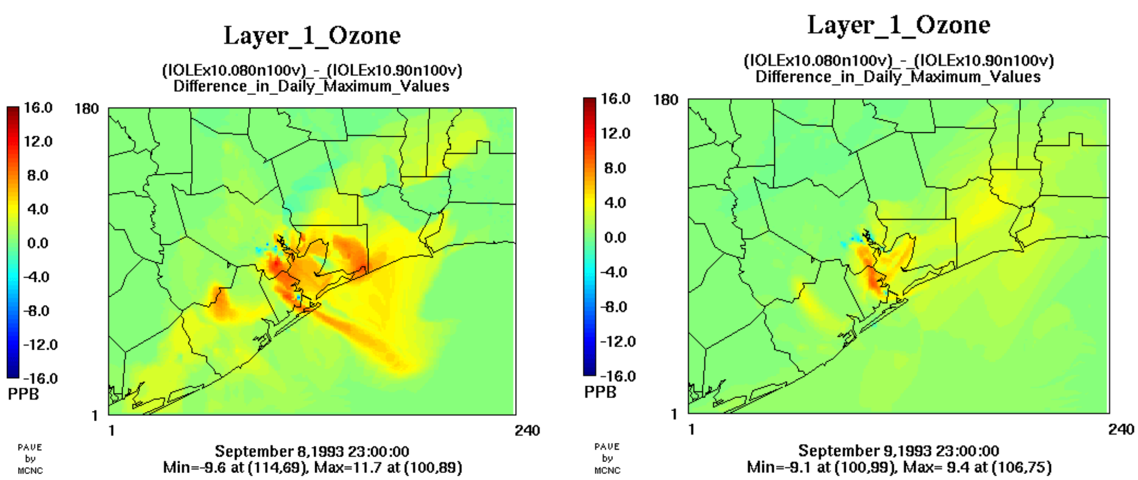

Figure A-8. Effects of doubled industrial NOx emissions on daily maximum ozone concentrations for future year 2007

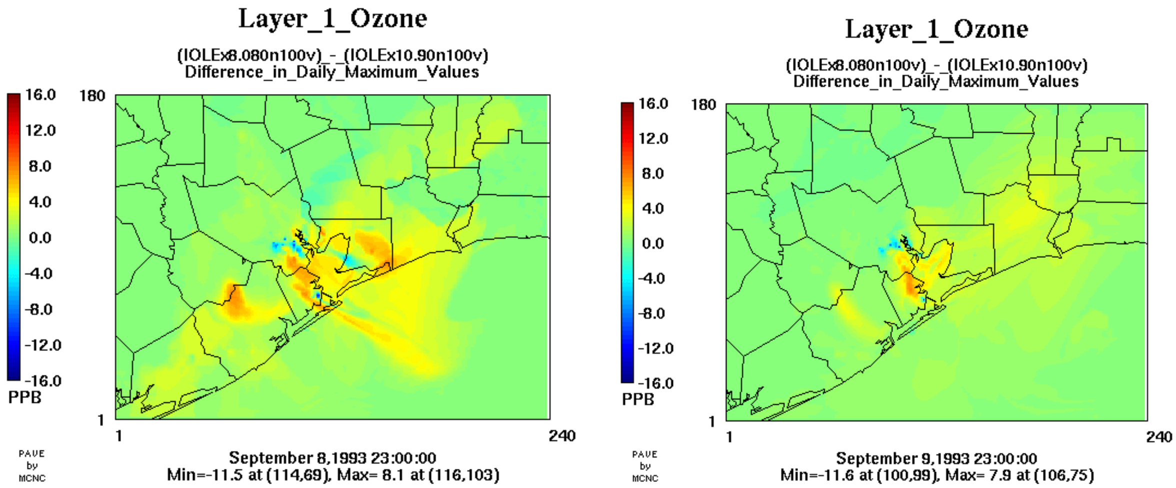

Figure A-9. Effects of doubled industrial NOx emissions and 20% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

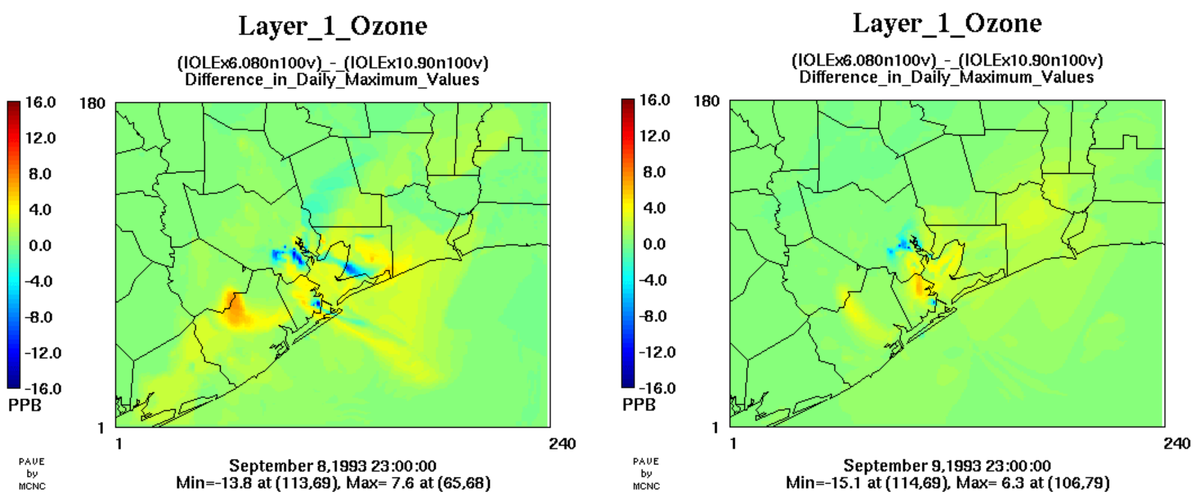

Figure A-10. Effects of doubled industrial NOx emissions and 40% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

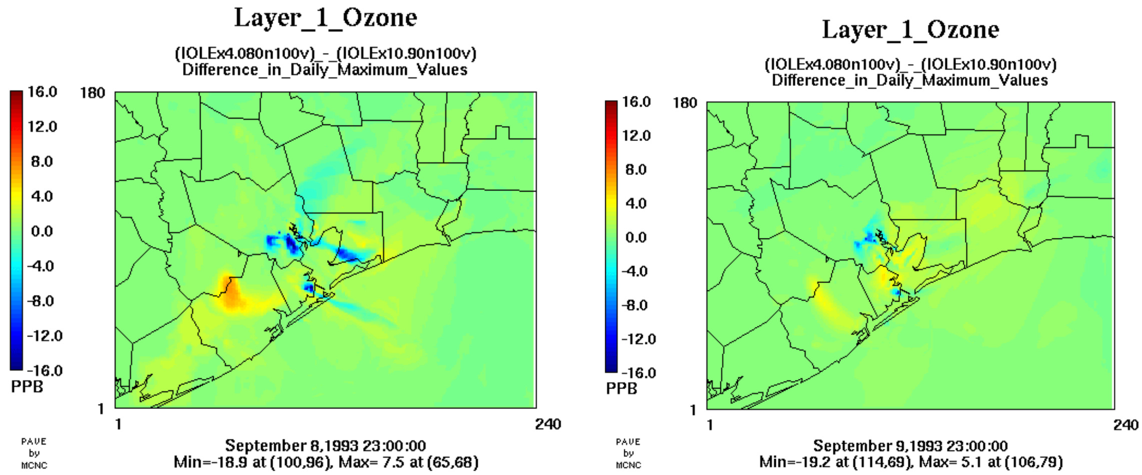

Figure A-11. Effects of doubled industrial NOx emissions and 60% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

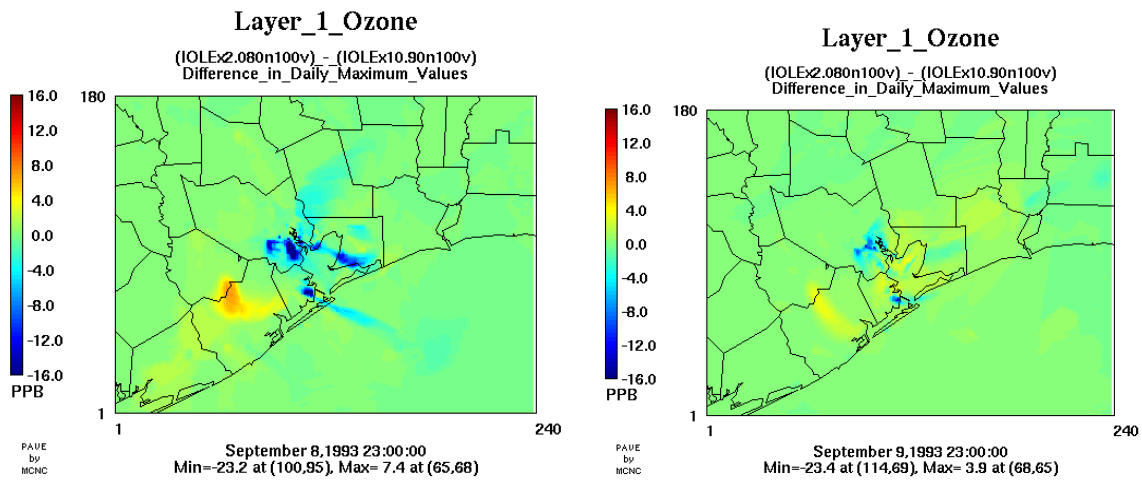

Figure A-12. Effects of doubled industrial NOx emissions and 80% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

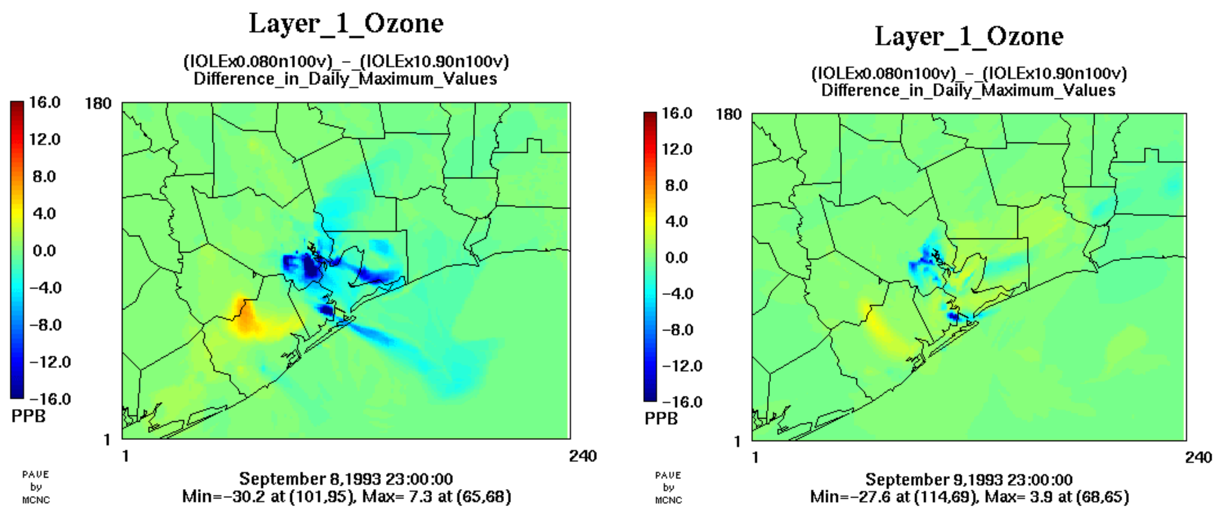

Figure A-13. Effects of doubled industrial NOx emissions and 100% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

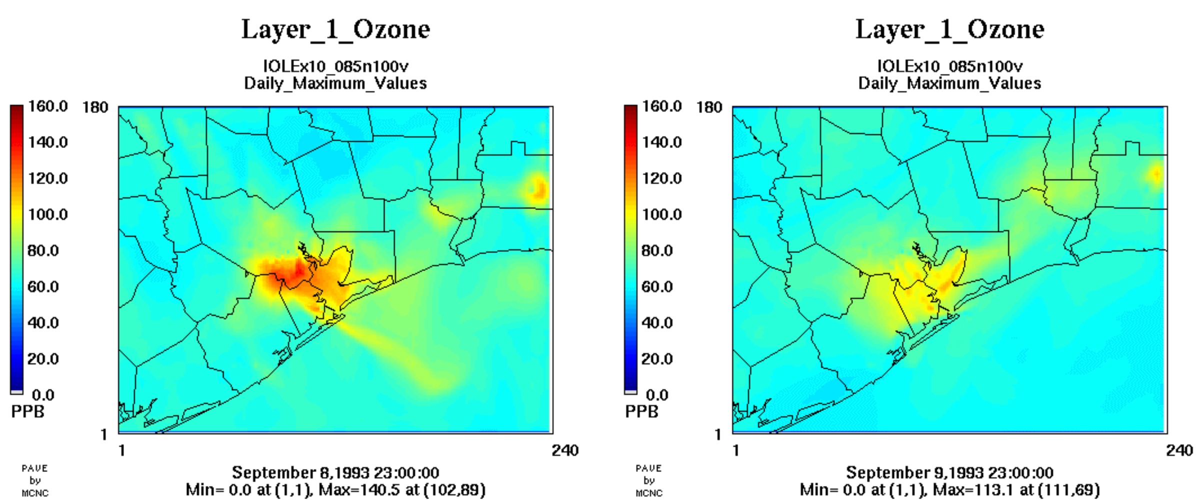

Figure A-14. Daily maximum ozone concentrations for future year 2007 at 10x industrial olefins and 150% Strategy I8a NOx emission levels (85% reduction).

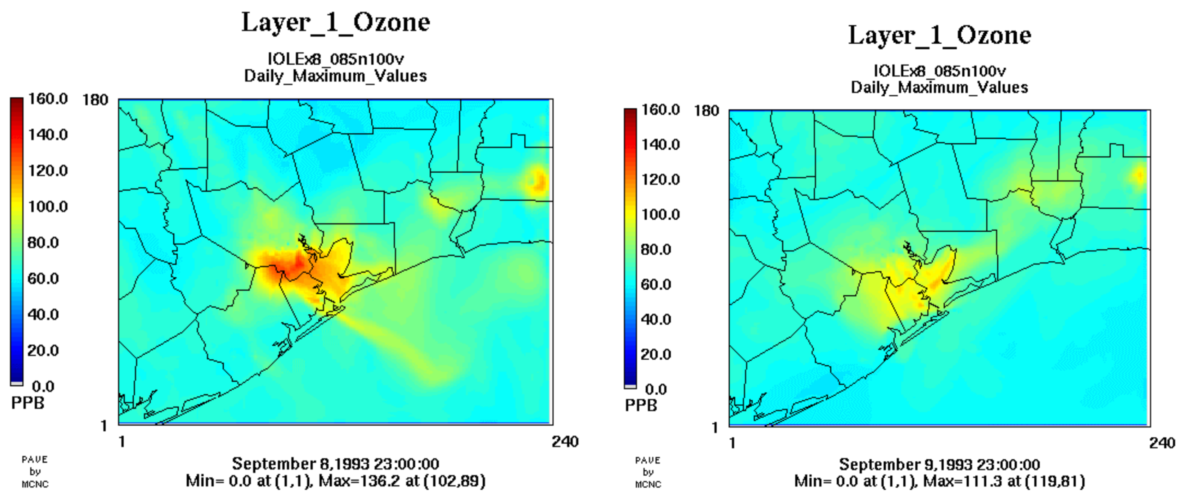

Figure A-15. Daily maximum ozone concentrations for future year 2007 at 8x industrial olefins and 150% Strategy I8a NOx emission levels (80% reduction).

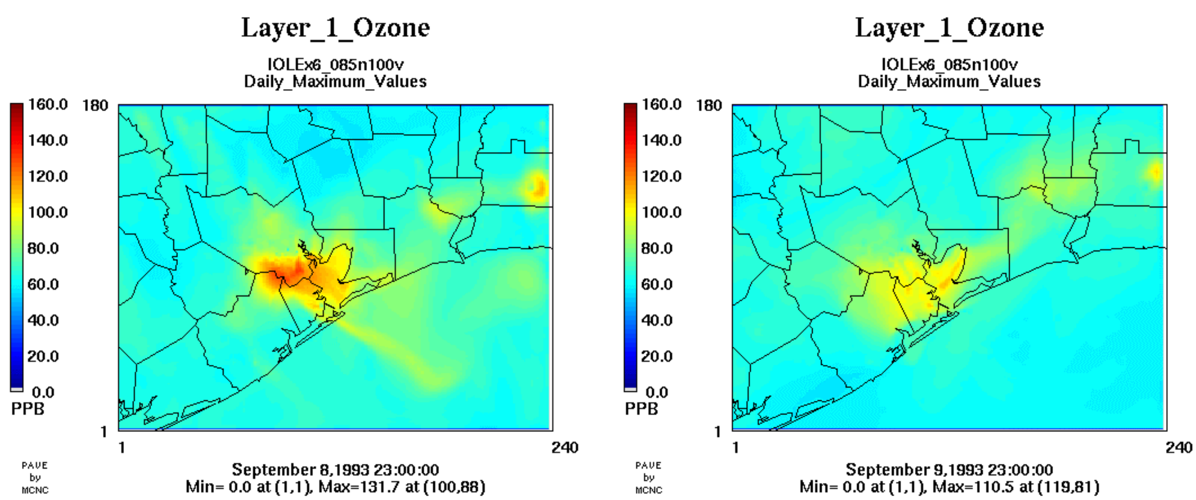

Figure A-16. Daily maximum ozone concentrations for future year 2007 at 6x industrial olefins and 150% Strategy I8a NOx emission levels (80% reduction).

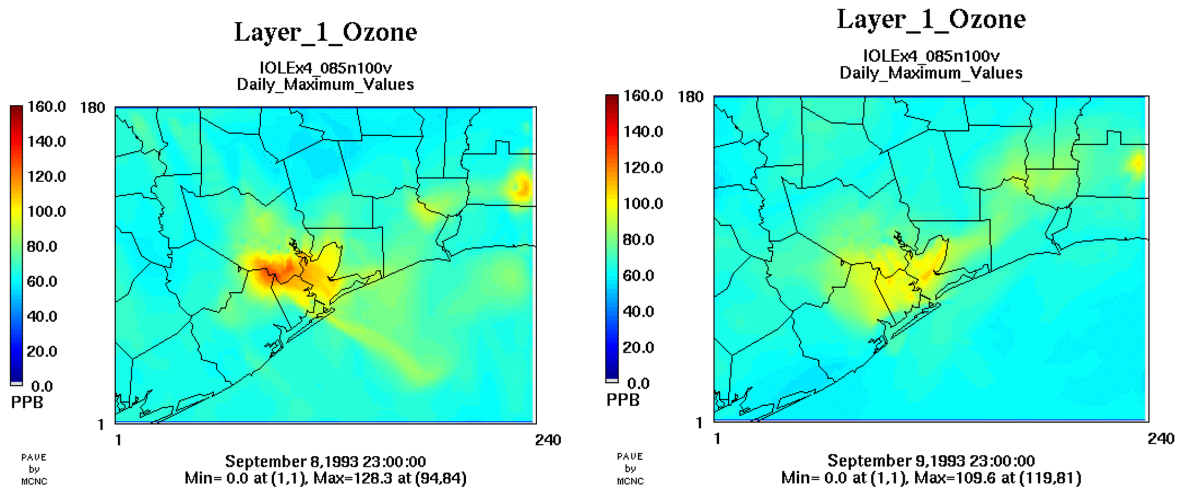

Figure A-17. Daily maximum ozone concentrations for future year 2007 at 4x industrial olefins and 150% Strategy I8a NOx emission levels (80% reduction).

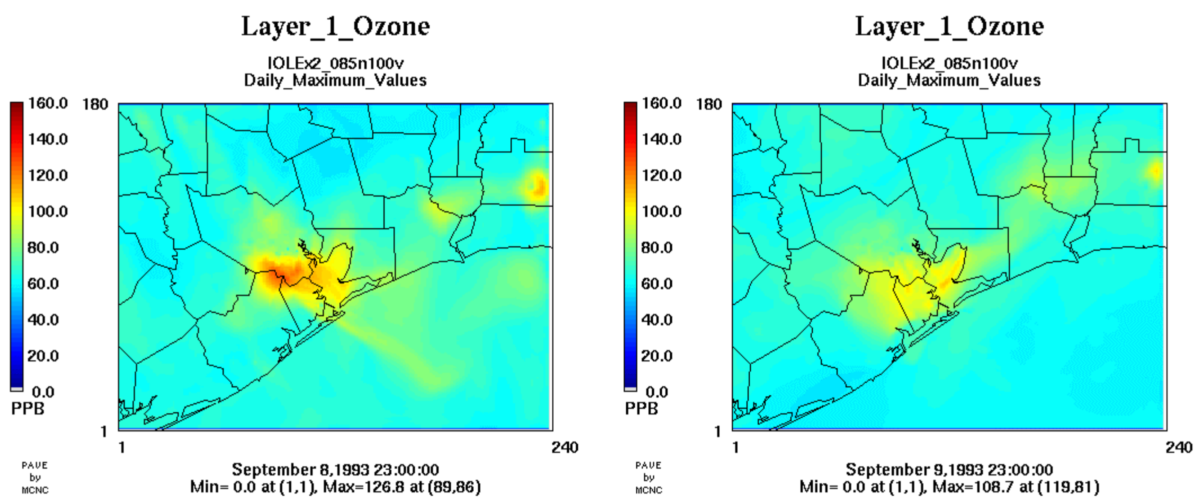

Figure A-18. Daily maximum ozone concentrations for future year 2007 at 2x industrial olefins and 150% Strategy I8a NOx emission levels (80% reduction).

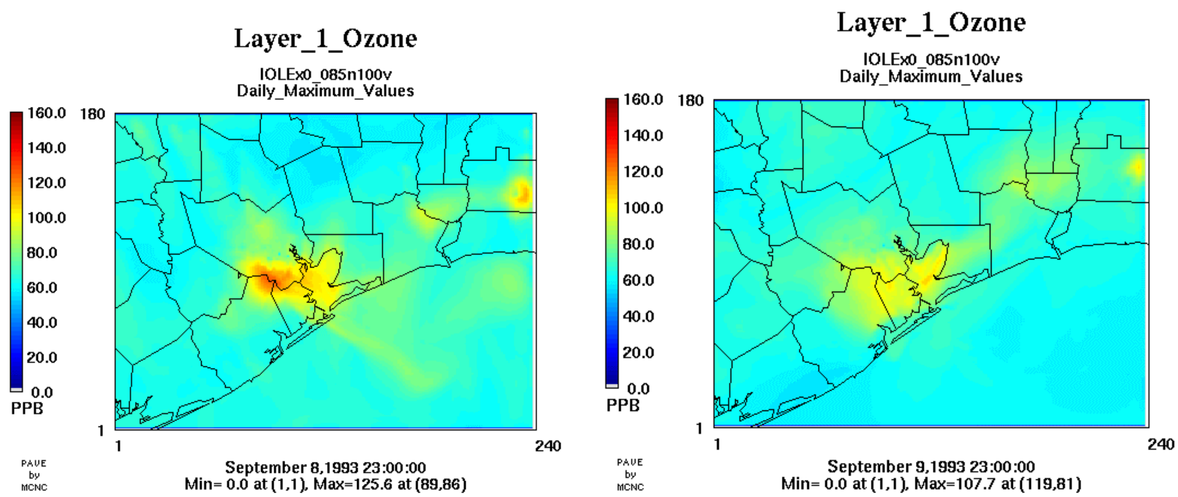

Figure A-19. Daily maximum ozone concentrations for future year 2007 at 0x industrial olefins and 150% Strategy I8a NOx emission levels (80% reduction).

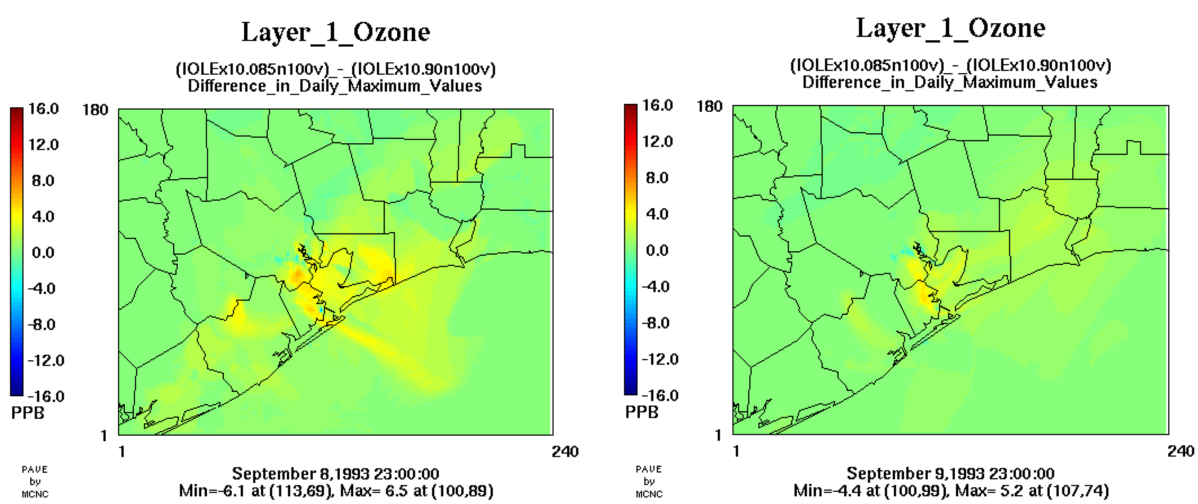

Figure A-20. Effects of 150% industrial NOx emissions on daily maximum ozone concentrations for future year 2007 at 10x olefin emission levels

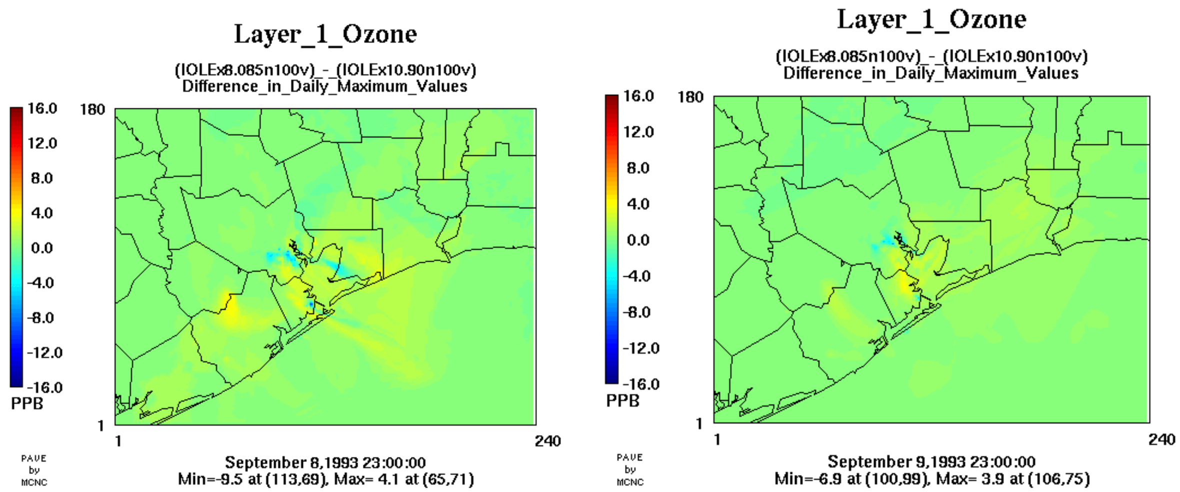

Figure A-21. Effects of 150% industrial NOx emissions and 20% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

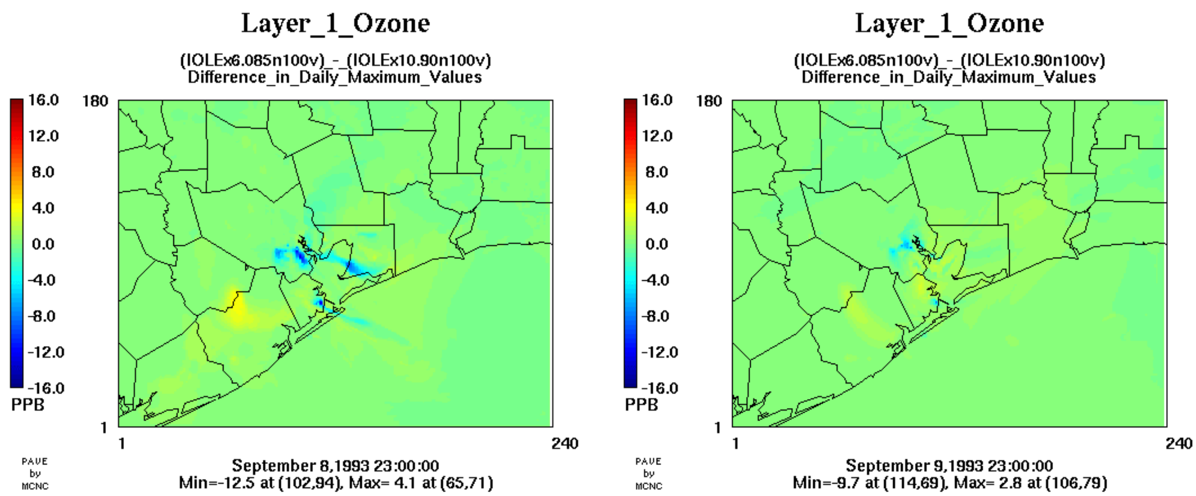

Figure A-22. Effects of 150% industrial NOx emissions and 40% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

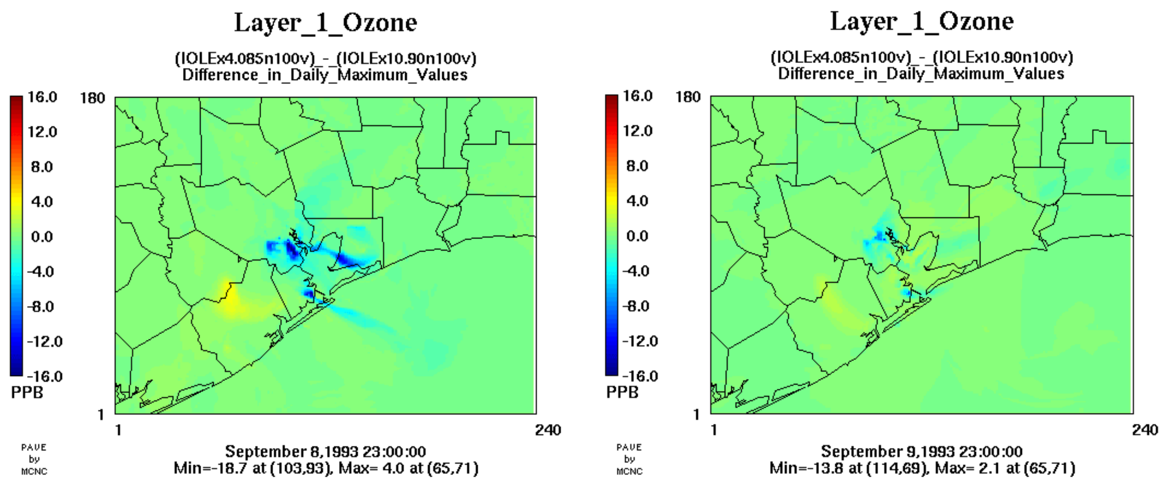

Figure A-23. Effects of 150% industrial NOx emissions and 60% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

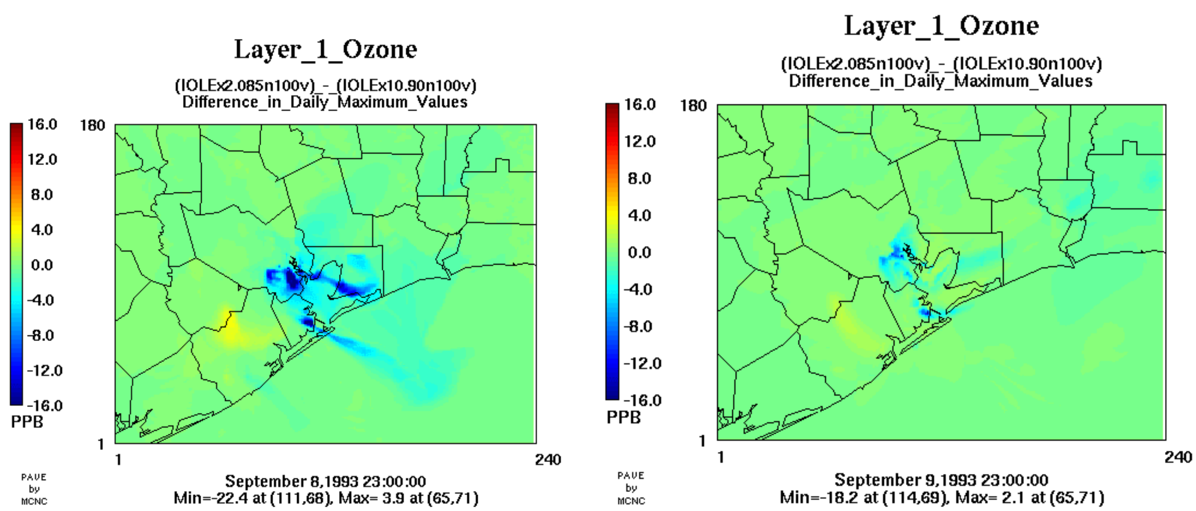

Figure A-24. Effects of 150% industrial NOx emissions and 80% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

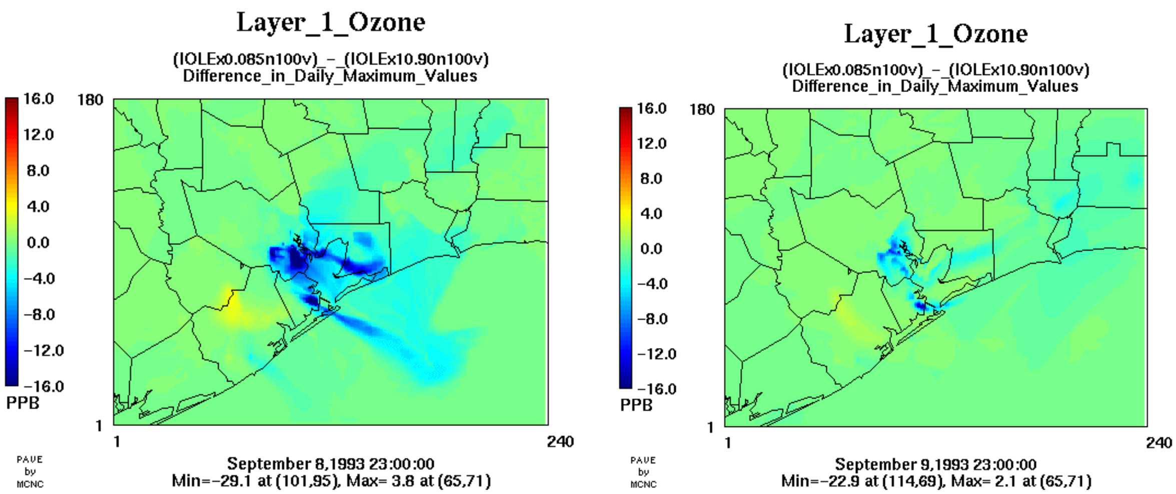

Figure A-25. Effects of 150% industrial NOx emissions and 100% reduction of industrial olefin emissions on daily maximum ozone concentrations for future year 2007.

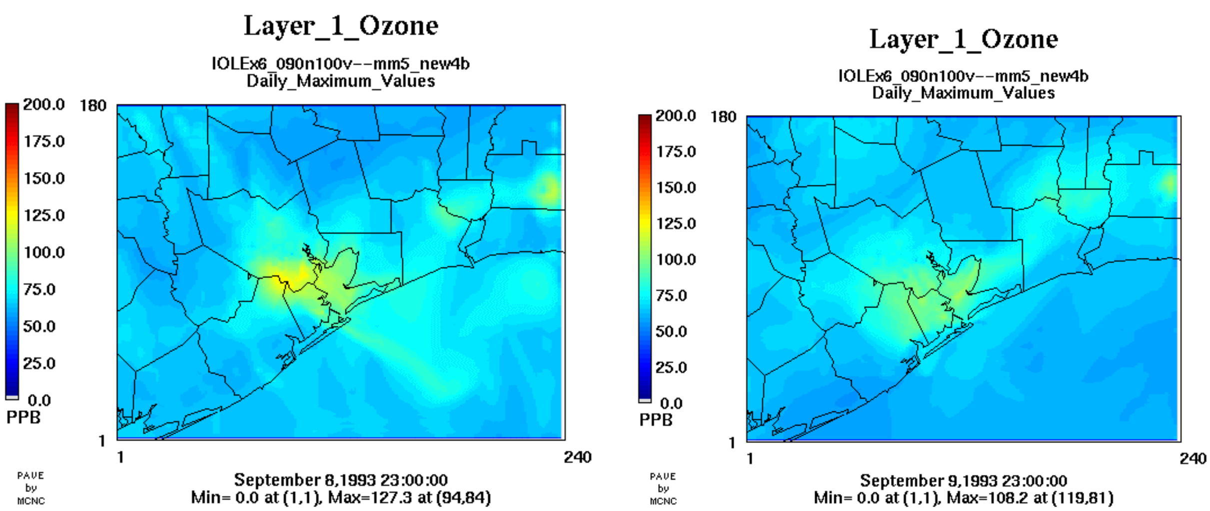

Figure A-26. Daily maximum ozone concentrations for future year 2007 at 6x industrial olefins and Strategy I8a NOx emission levels.

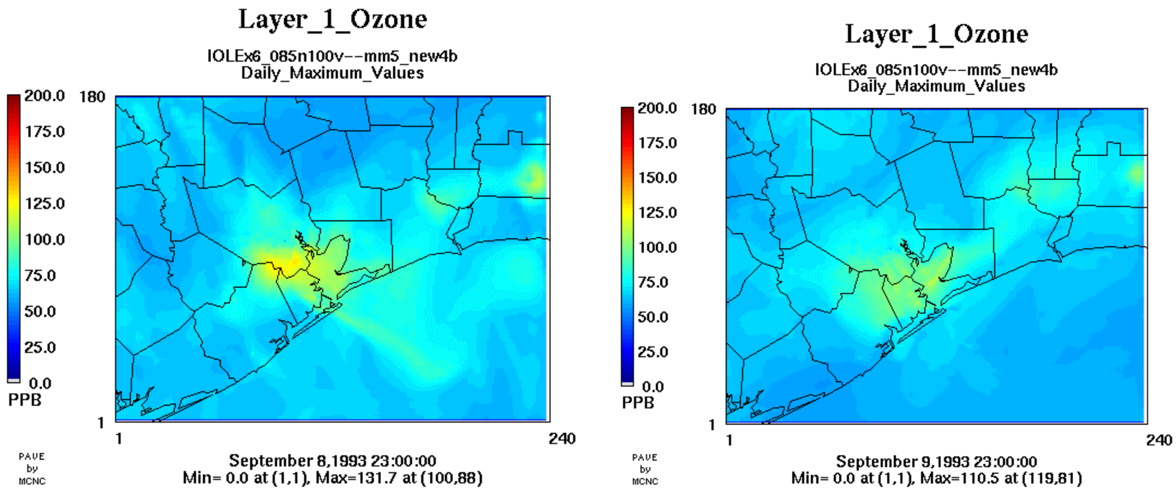

Figure A-27. Daily maximum ozone concentrations for future year 2007 at 6x industrial olefins and 150% Strategy I8a NOx emission levels (80% reduction).

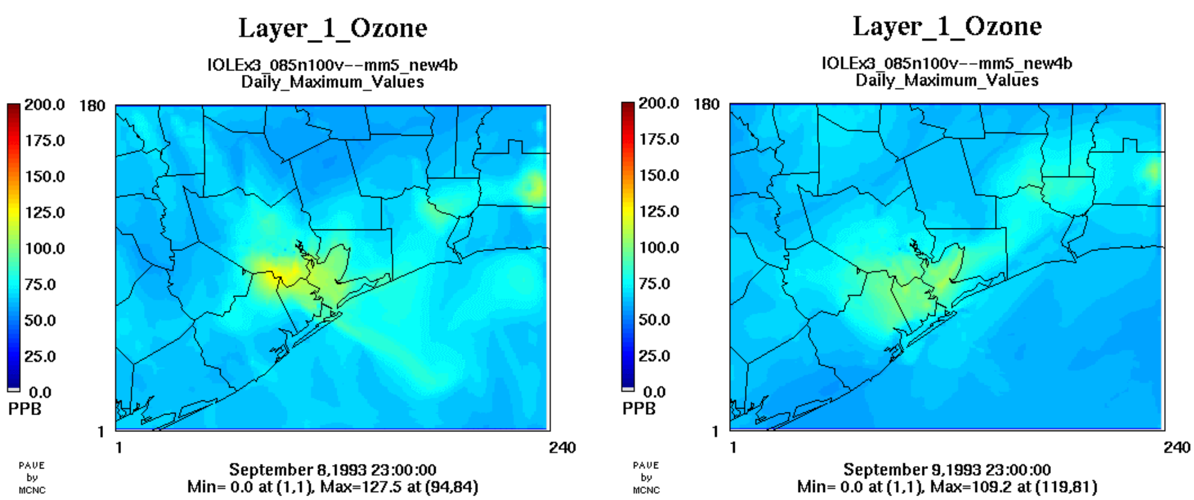

Figure A-28. Daily maximum ozone concentrations for future year 2007 at 3x industrial olefins and 150% Strategy I8a NOx emission levels (80% reduction).

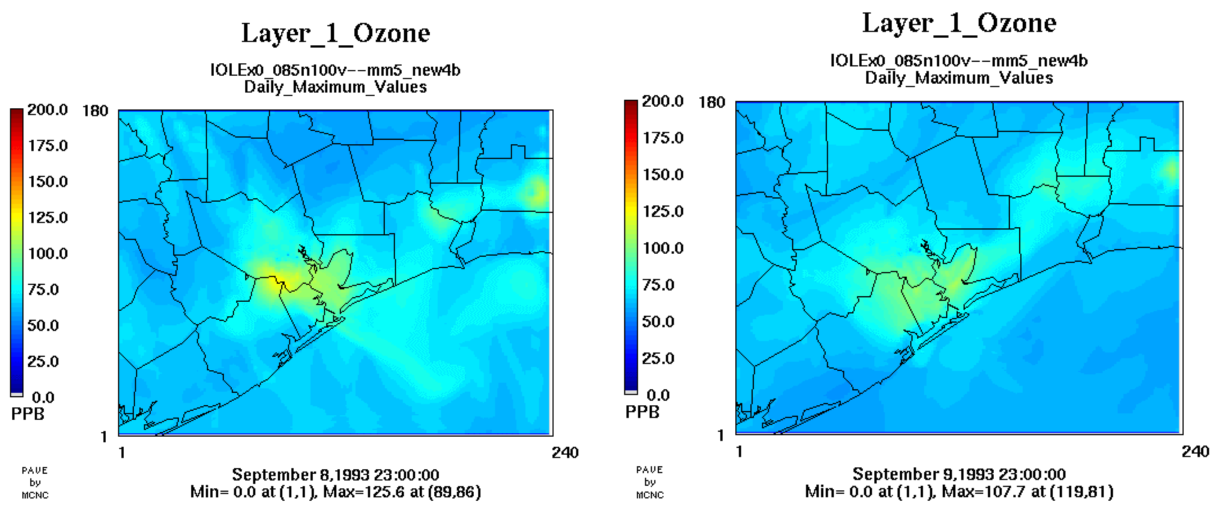

Figure A-29. Daily maximum ozone concentrations for future year 2007 at 0x industrial olefins and 150% Strategy I8a NOx emission levels (80% reduction).